limits that engineering specifications should never exceed. The ranges of 24 different voluntary bodily movements of the head, upper arm, forearm, hand, thigh, lower leg, and foot are presented in Table 7. The movements are defined in terms of angular degrees for the mean, the standard deviation of the distribution, and the probable error of the mean. All measurements in this table were made by Glanville and Kreezer on a group of 10 subjects.[58]

b. Forces Exertable in Various Body Positions. The positions of the different parts of the body from which the maximum forces can be exerted have been determined by Reijs by means of a dynamometer measuring changes in muscular power during movements. His data may be summarized as follows:

The foot can exert its maximum power in a plantarflexion (or downward) movement when the angle of the ankle joint is about 78°; as the angle increases, the power decreases. For the hand, palmarflexion is a more powerful movement than is dorsiflexion, the average power ratio approximating 10:6 with the maximum for palmarflexion at a wrist angle of about 156° and for dorsiflexion at about 168°.

In the abduction of the leg (movement out from the body) the power drops sharply as the angle of the leg increases from 0 to 50°. In adduction, or movement towards the body, the power is greatest at a position of 32 to 48° and drops slightly as the angle decreases. For the arm, adduction is a more powerful movement than is abduction. The former is greatest between 34 and 68°, while the latter is lowest between these same figures. Flexion of the arm at the shoulder gives greater force than does extension, having its maximum between 68 and 102°. Extension power is greatest at 102°.

Trunk lifting power also was investigated and was found to be least when the trunk is nearly horizontal. There is a consistent increase as the trunk becomes more erect.[59]

c. Rate and Accuracy of Body Movements. When linear body movements are made as rapidly and accurately as possible, both the average and the maximum velocities of movement increase as the length of the movement increases (at least up to 16 inches, the maximum distance studied). Variability in accuracy and speed also increases with the length of the movement.[60] The percentage of error in the accuracy of movements is greatest at short distances and decreases as the distance increases. There is, however, a slight tendency to overreach at short distances and underreach at longer distances. It was noted that the accuracy with which a movement can be stopped at a desired point is not greatly influenced by the distance from the body at which the stop is attempted as long as the length

[59] J. H. O. Reijs, Über die Veränderung der Kraft während der Bewegung, *Pflügers Arch. ges. Physiol.*, **191**, 234–357 (1921).

[60] A. T. Slater-Hammel and J. S. Brown, Discrete movements in the horizontal plane as a function of their length and direction, *Rept. No. 2 on Project 2*, Contract N5ori-57, Special Devices Center, October, 1947.

of movement is constant.[61] For subjects who are trying for accuracy as well as speed in making movements confined to specific limits the mean maximum speeds were found to be 33, 96, and 242 cm. per second for distances of 2.5, 10, and 40 cm., respectively.[62] Right-to-left movements with the right hand are slightly faster than are left-to-right movements. The time to complete movements with the preferred hand is a little less than for two-hand movements, although no differences exist in accuracy.[63]

In studying hand-motion speeds for an industrial task where accuracy was desirable and movement distance was confined, Barnes found somewhat similar rates: 85, 160, and 221 cm. per second for 20.3, 40.6, and 60.9 cm., respectively.[64] These data would indicate that maximum speed will probably not be above 300 cm. per second if the movements are limited to distances of less than about 60 cm. and if accuracy in stopping is required. However, if movements are unrestricted in extent and accuracy but speed is stressed, the rate may well exceed 600 cm. per second.

For winding-type controls the maximum speed at which operators can turn handwheels and still match pointers in a continuous task appears to be about 200 to 250 r.p.m., although large-size handwheels, increases in friction, inconvenient positioning, and awkward hand grip will all tend to lower this maximum speed. Although there is an optimal speed band for each situation within which minimum error occurs, a speed of 180 r.p.m. may be given as a general optimal figure representing many different conditions.[65]

d. Accuracy of Operation with One or Two Hands. No important difference between the reaction time of the hands has been observed.[66] However, among right-handed people the right hand appeared to be superior to the left in performing tasks where the criterion is strength. The preferred hand is also superior to the nonpreferred hand in tasks requiring continuous, accurate control.[67] The use of both hands for a continuous control task is better than a one-hand control (preferred or nonpreferred hand) in certain cases where accuracy is the criterion, but this difference can probably be minimized by changes in the equipment or in the manipulative techniques used in operating the equipment. Although the evaluation

[61] J. S. Brown and E. B. Knauft, Positioning reactions of uniform length executed at various distances from the body, *Rept. No. 4 on Project 2*, Contract N5ori-57, July, 1948.

[62] J. S. Brown and A. T. Slater-Hammel, The effect of speed-up instructions upon the performance of discrete movements in the horizontal plane, *Rept. No. 3 on Project 2*, Contract N5ori-57, January, 1948.

[63] J. S. Brown, A. T. Slater-Hammel, and E. A. Bilodeau, Characteristics of discrete movements in the horizontal plane when executed with one and with two hands, *Rept. No. 6 on Project 2*, Contract N5ori-57, August, 1948.

[64] R. M. Barnes, *Motion and Time Study*. Wiley, New York, 1949.

[65] The Foxboro Company, Foxboro, Mass., Handwheel speed and accuracy of tracking, *OSRD Rept. No. 3452*, 1943.

[66] R. S. Woodworth, *Experimental Psychology*. Holt, New York, 1938.

[67] D. C. Ellson and D. R. Craig, A comparison of one-handed and two-handed tracking, *Memorandum Rept. No. MCREXD-694-2M*, Air Materiel Command, USAF, n.d.