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MAXIMUM TORQUE EXERTABLE ON KNOBS OF VARIOUS SIZES AND RIM SURFACES

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AEROSPACE MEDICAL DIVISION
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FOREWORD

This research was conducted between June 1959 and October 1960 by the Controls Section, Engineering Psychology Branch, Behavioral Sciences Laboratory, 6570th Aerospace Medical Research Laboratories, in response to a request from the Specification Section, Electronics Engineering Branch, Electronics Technology Laboratory. The work was done under Project No. 7184, "Human Performance in Advanced Systems," Task No. 718402, "Criteria for the Design and Arrangement of Controls and Control Systems," with Dr. John P. Hornseth acting as task scientist. Mr. J.V. Bradley initiated the study and arranged for the construction of the knobs. The author completed the apparatus and conducted this experiment.

The author wishes to express his appreciation to Dr. John H. Bowen, Controls Section, for his assistance in planning the experimental design; Mr. Charles Clauser and Capt. Robert S. Zeigen of the Anthropology Section, Engineering Psychology Branch, for their assistance in the description and selection of subjects; the personnel of the Instrumentation Branch, Test Engineering Division, Directorate of Flight and All Weather Testing, for their cooperation in the construction and calibration of the strain gages; and Mr. Stanley Back of the University of Dayton Data Reduction Division for assistance in computation of the analysis.

ABSTRACT

We initiated this study to determine the maximum torque a seated operator can apply in turning a knob with the bare thumb and fingertips of his right hand. We also wanted to develop a procedure by which a given knob or set of knobs may be evaluated with respect to maximum torque exertable.

A set of 60 knobs, each 1/2 inch thick, was used. The knobs had 20 diameters from 1/8 to 5 inches. For each diameter there were three different rim surfaces: smooth, rectangular-knurl, and diamond-knurl. Each of 45 subjects was tested with every diameter-surface combination. In addition, 15 of the subjects repeated the experiment. The maximum torque exertable increased with knob diameter. For all knob sizes, rectangular- and diamond-knurled knobs permitted greater torques than did smooth knobs. Very little difference in maximum torque exertable was observed between the rectangular- and diamond-knurled surfaces.

PUBLICATION REVIEW

This document has been reviewed and approved for publication.

Walter F. Grether
WALTER F. GRETHER
Technical Director
Behavioral Sciences Laboratory

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INTRODUCTION

Many variables—size, shape, spacing, use, mechanical linkage, etc.—enter into the final selection of a knob or a set of knobs for any given system. We designed this experiment to specify one of these variables, the maximum torque exertable for a series of knobs under a specified set of conditions. We have outlined a procedure by which the maximum torque for any given knob or set of knobs may be obtained and evaluated (Appendix II).

In carrying out future work in workplace layout, including the effects of location on torque capabilities, basic data is needed on the maximum torque capabilities for various knobs as an aid both in constructing apparatus and selecting knobs.

The Electronics Technology Laboratory expressed a very urgent need for data of this kind to obtain an idea of the values concerned in specifying such engineering factors as shaft size, fasteners, torques applied before slippage or breakage occurs, and other similar factors.

APPARATUS

A series of 60 aluminum knobs, each 1/2 inch thick, was used in this experiment. The diameters of the knobs ranged from 1/2 inch to 1 inch in 1/8-inch increments, from 1 inch to 3 inches in 1/4-inch increments, and from 3 inches to 5 inches in 1/2-inch increments. Each size included three knobs, the rim of each possessing one of the following finishes: smooth surface; a full-depth, medium, rectangular-knurled surface; and a full-depth, medium, diamond-knurled surface (figure 1).

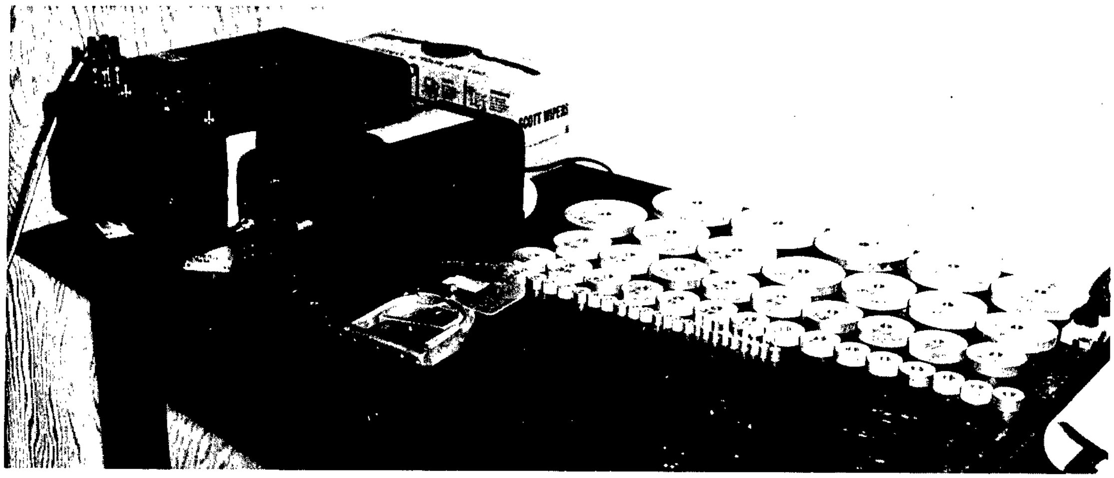
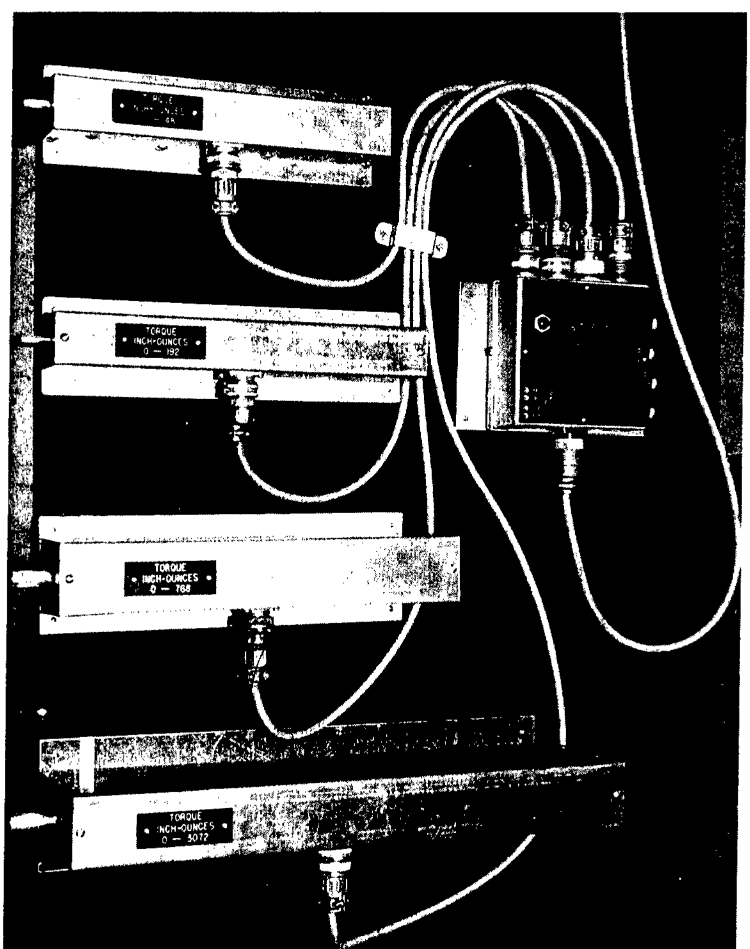


Figure 1. Amplifier, Oscillograph, Dynamometer, Set of Knobs Used

The measuring device consisted of four flat bars, each having an appropriate strain gage bonded to it. One end of the bar was anchored, and the other was free to rotate in a bearing. The subject applied torque to the free end of the bar, and the strain gage measured the distortion of the bar due to the application of torque (figure 2).



To cover the range of torques that would be obtained through the range of knob sizes used, the strain gages were calibrated so that each had a capacity of four times the one preceding. In order, from the smallest to the largest, the measuring ranges were:

1. 0-3 inch-pounds
2. 0-1 foot-pounds
3. 0-4 foot-pounds
4. 0-16 foot-pounds

For each bar, the application of maximum torque produced a 20-degree deflection of the shaft. This deflection produced an effect upon the strain gage, which, when applied through a Universal Brush Amplifier, caused full deflection of the needle of the recording oscillograph.

Figure 2 (left). Strain Gages with Selector and Balance Box

The four strain gages were mounted on a table, the top of which was stepped to align the shafts of the gages parallel to the floor. The table in turn was mounted on a track so that, by moving the table back and forth against appropriate stops, the shaft of each gage could be placed in the same spatial position, relative to the subject who was seated in a Long-Range Cargo-Type Pilot's Seat. The tip of this shaft was 29 inches above the floor, and 26 inches directly forward from the back of the subject's right shoulder.

PROCEDURE

The subjects consisted of 11 military and 4 civilian men from the 6570th Aerospace Medical Research Laboratories, and 30 male students from the University of Dayton. Fifteen of the University of Dayton students were used a second time to fill out the total of 60 experimental runs to complete a 60 x 60 balanced design.

The subjects were selected by age, stature, and weight to approximate the distribution of the Air Force flying population as anthropometrically measured in a 1950 survey (ref. 5). See table I. Measures of bicep circumference, forearm circumference, hand length, hand breadth, and hand strength were taken for each subject. Each of the measures was correlated with the maximum torques obtained to determine if any may be used as a predictor of the obtained torque.

TABLE I

ANTHROPOMETRIC COMPARISON OF THE PRESENT SAMPLE WITH 1950 AIR FORCE PERSONNEL*

	Present Sample (45 Subjects)		1950 Air Force Personnel (4000+ Subjects)	
	Mean	S.D.	Mean	S.D.
Age	25.3	6.6	27.9	4.2
Weight	166.5	22.6	163.7	20.9
Stature	69.1	2.7	69.1	2.4
Biceps Circumference	12.9	0.9	12.8	1.1
Forearm Circumference	11.4	0.8	11.5	0.7
Hand Length	7.6	0.4	7.5	0.3
Hand Breadth	3.4	0.2	3.5	0.2

*All dimensions are in inches except age and weight which are expressed in years and pounds, respectively.

The knobs were presented to the subject one at a time at 5-minute intervals to provide recovery from muscle fatigue. Twelve knobs were presented in one day. The subject completed the 60-knob sequence in 5 sessions on 5 consecutive days at the same hour each day.

To reduce variation in the subject's attitude and to insure complete and correct instructions to each subject, prerecorded directions were given to the subject at the beginning of each day's trials (Appendix I).

The subject then was told to strap himself into the pilot's seat, and was shown how to adjust the seat for height. Air Force specifications set the mode of adjustment for the height of the seat in an aircraft cockpit by the eye height of the pilot. For this reason, a device was used which contained three parallel cords, perpendicular to the subject's line of sight. The subject then adjusted the seat height until he could see only the front cord. The seat height obtained on the first of the 5 days was measured and recorded, and the seat was preset for the subject before each subsequent day's trials. Figure 3 shows the subject in the ready position.

Figure 3. Step Table, Dynamometers, and Aircraft Seat with Subject in Ready Position

During the 5-minute interval between trials, a series of simple puzzles was used. Part of this series consisted of small, flat, glass-covered cases, in which pins, balls, or other objects were manipulated into holes or specified locations. The other part consisted of a number of wire puzzles of the bent-nail variety. This type of task was selected for two reasons: to reduce inter-trial variability by having every subject occupy his time in exactly the same manner, and for the simple but challenging qualities, keeping the subject interested during what would otherwise have been idle time.

When each trial was about to begin, the subject was told: "Wipe off your fingertips. Grasp the knob with your fingertips, lining up your index finger with the indicator provided, and twist the knob as hard as you can." A paper towel was furnished for the subject to wipe any perspiration off his fingers. An indicator, an aluminum finger attached to the top of each strain gage, served to standardize the starting position.

RESULTS

Table II shows the summary of an analysis determining whether or not the 15 subjects that were repeated obtained the same results on the second test as they did on the first. Replications were nonsignificant, the null hypothesis was accepted, and the mean values for the two tests were used to obtain 44 degrees of freedom for individuals in the analysis summary shown in tables III and IV:

TABLE II

TEST ON REPLICATIONS

Source	d.f.	s.s	m.s.	F
Replications	1	51774.8	51774.8	2.16
Replications x Individuals	15	358763.5	23917.6	

The summary of the analysis of variance, including all surfaces, is shown in table III. All main effects are significant, and all the interactions are significant beyond the 5 percent level.

Table IV shows a summary of the analysis of variance for the two knurled surfaces only. All main effects in this analysis are significant, and all the interactions except between surfaces and individuals are significant beyond the 5 percent level.

Table V shows the mean maximum torque by knob sizes and rim surfaces, along with the appropriate standard deviations. Figure 4 shows a plot of this table on a graph.

TABLE III

SUMMARY OF ANALYSIS OF VARIANCE FOR ALL CONDITIONS

Source	d.f.	s.s.	m.s.	F.
Knob Surfaces	2	6526179.2	3263089.6	391.91*
Knob Sizes	19	166286829.6	8751938.4	567.53*
Surfaces x Sizes	38	4366011.4	114895.0	4.64*
Individuals	44	8033724.2	182584.6	73.73*
Surfaces x Individuals	88	732699.8	8326.1	3.36*
Sizes x Individuals	836	12891994.4	15421.0	6.23*
Residual	1672	4140443.2	2476.3	

*Significant beyond the 5 percent level.

TABLE IV

SUMMARY OF ANALYSIS OF VARIANCE
FOR TWO KNURLED SURFACES ONLY

Source	d.f.	s.s.	m.s.	F.
Knob Surfaces	1	58227.9	58227.9	18.80*
Knob Sizes	19	135726531.9	7143501.7	566.90*
Surfaces x Sizes	19	247698.1	13036.7	5.44*
Individuals	44	6901822.4	156859.6	65.39*
Surfaces x Individuals	44	136299.9	3097.7	1.29
Sizes x Individuals	836	10535190.1	12601.9	5.25*
Residual	836	2005413.9	2398.8	

*Significant beyond the 5 percent level.

TABLE V

MEAN AND STANDARD DEVIATION OF MAXIMUM TORQUE BY KNOB SIZE
(Torque in Inch-Ounces)

Knob Size (Inches)	RIM SURFACE					
	Rectangular Knurl		Diamond Knurl		Smooth	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
1/8	8.4	3.1	9.1	3.1	3.0	1.5
1/4	18.6	5.4	19.6	5.4	8.3	3.3
3/8	27.7	7.6	31.8	9.1	13.4	4.4
1/2	42.6	12.8	45.9	13.5	21.8	7.6
5/8	60.3	17.3	64.9	21.5	27.2	8.6
3/4	85.4	28.7	93.1	33.1	39.8	10.6
7/8	104.9	35.1	112.6	40.2	47.9	15.6
1	115.6	31.8	116.0	35.5	59.1	21.3
1-1/4	120.7	35.6	132.9	37.7	59.9	17.2
1-1/2	156.6	41.0	146.8	37.5	97.4	26.4
1-3/4	199.6	51.5	205.3	52.8	124.7	38.7
2	244.5	64.7	210.2	48.9	148.0	46.7
2-1/4	294.4	78.5	287.5	74.5	187.0	52.0
2-1/2	367.9	103.2	371.9	113.6	236.2	63.1
2-3/4	403.1	95.1	423.9	108.4	238.9	69.2
3	444.3	114.2	477.7	136.6	267.2	81.1
3-1/2	553.4	147.1	607.3	158.9	400.4	116.6
4	694.8	180.8	698.0	173.9	454.2	135.3
4-1/2	814.8	219.7	855.7	236.0	542.4	150.9
5	898.5	219.5	973.4	262.8	716.4	225.8

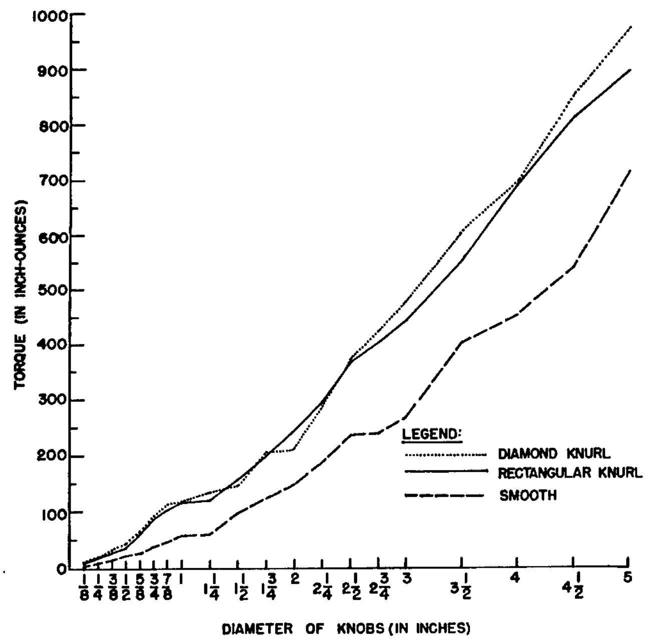


Figure 4. Mean Maximum Torque Exertable as a Function of Knob Diameter for Each Rim Surface

DISCUSSION

In the summary of the analysis of variance including all conditions (table III), we see a significant interaction between surfaces and sizes. Consequently, we conclude that, averaged over all sizes, the diamond knurl is the best. However, for a particular size, this conclusion might not hold.

Figure 4 shows that, between the diamond and the rectangular surfaces, a small difference generally exists in favor of the diamond knurl. However, this difference is reversed for 1-1/2-, 2-, and 2-1/4-inch knobs, showing a difference in favor of the rectangular-knurled surface at these points. Looking further, we see a very great difference between the smooth surfaces and the other two surfaces at large diameters, which decreases absolutely and increases proportionally as it approaches small diameters. This rapid decrease in difference may cause much of the interaction that exists between surfaces and sizes. In view of this information, the experimenter was led to an analysis considering only the diamond knurl and the rectangular knurl (table IV). In this analysis, the interaction that previously existed between surfaces and individuals is nonsignificant. However, the interaction between surfaces and sizes is significant, leading us to the same conclusion as above: the diamond knurl is the best.

A regression on the mean torque over conditions was made of the following anthropological measures: height, weight, age, hand length, hand breadth, forearm circumference, bicep circumference, and grip strength. The results showed that a combination of grip strength and weight accounted for about 25 percent of the variance in maximum torque averaged over all conditions. In testing further, we found an interaction between conditions and individuals. In other words, the results under different conditions were different when performed by different individuals. This interaction invalidated any conclusions that might be drawn concerning the prediction of a mean torque over conditions by means of the anthropological measures.

SUMMARY AND CONCLUSIONS

Over the range of knob diameters investigated (1/8 inch to 5 inches), the maximum torque exertable increased with knob diameter. For any particular knob size, a rectangular- or diamond-knurled knob permitted greater application of torques than did a smooth knob. Thus, a smooth-surfaced knob is eliminated from consideration where maximum or near maximum torque is desired. The diamond-knurled surface was slightly better than the rectangular-knurled surface.

Table V may be used as a guide to insure that, for a given knob, the torque needed for barehanded operation by a seated operator does not exceed his capability. For example, suppose a 1-1/2-inch-diameter, diamond-knurled knob were located on a panel directly in front of a seated operator. Reading from table V, the mean torque exertable on this knob is 146.8 inch-ounces, and the standard deviation is 37.5 inch-ounces. If the torque needed to operate the knob on the panel was set at 109.3 inch-ounces (mean minus 1 S.D.), approximately 84 percent of the Air Force population could be expected to be able to operate the control.

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APPENDIX I

PRERECORDED DIRECTION TO SUBJECT

"The problem in this experiment is to measure the maximum twisting force which you can exert on a knob. The knobs range from 1/8 inch in diameter to 5 inches in diameter, and each size knob has three different rim surfaces. This study is being carried out to establish a range of values to work with in future studies in workspace layout and knob evaluation. This is not a study that will directly result in location and placement of any controls in or on equipment. The equipment will never give you an electric shock.

"The test will consist of 5 sessions of 1 hour apiece, 1 session per day. You will have been presented a total of 60 knobs at the end of the fifth session. You will be presented knobs at the rate of 1 every 5 minutes. During the interval between knob presentations, you will be given a task to do. The directions will be with the task.

"When you begin the experiment, you will be asked to sit in a cargo-type pilot's seat. You will then be strapped in with a lap belt and shoulder harness. The purpose of this is to keep you from excessively leaning forward. You will see, in front of you, a stand with three cords strung across horizontally in front of you, one behind the other. I want you to adjust the height of the seat so that, when you are sitting comfortably, the cords line up so that you can only see the front cord.

"When presenting you with a knob, I will place a knob on a shaft and locate it in front of you. You will be given a wiper when you begin, and I would like you to wipe your fingertips before each test. When I tell you, and only then, grasp the knob with your fingertips, lining up the tip of your index or first finger with the indicator provided on each gage. When this is done, rotate the knob clockwise, or to the right as hard as you can, then release it.

"I will answer any questions you have concerning the test procedure. Ask your questions now, as there will be a minimum of time for discussion during the experiment; and remember, rotate the knob clockwise as hard as you can once, then release it."

APPENDIX II

PROPOSED EXPERIMENTAL PROCEDURE

For future determinations with respect to torque capabilities on knobs of various shapes, sizes, and surfaces that may be developed and submitted for evaluation, a device for measuring torque, similar to the one described in this report, may be constructed, and the maximum torque capabilities may be determined and compared. The knobs should be presented in the same location with relation to the subject, and the subject should be seated and strapped into an aircraft-type seat.

A few knobs may be selected from those presented in this report of as nearly as possible the same size and surface as those that are to be investigated. These knobs would serve as controls, and as an adjusting factor to determine the level of performance the subjects selected would attain in relation to those used in this study. This would make it possible to see if the knobs tested are better or worse in general than those used as controls. The data for the controls may be compared with the data in this report; hence, the investigated knobs may be compared with those presented in this report. The knobs selected from this report should be pooled with the knobs to be investigated.

The experimental runs, each consisting of all the knobs (conditions) to be tested, should be counterbalanced (ref. 3). A minimum of 8 to 10 subjects should be used, and each subject should perform two experimental runs, not in succession. When this is completed, the knobs that served as controls may be separated out, and the level of performance may be compared with the results obtained in table IV of this report.

As an example, it may be desired to determine the capabilities of a set of 5 different knobs, giving 5 different conditions to be tested. The first step would be to select two (the number is arbitrary) knobs from those used in this report of the same surface within the size range of knobs to be investigated. These 2 knobs would be pooled with the 5 knobs to be investigated, increasing the number of conditions to 7. These seven conditions should then be counterbalanced, each set of conditions constituting one experimental run. There should be a minimum of 16 to 20 of these experimental runs made up, depending upon the number of subjects required. If, for example, 10 subjects are chosen, each of these subjects will perform 2 experimental runs, making a total of 20 experimental runs. The data collected may then be submitted to an appropriate analysis.

Aerospace Medical Division, 6570th Aerospace Medical Research Laboratories, Wright-Patterson AF Base, Ohio.
Rpt No. MRL-TDR-62-17. MAXIMUM TORQUE EXERTABLE ON KNOBS OF VARIOUS SIZES AND RIM SURFACES. Final report, March 62, iii + 11p. incl illus., tables.
Unclassified report

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5. Test Methods
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