

of one- and two-handed controls depends on the specific type being studied, performance with a two-hand control is generally superior to that with a one-hand control, both with and without frictional load.^{69,70} The double handcrank has advantages where the load is appreciable and where the steadying effect from both hands on the wheel is desirable, such as under conditions of unsteady footing. It has disadvantages in that it must be mounted almost directly in front of the operator at an appropriate height, whereas the single handwheel can be operated easily within a wide range of positions.

Other than the two-handed crank, a single crank mounted on a transverse axis was found to be most efficient for continuous-control tasks where accuracy over a period of time was necessary.^{69,70} This was true particularly where a load had to be overcome. Reciprocating hand and arm movements, in a horizontal plane, are generally smoother, less fatiguing, and more accurate than are vertical movements. Furthermore, movements outward from the middle of the body in any direction are usually smoother, less tiring, and more accurate than movements inward.

e. Handedness and Hand Strength. The percentage of left-handed and ambidextrous people always increases when dextrality is determined by objective tests rather than subjective judgments. The latter are extremely inaccurate and should be avoided. As an example, schoolteachers reporting on 225,000 pupils from grades 1 through 12 found that a total of 8.2 per cent of this population was left-handed. However, when 10 types of gross-muscular reaction were tested on 190 subjects, 21 per cent proved to be left-handed (18 per cent male and 23 per cent female). On 4 specific motor tests, with and without vision, given to 100 subjects, this percentage rose to 34 per cent male and 38 per cent female with between 1 and 2 per cent ambidextrous.⁷¹ It has been convincingly demonstrated that handedness is a continuous variable and not an all-or-nothing attribute. The dextrality index, or left-hand strength expressed as a percentage of the right-hand, of 360 civilian drivers was 93 per cent for dynamometer hand grip and 92 per cent for repetitive squeezes to exhaustion.

Hand strength, measured by dynamometer, showed 161 Naval enlisted men to have a maximum grip of 119 pounds $\pm$ a S.D. of 14 pounds.⁷² A group of 350

⁶⁹ D. C. Ellson and D. R. Craig, A comparison of a two-handed and several one-handed control techniques in a tracking task, *Memorandum Rept. No. MCREXD-694-2L*, Air Materiel Command, USAF, n.d.

⁷⁰ The Foxboro Company, Foxboro, Mass., Relative accuracy of handwheel tracking with one and both hands, *OSRD Report No. 3455*.

⁷¹ The Foxboro Company, Foxboro, Mass., A supplementary study of factors determining accuracy of tracking by means of handwheel controls, *OSRD Report No. 3452*, December, 1942.

⁷² Handbook of human engineering data for design engineers, Tuft's College Institute for Applied Experimental Psychology, *Tech. Rept. SDC 189-1-1*, NavExos P-643, Special Devices Center, Office of Naval Research, Dept. of the Navy, 1949.

⁷³ M. B. Fisher and J. E. Birren, Standardization of a test of hand strength, *Research Project X-293, Report No. 5*, Naval Medical Research Institute, National Naval Medical Center, April, 1945.

civilian drivers measured by the Harvard School of Public Health gave a maximum grip of 124 pounds with the right hand and 115 pounds with the left hand. For 200 university men the maximum strength of the right hand was 108 ± 21 pounds and of the left hand, 95 ± 18 pounds. During the one-minute period that this test was given the maximum strength was quickly obtained and thereafter there was a gradual but irregular falling off in strength.⁷³

Measurements of hand strength on a group of 552 male, manual, industrial workers showed the maximum hand strength in the middle twenties, with a continuous decline thereafter. At the age of 60 this decline amounted to 20.4 pounds, or 16.5 per cent from the maximum. Maximum strength was at the age range of 23 to 27 years.⁷⁴ The findings agree with other data, which show that strength increases up to the middle or late twenties and declines continuously thereafter. In most studies the rate of decline increases with age.

2. Principles of Control Design

a. Location. In the placement of controls in the operator's workplace, consideration should be given not only to the range of functional arm reach, as discussed above, but also to the frequency with which each control is to be used, the type of control and manner in which it is to be operated (push button, lever, crank, knob, and so forth), the forces involved, accuracy and speed required, the sequence in which it is to be used with respect to other controls, and the conditions under which it is to be used—especially its importance in emergencies. Some machine operators, for example, must occasionally reach for controls without removing themselves from their work. Sometimes controls are reached for blindly even though visual cues could be used. Studies have been conducted to determine the accuracy and speed with which individuals are able to locate positions at arm's length within the area easily reached from a seated position without the aid of visual cues. In one study, 50 men were tested for the accuracy with which they could reach 20 different targets mounted in different areas around them at distances of 30 inches from the mid-point of the shoulders. Visual references were available to them but they could not see the targets or their own bodies. It was found that accuracy was best for forward areas. For side areas, accuracy was best for points lower than the level of the shoulders and for points nearer the front. People tend to reach too low for points above the shoulder level, too high for points below the shoulder level, and too far to the rear for points located on either side.⁷⁵ Results of the study indicate that forward areas between the shoulder level and the waistline probably are ideal for the location of controls. Controls placed above the shoulder

⁷⁴ W. Tuttle, C. D. Janney, and C. W. Thompson, Relation of maximum grip strength to grip strength endurance, *J. Appl. Physiol.*, 2, 663-670 (1950).

⁷⁵ M. B. Fisher and J. E. Birren, Age and hand strength, *Research Project X-293, Report No. 5*, Naval Medical Research Institute, National Naval Medical Center, December, 1945.

⁷⁶ M. Fitts, "A Study of Location Discrimination Ability," in P. M. Fitts, ed., *Psychological Research in Equipment Design, Rept. No. 19*, USAAF Aviation Psychology Program, Government Printing Office, Washington, 1947, Ch. 15.