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Flexion and Extension Angles of Resting Fingers and Wrist

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Flexion and Extension Angles of Resting Fingers and Wrist

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This study determined flexion and extension angles of resting fingers and wrist in terms of forearm posture (neutral, pronation and supination) and shoulder flexion (0°, 45°, 90° and 135°). The participants participated in 12 angle measurements for 16 finger joints and wrist. The finger joints flexed more in supination than in neutral posture and pronation and the thumb flexed more than the other fingers because of the gravity and skin tension. This phenomenon became more apparent as the shoulder flexed. The carpometacarpal joint had the largest flexion angle in the thumb joints, whereas the proximal interphalangeal joints had the largest flexion angles in the other finger joints. The resting posture of the wrist extended of ~16° in any forearm postures when the shoulder was at 0°. The results of this study could be useful for rehabilitation tool and product designs.

finger wrist resting posture angle

1. INTRODUCTION

People use various postures during activities in daily life and industry. Postures are important in designing task methods, because they could influence human capabilities [1]. The human hand and wrist are complex structures and they can perform diverse movements to manipulate tools and objects [2, 3]. Thus, they have attracted great attention of researchers in many areas such as product design, ergonomics and rehabilitation.

Postures of a hand and a wrist are often considered while designing a product that can fit a hand and provide sufficient space in a hand–product coupling for comfort and performance [4, 5, 6]. They are also included in most checklists of working postures evaluation using the flat hand and wrist whose joints are straight or 0° (neutral posture), as a standard under the assumption there is no physical load on the hand and wrist [7, 8, 9, 10, 11]. However, this posture requires intentional force exertion to flatten the hand and wrist.

Clinicians in rehabilitation describes the positions of resting hand and wrist as 'safe hand position' or 'safe splint position' for splint used to treat the patients with hand injuries. They are defined as normal anatomic positions of the hand or a position for bone injuries and soft tissues treatment [12, 13]. Table 1 shows the finger joint flexion and wrist extension angles in the safe hand position. Table 1 shows that the metacarpophalangeal (MCP) joint ranges from 45° to 90°, the proximal interphalangeal (PIP) joint from 0° to 20°, the distal interphalangeal (DIP) joint from 0° to 10° and the wrist joints range from –45° to 0°.

Workers in industry have generally healthy hands and keep changing hand posture during work, however, the safe hand position is developed for the treatment of an injured hand so that it would be inappropriate to utilize it in ergonomics. Moreover, the safe hand position is measured in a certain forearm and shoulder posture. Most studies summarized in Table 1 measured joint angles at 90° of the shoulder and in a pronation

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TABLE 1. Flexion (Positive) and Extension (Negative) Angles of Finger and Wrist Joints in Safe Hand Position

Study	Finger Joint			Wrist
	MCP	PIP	DIP	
Daniels, Zook & Lynch [12]	45°–70°	10°	10°	n.d.
Taylor, Hanna & Belcher [13]	70°–90°	0°	0°	–40°––30°
Bach, Draslov & Jørgensen [14]	60°	0°	0°	–20°–0°
Bednar [15]	60°–70°	0°–10°	n.d.	–15°––10°
Clark [16]	60°	10	5°	–25
Taams, Ash & Johannes [17]	70°–90°	0°–20°	n.d.	–45°––30°
Tan, Mathis & El-Gamal [18]	80°	n.d.	n.d.	–30°

Notes. MCP = metacarpophalangeal joint, PIP = proximal interphalangeal joint, DIP = distal interphalangeal joint, n.d. = not discussed.

forearm posture, only Tan, Mathis and El-Gamal used a neutral forearm posture [18]. Li [19], and Nordin and Frankel [20] stressed that the postures of the finger and wrist located at the distal part of the upper extremity depended on forearm and shoulder positions because of their mechanical links and passive stretching of soft tissues and muscles. The safe hand position also did not provide any information on the thumb which was the most important digit for hand functions [21].

The objective of this study was to determine the flexion and extension angles of the resting finger joints and wrist, including the thumb, without any force exertion of the hand and wrist for various forearm and shoulder positions.

2. METHODS

2.1. Participants

The sample group consisted of 20 males and 20 females undergraduate and graduate students. They were selected in the experiment of resting finger and wrist angle measurement. They did not have any traumatic hand injuries and illnesses, or suffered from medical conditions that affected the hand and wrist postures. They were all right-handed. Table 2 shows their average age, height, weight, hand length, hand width and depth. The participants were informed about the procedures before they gave their consent (in accordance with the University Institutional Review Board requirements).

2.2. Measurements

The resting finger and wrist joint angles were measured with a Vicon motion system with four MX-3+ and three MX-F40 cameras (Vicon, UK) at a sampling rate of 50 Hz. Twenty-five reflective hemispheric markers of 4 mm in diameter were adhered to the dorsal side of the hand and forearm (Figure 1): finger tips, heads of middle phalanges, heads of proximal phalanges, heads of metacarpals of index, middle, ring and little fingers, fingertip, head of proximal phalange, head of metacarpal of the thumb, bases of second and fifth metacarpals, styloid processes, and dorsal sides of the ulna and radius of the wrist [22, 23, 24, 25].

TABLE 2. Physical Characteristics of Participants, *M* (*SD*)

Characteristic	Male	Female	Total
Age (years)	26.30 (2.10)	23.35 (2.46)	24.83 (2.72)
Height (cm)	177.80 (4.13)	161.55 (4.66)	169.68 (9.24)
Weight (kg)	63.90 (15.52)	76.65 (11.20)	51.15 (5.57)
Hand length (cm)	18.76 (0.57)	16.80 (0.72)	17.78 (1.18)
Hand width (cm)	8.63 (0.47)	7.48 (0.39)	8.05 (0.72)
Hand depth (cm)	2.56 (0.24)	2.23 (0.39)	2.40 (0.36)

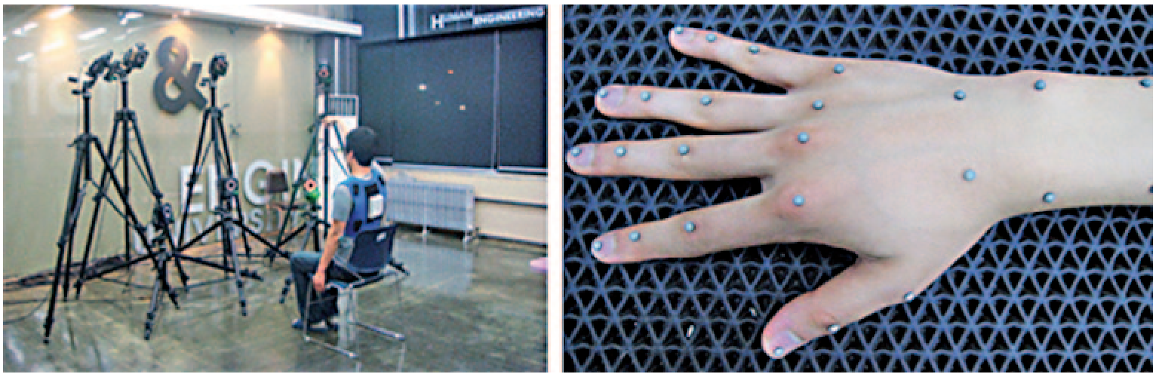

Figure 1. VICON motion system (left) and markers on hand and forearm (right).

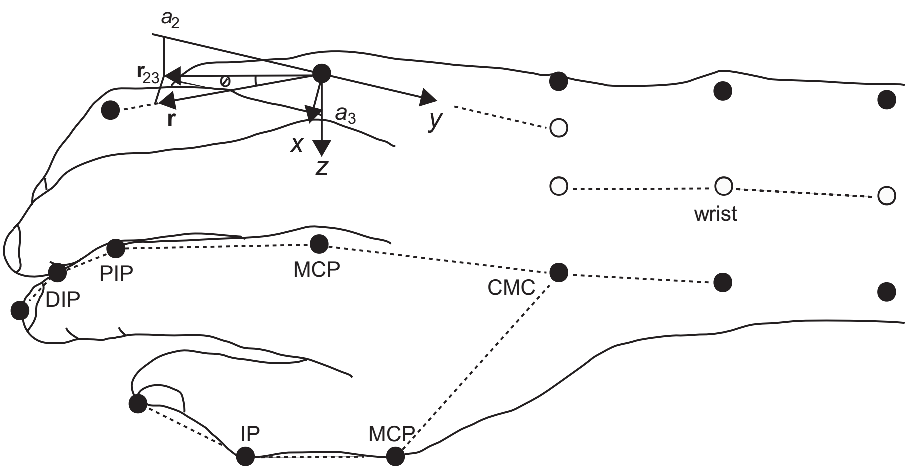

Figure 2. Co-ordinate system and joint angles of fingers and wrist. *Notes.* ● = reflective markers, ○ = virtual markers. CMC = carpometacarpal joint, MCP = metacarpophalangeal joint, IP = interphalangeal joint, PIP = proximal interphalangeal joint, DIP = distal interphalangeal joint.

The coordinate system for the finger and wrist was in accordance with the recommendation of the International Society of Biomechanics [26]. For the right hand, the positive x axis was directed forward, the positive y axis upward and the positive z axis from left (little finger) to right (thumb) in the anatomical hand position. Thus, x and y axes formed a sagittal plane and y and z axes formed a frontal plane (Figure 2).

Flexion and extension angles of the finger and wrist were calculated with an angle between the long axis of a corresponding phalange and its projection on the frontal plane with Equation (1) [27]:

$$\phi = \arccos\left(\frac{\mathbf{r} \times \mathbf{r}_{23}}{|\mathbf{r}||\mathbf{r}_{23}|}\right) = \arccos\sqrt{a_2^2 + a_3^2}, \qquad (1)$$

where ϕ = flexion and extension angles, $\mathbf{r}$ = unit vector of the long axis of a phalange, $\mathbf{r}_{23}$ = projection of vector $\mathbf{r}$ on the frontal plane, a_2 and a_3 = components of vector $\mathbf{r}$ on the y and z axes, respectively.

The present study used the markers to estimate the angles instead of actual finger joint centers because there were great similarities of the angles identified by both surface markers and finger joint centers, even during hand movements [28, 29, 30]. Flexion was positive and extension was negative.

2.3. Procedure

The participant wore a short sleeved shirt to reduce interference with clothing during movements.

When the markers were attached to the fingers and wrist, the participant practiced a couple of postures to become familiar with the experiment without exerting force on his or her hand and wrist. Only one researcher was involved in attaching markers during an entire experiment for reproducibility. The participant sat upright on a chair, facing the palm medially for a neutral forearm posture. Then, the participant randomly performed 12 trials, according to the experimental conditions (Figure 1). The forearm posture of supination was defined as the palm facing anteriorly, whereas pronation was defined as the palm facing posteriorly with the shoulder hanging downward at 0°. The shoulder also flexed at 0°, 45°, 90° and 135°, which were measured by an analogue goniometer (Jamar, USA). The participants subjectively posed resting finger and wrist postures at a specified forearm posture and shoulder angle. The joint angles of the resting fingers and wrist were measured for 5 s in each trial with a 2-min rest between trials to minimize fatigue. The participants kept the elbow straight during the experimental conditions.

2.4. Experiment Design

Analysis of variance (ANOVA) was performed with SAS 9.1 with a significance level of .05. The independent variables of a 2×3×4 mixed design were two levels of gender (male and female), three levels of forearm posture (neutral, pronation and supination) and four levels of shoulder flexion (0°, 45°, 90° and 135°). The 16 dependent variables were the flexion and extension angles of the carpometacarpal (CMC), the MCP and interphalangeal (IP) joints of the thumb, the MCP, the PIP and the DIP joints of the index, middle, ring and little fingers, and the wrist. Average angles of 5-s duration were analysed. This study reported

TABLE 3. Thumb Joint Angles, *M* (*SD*)

Forearm Posture	Shoulder Flexion	CMC	MCP	IP
Neutral	0°	47° (10°)	43° (10°)	9° (6°)
	45°	50° (7°)	41° (11°)	9° (5°)
	90°	48° (6°)	38° (13°)	10° (6°)
	135°	35° (16°)	34° (14°)	11° (8°)
	M (*SD*)	45° (12°) b	39° (12°) b	10° (6°) b
Pronation	0°	48° (9°)	39° (12°)	10° (5°)
	45°	43° (16°)	35° (14°)	8° (4°)
	90°	47° (7°)	35° (10°)	7° (2°)
	135°	46° (8°)	32° (12°)	7° (4°)
	M (*SD*)	46° (10°) b	35° (12°) c	8° (4°) c
Supination	0°	49° (8°)	40° (11°)	10° (5°)
	45°	51° (16°)	44° (14°)	16° (9°)
	90°	48° (15°)	45° (15°)	21° (11°)
	135°	52° (12°)	44° (16°)	23° (9°)
	M (*SD*)	50° (13°) a	43° (14°) a	17° (10°) a
M (*SD*)	0°	48° (9°) α	41° (11°) α	10° (5°) γ
	45°	48° (14°) α	39° (13°) α	10° (7°) γ
	90°	48° (10°) α	39° (13°) α	12° (10°) β
	135°	44° (14°) β	37° (15°) β	14° (10°) α
	M (*SD*)	47° (12°)	39° (13°)	11° (8°)

Notes. CMC = carpometacarpal joint, MCP = metacarpophalangeal joint, IP = interphalangeal joint. Latin letters represent Tukey test results for forearm posture and Greek letters represent Tukey test results for shoulder flexion.

the main effects for each dependent variable only because of the complexity of the interaction interpretation. Tukey's post hoc tests were performed on all significant main effects.

3. RESULTS

3.1. Thumb

ANOVA showed that forearm posture and shoulder flexion were statistically significant for all the thumb joint angles of the CMC, MCP and IP ($p < .001$). Tukey tests revealed that supination had larger flexion angle of the CMC joint than pronation and neutral posture. Supination had the largest angles and pronation had the smallest angles among the three forearm postures for the MCP and IP joints. The CMC and MCP joints had large angles at shoulder flexion of 0°, 45° and 90°, and the angles were the smallest at 135°. The IP joint showed an opposite result; joint angles were larger for the shoulder flexion of 135° and smaller for 0° and 45° (Table 3).

3.2. Index Finger

Main effects of forearm posture and shoulder flexion for the index finger joint angles of the MCP, PIP and DIP were statistically significant ($p < .001$). Supination had the largest angles for the PIP and DIP joints, whereas supination and neutral forearm postures had the largest angles for the MCP joint. Pronation had the smallest angles for the index finger joints. The MCP joint had larger angles at shoulder flexion of 135° than 0°, 45° and 90°. The PIP and the DIP joints also had the largest angles at shoulder flexion of 135° and the smallest angles at 0° (Table 4).

TABLE 4. Index Finger Joint Angles, *M* (*SD*)

Forearm Posture	Shoulder Flexion	MCP	PIP	DIP
Neutral	0°	27° (4°)	26° (8°)	10° (5°)
	45°	28° (4°)	28° (8°)	10° (5°)
	90°	28° (10°)	29° (8°)	9° (4°)
	135°	32° (11°)	31° (10°)	11° (5°)
	M (*SD*)	29° (8°) a	29° (8°) b	10° (5°) b
Pronation	0°	26° (7°)	25° (8°)	10° (5°)
	45°	27° (4°)	24° (8°)	9° (5°)
	90°	26° (5°)	20° (8°)	7° (4°)
	135°	27° (14°)	22° (8°)	8° (4°)
	M (*SD*)	26° (8°) b	23° (8°) c	9° (5°) c
Supination	0°	24° (8°)	29° (7°)	10° (5°)
	45°	26° (10°)	42° (9°)	14° (5°)
	90°	30° (10°)	45° (11°)	15° (5°)
	135°	30° (10°)	47° (14°)	18° (5°)
	M (*SD*)	28° (10°) a	41° (13°) a	14° (6°) a
M (*SD*)	0°	26° (6°) β	27° (8°) γ	10° (5°) γ
	45°	27° (6°) β	30° (11°) β	11° (6°) β
	90°	27° (8°) β	31° (14°) β	10° (6°) β
	135°	30° (11°) α	34° (15°) α	12° (6°) α
	M (*SD*)	28° (9°)	30° (12°)	11° (6°)

Notes. MCP = metacarpophalangeal joint, PIP = proximal interphalangeal joint, DIP = distal interphalangeal joint. Latin letters represent Tukey test results for forearm posture and Greek letters represent Tukey test results for shoulder flexion.

3.3. Middle Finger

Main effects of forearm posture and shoulder for the middle finger joint angles of the MCP, PIP and DIP were statistically significant ($p < .001$). Supination had larger MCP joint angle than neutral posture and pronation. Supination had the largest joint angle and pronation had the smallest angle for the PIP and DIP joint. The MCP joint had the largest angle at shoulder flexion of 135° and the smallest at 0° and 45°. The PIP joint had larger angles at shoulder flexion of 45°, 90° and 135° than 0°. The DIP joint had the largest angle at shoulder flexion of 135° but the smallest at 0° (Table 5).

3.4. Ring Finger

Forearm posture and shoulder flexion significantly affected the ring finger joint angles of the MCP, PIP and DIP ($p < .001$). Supination had the largest angles and pronation had the smallest angles for the ring finger joints. The three joints had the largest angles at shoulder flexion of 135° but the smallest angles at 0° (Table 6).

3.5. Little Finger

Forearm posture and shoulder flexion were significant for the little finger joint angles of the MCP, PIP and DIP ($p < .001$). Neutral forearm posture had a slightly larger joint angle than pronation and supination for the MCP joint. However, supination had the largest angles and pronation had the smallest angles for the PIP and DIP joints. The MCP joint had the largest angle at shoulder flexion of 135° and the smallest at 0° and 45°. The PIP joint had larger angles at shoulder flexion of 45°, 90° and 135° than at 0°. The DIP joint had the largest angles at shoulder flexion of 90° and 135° but the smallest at 0° (Table 7).

TABLE 5. Middle Finger Joint Angles, *M* (*SD*)

Forearm Posture	Shoulder Flexion	MCP	PIP	DIP
Neutral	0°	32° (4°)	27° (11°)	10° (5°)
	45°	31° (6°)	31° (10°)	11° (5°)
	90°	32° (8°)	30° (11°)	11° (6°)
	135°	33° (10°)	30° (11°)	11° (6°)
	M (*SD*)	32° (7°) b	30° (11°) b	11° (5°) b
Pronation	0°	32° (5°)	28° (9°)	10° (5°)
	45°	29° (7°)	27° (9°)	10° (5°)
	90°	31° (6°)	24° (8°)	8° (4°)
	135°	34° (6°)	26° (9°)	7° (3°)
	M (*SD*)	30° (6°) b	26° (9°) c	9° (5°) c
Supination	0°	30° (7°)	28° (8°)	11° (5°)
	45°	35° (11°)	45° (10°)	16° (7°)
	90°	36° (12°)	49° (16°)	18° (9°)
	135°	36° (13°)	48° (16°)	20° (10°)
	M (*SD*)	34° (11°) a	42° (16°) a	16° (8°) a
M (*SD*)	0°	31° (6°) γ	28° (10°) β	10° (5°) γ
	45°	32° (8°) γ	33° (12°) α	12° (6°) β
	90°	33° (9°) β	34° (16°) α	12° (8°) β
	135°	34° (10°) α	35° (15°) α	13° (8°) α
	M (*SD*)	33° (9°)	32° (14°)	12° (7°)

Notes. MCP = metacarpophalangeal joint, PIP = proximal interphalangeal joint, DIP = distal interphalangeal joint. Latin letters represent Tukey test results for forearm posture and Greek letters represent Tukey test resuls for shoulder flexion.

TABLE 6. Ring Finger Joint Angles, *M* (*SD*)

Forearm Posture	Shoulder Flexion	MCP	PIP	DIP
Neutral	0°	24° (5°)	32° (9°)	8° (4°)
	45°	25° (4°)	33° (10°)	9° (5°)
	90°	23° (8°)	35° (11°)	10° (5°)
	135°	28° (7°)	38° (11°)	10° (5°)
	M (*SD*)	25° (6°) b	34° (10°) b	9° (5°) b
Pronation	0°	23° (5°)	30° (11°)	8° (4°)
	45°	21° (6°)	31° (8°)	8° (3°)
	90°	23° (5°)	29° (8°)	8° (4°)
	135°	25° (6°)	31° (7°)	8° (4°)
	M (*SD*)	23° (6°) c	30° (9°) c	8° (4°) c
Supination	0°	22° (5°)	33° (9°)	9° (4°)
	45°	29° (9°)	44° (17°)	12° (7°)
	90°	29° (11°)	51° (14°)	15° (7°)
	135°	33° (8°)	53° (18°)	17° (9°)
	M (*SD*)	28° (9°) a	45° (17°) a	13° (8°) a
M (*SD*)	0°	23° (5°) γ	32° (10°) γ	8° (4°) γ
	45°	24° (7°) β	35° (13°) β	10° (5°) β
	90°	25° (9°) β	38° (15°) β	11° (6°) β
	135°	29° (8°) α	41° (16°) α	12° (8°) α
	M (*SD*)	25° (7°)	36° (14°)	10° (6°)

Notes. MCP = metacarpophalangeal joint, PIP = proximal interphalangeal joint, DIP = distal interphalangeal joint. Latin letters represent Tukey test results for forearm posture and Greek letters represent Tukey test results for shoulder flexion.

TABLE 7. Little Finger Joint Angles, *M* (*SD*)

Forearm Posture	Shoulder Flexion	MCP	PIP	DIP
Neutral	0°	29° (7°)	34° (11°)	12° (7°)
	45°	31° (5°)	37° (6°)	13° (6°)
	90°	31° (9°)	38° (7°)	13° (7°)
	135°	36° (5°)	39° (8°)	14° (8°)
	M (*SD*)	32° (7°) a	37° (8°) b	13° (7°) b
Pronation	0°	29° (7°)	36° (8°)	10° (6°)
	45°	30° (7°)	36° (5°)	10° (5°)
	90°	32° (6°)	34° (7°)	9° (5°)
	135°	31° (9°)	33° (7°)	8° (4°)
	M (*SD*)	31° (7°) b	35° (7°) c	9° (5°) c
Supination	0°	28° (5°)	36° (9°)	11° (5°)
	45°	27° (11°)	49° (7°)	19° (11°)
	90°	31° (9°)	50° (10°)	21° (11°)
	135°	36° (12°)	47° (15°)	21° (10°)
	M (*SD*)	31° (10°) b	45° (12°) a	18° (10°) a

Notes. MCP = metacarpophalangeal joint, PIP = proximal interphalangeal joint, DIP = distal interphalangeal joint. Latin letters represent Tukey test results for forearm posture and Greek letters represent Tukey test results for shoulder flexion.

TABLE 7. (*continued*)

Forearm Posture	Shoulder Flexion	MCP	PIP	DIP
M (*SD*)	0°	29° (6°) γ	35° (9°) β	11° (6°) γ
	45°	29° (8°) γ	39° (8°) α	13° (8°) β
	90°	31° (8°) β	40° (10°) α	14° (9°) α
	135°	34° (9°) α	40° (12°) α	15° (10°) α
	M (*SD*)	31° (8°)	39° (10°)	13° (8°)

Notes. MCP = metacarpophalangeal joint, PIP = proximal interphalangeal joint, DIP = distal interphalangeal joint. Latin letters represent Tukey test results for forearm posture and Greek letters represent Tukey test results for shoulder flexion.

3.6. Wrist

Main effects of forearm posture and shoulder flexion for the wrist were significant ($p < .001$). The wrist was flexed at 10° and 8° at the neutral forearm posture and pronation, respectively, but extended at 28° in supination. The wrist was close to a neutral posture with wrist angles ranging from 1° to 4° at shoulder flexion of 45°, 90° and 135° but it was extended at 16° at shoulder flexion of 0° (Table 8).

TABLE 8. Wrist Angles, *M* (*SD*)

Forearm Posture	Shoulder Flexion	Wrist
Neutral	0°	–16° (6°)
	45°	16° (8°)
	90°	17° (7°)
	135°	24° (14°)
	M (*SD*)	10° (18°) a
Pronation	0°	–15° (8°)
	45°	8° (5°)
	90°	16° (8°)
	135°	30° (14°)
	M (*SD*)	8° (19°) a
Supination	0°	–17° (6°)
	45°	–26° (7°)
	90°	–33° (12°)
	135°	–36° (12°)
	M (*SD*)	–28° (12°) b
M (*SD*)	0°	–16° (6°) β
	45°	3° (18°) α
	90°	1° (25°) α
	135°	4° (33°) α
	M (*SD*)	–3° (24°)

Notes. Latin letters represent Tukey test results for forearm posture and Greek letters represent Tukey test results for shoulder flexion.

4. DISCUSSION

The results of the study showed that the fingers flexed more in supination than in neutral posture and pronation. The flexion angles of the finger joints increased as the shoulder flexed. Although statistical analyses could not be performed because of the differences between thumb joints and the joints of other fingers, the thumb flexed more (32° ± 19°) than the other fingers (23° ± 13° for the index finger, 25° ± 14° for the middle finger, 24° ± 15° for the ring finger and 27° ± 14° for the little finger) because of the mobility of the CMC joint of the thumb [3]. Moreover, the thumb flexed more at the CMC joint (47° ± 12°) than at the MCP (39° ± 13°) and IP (11° ± 8°) joints, but the other fingers flexed more at the PIP joint than at the MCP and DIP joints. Garrett found a similar pattern using X-ray measurement and reported that the PIP and DIP joints flexion angles were 40° (PIP) and 9° (DIP) for the index finger, 49° (PIP) and 14° (DIP) for the middle finger, 55° (PIP) and 17° (DIP) for the ring finger and 47° (PIP) and 22° (DIP) for the little finger [31]. These angles were larger than the angles found in the present study, because Garrett used a straight wrist which could cause that the PIP and DIP joints of the fingers flexed more than the resting wrist used in the present study [31]. The wrist extended in supination (–28° ± 12°) but flexed in neutral posture (10° ± 18°) and pronation (8° ± 19°). The wrist extension angles gradually increased in supination when the shoulder flexed, but the wrist extended of about –16° at 0° shoulder flexion and flexed at more than 45° of shoulder flexion in neutral posture and pronation.

The MCP joint angle recommended in the safe hand position (Table 1) was larger but the PIP and DIP joints angles were smaller than the resting finger joint angles described in this study. Splint, used to immobilize the hand in rehabilitation, intentionally increases the MCP joint angle that causes the extension of the PIP and DIP joint to avoid corresponding ligament and skin deformities in the healing phase from fractures and burns [15]. Moreover, Brand and Hollister suggested 45° flexion of all finger joints for the resting fiber lengths of forearm muscles [32]. Taylor and Schwarz found the resting wrist angle of 35° extension, at which a maximum three-jaw pinching force can be exerted [3]. These finger and wrist angles were larger than those described in the present study. The differences between the previous studies and the present study could be caused by gravity and skin tension. In supination, the wrist extends because of the hand mass but the fingers flex toward the palm because of the masses of the phalanges. However, in pronation, the fingers flex less because of the skin tension on the dorsal side of the hand caused by wrist flexion. These phenomena are more visible as the shoulder flexes. According to Russell, Bush, Russell, et al.'s findings, when the hand rotates, there is less skin tension on the ulnar side of the forearm close to the little finger than on the radial side close to the thumb [33]. This may cause similar flexion angles of the MCP joint of the little finger in all forearm postures.

Most posture evaluation checklists regard hand and wrist positions at 0° as a neutral posture, which is considered as a reference because it assumes that the hand and wrist requires no force exertion, however, it requires force exertion to flatten the hand and wrist. Thus, this study measured resting finger and wrist angles without their force exertions and revealed that the fingers and wrist either flexed or extended at resting positions, which were not equal to 0°. These resting flexion and extension angles could be used as references for hand and wrist posture evaluations. Both joint angle and force should be considered together in developing a posture evaluation checklist.

4.1. Limitations

This study revealed that hand and wrist angles are related to forearm postures and shoulder flexion. Not considering various participants groups is the limitation of this study. Future research should consider diverse populations including the elderly, disabled and ethnics. Careful selection of participants with different hand sizes and age would be useful to generalize the results. The participants of this study were asked not to exert force on the hand and wrist but muscle activities were not measured during the experiment. Muscle activities of the hand and wrist should be examined in the future study.

5. CONCLUSIONS

This study provided the specific flexion and extension angles of the resting finger joints and wrist due to forearm posture and shoulder flexion. It is evident that the finger joints flexed more in supination than in neutral posture and pronation, but the wrist extended in supination and flexed in neutral posture and pronation because of gravity and skin tension. This phenomenon became noticeable as the shoulder flexed. When the arm is hanging down, the resting wrist extends of ~16° in any forearm posture.

The results of this study provided additional information to Garrett's results in terms of more accurate anthropometric data of resting hand [31]. The results could be used in designing rehabilitation tools for the patients with hand injuries by comparing joint angles of normal persons and patients in resting conditions. The resting hand and wrist angles might be used in designing products like computer mouse, hand tool, hand rail and cell phone.

REFERENCES

1. Chung MK, Lee I, Kee D. Assessment of postural load for lower limb postures based on perceived discomfort. Int J Ind Ergon. 2003;31(1):17–32.
2. Domalain M, Vigouroux L, Danion F, Sevrez V, Berton E. Effect of object width on precision grip force and finger posture. Ergonomics. 2008;51(9):1441–53.
3. Taylor CL, Schwarz RJ. The anatomy and mechanics of the human hand. Artif Limbs. 1955;2(2):22–35.

4. Jung MC, Hallbeck MS. Ergonomic redesign and evaluation for a clamping tool handle. Appl Ergon. 2005;36(5):619–24.
5. Keyserling WM. A computer-aided system to evaluate postural stress in the workplace. Am Ind Hyg Assoc J. 1986;47(10):641–9.
6. Trejo A, Jung MC, Oleynikov D, Hallbeck MS. Effect of handle design and target location on insertion and aim with a laparoscopic surgical tool. Appl Ergon. 2007;38(6):745–53.
7. Armstrong TJ, Foulke JA, Joseph BS, Goldstein SA. Investigation of cumulative trauma disorders in a poultry processing plant. Am Ind Hyg Assoc J. 1982;43(2): 103–16.
8. Hignett S, McAtamney L. Rapid entire body assessment (REBA). Appl Ergon. 2000;31(2):201–5.
9. McAtamney L, Corlett EN. RULA: a survey method for the investigation of work-related upper limb disorders. Appl Ergon. 1993; 24(2):91–9.
10. Moore JS, Garg A. The strain index: a proposed method to analyze jobs for risk of distal upper extremity disorders. Am Ind Hyg Assoc J. 1995;56(5):443–58.
11. Cook JR, Baker NA, Cham R, Hale E, Redfern MS. Measurements of wrist and finger postures: a comparison of goniometric and motion capture techniques. J Appl Biomech. 2007;23(1):70–8.
12. Daniels JM 2nd, Zook EG, Lynch JM. Hand and wrist injuries: part I. Nonemergent evaluation. Am Fam Physician. 2004;69(8): 1941–8. Retrieved March 4, 2014, from: http://www.aafp.org/afp/2004/0415/p1941.html.
13. Taylor E, Hanna J, Belcher HJCR. Splinting of the hand and wrist. Curr Orthopaed. 2003; 17(6):465–74.
14. Bach J, Draslov B, Jørgensen B. Positioning splinting and pressure management of the burned hand: A method. Scand J Plast Reconstr Surg. 1984;18(1):145–7.
15. Bednar JM. The treatment of hand fractures by the application of casts and splints. Oper Tech Orthop. 1997;7(2):93–5.
16. Clark DC. Common acute hand infections. Am Fam Physician. 2003;68(11):2167–76. Retrieved March 4, 2014, from: http://www.aafp.org/afp/2003/1201/p2167.html.
17. Taams KO, Ash GJ, Johannes S. Maintaining the safe position in a palmar splint: the “double-T” plaster splint. J Hand Surg Br. 1996;21(3):396–9.
18. Tan SR, Mathis LM, El-Gamal HM. Surgical pearl: safe splinting positions for skin grafts on the hand and wrist. J Am Acad Dermatol. 2005;52(4):686–7.
19. Li ZM. The influence of wrist position on individual finger forces during forceful grip. J Hand Surg Am. 2002;27(5):886–96.
20. Nordin M, Frankel VH, editors. Basic biomechanics of the musculoskeletal system. Philadelphia, PA, USA: Lea & Febiger; 1989.
21. Kaufman KR, An KN, Litchy WJ, Cooney WP 3rd, Chao EYS. In-vivo function of the thumb muscles. Clin Biomech (Bristol, Avon). 1999;14(2):141–50.
22. Carpinella I, Mazzoleni P, Rabuffetti M, Thorsen R, Ferrarin M. Experimental protocol for the kinematic analysis of the hand: definition and repeatability. Gait Posture. 2006;23(4):445–54.
23. Gupta A, Rash GS, Somia NN, Wachowiak MP, Jones J, Desoky A. The motion path of the digits. J Hand Surg Am. 1998;23(6): 1038–42.
24. Metcalf CD, Notley SV, Chappell PH, Burridge JH, Yule VT. Validation and application of a computational model for wrist and hand movements using surface markers. IEEE Trans Biomed Eng. 2008; 55(3):1199–210
25. Zhang X, Lee SW, Braido P. Determining finger segmental centers of rotation in flexion-extension based on surface marker measurement. J Biomech. 2003;36(8): 1097–102.
26. Wu G, van der Helm FC, Veeger HE, Makhsous M, Van Roy P, Anglin C, et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—part II: shoulder, elbow, wrist and hand. J Biomech. 2005;38(5):981–92.
27. Cheng PL, Pearcy M. A three-dimensional definition for the flexion/extension and

abduction/adduction angles. Med Biol Eng Comput. 1999;37(4):440–4.

28. Kuo LC, Su FC, Chiu HY, Yu CY. Feasibility of using a video-based motion analysis system for measuring thumb kinematics. J Biomech. 2002;35(11): 1499–506.
29. Kuo LC, Cooney WP 3rd, Oyama M, Kaufman KR, Su FC, An KN. Feasibility of using surface markers for assessing motion of the thumb trapeziometacarpal joint. Clin Biomech (Bristol, Avon). 2003;18(6):558–63.
30. Rash GS, Belliappa PP, Wachowiak MP, Somia NN, Gupta A. A demonstration of the validity of a 3-D video motion analysis method for measuring finger flexion and extension. J Biomech. 1999;32(12): 1337–41.
31. Garrett JW. The adult human hand: some anthropometric and biomechanical considerations. Hum Factors. 1971;13(2): 117–31.
32. Brand PW, Hollister AM. Clinical mechanics of the hand. 3rd ed. St. Louis, MO, USA: Mosby-Year Book; 1999.
33. Russell CJH, Bush JA, Russell GWP, Thorlby A, McGrouther DA, Lees VC. Dynamic skin tension in the forearm: effects of pronation and supination. J Hand Surg Am. 2009;34(3):423–31.