THE EFFECT OF THE DEGREE OF ELBOW FLEXION ON THE MAXIMUM TORQUES DEVELOPED IN PRONATION AND SUPINATION OF THE RIGHT HAND

By NANCY SALTER and H. D. DARCUS

Unit for Research on Climate and Working Efficiency of the Medical Research Council, Department of Anatomy, University of Oxford

This work is a continuation of a previous investigation made by Darcus (1951) on the effect of different hand, elbow and shoulder positions on the maximum isometric torques that can be exerted in attempted pronation and supination of the right hand.

METHODS

The maximum torques that can be developed isometrically in attempted pronation and supination were determined with the hand in six positions between full pronation and full supination. The measurements were carried out with the arm adducted and with the elbow flexed to 150° (A), 90° (B) and 30° (C) (full extension of the elbow ≡ 180°).

The position of the hand with the palm facing medially was taken as 0°. Angular displacements of pronation were recorded as minus and of supination as plus. Data were obtained with the hand at −60, −30, 0, +30, +60 and +90°. All these positions fell within the full range of movement of each subject.

The subjects were three naval ratings, ages 18, 19 and 27 years, with no apparent physical defect. Each was right-handed. They had had no previous experience of the apparatus.

All hand positions in each of the three elbow positions were studied in all three subjects on each of 6 consecutive days. The order in which the hand positions and the direction of the attempted movement were taken was randomized. Half an hour was allowed between the runs in each different elbow position.

The torques were recorded by means of an electrical strain-gauge dynamometer (Darcus, 1951).

RESULTS

The effect of hand position on the maximum torques developed in attempted pronation and supination. The results of the present series of experiments confirm that there is a linear relationship between the position of the hand and the isometric torque developed, and that as the position of the hand alters in the direction of supination, so the isometric pronation torque increases and the supination torque decreases (Fig. 1). In one individual there is an exception to this general finding; with the elbow flexed to 30°, there was found to be no significant correlation between the torque of supination and the position of the hand. Although this linear relationship generally exists, it can be seen from graphs drawn from the raw data (Fig. 1) that the slope of the curves is steeper towards the full pronation end of the pronation curves and towards the full supination end of the supination curves. In both the

pronation and supination curves, there is a sharp change of slope at hand position +30°. This, however, is more marked in pronation.

For each subject, the slopes of the pronation curves are steeper than those of the corresponding supination curves. The slopes of the curves, both for pronation and supination, are greatest when the elbow is flexed to 150°, and least when the elbow is flexed to 30° (Fig. 1 and Table 1).

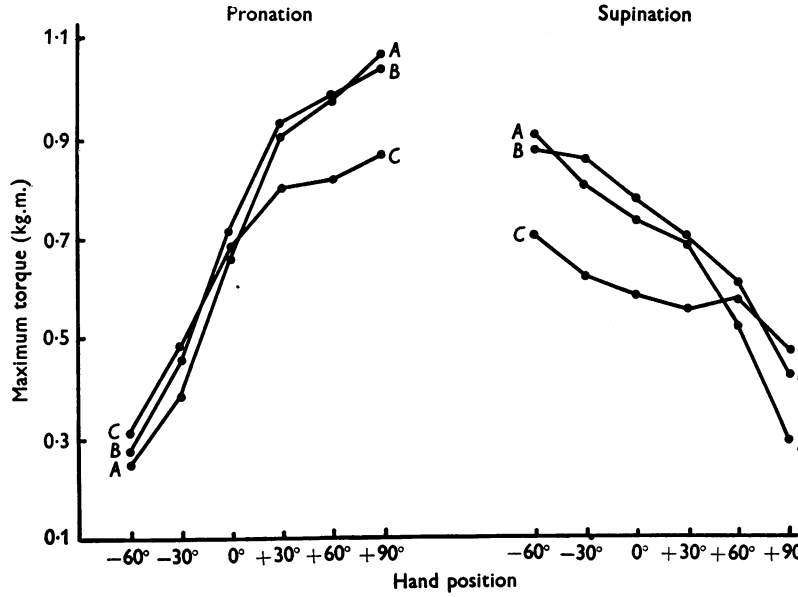

Fig. 1. Maximum torques exerted in different hand positions. Average of eighteen observations on the three subjects: (A) elbow flexed to 150°, (B) to 90°, and (C) to 30°.

Table 1. *Average difference between torques exerted in successive hand positions*

Subject	Flexion of elbow (°)	Pronation (kg.m.)	Supination (kg.m.)
I	150 (A)	0·147	0·123
II	150	0·167	0·108
III	150	0·207	0·109
I	90 (B)	0·132	0·102
II	90	0·159	0·091
III	90	0·190	0·073
I	30 (C)	0·054	0·001
II	30	0·105	0·048
III	30	0·174	0·060

The effect of elbow position on the average maximum torques in attempted pronation and supination. As discussed in the previous paper, a more representative estimate of the relative strengths of pronation and supination in the different elbow positions may be obtained by calculating from the regression lines the torques at the mid-point of the full range of movement (Table 2). As the mid-point of the range tested (i.e. +15°) does not differ greatly from the mid-point of the full range in any elbow position, the results obtained from the raw data are essentially the same (Table 2).

It can be seen in Fig. 2 that the strongest position for pronation and for supination is with the elbow flexed to 90° and the weakest with the elbow flexed to 30°, with

one exception. This is in subject II, in which the pronation torque is smallest with the elbow flexed to 150°, but the difference between the torque in this position and that with the elbow flexed to 30° is small (0·01 kg.m.) and not significant.

The degree of elbow flexion has a much more pronounced effect on the supination torque than on the pronation torque. The average difference between the average supination torques in each of the elbow positions is double that between the average pronation torques.

Table 2. *Average torque of pronation and supination for the range of hand positions tested and at the mid-point of the full range of movement*

		Range tested (−60° to +90°)			Mid-point of full range			
		Average torque			Average torque			
Subject	Elbow flexion (°)	Pronation (kg.m.)	Supination (kg.m.)	Percentage difference (S≡100)	Pronation (kg.m.)	Supination (kg.m.)	Percentage difference (S≡100)	Mid-point of full range (°)
I	150 (A)	0·69	0·60	15·0	0·69	0·59	16·9	+14·5
	90 (B)	0·67	0·69	−2·9	0·69	0·68	1·5	+18·0
	30 (C)	0·61	0·58	5·2	0·62	0·58	6·9	+21·0
II	150 (A)	0·56	0·54	3·7	0·55	0·55	0	+12·0
	90 (B)	0·61	0·60	1·7	0·62	0·60	3·3	+16·5
	30 (C)	0·54	0·49	10·2	0·56	0·48	16·7	+23·0
III	150 (A)	0·87	0·83	4·8	0·93	0·81	14·8	+20·0
	90 (B)	0·92	0·83	10·8	0·94	0·82	14·6	+19·5
	30 (C)	0·84	0·69	21·7	0·89	0·68	30·9	+23·0
Means	150 (A)	0·71	0·66	7·4	0·72	0·65	11·2	—
	90 (B)	0·73	0·71	3·7	0·75	0·70	7·1	—
	30 (C)	0·66	0·59	13·0	0·69	0·58	19·0	—

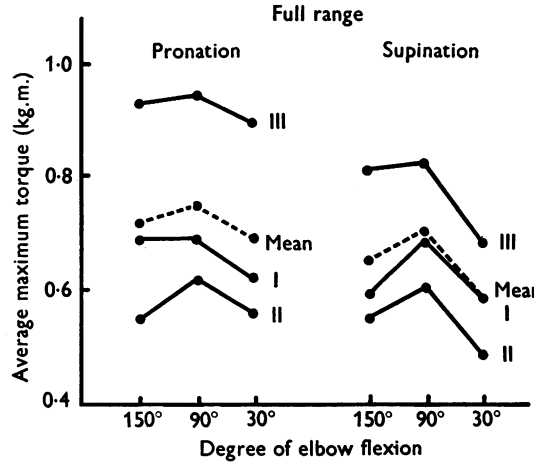

Fig. 2. The estimated average maximum torques at the mid-point of the full range of movement in the three elbow positions for each subject.

Differences between the force of pronation and supination. At the mid-points of the full range in the three elbow positions in the three subjects, pronation is stronger than supination in eight cases and the same in one. In general, the greatest differences are found when the elbow is flexed to 30° and the least when it is flexed to 90°. The estimated positions of the hand at which the torque of pronation equals that of supination are given in Table 3.

Variation in the maximum torque developed. If the average maximum pronation or supination torque recorded in each run is expressed as the percentage of the average of the six runs for each elbow position in each subject, it can be seen that there are marked variations in these percentage torques on different occasions (Fig. 3). This figure indicates that, considering all elbow positions, there is neither a consistent increase nor decrease of statistical significance in any of the subjects

Table 3. *The hand position at which the torque of pronation equals that of supination (estimated from the regression lines)*

Degree of elbow flexion	Subjects I	II	III
150	+5	+12	+10
90	+16	+12	+4
30	+1	+3	+6

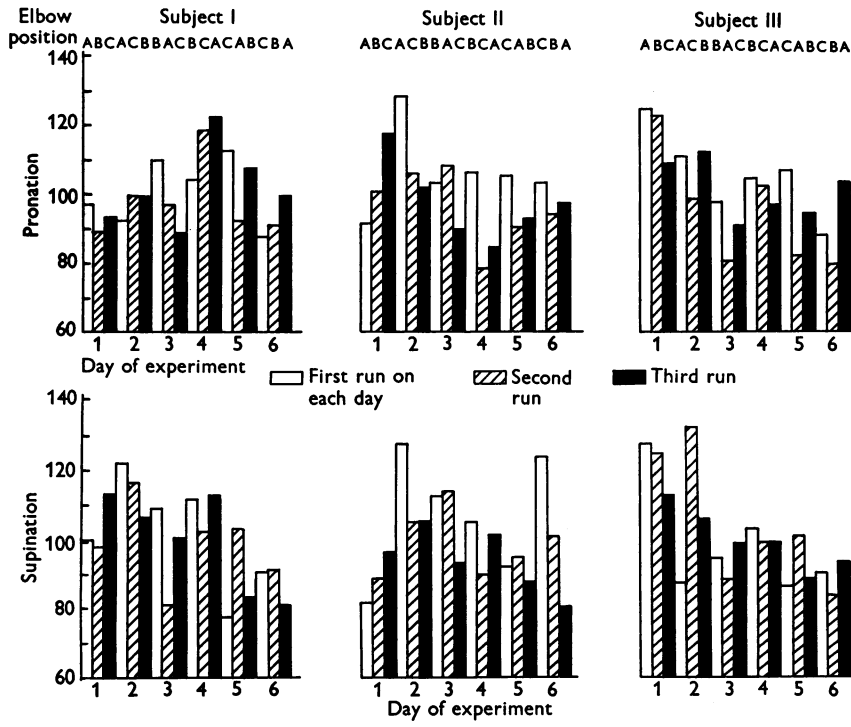

Fig. 3. The total maximum torque for each run in each elbow position expressed as a percentage of the average for each position.

during the experimental period. The same applies to the torque exerted in each elbow position in the same individual on successive days. Neither is there any correlation between the pronation or supination torques exerted and the order of the runs. Furthermore, in each elbow position, no relationship exists between the percentage pronation and supination torques. For example, if in any one run, that for pronation is greater than the average for the six runs, then that for supination does not necessarily vary in the same direction.

In each of the elbow positions, there was marked variation in the readings obtained in each of the hand positions on successive occasions. These variations were greatest in the weakest hand positions.

DISCUSSION

Although a somewhat larger range of hand positions was tested, the results of these experiments concerning the linear relationship between isometric torques and hand positions, the relative strength of pronation and supination and the variations found in the maximum torques exerted, confirm those found in the previous investigation (Darcus, 1951). The results obtained in each of the experiments with the shoulder adducted and the elbow flexed to 90° are similar (Table 4).

Table 4. *A comparison between the results with the shoulder adducted and the elbow flexed obtained in the present investigation (A) and those obtained by Darcus (1951) (B).*

	Average torque at mid-point of full range		Percentage difference (S ≡ 100)	Average difference of torque in successive hand positions		Mid-point of full range of movement (°)	Hand position in which pronation = supination torque (°)
	Pronation (kg.m.)	Supination (kg.m.)		Pronation (kg.m.)	Supination (kg.m.)		
A	0·75	0·70	7·1	0·160	0·089	21	12
B	0·78	0·69	15·0	0·219	0·132	18	11

The effect of the degree of elbow flexion on the maximum torque. The results show that, of the positions of elbow flexion studied, that in which the elbow is flexed to a right angle is the strongest, both for pronation and for supination. This may be accounted for by the fact that the mechanical advantage of the humeral head of pronator teres, of biceps and of the humeral head of supinator is maximal near this degree of flexion; the mechanical advantage decreasing on either side of this point (Fick, 1911). The fact that the strength of pronation and supination is greatest in the position of rectangular flexion confirms the statements that appear in text-books of anatomy (Morris, 1902; Bryce, 1923; Walmsley, 1934; Steindler, 1935).

Of the other two positions studied, the finding that pronation and supination are stronger at 150° flexion than at 30° flexion may be explained by the fact that, although the mechanical advantage of the muscles is similar, when the elbow is flexed to 30° their length is shorter and their contractile force is therefore smaller.

The fact that elbow flexion has a greater effect on the strength of supination than on that of pronation may be explained by referring to the muscles producing these movements. Pronation is produced mainly by the humeral and ulnar heads of pronator teres and by pronator quadratus. Of these, only the humeral head of pronator teres is affected by elbow flexion. Supination is produced mainly by the humeral and ulnar heads of supinator and by biceps. Of these, biceps and the humeral head of supinator are affected by elbow flexion. Thus more of the muscles concerned in supination are affected by varying degrees of elbow flexion than are those in pronation.

No explanation is offered for the greater differences between the pronation torques exerted in successive hand positions than between the supination torques, nor for

the fact that the differences of torque between successive hand positions for both pronation and supination increase as the elbow is flexed.

It has been calculated that, with the elbow in various degrees of flexion, the pronation and supination torques are equal when the hand position (as measured from the plane of the hand-grip) is on the average 8° towards the supination side of the neutral point. Although no precise data are available, it can be shown that, when the hand is in this position, the distal ends of the radius and ulnar are in approximately the same vertical plane. Thus, it may be demonstrated in the light of further work that, in general, the power of pronation and supination with the elbow flexed is equal when the distal ends of the radius and ulna are in the same vertical plane.

SUMMARY

1. The torque exerted in attempted pronation and supination of the right hand was studied in three subjects, with the shoulder adducted, in different positions of the elbow and hand.

2. The linear relationship between hand position and the maximum pronation and supination torque was confirmed, although the raw data indicate that the slope of the curves is steeper towards the full pronation end of the pronation curves and towards the full supination end of the supination curves.

3. In all subjects, both pronation and supination are strongest with the elbow flexed to 90° and generally weakest with the elbow flexed to 150°. The differences in the torques exerted in different elbow positions were more pronounced in supination than in pronation.

4. At the mid-point of the full range of movement, pronation was stronger than supination in eight cases and the same in one. They are equal when the hand is on the average 8° towards the supination side of the mid-point. This may correspond to the position in which the distal end of the radius and ulna are in the same vertical plane.

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