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The range and power of ulnar and radial deviation of the fingers

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INTRODUCTION

There is very little quantitative information on the range and power of lateral movements of the fingers, perhaps because their mechanisms of flexion and extension have so fascinated investigators that they have paid less attention to the problem presented by radial and ulnar deviation. It therefore seems worth while to report a study of the range of active deviation at the metacarpophalangeal joints and of the forces produced by these movements.

RANGE OF MOVEMENT

Methods

In the first part of the investigation, in which the movements were examined radiologically, 37 medical students, 18 males and 19 females, took part. The subject's left hand was placed palm down on the cassette and he was asked to keep the metacarpophalangeal joints in contact with it during the exposure. The deviations on the resulting radiograph were measured with the aid of a protractor and two thin perspex strips. Each of these had a hair line down the centre, which was placed in the long axis of the appropriate bone. Each angle was measured twice on different occasions by the same investigator, and the mean of the resulting measurements was taken.

Results

(1) *Maximal convergence and divergence*

Six subjects (three males and three females) were instructed, first to spread the fingers as far apart as possible, and then to close them up hard. Table 1 shows the angles made by the metacarpals with each other in both positions; in this table, as in all the others in this section, the mean angles are given in degrees, followed by the standard deviation. It is clear from the table that all movement took place at the metacarpophalangeal joints. No rotation of the metacarpals was observed.

The angles made by the proximal phalanges with their corresponding metacarpals were then measured, deviations to the ulnar side being given a negative value, and those to the radial side a positive one. The results are shown in Table 2, together with the total range of movement of each finger. The table indicates that the movements of spreading and converging the fingers occurred to and from the centre line of the middle finger, which moved very little. The range of movement of each finger differed significantly from those of the others ($P < 0.01$ in each case), the little finger being the most mobile.

Table 1. *Angles between metacarpals during maximal convergence and divergence*

(Six subjects)

	Maximal convergence	Maximal divergence
Little and ring fingers	7.0 ± 1.8	6.7 ± 1.0
Ring and middle fingers	7.0 ± 1.0	7.5 ± 1.3
Middle and index fingers	8.8 ± 0.8	9.2 ± 0.9
Index and little fingers*	23.4 ± 2.9	23.6 ± 2.4

* The figures for the angles between index and little fingers do not correspond exactly to the sum of the other three angles; the discrepancy represents inaccuracies in the method of measurement.

Table 2. *Movement of phalanges in maximal convergence and divergence*

(Six subjects)

	Mean angles between proximal phalanx and metacarpal		
Finger	Maximal convergence	Maximal divergence	Range of movement
Little	$+16.6 \pm 6.0$	-25.6 ± 3.4	42.2 ± 7.1
Ring	$+8.2 \pm 4.2$	-9.2 ± 3.0	17.4 ± 3.4
Middle	-0.3 ± 3.2	-0.1 ± 4.0	0.2 ± 2.0
Index	-14.2 ± 4.1	$+11.6 \pm 1.8$	25.8 ± 3.3

(2) *Mass deviations*

The same six subjects then deviated all their fingers as strongly as possible, first to the ulnar, and then to the radial side, while retaining the fingers in contact with each other. In Table 3 the angles made by the proximal phalanges of the little and index fingers with their metacarpals under these conditions are compared with the angles obtained during maximal divergence.

Table 3 shows that the restriction on the range of divergent movement of both index

Table 3. *Deviations of index and little fingers in mass deviation and maximal divergence*

(Six subjects)

	Mean maximal deviations		
	Mass deviation	Maximal divergence	Mean differences
Position of little finger during ulnar deviation	$+8.5 \pm 6.6$	-25.6 ± 3.4	34.1 ± 4.5
Position of index finger during radial deviation	-14.8 ± 4.8	$+11.6 \pm 1.8$	26.4 ± 3.4

and little finger imposed by keeping all the fingers in contact with each other was of the order of 30°. It is also striking that in the mass radial deviations the mean figure for the index was a negative deviation of 14·8°, almost identical with the figure obtained during maximal *convergence* of the fingers (Table 2).

(3) *Individual deviations*

In another eleven subjects (five males and six females) the phalanges of the middle finger were arranged, by inspection and palpation, as nearly in a straight line with their metacarpal as possible, and the other fingers were held in loose contact with it. The subject then deviated his index finger as far as possible radially, the other fingers remaining together. The index was then returned to its original position and the little finger was fully deviated to the ulnar side. The results are shown in Table 4.

Table 4. *Individual deviations of index and little fingers*

(Eleven subjects)

	Mean ulnar deviation of little finger (angle of phalanx with metacarpal)	Mean radial deviation of index finger (angle of phalanx with metacarpal)
Males	$-16{\cdot}3 \pm 7{\cdot}3$	$+11{\cdot}3 \pm 5{\cdot}9$
Females	$-20{\cdot}6 \pm 6{\cdot}4$	$+10{\cdot}9 \pm 4{\cdot}1$
Total	$-18{\cdot}6 \pm 6{\cdot}8$	$+11{\cdot}1 \pm 4{\cdot}7$

It will be observed that the little finger had a greater range of ulnar deviation than the index had of radial deviation. This difference reaches statistical significance in the female subjects ($P < 0{\cdot}02$) but not in the males or in the total.

In one subject no change occurred in the alignment of the middle finger during the operation; in all the others the middle finger deviated to the radial side during ulnar deviation of the little finger by a mean angle of 4·7°.

(4) *Effect of position of other fingers*

In another eight subjects (four males and four females) the fingers were first fully deviated to the ulnar side and the little finger was then further deviated as far as possible away from the others. Subsequently all the fingers were deviated radially as

Table 5. *Effect of position of other fingers on deviations of index and little fingers*

(Eight subjects)

Maximal ulnar deviation of little finger with others fully deviated to		Maximal radial deviation of index finger with others fully deviated to	
Ulnar side	Radial side	Ulnar side	Radial side
$-20{\cdot}3 \pm 7{\cdot}0$	$-17{\cdot}9 \pm 9{\cdot}5$	$+13{\cdot}3 \pm 5{\cdot}4$	$+16{\cdot}5 \pm 2{\cdot}9$

far as possible, and the little finger was maximally deviated to the ulnar side from this second position. A similar procedure was then adopted in relation to radial deviation of the index finger. The results in Table 5 do not differ significantly from each other, indicating that maximal radial deviation of the index and maximal ulnar deviation of the little finger were not affected by the position adopted by the other fingers at the time.

(5) *Maximal deviations*

Another 12 subjects (six males and six females) were instructed to deviate all their fingers simultaneously as far as possible to the ulnar side, no attempt being made to keep them together. This was followed by a similar maximal radial deviation of all fingers, the thumb being extended out of the way as a preliminary.

Table 6. *Apparent angles between metacarpals during maximal deviations*

(Twelve subjects)

	Maximal ulnar deviation	Maximal radial deviation
Little and ring fingers	$8{\cdot}2 \pm 1{\cdot}5$	$5{\cdot}5 \pm 1{\cdot}9$
Ring and middle fingers	$6{\cdot}6 \pm 1{\cdot}3$	$6{\cdot}6 \pm 1{\cdot}3$
Middle and index fingers	$7{\cdot}5 \pm 1{\cdot}1$	$8{\cdot}7 \pm 1{\cdot}2$

Table 7. *Movement of phalanges in maximal deviation*

(Twelve subjects)

Finger	Mean maximal ulnar deviation	Mean maximal radial deviation	Range of movement	Midpoint of range
Little	$-25{\cdot}2 \pm 7{\cdot}5$	$+11{\cdot}8 \pm 5{\cdot}5$	$37{\cdot}0 \pm 9{\cdot}8$	$-6{\cdot}7 \pm 4{\cdot}3$
Ring	$-10{\cdot}3 \pm 4{\cdot}6$	$+11{\cdot}7 \pm 3{\cdot}8$	$22{\cdot}0 \pm 6{\cdot}5$	$+0{\cdot}7 \pm 2{\cdot}7$
Middle	$-12{\cdot}8 \pm 5{\cdot}8$	$+12{\cdot}5 \pm 3{\cdot}5$	$25{\cdot}3 \pm 6{\cdot}5$	$-1{\cdot}9 \pm 5{\cdot}2$
Index	$-15{\cdot}6 \pm 13{\cdot}3$	$+14{\cdot}3 \pm 5{\cdot}2$	$29{\cdot}9 \pm 10{\cdot}9$	$-0{\cdot}5 \pm 8{\cdot}4$

In these experiments there was always a degree of rotation of the metacarpals, which was sometimes quite marked. This was most commonly seen in the fifth metacarpal, which rotated so that the pad of the finger came to face slightly radially during radial deviation, and the second metacarpal, which rotated in the opposite direction during ulnar deviation. The other metacarpals exhibited similar, but lesser, amounts of rotation. This movement was presumably associated with an attempt at cupping of the hand and, in cases in which it was well marked, the angle between the rotating metacarpal and its neighbour appeared to alter, as is shown in Table 6, due to the rotating metacarpal being partly drawn into a position of opposition.

The angle between little and ring finger metacarpals appears smaller in radial than in ulnar deviation ($P < 0{\cdot}001$), and the angle between the index and middle finger metacarpals appears smaller in ulnar than in radial deviation ($P < 0{\cdot}005$); there is no change in the angle between the ring and middle finger metacarpals.

Table 7 shows the mean angles achieved by each phalanx with its corresponding metacarpal during maximal ulnar and radial deviation. Because of the metacarpal movements it is virtually certain that the ulnar deviations of the index and the radial deviations of the little finger are somewhat underestimated, since the movement would be viewed at a slight angle by the X-ray tube. However, since some rotation of the metacarpals in the opposite direction occurred during the contrary movements, it is likely that these are also, though perhaps not so greatly, underestimated. It is impossible to put a numerical value on the error, but it is not likely (see Table 6) to be more than a couple of degrees or so.

The standard deviations in Table 7 reflect the considerable individual variation, particularly in the index finger. For example, two subjects could not bring this finger out of radial deviation during a maximal effort at ulnar deviation, whereas three others achieved more than 25° of ulnar deviation.

The maximal ulnar deviation of the little finger is greater than its maximal radial deviation ($P < 0{\cdot}001$), and this gives it a midway position of nearly 7° of ulnar deviation. There are no statistically significant differences between the ulnar and radial deviations of the other fingers, which therefore have mean positions more or less in line with their metacarpals.

The range of movement of the little finger is significantly greater than the ranges of the ring ($P < 0{\cdot}001$) and middle fingers ($P < 0{\cdot}005$). It is greater, but not significantly so, than the range of the index finger, which is in turn significantly greater than that of the ring finger ($P < 0{\cdot}05$).

There were no statistically significant differences between the male and female subjects.

(6) *Comparison of maximal and mass deviations*

Of the twelve subjects used in the previous experiment, six (three males and three females) also undertook mass deviation of the kind previously described in Expt. 2. Table 8 shows that every finger suffered a reduction in its range of movement during mass deviation as compared with maximal deviation; the differences are all

Table 8. *Mean maximal deviations compared with mass deviations*

(Six subjects)

	Ulnar deviation		Radial deviation		Range of movement	
Finger	Maximal	Mass	Maximal	Mass	Maximal	Mass
Little	$-21{\cdot}2 \pm 9{\cdot}4$	$+5{\cdot}2 \pm 9{\cdot}8$	$+12{\cdot}8 \pm 3{\cdot}1$	$+15{\cdot}4 \pm 3{\cdot}1$	$34{\cdot}0 \pm 8{\cdot}1$	$10{\cdot}2 \pm 11{\cdot}2$
Ring	$-8{\cdot}8 \pm 2{\cdot}3$	$-2{\cdot}6 \pm 6{\cdot}7$	$+11{\cdot}8 \pm 3{\cdot}1$	$+10{\cdot}2 \pm 2{\cdot}2$	$20{\cdot}6 \pm 3{\cdot}2$	$12{\cdot}8 \pm 6{\cdot}9$
Middle	$-12{\cdot}7 \pm 3{\cdot}3$	$-11{\cdot}3 \pm 5{\cdot}8$	$+13{\cdot}3 \pm 3{\cdot}8$	$+2{\cdot}9 \pm 4{\cdot}1$	$26{\cdot}0 \pm 4{\cdot}6$	$14{\cdot}6 \pm 9{\cdot}1$
Index	$-19{\cdot}8 \pm 13{\cdot}4$	$-24{\cdot}8 \pm 7{\cdot}1$	$+14{\cdot}2 \pm 6{\cdot}4$	$-11{\cdot}8 \pm 2{\cdot}9$	$34{\cdot}0 \pm 9{\cdot}2$	$13{\cdot}0 \pm 8{\cdot}6$

statistically significant (little finger $P < 0{\cdot}005$; ring finger $P < 0{\cdot}05$; middle finger $P < 0{\cdot}02$; index $P < 0{\cdot}005$). It is interesting that the 'maximal' figure for ulnar deviation of the index is actually *less*, (though not significantly so) than the corresponding 'mass' figure; the result is due to one subject, mentioned above, who for some reason could not deviate her index to the ulnar side beyond an angle of $+6{\cdot}5°$

during maximal deviation, though in the mass deviation she achieved an angle of $-25°$.

As in the group recorded in Table 3, the little finger remained deviated radially during mass ulnar deviation, and in mass radial deviation the index finger remained deviated to the ulnar side.

(7) *Comparison of mass deviations in males and females*

In Expts. 2 and 6 a total of 12 subjects (six male and six female) undertook mass ulnar and radial deviations, and in this aggregated group (Table 9) the range of movement of the little and index fingers was significantly greater in the females than in the males ($P < 0{\cdot}05$ in each case). If the figures for all the fingers are considered together, the females have a highly significant advantage ($P < 0{\cdot}001$).

Table 9. *Ranges of male and female mass deviations*

(Twelve subjects)

Finger	Mean range		
	Males	Females	All subjects
Little	$4{\cdot}4 \pm 2{\cdot}9$	$14{\cdot}3 \pm 10{\cdot}1$	$9{\cdot}3 \pm 8{\cdot}7$
Ring	$8{\cdot}2 \pm 2{\cdot}3$	$14{\cdot}5 \pm 7{\cdot}2$	$11{\cdot}3 \pm 6{\cdot}1$
Middle	$9{\cdot}3 \pm 3{\cdot}5$	$15{\cdot}9 \pm 8{\cdot}7$	$12{\cdot}6 \pm 7{\cdot}2$
Index	$8{\cdot}0 \pm 2{\cdot}1$	$15{\cdot}3 \pm 7{\cdot}7$	$11{\cdot}6 \pm 6{\cdot}6$
All fingers together	$7{\cdot}5 \pm 3{\cdot}2$	$15{\cdot}0 \pm 8{\cdot}0$	$11{\cdot}2 \pm 7{\cdot}1$

POWER OF MOVEMENT

Subjects and material

The 46 subjects used in the second part of the investigation were either medical students or members of the staff of the department. There were 30 males and 16 females, and in all instances the fingers investigated were those of the left hand; only four of the subjects were left handed. Each subject was asked about any special skills involving the left hand—for example, playing of musical instruments or typing.

In an initial survey a few other subjects were rejected because they had one or more digits too powerful for the apparatus available to us. We therefore did not record the upper limits of the forces capable of being exerted by a truly random sample of volunteers, but since all experiments involved direct comparisons rather than absolute values, the validity of the results is not impaired.

A pressure transducer was made for us by the Department of Medical Physics; it consisted of two small rectangular metal strips mounted parallel to each other and 1 cm apart. When pressure was exerted by the finger so as to tend to approximate the ends of the strips the resulting current, read on an ammeter, was linearly proportional to the force applied. The instrument was calibrated in grams by mounting the transducer horizontally and suspending known weights from it. Since the movement of the strip in response to finger pressure was only 1–2 mm, the forces recorded were those of isometric contraction.

The apparatus was firmly mounted on a perforated board in such a way that when the palm of the hand was placed on the board only movement of the finger in the plane of the board could activate the transducer. The board was roughened to afford a good frictional surface for the palm and fingers, and for most of the work was fixed vertically to the side of a chair on a sliding mount which could be adjusted to the length of the subject's arm (Fig. 1). The transducer could be turned round so that either radial or ulnar deviation could be studied.

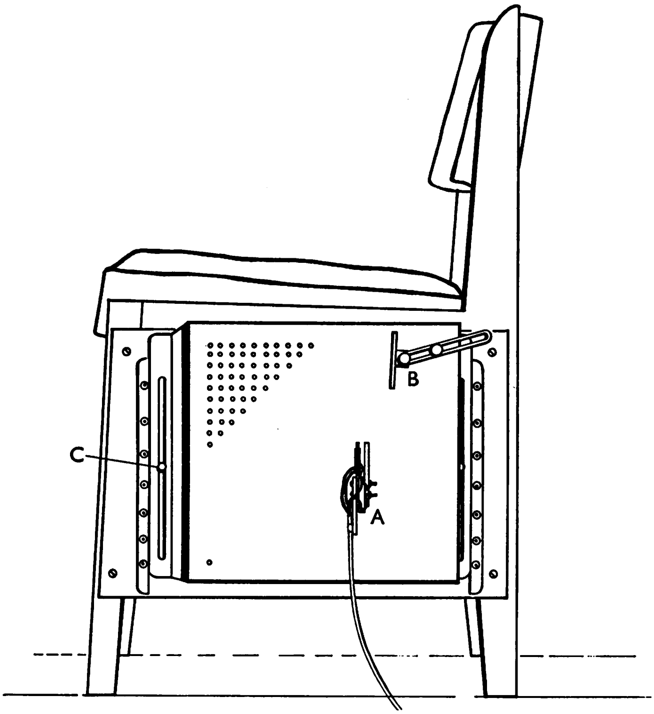

Fig. 1. Chair with perforated board in position (not all the perforations are shown). A, Transducer; B, adjustable metal bar for restraining ulnar side of hand; C, nut in slot allowing adjustments in height of board.

Technique

(1) *Placement of subject*

The subject's left hand was placed flat against the base board with the nail fold of the finger under examination opposite the free end of the metal strip so that the lever length of the finger was constant in all observations made upon it. The finger was parallel to the plane of the transducer strip, and the other fingers were restrained by a small metal peg placed in a convenient hole in the base board (Fig. 2). The ulnar border of the hand was restrained by an adjustable metal bar. These precautions were intended to prevent movement of any part of the hand, other than the finger under investigation, having an effect on the transducer.

Most subjects experienced some difficulty in performing pure lateral movements of the fingers, and showed a tendency to flex them at the metacarpophalangeal joints.

Since this would have introduced a variable and uncontrollable factor into the experiments, the joints were held in extension by light manual pressure applied over the metacarpal region well proximal to the metacarpophalangeal joints.

(2) *Recording*

The subject was then asked to exert maximum pressure against the transducer for 3 s, time being kept by a metronome sounding at one second intervals. The result recorded was the highest maintained reading on the ammeter during that time, any initial surge being ignored. Subjects could not see the ammeter, and were kept ignorant of their performance.

(3) *The standard session*

It was soon found that there might be considerable differences between successive recordings from the same finger, and it was therefore decided to use the mean of six consecutive thrusts with a given finger as the standard of comparison. A standard testing session was devised, in which a reading was taken from each finger in turn, starting with the little finger and ending with the index; this sequence was repeated six times, so giving six readings for each finger. The time allowed for making the necessary adjustments and taking the reading was a quarter of a minute, so that a 'round' of four readings occupied 1 min. The whole session thus took 6 min, timing being done with a stop-watch.

The question of possible fatigue during a standard session at once arose, and in 20 subjects the differences between the six 'rounds' in a single session of ulnar deviation were investigated. There was no statistical evidence of any fatigue, or, conversely, of any improvement during a session, nor was there any such evidence when the data were further broken down to examine possible differences in the performance of individual fingers. It therefore appeared that fatigue was not a factor which had to be considered within a given session.

(4) *Effect of initial stretch of muscles*

Another obvious point concerned the degree of separation between the thrusting finger and the neighbour towards which it was attempting to move. This could never be less than the width of the transducer (1 cm), but by varying the distance of the 'target' finger (Fig. 2) from the transducer by the position of the metal peg it was possible to show that, as might be expected, the thrust increased with the distance between the finger tips.

The magnitude of the effect was investigated by measuring the ulnar thrust of the middle finger while the ring finger was forced away from it by the peg at successively greater angles. Variations in the size of the hands and in the lengths of fingers caused individual variations in the angles produced by this procedure, but the four positions of the peg which were used produced angles of roughly 5, 10, 20 and 35°; no subject was able to diverge his fingers beyond the fourth position of the peg. The results are shown in Table 10, and indicate a significant difference between the first position and the third and fourth positions. For this reason, in all subsequent work, the restraining peg was placed as close to the transducer as possible, so keeping the angle between the thrusting finger and its neighbour minimal.

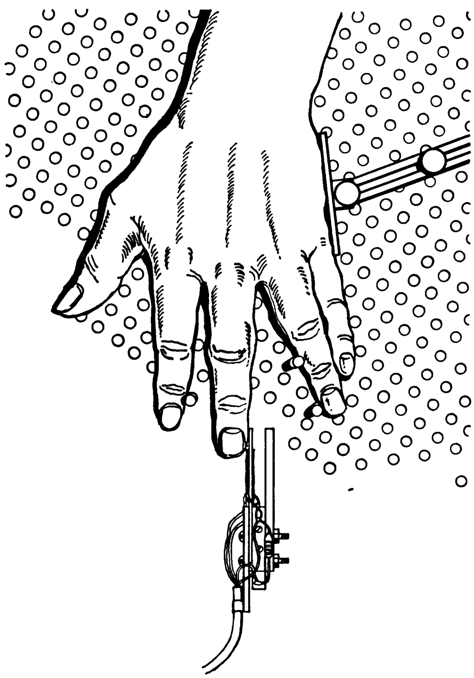

Fig. 2. Position for testing ulnar deviation of middle finger. The index finger is prevented from assisting it by a peg inserted into one of the holes in the board. In this experiment the effect of altering the angle between the thrusting finger and the finger towards which it is thrusting (the 'target' finger) is being investigated; the target finger is held away from the thrusting finger by another two pegs (see text): in practice only one such peg was used.

Table 10. *Effect of initial stretch of muscle*

(Six repetitions in each of 5 subjects: mean thrusts in grams)

	Position 1 (angle approx. 5°)	Position 2 (angle approx. 10°)	Position 3 (angle approx. 20°)	Position 4 (angle approx. 35°)
Mean	633·3*	685·0**	764·6	837·7
s	171·1	175·3	182·7	170·5

* Significantly lower than position 3 figure ($p < 0{\cdot}01$) and position 4 figure ($p < 0{\cdot}001$).
** Significantly lower than position 4 figure ($p < 0{\cdot}005$).

(5) *Effect of position of upper limb*

Most of the experimental work in this series was done with the subject sitting with the hand hanging down by his side and the board mounted vertically. Not only was this the most comfortable position for both subject and observer, but it was the only position in which the nerve blocking experiments which followed this investigation could be carried out. In certain of the experiments, however, it proved necessary to work with the board horizontal and the subject's elbow on the table; it was clearly essential to find out whether this change of posture would affect the results.

Accordingly, a group of six subjects underwent a standard session on the horizontal board which was compared with another standard session on the vertical board. Because of the possibility of 'learning' taking place, three of the group began with the horizontal session, and three with the vertical session. No statistically significant differences were found between the results from the two different positions.

Results

(1) *Learning*

A group of eight subjects (four males and four females) underwent six standard sessions of ulnar deviation with intervals of 1 week between each session. Seven of the subjects exhibited some evidence of learning in that one or more of their subsequent sessions showed a statistically significant improvement ($P < 0.05$ or better) on their initial mean score per thrust. The remaining subject showed a statistically significant deterioration, the scores for the third and subsequent sessions in this individual all being significantly lower than the initial score.

Table 11. *Effect of learning*

(Eight subjects; six sessions at weekly intervals: mean thrusts in grams)

	Session number					
Subject	1	2	3	4	5	6
1	378·3	325·4	316·3	382·9	484·6*	434·2
2	301·7	352·5	347·9	314·6	380·8*	510·0***
3	614·2	710·4	766·3*	751·3	722·9	770·4*
4	399·6	383·8	312·5*	310·0*	297·1**	302·1*†
5	360·0	435·8	474·6*	485·4*	444·6	544·2***
6	472·1	539·6	563·3	630·0	617·9	718·3**
7	338·6	369·2	387·9	432·5	437·5	459·6*
8	579·2	616·3	639·6	702·5*	618·8	683·3
Mean	430·5	466·6	476·0	499·4**	500·5**	550·6***

* Significantly different ($p < 0.05$) from first session.
** Significantly different ($p < 0.01$) from first session.
*** Significantly different ($p < 0.001$) from first session.
The differences are all increases except in subject 4, where they are decreases.
† Deterioration.

The mean scores for all digits considered together showed a steady rise, which by the fourth session had become statistically significant. By the final session the mean score showed a 28 % improvement on the initial score.

All individual fingers improved on their initial performance, but the improvement was more striking in some than in others. The rise in the scores of the ring finger (62 % between first and final session) became statistically significant at the 5 % level at the second session; the improvement of the middle finger (37 % overall) became significant by the fourth session; that for the little finger (34 %) by the fifth session, and that for the index finger (8 %) never achieved statistical significance (Fig. 3).

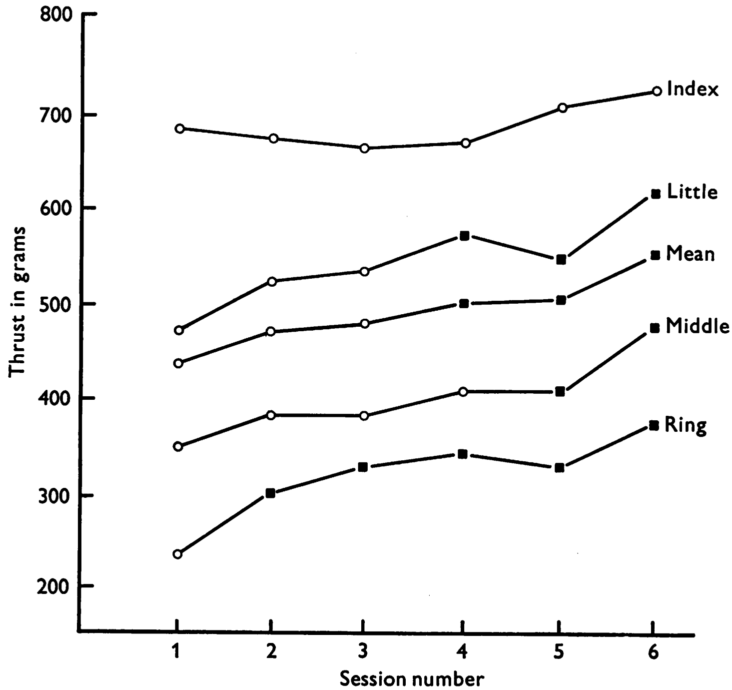

Fig. 3. Effect of 'learning' on mean scores of individual fingers in eight subjects. The black squares indicate a statistically significant ($P < 0{\cdot}05$ or better) improvement on the mean score obtained in session number 1.

(2) *Relative strengths of individual fingers: ulnar deviation*

Fig. 3 indicates that ulnar deviation was not equally powerful in all fingers, and the point was further investigated in an additional 12 subjects, making a total of 20, of whom 11 were male and 9 female. All the figures shown in Table 12 were obtained at the initial sessions for each subject, and therefore represent the untrained situation.

The means in the table all differ significantly from each other ($P < 0{\cdot}001$ in each case), so that the order of untrained strength in ulnar deviation was: index, little, middle, and ring fingers. If the mean thrust of the index finger is taken as 100 %, the relative thrusts of the other fingers were: little finger 82 %, middle finger 57 %, and ring finger 44 %. When the females are compared with the males, the results shown in Table 13 are obtained. The female means, as would be expected, are significantly smaller than the male means, and the greatest difference is in the power of the middle finger.

A comparison was also made between the nine subjects in this group who typed or played musical instruments (piano, guitar, etc.) demanding a use of the fine control of the left hand, and the remainder who disclaimed such experience. No significant differences were found between the two groups, nor did there appear to be any advantage in being left-handed, though the numbers in this group were too small to allow of statistical treatment.

Table 12. *Relative strengths of fingers*

(Twenty subjects: mean thrusts in grams; ulnar deviation)

	Finger			
	Little	Ring	Middle	Index
Mean	658·4	357·2	459·5	807·5
s	232·4	142·0	177·9	216·5

Table 13. *Relative strengths of fingers: comparison of males and females*

(Eleven males, nine females; mean thrusts in grams; ulnar deviation)

	Finger				
	Little	Ring	Middle	Index	Mean
Males	713·3	383·5	541·2	902·1	635·0
Females	569·1	325·2	359·6	691·9	486·4
Female mean as % of male mean	80	85	66	77	77
Significance of difference: P less than	0·001	0·05	0·001	0·001	0·001

(3) *Comparison of ulnar and radial deviations*

In 12 subjects the force of radial deviation of the fingers was measured and compared with the force of ulnar deviation of the same fingers in the same subjects. Because of the possible influence of learning, the standard session for ulnar deviation preceded the session for radial deviation in six of the subjects, and followed it in the remainder.

The results in Table 14 show that the descending order of strength in radial deviation was: index, middle finger, little finger, and ring finger; all differences are statistically significant ($P < 0{\cdot}001$). The index was thus the most powerful of the fingers in both radial and ulnar deviation, and the ring finger the weakest: in radial deviation the middle finger became stronger than the little finger, whereas in ulnar deviation the reverse was true.

If the mean radial thrust of the index finger is taken as 100, the relative thrusts of the other fingers were:

Radial deviation of index	100 %
Ulnar deviation of index	86 %
Ulnar deviation of little finger	73 %
Radial deviation of middle finger	71 %
Radial deviation of little finger	62 %
Ulnar deviation of middle finger	50 %
Radial deviation of ring finger	49 %
Ulnar deviation of ring finger	44 %

Table 14. *Radial against ulnar deviation*

(Mean thrusts in grams, each derived from six observations)

	Little finger		Ring finger	
Subject	Radial	Ulnar	Radial	Ulnar
1	545·0	1006·7 (*a*)	548·3 (*a*)	363·6
2	461·7	446·7	398·3	408·3
3	520·0	686·7 (*b*)	380·0	403·3
4	346·7	615·0 (*a*)	245·0	323·3 (*b*)
5	711·7 (*a*)	360·0	421·7	380·0
6	531·7	856·7 (*b*)	531·7	650·0
7	320·0	500·0 (*b*)	425·0 (*a*)	165·0
8	400·0	623·3 (*a*)	323·3 (*a*)	246·7
9	783·3	890·0	643·3	775·0
10	401·7	548·3 (*b*)	340·0	278·3
11	940·0	1081·7 (*c*)	701·7	785·0
12	866·7	476·7 (*a*)	481·7 (*a*)	70·0
Mean	569·0	674·4 (*b*)	453·3	404·0
s	21·1	23·5	14·5	22·9
	Ulnar stronger		Neither stronger	

	Middle finger		Index finger	
Subject	Radial	Ulnar	Radial	Ulnar
1	883·3	620·0	1015·0	993·3
2	751·7 (*a*)	453·3	750·0	776·7
3	681·7 (*a*)	480·0	1016·7 (*c*)	893·3
4	350·0	321·7	836·7 (*b*)	618·3
5	763·3 (*a*)	371·7	1065·0 (*a*)	481·7
6	890·0 (*a*)	728·3	1031·7	1051·7
7	596·7 (*a*)	296·7	925·0 (*a*)	565·0
8	583·3 (*a*)	360·0	910·0 (*b*)	591·7
9	751·7	656·7	1090·0	1090·0
10	585·0 (*a*)	335·0	945·0 (*c*)	780·0
11	671·7	616·7	1031·7 (*b*)	906·7
12	338·3	323·3	410·0	731·6 (*a*)
Mean	653·9 (*a*)	463·6	918·9 (*a*)	790·0
s	18·7	16·3	19·4	20·6
	Radial stronger		Radial stronger	

a = significantly stronger than thrust in opposite direction ($p < 0·001$).
b = significantly stronger than thrust in opposite direction ($p < 0·01$).
c = significantly stronger than thrust in opposite direction ($p < 0·05$).

The table also shows that in the little finger ulnar deviation was significantly stronger than radial deviation, but that in the middle and index fingers radial deviation was the stronger movement, while in the ring finger there was no significant difference between the two.

(4) *Effect of flexion of metacarpophalangeal joints*

Six subjects each performed three standard sessions; in one the metacarpophalangeal joints were flexed at an angle of 180°, in another at 135°, and in the third at 90°. The order in which the sessions were taken was as usual randomized. In all cases the board was horizontal, and for the 90° angle the fingers were placed horizontally on the raised board, the palm being in the vertical plane at the edge of the board. For the 135° angle a 45° wedge was attached to the side of the board and the palm was placed on this with the fingers flat on the board.

Table 15. *Effect of angle of metacarpophalangeal joints*

(Interphalangeal joints straight; metacarpophalangeal joints at angles of 180°, 135° and 90°. Mean thrusts in grams derived from six observations on each finger of six subjects)

Finger	Little			Ring		
Angles	180°	135°	90°	180°	135°	90°
Mean thrust	600·3	663·3	345·6	354·2	546·1	303·6
s	190·5	255·4	171·2	218·3	211·3	117·6
	Middle			Index		
Angles	180°	135°	90°	180°	135°	90°
Mean thrust	421·7	632·2	532·5	786·9	784·2	728·3
s	134·7	270·5	225·0	198·6	259·0	199·9

	Means of all fingers considered together		
Angles	180°	135°	90°
Mean thrust	540·8**	656·5*	477·5
s	251·3	261·8	247·6

* Significantly greater than either 180° or 90° ($p < 0{\cdot}001$)
** Significantly greater than 90° ($p < 0{\cdot}05$)

Table 15 shows that there was a significant difference between the overall means in the three positions, ulnar thrust being most powerful when the joints were flexed to 135°, and least powerful when they were further flexed to 90°. Individual fingers showed some variation from this pattern; for example, the middle finger was unusual in that an angle of 90° gave a thrust significantly better than an angle of 180° ($P < 0{\cdot}02$), and the index finger showed no significant differences in thrust with varying angles. In the little finger 135° was not significantly better than 180°, but both were better ($P < 0{\cdot}001$) than 90°. In the ring finger 135° was better than both 180° and 90° ($P < 0{\cdot}001$).

DISCUSSION

Under the experimental conditions imposed the movements of maximal divergence and convergence of the fingers occurred entirely at the metacarpophalangeal joints. But when the fingers were strongly deviated to one side or the other, there was rotation of the metacarpals so that the pads of the fingers attempted to turn in the direction of the movement. This rotation was greatest in the second metacarpal in ulnar deviation, and in the fifth metacarpal in radial deviation. There also appeared to be some cupping of the ulnar side of the hand during radial deviation of the fingers, so that, on a radiograph in which the path of the rays was normal to the anatomical position of the hand, the angle between the fifth and fourth metacarpals appeared to lessen. This movement was presumably due to activity of the opponens digiti minimi.

Hakstian & Tubiana (1967) measured with a goniometer the range of passive movement of the fingers in 100 living hands and in 80 dissected specimens, and concluded that the long axis of the hand should be taken as a line through the ring finger. Our results with active movement do not support this contention, for divergence and convergence of the fingers appeared to centre on the middle finger, as found by Duchenne (1867).

During this movement the excursion of the little finger was considerably greater than that of the other fingers, and this relative freedom of the little finger was confirmed (at least for our female subjects) in experiments in which individual deviation of the little finger was compared with individual deviation of the index (Table 4). These movements were not influenced by the position of the other fingers at the time (Table 5), but mass deviation of the fingers as a group substantially reduced the freedom of every individual finger (Table 8). The reason for this is not clear; one can understand that the range of the more mobile fingers would be brought down to correspond with that of the least mobile one, but not that *every* finger should have its mobility restricted. It is also interesting that the female subjects should be superior in their ability to deviate their fingers as a unit; it could be argued that this was due to a relative laxity of the capsules of the metacarpophalangeal joints, were it not for the fact that there was no sex difference in the ability of the same subjects to perform maximal individual deviations of the fingers.

Table 16. *Comparison of active and passive deviations*

Finger	Maximal ulnar deviation		Maximal radial deviation		Midpoint of range	
	Active*	Passive†	Active*	Passive†	Active*	Passive†
Little	−25·2	−31·6	+11·8	+15·9	−6·7	−7·8
Ring	−10·3	−22·0	+11·7	+14·4	+0·7	−3·8
Middle	−12·8	−33·4	+12·5	+8·0	−1·9	−12·7
Index	−15·6	−41·5	+14·3	+12·7	−0·5	−14·4

* Present investigation. † Hakstian & Tubiana (1967).

In these maximal deviations the little finger again had the greatest range of movement, and the mid-point of its range fell at about 7° of ulnar deviation; the mid-points of the ranges of the other fingers were practically in a straight line with their metacarpals. If the mid-point is taken as the 'position of rest', this would indicate that only the little finger lies in ulnar deviation when the hand is at rest. This conclusion is contrary to that of Hakstian & Tubiana, who took as the position of rest the mid-point of the range of *passive* movement, and concluded that all four fingers lay in ulnar deviation when at rest, the ring finger having the least and the index the greatest divergence from the line of the metacarpal. They suggested that the 'normal zone of function' of the fingers centres round a position of ulnar deviation. As might be anticipated (Salter, 1955), the ranges they obtained by passive movement were greater than the ranges we recorded for active movement, but it is noteworthy that the difference was greater in the ulnar than in the radial direction (Table 16), and particularly so in the index and the middle finger. The reason for this discrepancy is almost certainly the asymmetry of the collateral ligaments of the metacarpophalangeal joints (Landsmeer, 1955), which is most marked in the index and middle fingers, and which limits radial deviation while allowing fairly free ulnar deviation. It should perhaps be stressed that in none of our subjects was ulnar deviation limited by the obstruction of other fingers. The fact that in the experiments of Hakstian & Tubiana the metacarpophalangeal joints were slightly flexed is not relevant, since their results remained substantially the same when the joints were straight.

The whole concept of the 'position of rest' is rather vague. Ellis (1878) described it as 'somewhere about a mean between the ranges of easy motion', and the term is now used to refer to a position in which there is universal slackness of the ligaments as well as complete relaxation of the muscles (Barnett, Davies & MacConaill, 1961). It seems just as reasonable to use the range of active movement to determine the 'normal zone of function' as to use passive movement; the one result gives the rest position of the muscles and the other the rest position of the ligaments.

Several attempts have been made to devise apparatus to measure the forces exerted by movements of the fingers, and the literature is reviewed by Mannerfelt (1966), who used a specially constructed dynamometer. His method differs substantially from ours, principally in the length of lever used, so his numerical results are not comparable. No one seems to have used strain gauge transducers for this purpose, which is surprising in view of their convenience and accuracy. Clinical methods of assessing the power of ulnar and radial deviation are crude, the most commonly used test being that in which a card is held between two fingers by the patient and withdrawn against his resistance by the examiner. The quantitative technique of evaluating isometric contractions described in this paper is simple, and the method might prove useful in nerve injury clinics, where it could afford an objective measurement of recovery (Salter, 1955). A similar method could be used to assess recovery in the short muscles of the thumb, and indeed we ourselves have employed a heavier transducer to investigate adduction of the thumb.

Our results show that ulnar deviation of the fingers, like most movements, can be 'learned', and that improvement with repetition was maximal in the ring finger and minimal in the index. It is possible that in most people the index is already fully 'educated' in the movement, whereas the ring finger is not commonly used as an ulnar deviator in everyday life. There is no ready explanation for the deterioration, as opposed to improvement, shown by one of the experimental subjects. Loss of interest or boredom does not seem likely as this subject was among the keenest in the group.

The relative untrained strengths of the individual fingers are of some importance in relation to the almost invariable occurrence of ulnar, as opposed to radial, deviation in rheumatoid arthritis and other clinical conditions. Present opinion seems to favour the anatomy of the metacarpophalangeal joints as the primary factor in ulnar drift, but the pull of the intrinsic muscles is sometimes incriminated as an accessory (Marmor, 1963; Smith & Kaplan, 1967). The finding that in full extension of these joints the movement of ulnar deviation is only stronger than that of radial deviation in the little finger, whereas radial deviation is the stronger in both index and middle fingers, does not fit well with any hypothesis which depends on an unbalanced pull of the intrinsic muscles. Hakstian & Tubiana (1967) used their conclusion that the fingers normally operate from a position of ulnar deviation to explain why they would naturally tend to be pulled further in this direction rather than to be forced right round into radial deviation. As mentioned above, our findings do not support this idea.

Table 17. *Muscles known or suspected to be concerned in radial and ulnar deviation of individual fingers*

Finger	Ulnar deviation	Radial deviation
Little	Abductor digiti minimi Extensor digiti minimi Flexor carpi ulnaris† Extensor digitorum‡	Fourth palmar interosseus Fourth lumbrical* Flexor digitorum profundus‡ Flexor digitorum superficialis‡
Ring	Fourth dorsal interosseus Extensor digitorum‡	Third palmar interosseus Third lumbrical‡ Flexor digitorum profundus‡ Flexor digitorum superficialis‡
Middle	Third dorsal interosseus	Second dorsal interosseus Second lumbrical‡
Index	Second palmar interosseus Extensor indicis Flexor digitorum profundus‡ Flexor digitorum superficialis‡	First dorsal interosseus First lumbrical* Extensor digitorum‡

* Perhaps more likely than other lumbricals.
† Fibres may be directly continuous with abductor.
‡ Doubtful.

It is perhaps not surprising that the index finger should be the strongest individual finger in both ulnar and radial deviation, and indeed it seems very well equipped to make forceful movements of this kind, perhaps because of their importance in precision grips (Bowden & Napier, 1961). It is a little more unexpected to find the little finger stronger than the more massive middle finger in ulnar deviation, but the little finger has two or more abductors, while the middle finger has a more meagre power supply (Table 17). It would be interesting to know the reason why the middle finger showed the greatest sex difference in power, but again no explanation comes to mind. Those who played musical instruments or typed performed no better than the others, possibly because these occupations, so well publicized as requiring full function of the intrinsic musculature, may tend to involve the range rather than the power of the interossei.

Table 17 shows the various muscles currently supposed to be concerned in the movements of ulnar and radial deviation of the fingers. The interossei are universally agreed to be of primary importance, and it is also accepted that the long extensors 'spread' the fingers as they extend them, while the long flexors converge them as they flex them. These muscles, however, probably do not influence deviations of individual fingers (Wood Jones, 1919), with the exception of the tendon of the extensor digitorum to the index finger, which in paralysis of the first dorsal interosseus can, when stimulated faradically, deviate the index radially (Duchenne, 1867). The extensor digiti minimi is claimed as an important and strong ulnar deviator of the little finger (Duchenne, 1867; Wood Jones, 1919, 1949), and electromyography (Forrest & Basmajian, 1965) reveals that during ulnar deviation of the little finger the opponens digiti minimi and the flexor digiti minimi brevis are also active, although the opponens cannot contribute in any way to movement at the metacarpophalangeal joint, and the direction of the pull of the flexor makes it also an unlikely abductor (Hollinshead, 1964). The tendon of flexor carpi ulnaris stabilizes the pisiform as a base for the abductor digiti minimi, and its fibres are often prolonged directly into the shorter muscle (Poirier & Charpy, 1901; Paturet, 1951); it seems possible that it might on occasion help to abduct the little finger, though the results of stimulation do not support this concept. Duchenne (1867) and Wood Jones (1919) claimed an ulnar deviating action for the extensor indicis, and on anatomical grounds it is at least as good a candidate for the job as the extensor digiti minimi in the little finger.

The action of the lumbricals in deviation of the fingers is much less clear, though their position on the lateral side of the extensor hood leads to the inference that they can assist radial movements. Duchenne (1867) found that only the first lumbrical could do this, and that in a limited fashion only. On the other hand, Braithwaite, Channell, Moore & Whillis (1948), who stimulated lumbricals exposed at operation, found that they produced radial deviation and rotation. They considered that, when the metacarpophalangeal joints are flexed, the lumbricals are more effective radial deviators than the dorsal interossei; Mannerfelt (1966) also believes the lumbricals can act to some extent in radial deviation. However, Eyler & Markee (1954), who investigated the results of nerve blocks in human and simian subjects, concluded that 'significant radial deviation of the digits by the lumbricals could not be demonstrated'. The exact evidence is nowhere stated, and one would have liked more detail before dismissing the lumbricals as radial deviators. Backhouse & Catton (1954) recorded from and stimulated the second lumbrical in intact human volunteers, and showed that this lumbrical appeared to have no effect either on radial deviation or on rotation of the middle finger. But in three out of 29 dissected hands examined by Eyler & Markee (1954) the fourth lumbrical was exclusively inserted into the proximal phalanx of the little finger, and it is difficult, in spite of the lack of positive functional evidence, to resist the conclusion that, in such cases at least, the fourth lumbrical could act as a radial deviator.

The size and attachments of the interossei may be important in determining individual variations in thrust. Eyler & Markee (1954) found that each palmar interosseus in their series of dissected hands was about twice the mass of a lumbrical and about half the mass of a dorsal interosseus. The first dorsal interosseus inserts almost exclusively into the proximal phalanx, while the third dorsal inserts almost exclusively into the extensor hood; the other dorsal interossei have mixed insertions (Landsmeer, 1949, 1955). The palmar interossei insert into the extensor hood, and have much less tendency to achieve a bony insertion than their dorsal colleagues (Eyler & Markee, 1954; Landsmeer, 1955). These facts help to explain why radial deviation of the index and middle finger in our series should be more powerful than ulnar deviation (Table 17), but also suggest that ulnar deviation of the ring finger ought to be stronger than radial deviation. Our findings tend in the opposite direction, but the difference is not statistically significant.

The abductor digiti minimi is fully comparable to a dorsal interosseus (Lewis, 1965), and has similar insertions to those of the fourth dorsal interosseus.

A further complication is added by the differences in the lines of pull of the various muscles concerned as the metacarpophalangeal joint is flexed. In our series, flexion to 135° facilitated the pull of the muscles producing ulnar deviation, but further flexion to 90° considerably hindered ulnar deviation, almost certainly because the collateral ligaments of the metacarpophalangeal joints are tightened up in this position (Landsmeer, 1955). In flexion it is possible that the extensor tendons may partly slip towards the side of an already deviated finger, and so help to deviate it further; this may be a factor contributing to the greater force it is possible to exert during partial flexion.

The attempted flexion of the metacarpophalangeal joints with which most of our subjects accompanied their efforts at deviation probably resulted from the pull of the major deviators, the interossei and the abductor digiti minimi.

SUMMARY AND CONCLUSIONS

1. Experiments on the range of the movements of ulnar and radial deviation of the fingers suggest that the long axis of the hand runs through the middle finger, and that the normal 'position of rest' of the proximal phalanges is in line with the metacarpals, except for the little finger, which probably lies in slight ulnar deviation.
2. The little finger has a significantly greater range of movement than the others.
3. If the fingers are kept together during ulnar or radial deviation, a considerable restriction on the movement of *every* finger results. Our female subjects were less hampered by this restriction than the male subjects, but were no better at free maximal deviation in either direction.
4. A method of quantitative and satisfactorily reproducible assessment of the forces produced by such movements is described, and could be used clinically.
5. 'Learning' of these movements occurs with practice, being maximal in the ring finger and minimal in the index.
6. Of the untrained fingers, the index is the strongest in both radial and ulnar deviation and the ring finger is the weakest. In ulnar deviation the little finger is stronger than the middle finger, but in radial deviation the reverse is true.
7. Radial deviation is stronger than ulnar deviation in the index and middle fingers, and ulnar deviation is stronger in the little finger; neither movement is stronger in the ring finger. The pull of the intrinsic muscles does not, therefore, appear to be a primary factor in initiating ulnar drift in disease conditions though once drift has begun their tension might aggravate it.
8. The power of ulnar deviation is increased by bending the metacarpophalangeal joints to an angle of 135°, but diminished by bending them to 90°.

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REFERENCES

BACKHOUSE, K. M. & CATTON, W. T. (1954). An experimental study of the functions of the lumbrical muscles in the human hand. *J. Anat.* **88**, 133–141.

BARNETT, C. H., DAVIES, D. V. & MACCONAILL, M. A. (1961). *Synovial Joints*. London: Longmans.

BOWDEN, R. E. M. & NAPIER, J. R. (1961). The assessment of hand function after peripheral nerve injuries. *J. Bone Jt Surg.* **43**B, 481–492.

BRAITHWAITE, F., CHANNELL, G. D., MOORE, F. T. & WHILLIS, J. (1948). The applied anatomy of the lumbrical and interosseous muscles of the hand. *Guy's Hosp. Rep.* **97**, 185–195.

DUCHENNE, G. B. A. (1867). *Physiologie des mouvements démontrée à l'aide de l'experimentation électrique et de l'observation clinique et applicable à l'étude des paralysies et des dégénerations.* Translated and edited by Kaplan, E. B. as *Physiology of Motion*. Philadelphia: Lippincott, 1949.

ELLIS, T. S. (1878). The position of rest in fatigue and in pain. *Br. med. J.* i, 84–85.

EYLER, D. L. & MARKEE, J. E. (1954). The anatomy and function of the intrinsic musculature of the fingers. *J. Bone Jt Surg.* **36**A, 1–9.

FORREST, W. J. & BASMAJIAN, J. V. (1965). Functions of human thenar and hypothenar muscles. *J. Bone Jt Surg.* **47**A, 1585–1594.

HAKSTIAN, R. W. & TUBIANA, R. (1967). Ulnar deviation of the fingers. *J. Bone Jt Surg.* **49**A, 299–316.

HOLLINSHEAD, W. H. (1964). *Anatomy for Surgeons:* Vol. 3, *Back and Limbs*. New York: Hoeber.

JONES, F. W. (1919). Voluntary muscular movements in cases of nerve lesions. *J. Anat.* **54**, 41–57.

JONES, F. W. (1949). *The Principles of Anatomy as seen in the Hand*, 2nd ed., London: Baillière, Tindall and Cox.

LANDSMEER, J. M. F. (1949). The anatomy of the dorsal aponeurosis of the human finger and its functional significance. *Anat. Rec.* **104**, 31–44.

LANDSMEER, J. M. F. (1955). Anatomical and functional investigations on the articulation of the human fingers. *Acta anat.* Suppl. **24**, 1–69.

LEWIS, O. J. (1965). The evolution of the mm. interossei in the primate hand. *Anat. Rec.* **153**, 275–288.

MANNERFELT, L. (1966). Studies on the hand in ulnar nerve paralysis. *Acta orthop. scand.* Suppl. **87**, 1–176.

MARMOR, L. (1963). The role of hand surgery in rheumatoid arthritis. *Surgery Gynec. Obstet.* **116**, 335–339.

PATURET, G. (1951). *Traité d'Anatomie Humaine*. Paris: Masson.

POIRIER, P. & CHARPY, A. (1901). *Traité d'Anatomie Humaine*. Paris: Masson.

SALTER, N. (1955). Methods of measurement of muscle and joint function. *J. Bone Jt Surg.* **37**B, 474–491.

SMITH, R. J. & KAPLAN, E. B. (1967). Rheumatoid deformities at the metacarpophalangeal joints of the fingers. *J. Bone Jt Surg.* **49**A, 31–47.