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NBSIR 73-156

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Consumer Product Systems Section
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August 7, 1973

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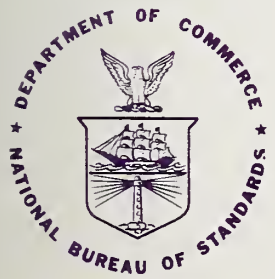

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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We wish to express our appreciation for the time and cooperation afforded us by the following child institutes and to the many children who so willingly participated in this study.

Adelphi Day Care Center

Boyds Day Care Center

Catholic Charities Model City Day Care Center

Diamond Farms Day Care Center

Gaithersburg Day Care Center

Greenwood Elementary

Londonderry Day Care Center

Merriland Day Care Center

Montgomery Village Day Care Center

Montrose Christian Center

Potomac Montessori School

Rockville Day Care Center

Sligo Day Nursery

St. Joseph's Day Care Center

Summit Hall Elementary

Tumble Inn

Viers Mill Day Care Center

Introduction

"The little boy and his sister were playing with a metal doll house. After several minutes, they began to fight over it, each of them tugging at its sides. Suddenly the clamps holding the structure opened and the doll house flew apart. One piece struck the boy in his face, slashing him from ear to mouth."

This incident, reported by Marlene Cimons in the October 23, 1972, issue of the Los Angeles Times News Service, is an example of the danger of children pushing, twisting, or pulling apart toys that may not be hazardous initially but that could be hazardous when broken. Incidents of this nature have evoked the concern of Government officials as well as parents across the nation for the safety of children when playing with toys.

The Child Protection and Toy Safety Act of 1969 was passed by Congress with the intention of eliminating hazards associated with children's toys. However, in order to develop reliable and realistic standards and test methods to deal with this problem, one must first know, among many other characteristics, the strength capability of children. For this reason, a study was conducted by the Product Evaluation Technology Division, National Bureau of Standards, to gain some information in this area.

The main objective of the child strength study was to determine what the forces are that children 2 through 6 years

old* are capable of exerting when pulling, pushing, twisting, and squeezing. This study was conducted with 556 children in the Washington Metropolitan area. A minimum of 50 males and 50 females in each of the 2 through 6 year old age groups was tested. Each age group consisted of a miminum sample of 20% black children, and included children from widely varying economic backgrounds. The children participating in the study attended rural, suburban, and inner-city schools which were selected at random from various child institutes in the Washington-Metropolitan area.

Four test devices were used to conduct the child strength study. Three of these devices, a push-pull tester and two twist testers, were developed and constructed at the National Bureau of Standards. A fourth device, which was used to measure squeeze forces, was purchased commercially.

Prior to beginning the child strength study, consultations were held with psychologists from the staff of the National Institute of Child Health and Human Development, National Institutes of Health, and the Technical Analysis Division, National Bureau of Standards. The information obtained during these discussions was instrumental in designing the test procedures used in this study.

*The age groups tested are designated as:

2 year old - 24 months old through 35 months old
3 year old - 36 months old through 47 months old
4 year old - 48 months old through 59 months old
5 year old - 60 months old through 71 months old
6 year old - 72 months old through 83 months old

Summary and Conclusions

The present study was designed to provide objective information that can serve as a basis for developing standards and test methods for children's toys.

The study involved children 2 through 6 years old of both sexes (at least 50 in each age and sex group) and four specially constructed test instruments that could be operated in a variety of configurations and modes, giving rise to 19 "tests."

The results of the study are exhibited in tables of:

a) The average strength values for each age and sex group, for each test;

b) Measures of variability in strength among children of the same group;

c) 95th percentiles for each of these groups.

A number of graphs are also included for a quick appraisal of the results.

Contrary to what might be expected in a study involving many uncontrollable variables, the results provided quantitatively precise and useful information on several points, the most important of which are the following:

1. Quantitative measures were obtained for the effect of age on the strength capability of children from 2 through 6 years old. An approximately linear increase with age was observed for the strength of

either sex, the rate of increase being higher for boys than for girls in all tests. The rate of increase was found to be a function of the particular test.

2. Very high correlations (0.95 or better) were found among all 19 tests.
3. Several of the tests gave almost identical results; thus:
   a) The top twist tester and the front twist tester, when used with the same knob size, gave very similar results.
   b) The push-pull tester gave almost identical results whether used with the knob or with the rubber sleeve.
4. The size of the knob, in the front and top twisters, was found to have an appreciable effect on the strength measurement, the latter increasing as the diameter of the knob increases.
5. In the squeeze test, the use of two hands markedly increased, but did not quite double, the measured strength of one hand.

All of these conclusions, and others of a more quantitative nature, can readily be derived from two empirical equations, one for the average strength, and the other for the 95th percentiles, that were developed from the data. The equations fit the data within experimental error.

A secondary result of the study is the observation that the differences in strength between white and black children showed no consistent patterns in the age range tested.

The similarities in the results found for several tests indicate that the number of tests to be used in future studies may be appreciably reduced. The observation that, in a few cases, the strength of some of the older children exceeded the range of the instrument should lead to an extension of this range in future studies.

Instrumentation Description

Push-Pull Tester

The push-pull tester, Figures 1, 2, and 3, was designed to measure the force that children, in each of the ages two through six years old, are capable of exerting when pushing and pulling. This instrument utilizes a rotary variable differential transformer and a set of compression springs to produce a voltage output proportional to the amount of force exerted on a pivotal vertical lever. A spherical knob, cylindrical rubber sleeve, or a two and one-half foot chain can be attached to the lever to measure forces exerted during different modes of manipulation. A series of colored lights, located on a panel behind the vertical lever, was used as a motivational tool to entice the child being tested to exert maximum effort. These lights illuminate sequentially as the amount of force being exerted on the lever is increased. The output from the push-pull tester can be recorded on a strip chart recorder for later reduction and analysis.

The strength ranges of the youngest and oldest children in the two through six year old age groups varied appreciably, based on the results of preliminary child performance tests. These results also indicated that the ranges for the push and pull directions accommodated both extremes of the forces exerted by the children involved in the child strength study. A major consideration in the selection of these ranges was the ability

of a two year old child to light a sufficient number of lights at the lower end of the force ranges to cause him to be adequately motivated to perform to his maximum capability. The measurement limits of the push-pull tester were fifty-five pounds (244.6 newtons) in the push direction and sixty-six and a half pounds (295.8 newtons) in the pull direction.

Top and Front Twist Testers

The top and front twist testers, Figures 4 and 5, were designed to measure the amount of torque that children are capable of exerting when twisting metal knobs of various sizes in both a horizontal and vertical configuration. The detachable knobs selected for use in the twist tests are one, one and a half, and two inches in diameter, with grooved edges to facilitate a better grip. These knobs are attached to a round, slotted shaft. A flexible steel spring is inserted through the slot in the shaft and securely anchored. When the knob is rotated, the shaft rotation is approximately proportional to the rotation of the knob. A rotary potentiometer, which is attached to the opposite end of the shaft, provides an electrical output which is directly proportional to the amount of torque exerted on the knobs being twisted. This signal is recorded on a strip chart recorder and then converted to inch-pounds.

In similar fashion to the push-pull tester, a series of sequentially illuminating lights is used to aid in motivating the child to twist as hard as possible.

Hand Dynamometer

A hand dynamometer, Figure 6, was purchased commercially and used to obtain data on the squeeze forces that children, ages two through six years old, are capable of exerting. This device consists essentially of a mainframe, an adjustable stirrup-shaped handle attached to an extension spring, a calibrated needle and dial, and a clutch to hold the adjustable handle in place. A rotary potentiometer is attached to the indicator, and when attached to a small power supply, provides an electrical output proportional to the force being exerted on the dynamometer handle.

Calibration

Prior to beginning the child strength study, the four test devices were calibrated and curves were constructed to facilitate data conversion. The calibration of these devices was checked periodically to insure that the data obtained remained as accurate as possible [reading error not to exceed 2 pounds (approximately 9 newtons) for any measurement] throughout the duration of the tests.

Test Procedure

The four test devices were placed on a table, approximately 20 inches from the floor, and the push-pull tester, front twist tester, and top twist tester were securely fastened to the table. The test devices were arranged in the same order during each testing period, i.e., the hand dynamometer, followed by the front twist tester, the top twist tester, and the push-pull tester, respectively.

For ease in demonstrating the operation of the test devices and conducting the tests, the two and three year old children were tested in separate groups of three; and the four, five, and six year old children were tested in groups of four. Prior to commencing any of the tests, a brief demonstration was given by the test instructor for each group of children. First, the instructor demonstrated the operation of the hand dynamometer by squeezing on the lever three times with each hand and then squeezing three times with both hands while pointing out how the indicator recorded the amount of force being exerted. Next, the operation of the front and top twist testers were demonstrated. The instructor placed one hand on the machine and the other hand on the knob selected for demonstration. She then twisted the knob three times in the counter clockwise direction and three times in the clockwise direction. During this period, the children were urged to observe the motivation lights as they illuminated sequentially as the knobs were turned

with an increasing amount of force. The children were reminded that they could use only one hand at a time on the twist knobs.

The instructor demonstrated the operation of the push-pull test device by placing one hand on the body of the device and the other hand on the knob attached to the vertical lever. She then pushed the knob forward three times and pulled the knob back three times while calling the children's attention to the sequentially illuminating motivation lights. The children were told that they could use either one or both hands when operating the push-pull device.

The children were usually so enthusiastic about playing with the machines that there was relatively no problem with respect to the fact that the instructor and child were not familiar with one another. Referring to the child by name and allowing a brief time for individual conversation helped to develop a more personal relationship between child and instructor.

For those children who obviously did not understand the mechanics of squeezing, twisting, pushing, and pulling, brief games were played during the demonstration. Some examples of the expressions used in the games are: (1) "Hold my two fingers with one of your hands and squeeze or bring them together;" (2) "Hold up one hand and pretend that you are turning a circle in the air towards the window - now twist the other way;" (3) "Place your hands against mine (fingers vertical) and push them away from you;" and (4) "Hold my hand and pull my body towards you."

The tests were conducted in three phases. A consideration of the fatigue factor resulted in allowing children to complete only one phase at a time. They rested approximately 10 minutes between each phase. Phase one consisted of the one and two hand squeeze test; twist tests on the front and top twist testers, using the two inch diameter knob; and push and pull tests using the round knob. Phase two consisted of twist tests on the front and top twist testers, using the one and a half inch diameter knobs; and push and pull tests with a rubber sleeve over the vertical lever of the push-pull tester. The third phase consisted of twist tests on the front and top twist testers, with one inch diameter knobs; and pull tests with a two and a half foot long chain attached to the lever of the push-pull tester.

Each child was allowed a minimum of three trials in each direction on any given test. The first trial was used by the test instructor as a general indication of the amount of force the child could be expected to exert for that particular test. Through observation, the instructor could then sense the degree of encouragement necessary to motivate the child to avoid frustrating him or making him feel a lack of adequate accomplishment. The children were given signs of encouragement by the instructor through gestures, facial and verbal expressions. In addition, the colored lights located on the push-pull and twist test devices were observed to be essential motivational tools.

Prior to conducting the squeeze tests, the size of each child's hand was measured and the stirrup-shaped handle of the hand dynamometer was adjusted (per manufacturer's instructions) to yield the optimal squeeze force. This adjustment was approximately one-half the distance between the vertex of the angle formed where the thumb joins the hand and the end of the child's longest finger.

It was assumed that the child's hand of preference was the hand with which the child was most likely to exert maximum force. Since in most cases the identity of the hand of preference was uncertain, the test instructor requested the child to use the other hand at least once during each test.

Stricter controls on the test procedure were purposefully omitted with regard to the performance of the tests previously described. This allowed the children to use innovation, intelligence, creativity, and ingenuity to achieve maximum performance, thus approximating a more normal play condition. A more rigidly controlled test procedure was attempted to eliminate some of the variables inherent in tests of this nature; however, this approach proved unsuccessful. Attempts were made to record the methods used by the children to manipulate the test devices during specific tests, such as one hand, both hands, elbow leverage, and knees or feet. This proved unsuccessful since the methods of manipulation changed so rapidly that it was impossible to accurately annotate the moving tape on the strip chart recorder. Attempts were also

made to restrict the child to one prescribed method of performing a given test. This procedure also proved unsuccessful since the children insisted on using that method which they felt would enable them to perform to their maximum capability. An example of the different methods that one child might use to manipulate a given test device during a specified test is illustrated in Figure 7 of this report.

One could easily question whether or not weight and body build have a direct correlation to a child's strength performance. A search of the literature relating to child strength revealed several interesting factors which were significant considerations in developing the test procedures used in this study. Investigations by Jones (1947), and Smith and Royce (1963), indicate that there is no sizable correlation between an individual's strength performance and body weight. Krogman and McCown (1971) concluded that there is no relation between strength and the body build of children 3 through 6 years old. In addition, Ikai and Steinhaus (1961) found that, "In every voluntarily executed, all-out maximal effort, psychologic rather than physiologic factors determine the limits of performance."

Test Results

A detailed statistical analysis of the data obtained during the Child Strength Study is presented in the Appendix of this report. In this section, some graphs and charts are

presented, from which the major findings of this study can readily be deduced.

In terms of the ultimate purpose of this study, the distinction between top and front twist, as well as between twisting in the clockwise and counterclockwise directions is of secondary importance. So is the distinction between the use of a knob or a rubber sleeve in the push and pull tests. Therefore, the data were condensed in the following way. For each child, the maximum value was selected for all twist tests using a given knob size. Similarly, for each child the maximum value was selected for both pull tests (excepting the chain), and for both push tests. However, for the squeeze test, both the two-hands and one-hand results were considered. This reduced the number of "tests" to eight: twist for three sizes of knobs, push, pull, chain-pull, and squeeze (one and two hands). Figures 8 through 13 show the average results, as well as the 5th and 95th percentiles*, for these eight tests for each age and sex group. A quick appraisal of the data can be made from Table 1 (reproduced in metric units in Table 1a), which lists the 95th percentiles, averages, and 5th percentiles for four tests from the condensed data for all age and sex groups tested.

*For a definition of the 95th percentile, refer to the Appendix (p. 18). The definition of the 5th percentile is determined by interchanging the numbers 95 and 5 in that definition. Estimates of these quantities were obtained, in this study, by taking the third largest (95th percentile) and the third smallest (5th percentile) value in each group.

At the basis of this study was the belief that all tests conducted were valid measures of the same basic characteristic, namely, the physical strength capability of a child. The correlation matrix presented in Table 5 of the Appendix can be used to test this assumption. These results show that the correlation between tests was quite high and support the hypothesis that, to a considerable extent, all tests measure the same basic characteristic.

As previously stated, each age and sex group consisted of at least 20% black children. This mix afforded an opportunity to study any difference that might exist between the strength capability of black and white children. Table 2 summarizes the information gained from analyzing the data acquired on the strength performance of these two groups. It is seen from the table that in spite of apparently significant differences between the two races for some age and sex groups, no overall pattern emerges in regard to this point.

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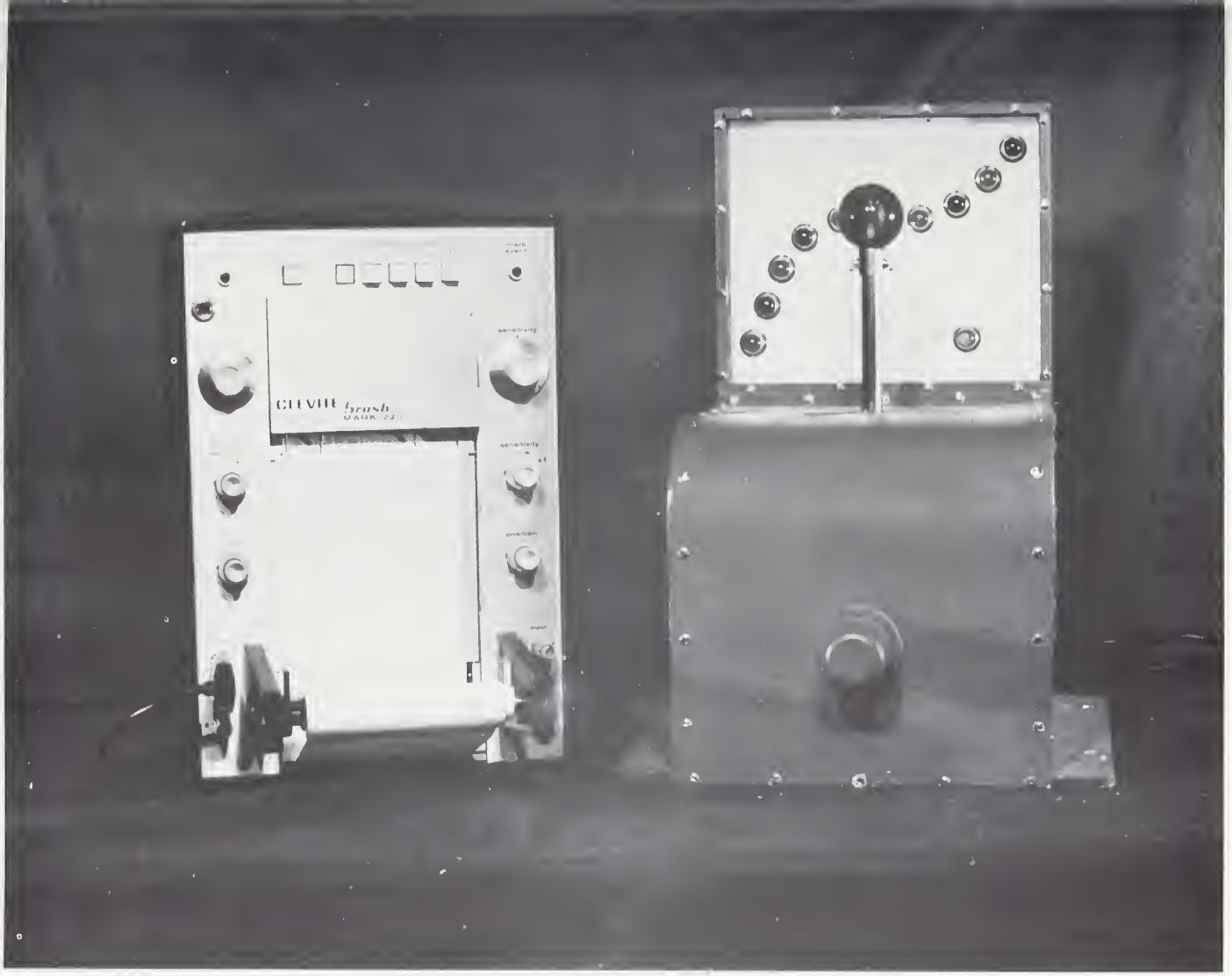


Figure 1. Push-Pull Tester with Knob Configuration: This device is used to measure the pushing and pulling forces that children are capable of exerting. The Push-Pull Tester, in the configuration shown (unit on the right), features a pivotal lever with a spherical knob mounted at the end. The lever can be pulled toward and pushed away from the test subject. A series of lights, mounted on a panel behind the lever, illuminate sequentially as increasing force is applied to the lever. These lights serve to motivate the test subject to perform to his maximum capability. The forces applied when activating the lever are recorded on a strip chart recorder (unit on the left).

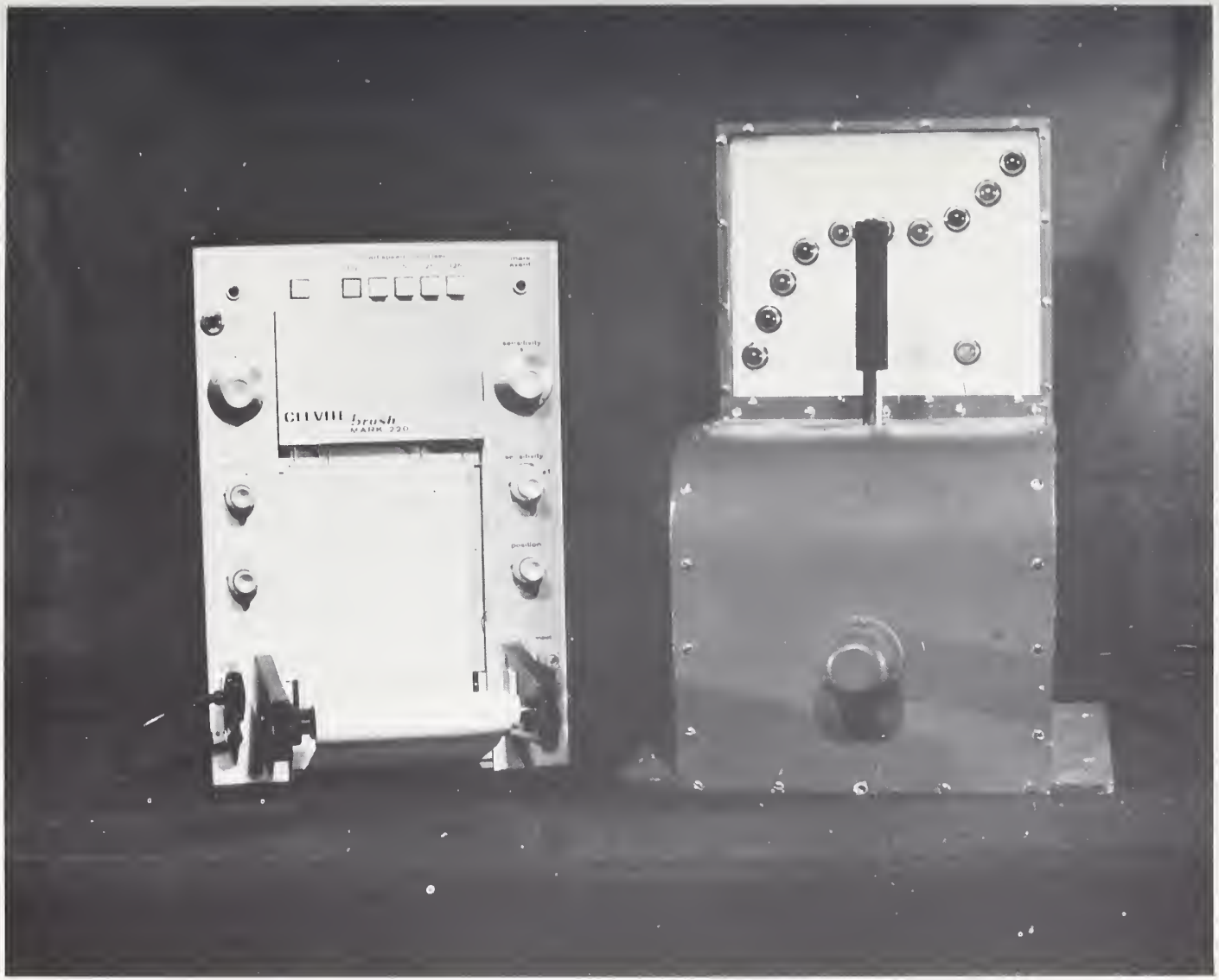


Figure 2. Push-Pull Tester with Rubber Sleeve Configuration: The Push-Pull Tester in the configuration shown features a rubber sleeve mounted over the pivotal lever protruding from the top of the test device. The function and operation of the device are identical to those described in Figure 1.

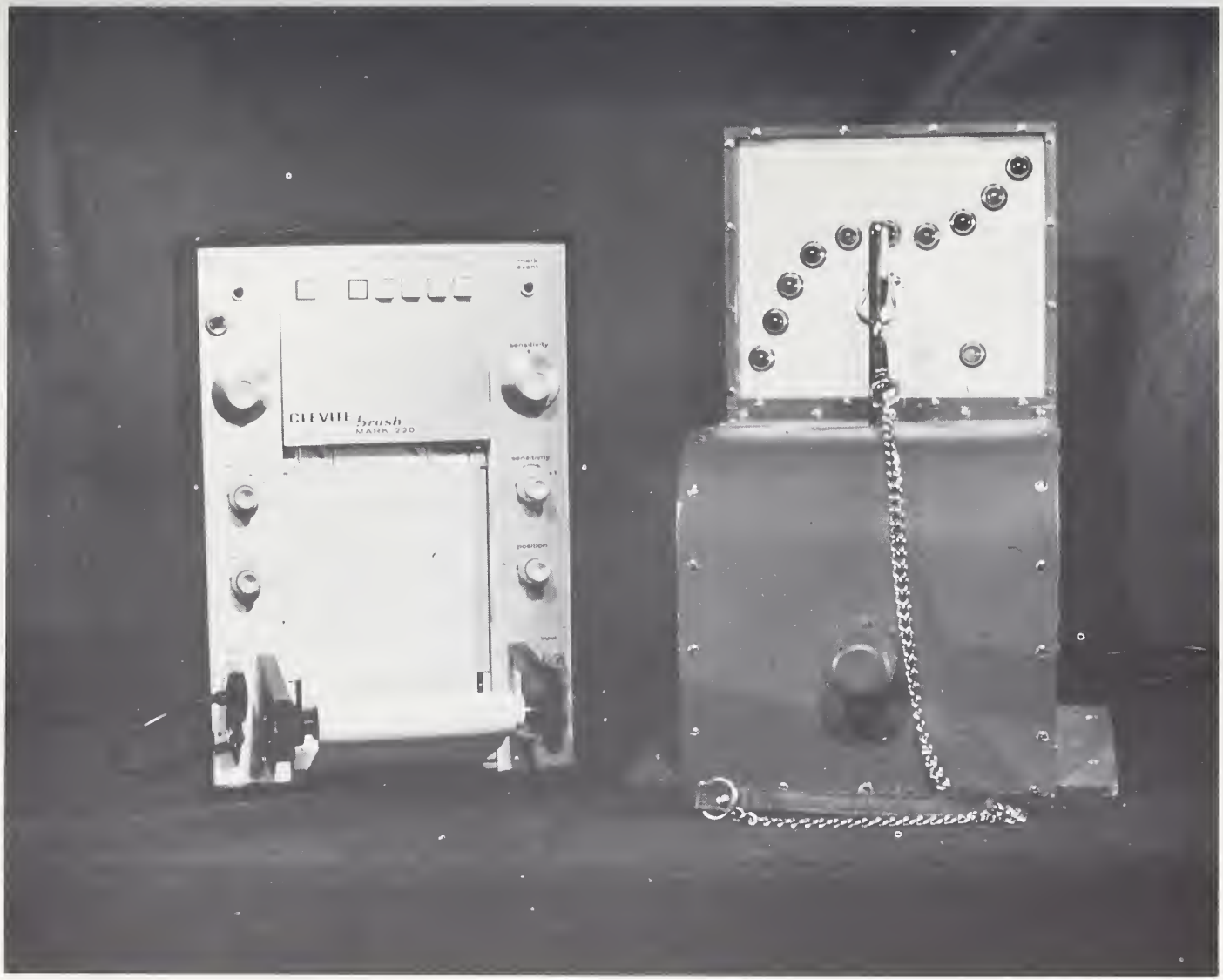


Figure 3. Push-Pull Tester with Chain Configuration: The Push-Pull Tester in the configuration shown features a 2 1/2 foot chain attached to the pivotal lever protruding from the top of the test device. The Push-Pull Tester in this configuration is used to measure the tugging forces exerted on the lever when the chain is pulled. The operation of the test device in this configuration is similar to the operation described in Figure 1..

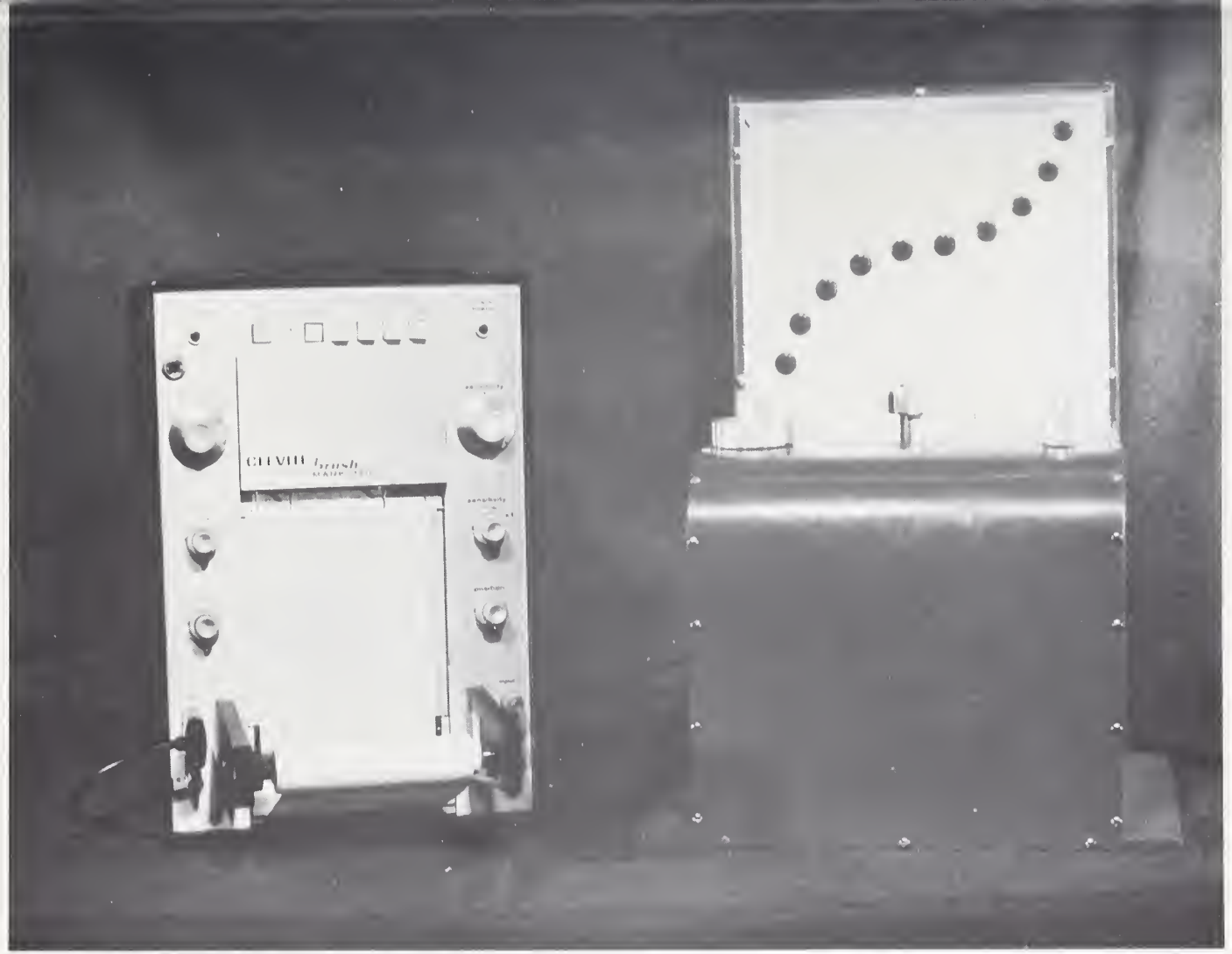


Figure 4. Top Twist Tester: This device is used to measure the amount of torque that children can apply when twisting knobs of various sizes. The Top Twist Tester (unit on the right) features a centrally located knob, mounted on top of the lower housing of the test device, which is twisted by the test subject. Knobs with three different diameters can be interchangeably mounted on a protruding shaft. A series of lights, mounted on a panel behind the knob, illuminate sequentially as increasing torque is applied to the knob. The lights serve to motivate the test subject.

A strip chart recorder (unit on the left) provides a permanent record of the forces exerted by the test subject.

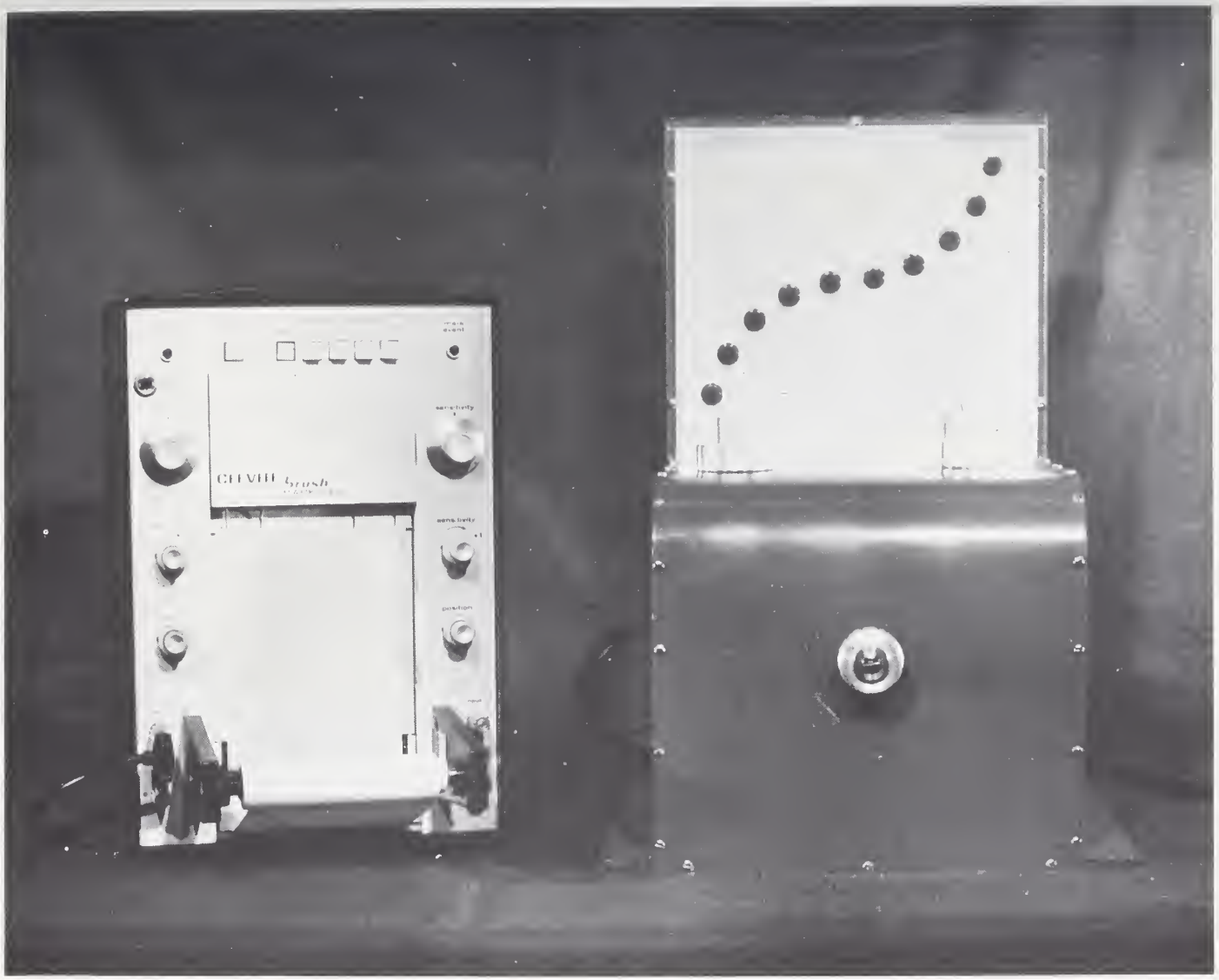


Figure 5. Front Twist Tester: The Front Twist Tester (unit on the right) features a centrally located knob, mounted on a shaft which protrudes from the front of the lower housing of the test device. The function and operation of the Front Twist Tester is similar to that of the Top Twist Tester described in Figure 4. A strip chart recorder (unit on the left) provides a permanent record of the forces exerted by the test subject.

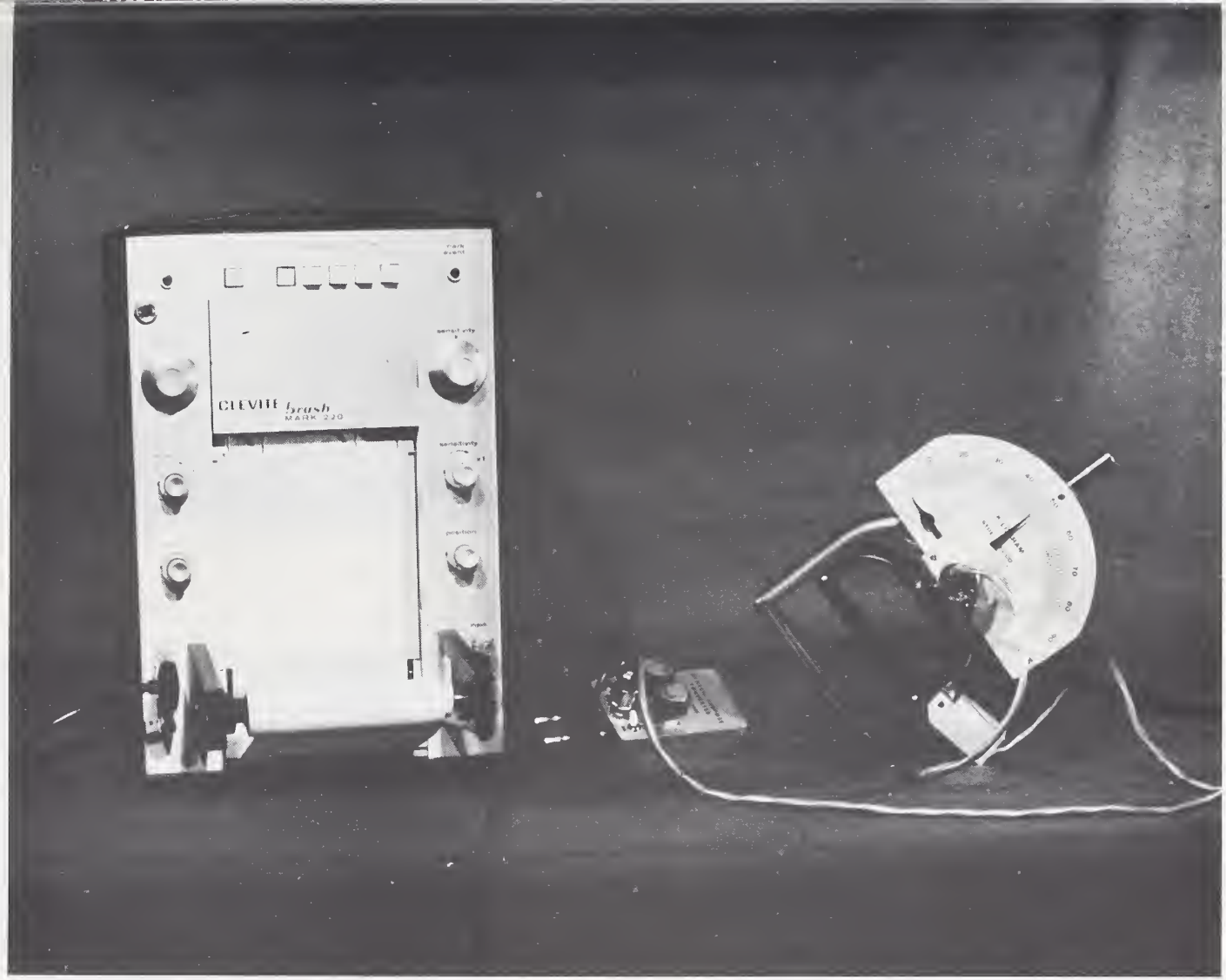


Figure 6. Hand Dynamometer: This Hand Dynamometer (unit on the right) is used to measure squeeze forces that can be applied by children. The test subject places either one hand or both hands around the stirrup-shaped handle, in the center of the device, and attempts to squeeze the stirrup to meet the main frame (surrounding the stirrup). The amount of force exerted can be read on the calibrated hand dynamometer scale or recorded on the strip chart recorder (unit on the left).

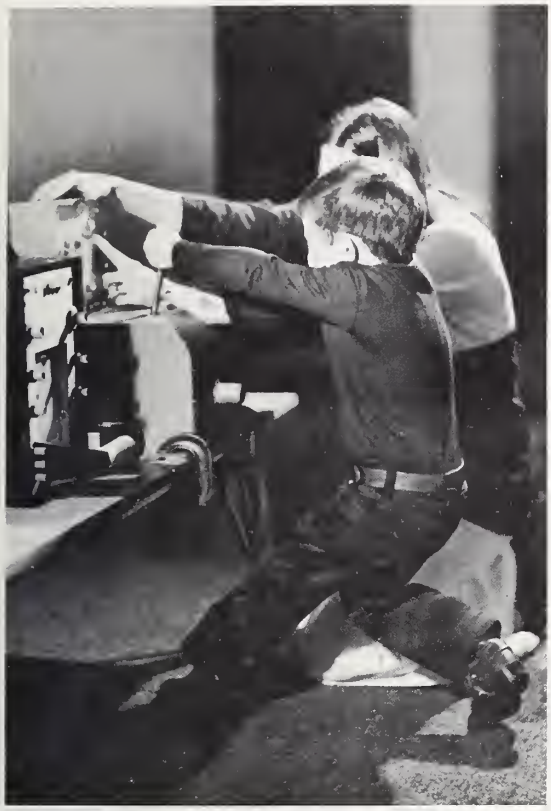


FIGURE 7. Motivation lights on the Push-Pull Tester encourage the test subject to apply maximum force. Note that various body positions are assumed by the subject, resulting in varying degrees of leverage.

Table 1. Condensed Force Values for Twist, Push, Pull and Squeeze Tests

95th Percentiles

Age (years)	Twist (2" knob)		Push Lever		Pull Lever		Squeeze (2 hands)	
	Female	Male	Female	Male	Female	Male	Female	Male
2	14.4	15.6	19.8	23.5	37.5	38.5	22.0	19.8
3	18.4	19.5	29.5	28.0	39.5	43.0	26.4	25.3
4	26.2	24.8	45.3	56.7*	58.0	60.5	34.1	37.4
5	30.0	30.5	52.8	60.5*	60.5	63.5	44.0	48.4
6	31.6	32.2	57.7*	63.1*	63.5	66.5	46.2	52.8

Averages

Age (years)	Twist (2" knob)		Push Lever		Pull Lever		Squeeze (2 hands)	
	Female	Male	Female	Male	Female	Male	Female	Male
2	9.1	10.1	10.9	13.9	20.2	23.1	12.8	13.8
3	12.6	13.2	16.7	18.2	27.2	27.4	15.8	16.9
4	17.2	18.7	26.4	32.5	36.0	40.4	24.1	26.6
5	26.4	22.4	34.3	39.5	45.8	49.4	31.8	32.8
6	23.2	25.8	39.3	46.9	50.3	56.3	35.0	40.3

5th Percentiles

Age (years)	Twist (2" knob)		Push Lever		Pull Lever		Squeeze (2 hands)	
	Female	Male	Female	Male	Female	Male	Female	Male
2	5.5	6.0	6.8	6.8	12.0	9.0	4.4	6.6
3	7.5	7.5	4.0	10.5	17.5	12.5	6.6	8.8
4	10.8	13.0	12.5	16.0	19.0	24.0	13.2	14.3
5	13.6	15.5	21.3	20.5	24.0	28.0	19.8	18.7
6	17.6	19.2	25.0	29.5	32.5	38.5	20.9	26.4

Note: 1. Values in this table are based on a minimum of 50 children in each age and sex group.

2. Push, pull and squeeze values are expressed in pounds; twist values are expressed in inch pounds.

*Estimated values computed by adding 2 standard deviations to the average value.

Table 1a. Condensed Force Values for Twist, Push, Pull and Squeeze Tests

95th Percentiles

Age (years)	Twist (2" knob)		Push Lever		Pull Lever		Squeeze (2 hands)	
	Female	Male	Female	Male	Female	Male	Female	Male
2	1.62	1.76	88	105	167	171	98	88
3	2.08	2.20	131	125	176	191	117	113
4	2.96	2.80	202	252*	258	269	152	166
5	3.39	3.44	235	269*	269	282	196	215
6	3.57	3.63	357*	281*	282	296	206	235

Averages

Age (years)	Twist (2" knob)		Push Lever		Pull Lever		Squeeze (2 hands)	
	Female	Male	Female	Male	Female	Male	Female	Male
2	1.03	1.14	49	62	90	103	57	61
3	1.42	1.49	74	81	121	122	70	75
4	1.94	2.11	117	145	160	180	107	118
5	2.98	2.53	153	176	204	220	141	146
6	2.62	2.91	175	209	224	250	156	179

5th Percentiles

Age (years)	Twist (2" knob)		Push Lever		Pull Lever		Squeeze (2 hands)	
	Female	Male	Female	Male	Female	Male	Female	Male
2	.62	.68	30	30	53	40	20	29
3	.85	.85	118	47	78	56	29	39
4	1.22	1.47	56	71	85	107	59	64
5	1.54	1.75	95	91	107	126	88	83
6	1.99	2.17	11	131	145	171	93	117

Note: 1. Values in this table are based on a minimum of 50 children in each age and sex group.

2. Push, pull and squeeze values are expressed in newtons, rounded off to the nearest newton; twist values are expressed in newton meters, rounded off to the nearest .01 newton meter.

*Estimated values computed by adding 2 standard deviations to the average value.

Table 2. Effect of Race*

Age	Sex	Number of tests for which white is stronger	black is stronger
2	F	1	18
	M	3	16
3	F	9	10
	M	18	1
4	F	14	5
	M	16	3
5	F	2	17
	M	4	15
6	F	18	1
	M	9	10
Total		94	96

*Based on averages of 50 children in each age and sex group, of which at least 20% are black children.

FIGURE 8. AVERAGES, 95th PERCENTILES AND 5th PERCENTILES OF CONDENSED TWIST DATA

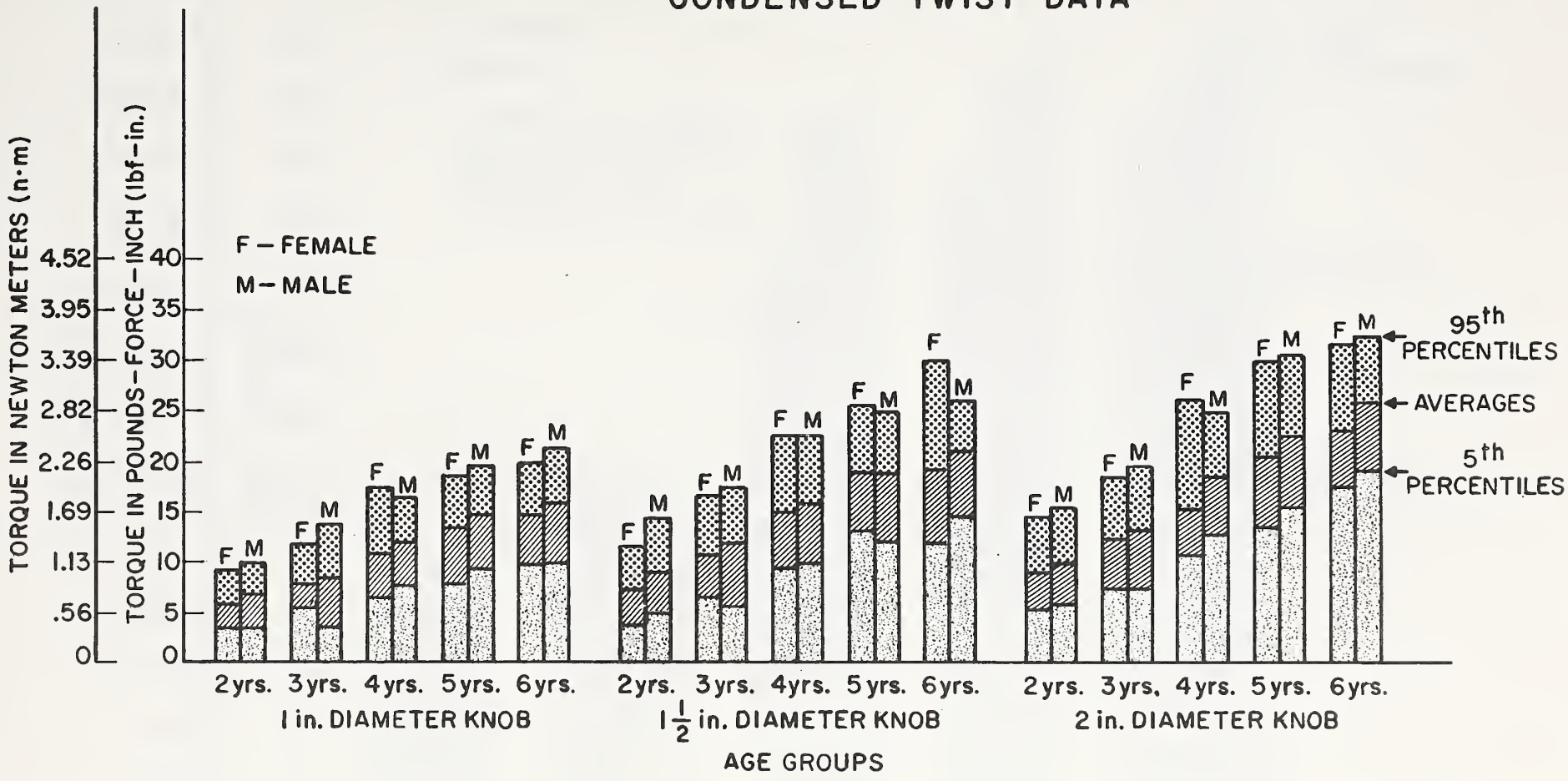


FIGURE 9. AVERAGES, 95th PERCENTILES AND 5th PERCENTILES OF CONDENSED PUSH DATA

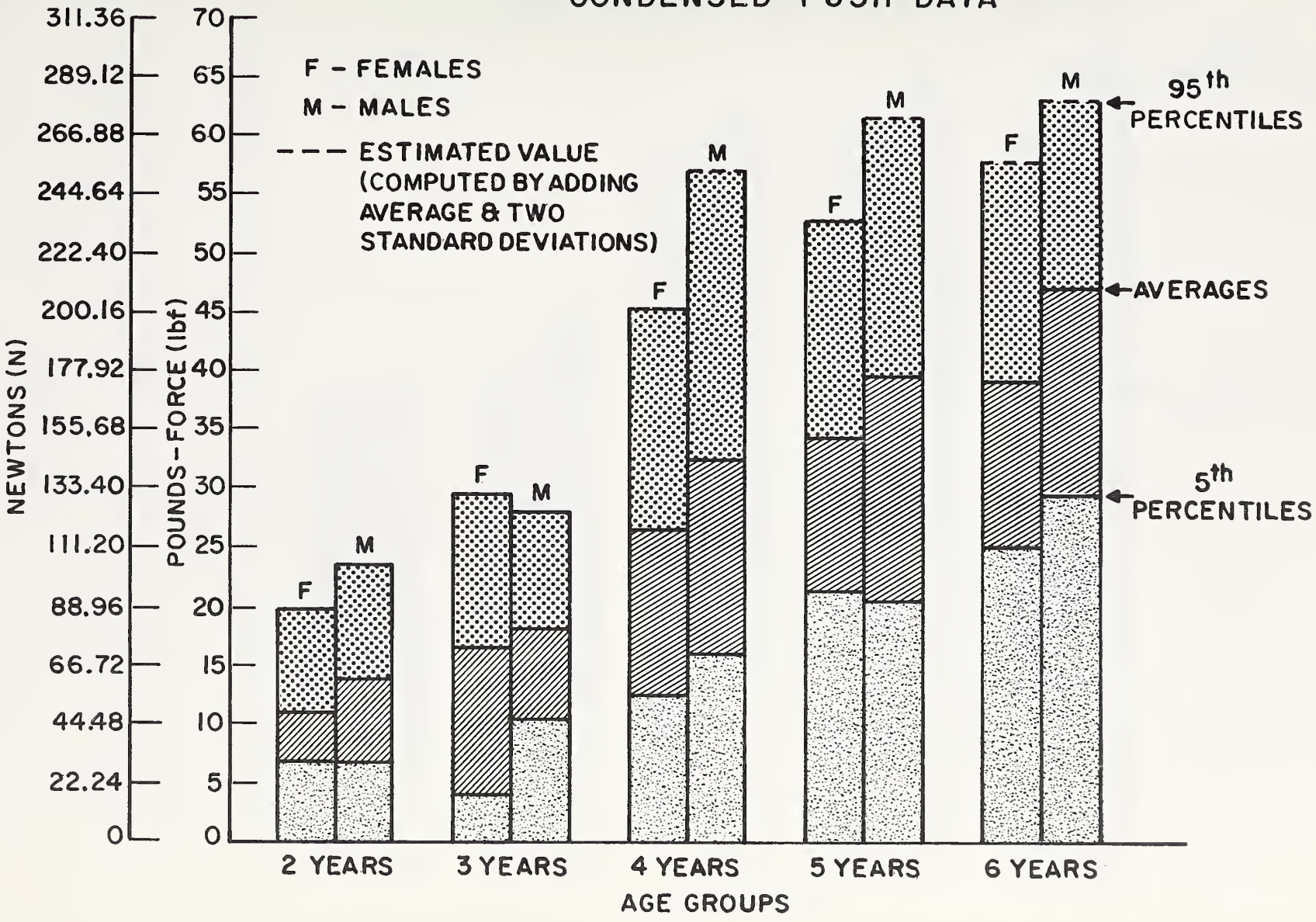


FIGURE 10. AVERAGES, 95th PERCENTILES AND 5th PERCENTILES
CONDENSED LEVER PULL DATA

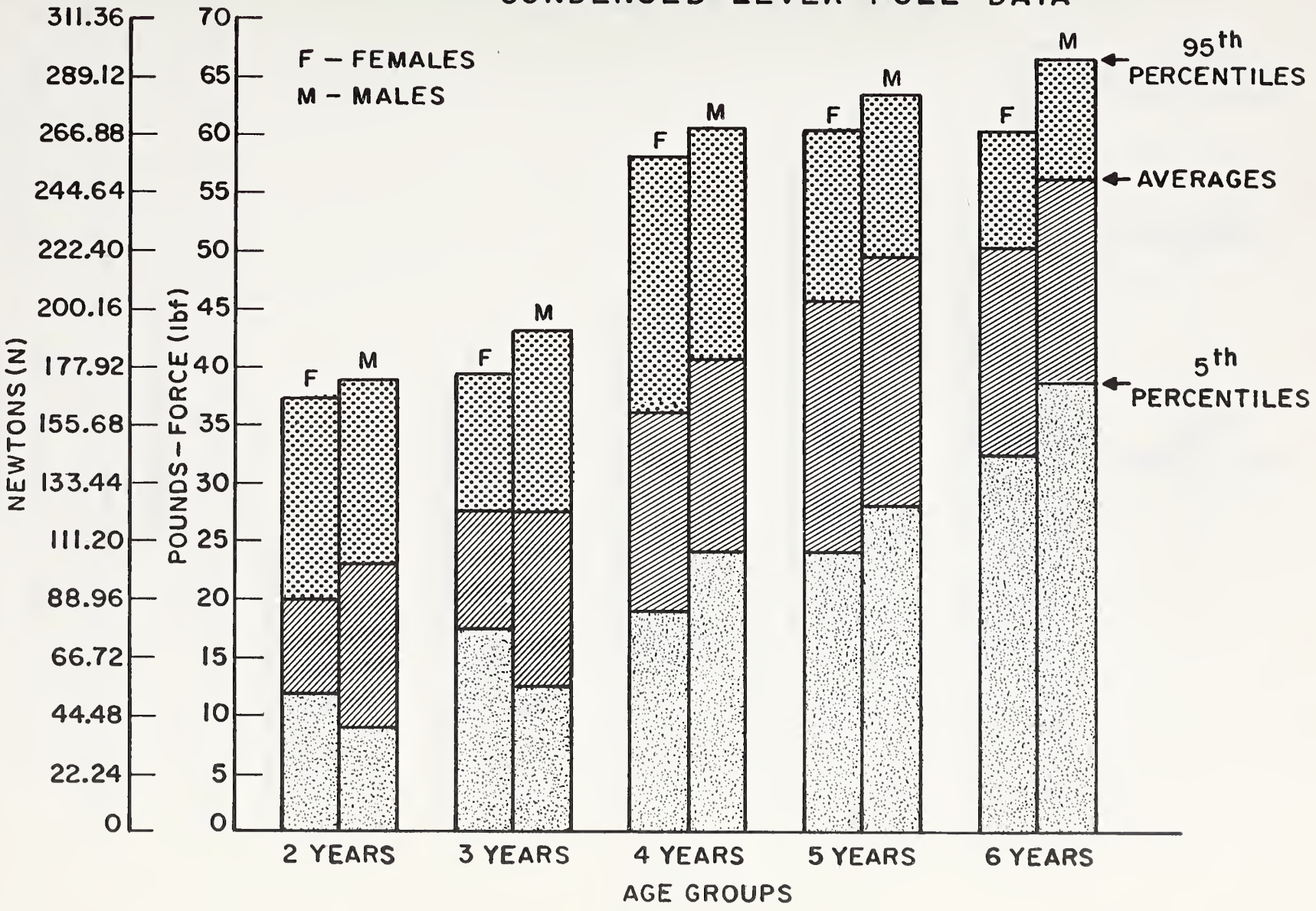


FIGURE 11. AVERAGES, 95th PERCENTILES AND 5th PERCENTILES OF CHAIN PULL DATA

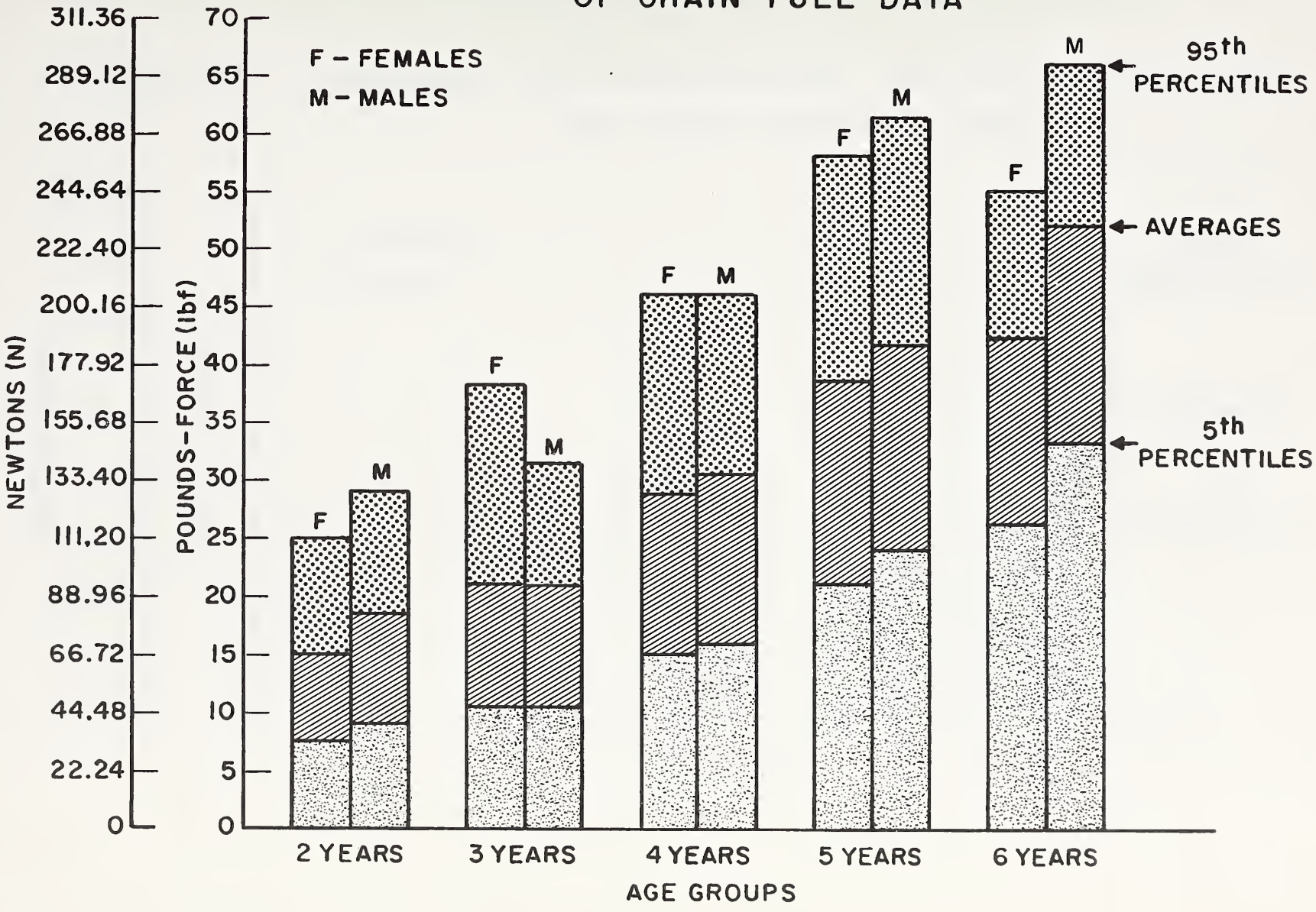


FIGURE 12. AVERAGES, 95th PERCENTILES AND 5th PERCENTILES
ONE-HAND SQUEEZE DATA

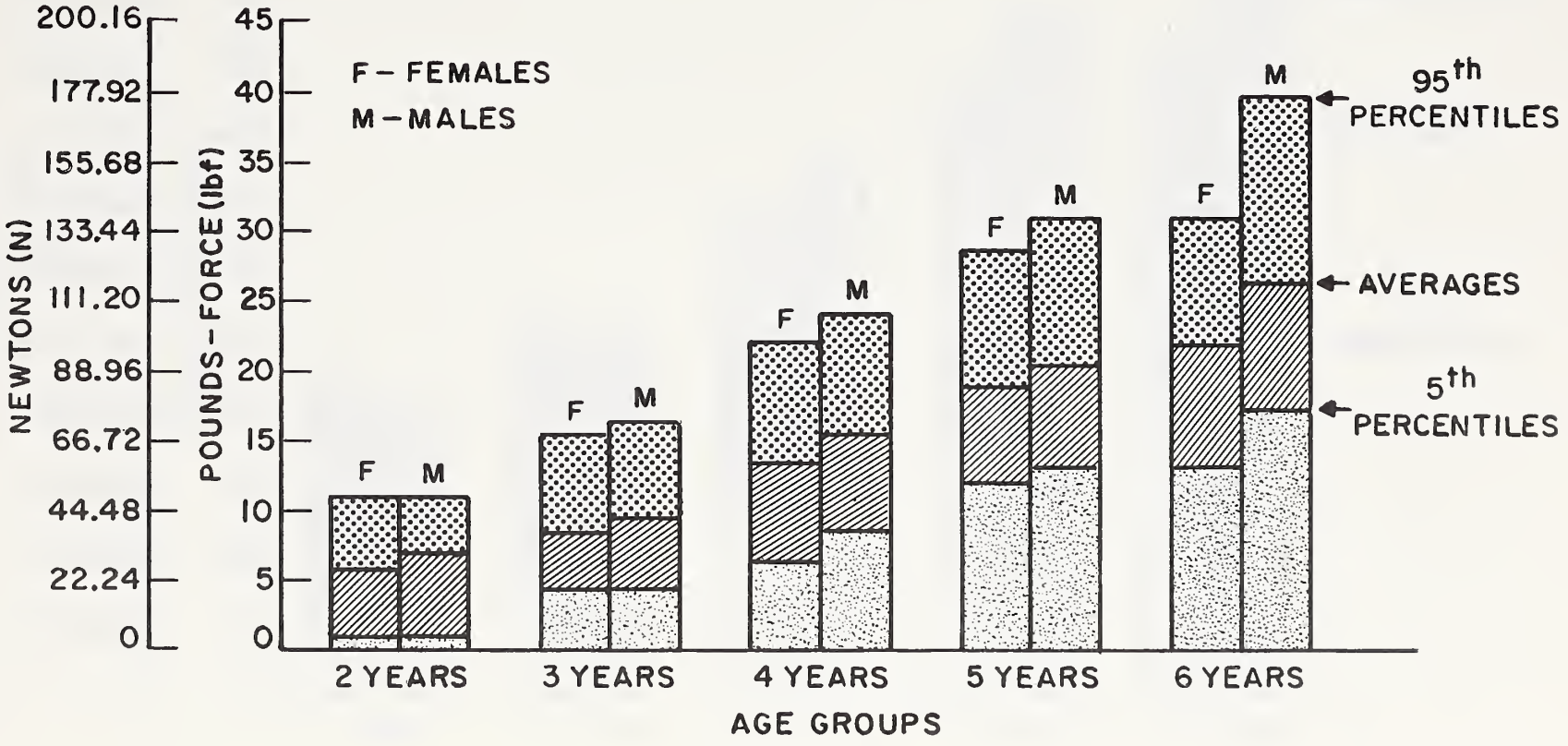
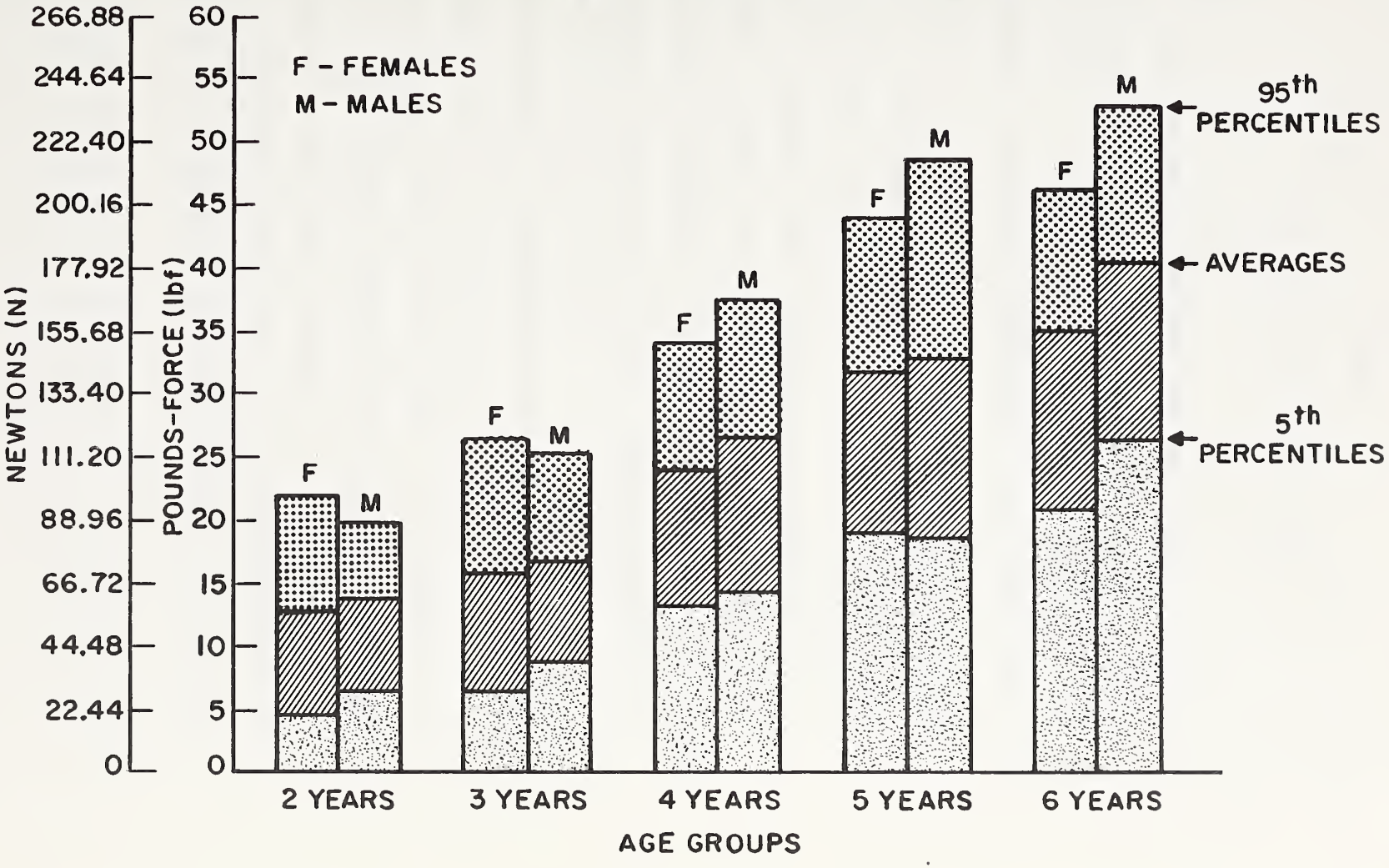


FIGURE 13. AVERAGES, 95th PERCENTILES AND 5th PERCENTILES
TWO-HAND SQUEEZE DATA



APPENDIX

Statistical Analysis of Data

Scope

In the preceeding sections, the main results of this study have been presented partly in graphic and partly in tabular form. To facilitate the drawing of practical conclusions, the data were "condensed," in the sense that for each child, only the maximum strength of several similar tests was considered. The present section covers the data in much greater detail. First, the results of all nineteen tests are examined, rather than just the condensed data. Secondly, measures of variability (standard deviation and coefficients of variation) among children of any given age and sex group are given for all tests. Thirdly, histograms are presented for a selected number of tests, and finally, a detailed analysis is presented of the interrelationships among the results for all nineteen tests, as well as among the results for the ten age and sex groups. This analysis led to two empirical equations which provide very useful summaries of the entire set of data obtained in this study. The statistical analysis outlined in the four points above will also help in establishing the overall validity of our study.

Basic Results

The results of all tests conducted are presented in Tables 1 through 4, in the form of two-way tables[1] of 19 rows, representing the nineteen tests, and ten columns, representing the 10 age and sex combinations. Table 1 contains the averages of each age and sex group for each test. Table 2 contains the standard deviation measuring the variability among children within each such group. In Table 3 these standard deviations have been converted to coefficients of variation. Finally, Table 4 lists the 95th percentiles for all groups. This is a value such that 95 percent of the entire population of children in a particular age and sex group, when measured by a particular test, will have a strength capability less than or equal to this value. In other words, 5 percent of the entire population of children in each group will exceed the 95th percentile of that group. Since all groups consisted of from fifty to sixty children, an acceptable estimate of the 95th percentile is obtained by taking the third largest result in each group. This procedure, which has the advantage of being non-parametric (independent of the nature of the frequency distribution), was used in the present case.

A comparison of Tables 2 and 3 shows that the coefficients of variation vary over an appreciably smaller range than the

[1]More significant figures are given in the tables than are warranted by the precision of the data. This is done to allow the reader to further examine the data, if he so wishes, without being handicapped by rounding errors.

standard deviations. In fact, the coefficients of variation for the various tests, when averaged over all ten age and sex groups, vary by a ratio of less than two to one. The value %CV = 30% is a reasonably good approximation for all cases, with the exception of the two year olds (for which it is higher) and the six year olds for some of the tests (for which it is lower).

It should be remembered that these coefficients of variation are measures of the relative variability among the results for children in the same age and sex group when performing the same test.

Histograms

Figures 1 through 5 present histograms for five selected tests, for all five age groups. The results for both sexes are combined in each histogram. The figures are presented mainly for information; no attempt was made to fit any particular statistical distribution curve to the data. For purposes of uniformity of presentation, the same class interval, of two pounds, was used in all cases, in spite of the fact that in some cases this led to too many intervals. The interested reader can, of course, derive histograms with fewer class intervals from these figures.

Interrelationships Among The Data

A glance at Tables 1 and 4 shows that the group averages, as well as the 95th percentiles, are not just a random assembly

of results. In each of these tables, definite patterns are present, resulting from the interrelationships among the various tests. The existence of these relationships is not unexpected, since the nineteen tests all measure, in various ways, the same basic characteristic, namely, the physical strength capability of the children tested.

A first appraisal of the relation among tests is obtained by calculating the correlation coefficient between any pair of tests. There are 171 such pairs. Rather than compute the correlations for the individual results obtained for each child, they were computed over the ten age and sex groups. Thus, each of the 171 correlations was calculated for 10 "points," i.e., 10 pairs of values. The correlations are listed in the correlation matrix shown in Table 5. All correlation coefficients exceeded 0.95, and 106 of the 171 pairs had a correlation coefficient of 0.99 or higher. These results support the hypothesis that to a very considerable extent all 19 tests measure the same basic characteristic. Nevertheless, some of the tests may be superior to others in ability to detect smaller differences in strength capability. The sensitivity of a test is directly proportional to its rate of change (slope) with increasing strength and inversely proportional to its experimental scatter. Applying this criterion to the 19 tests, it appeared that all four push and pull tests (knob and rubber sleeve) showed high sensitivity, whereas the top and front twisters were not consistently high in sensitivity. This

would indicate a slight superiority for the push and pull tests, but it must be understood that the sensitivity of any of the other tests is not appreciably different from that of these four tests.

Empirical Equations

Let A represent age, S sex, and T test (instrument, configuration, and mode of use); and let Y represent the test result for a particular child. Then, Y is a mathematical function of the form:

$$Y = f(A,S,T) + \varepsilon \qquad (1)$$

The quantity ε is a random fluctuation measuring the amount by which the strength of a particular child differs from the average of all children in his age and sex group.

Similarly, if Z represents the 95th percentile for any particular age, sex, and test combination, it is expected that a relation exists of the form:

$$Z = \phi(A,S,T) \qquad (2)$$

We now wish to find explicit expressions for the functions f and ϕ. The function f(A,S,T), occurring in equation (1) is to be derived from the averages $\bar{Y}$; and the function $\phi(A,S,T)$ shown in equation (2) is to be derived from the 95th percentiles.*

*The values in Table 4 are subject to the following shortcoming: in a given age and sex group, the third largest value for any two tests may or may not be associated with the same child. In fact, such associations do occur in the table. This would create difficulties if the values were to be the basis for tests of significance because of correlations between the data. However, for our purpose, which is one of estimation rather than hypothesis testing, these correlations are of no importance.

The empirical derivation of these functions followed the procedure described in reference (5).

Empirical Equations for Group Averages

It was found that the function f(A,S,T) (see equation 1) could be satisfactorily approximated by the following expression:

$$f(A,S,T) = Y_o + P_{(A,S)} \cdot Q_{(T)} \qquad (3)$$

where Y_o is a constant, $P_{(A,S)}$ is a quantity that depends only on age and sex, and $Q_{(T)}$ is a quantity that depends only on the "test" (instrument, configuration, and mode of use). The value of P is in all cases larger for the males than for the females. The value of $Y_o = 0.52$, and the values for $P_{(A,S)}$ and $Q_{(T)}$ are shown in Table 6. The values of $P_{(A,S)}$ are also shown in graphical form in Figure 6, as a function of age, using different symbols for the two sexes. The degree to which equation (3) fits the experimental data was examined in terms of the variability among children of the same age and sex group, and was found to be consistent with this variability.

The values of $Q_{(T)}$ are also instructive, showing the effect of the size of the knob and of direction (counter-clockwise vs. clockwise) in the front and top twisters, the similarity between the results obtained by these two instruments and the almost identical results obtained for "knob" and "rubber sleeve" in the push and pull tests.

By inserting in equation (3) the value $Y_o = 0.52$, and the appropriate values of P and Q, it is possible to predict the average result for any combination of age (2 through 6), sex, and "test."

Empirical Equation for 95th Percentiles

Similarly to the results for averages, it was found that the 95th percentiles could also be represented by a simple empirical function:

$$\phi(A,S,T) = Z'_o + P'_{(A,S)} \cdot Q'_{(T)} \qquad (4)$$

where $Z'_o = -0.92$, and the values of P' and Q' are shown in Table 7.

Observations similar to those made for the averages can be made on the basis of the results shown in Table 7 and illustrated in Figure 6.

Key for Tables 1-5

TT	Top twist tester
FT	Front twist tester
PSH	Push
PUL	Pull
CH	Chain
K	Knob
R	Rubber Sleeve
SQZ1	Squeeze, one hand
SQZ2	Squeeze, two hands
LL	Large (2") knob, left direction
LR	Large (2") knob, right direction
ML	Medium (1 1/2") knob, left direction
MR	Medium (1 1/2") knob, right direction
SL	Small (1") knob, left direction
SR	Small (1") knob, right direction
F	Female
M	Male

Note: In the tables and graphs presented in the Appendix, push, pull, and squeeze values have been expressed in pounds-force, and torque values have been expressed in inch-pounds. To convert these values to newtons and newton meters, multiply the values expressed in pounds-force by 4.448 and the values expressed in inch-pounds by .1129.

Table 1. Child Strength Capability Study
Averages Based on a Minimum of 50
Children in Eacn Age and Sex Group

Test \ Group	2F	2M	3F	3M	4F	4M	5F	5M	6F	6M	Average
TTSL	3.09	3.42	4.75	4.71	6.58	7.11	8.51	9.44	9.34	11.32	6.83
TTSR	4.19	5.11	6.24	6.55	9.24	9.72	10.42	11.54	10.59	11.99	8.56
FTSL	3.93	4.55	6.14	6.45	8.75	9.97	10.67	11.81	12.30	14.18	8.88
FTSR	5.45	6.02	7.39	7.34	10.19	11.07	12.54	13.15	13.75	15.22	10.21
TTML	5.40	6.36	8.24	8.86	11.64	12.15	13.10	14.69	14.49	17.44	11.24
FTML	4.89	5.89	7.82	8.67	11.25	12.42	13.84	15.05	16.03	17.89	11.38
TTMR	6.17	7.52	8.88	9.37	12.99	14.18	13.84	16.37	14.49	17.35	12.12
FTLL	5.89	6.56	8.81	9.80	13.01	14.09	15.39	17.31	18.66	20.49	13.00
FTMR	6.79	8.24	9.54	10.54	13.03	14.14	16.36	17.59	18.60	19.63	13.45
TTLL	6.41	7.29	9.40	10.25	13.72	14.65	16.96	18.36	18.90	22.32	13.83
SQZ1	5.75	6.98	8.45	9.53	13.49	15.48	19.06	20.41	21.96	26.52	14.76
TTLR	7.83	8.81	11.04	11.51	15.34	17.74	17.55	20.50	19.66	23.42	15.35
FTLR	7.53	8.98	11.04	11.50	14.82	16.14	19.55	20.59	21.23	24.00	15.54
SQZ2	12.76	13.83	15.77	16.87	24.14	26.56	31.76	32.80	34.99	40.25	24.98
KPSH	9.90	12.84	14.54	16.10	24.16	28.29	31.94	37.15	35.96	46.21	25.71
RPSH	9.19	11.67	15.08	16.48	24.55	30.13	32.48	37.62	36.88	44.61	25.87
CHPUL	15.08	18.49	20.93	20.67	28.88	30.49	38.46	41.67	42.23	52.37	30.93
KPUL	18.36	21.27	24.91	24.70	32.00	37.02	41.37	45.76	46.71	54.09	34.62
RPUL	18.55	21.19	24.03	24.76	35.01	37.29	43.38	46.93	48.53	54.30	35.40
Average	8.27	9.74	11.74	12.35	16.99	18.88	21.43	23.62	23.96	28.09	17.51

Note: All push, pull and squeeze values are expressed in pounds. All twist values are expressed in inch-pounds.

Table 2. Child Strength Capability Study
Standard Deviations Based on a Minimum of 50 Children in Each Age and Sex Group

Test \ Group	2F	2M	3F	3M	4F	4M	5F	5M	6F	6M	Average
TTSL	2.0	1.9	2.6	2.4	3.0	3.1	3.6	4.5	3.3	3.3	3.0
TTSR	1.7	2.0	2.5	2.6	3.0	2.8	3.6	3.2	3.4	3.5	2.8
FTSL	2.3	2.5	2.3	2.9	3.0	3.3	3.3	3.5	3.6	3.2	3.0
FTSR	2.1	2.2	2.6	2.9	3.1	2.7	3.4	3.2	3.5	3.6	2.9
TTML	2.3	2.8	3.3	3.1	3.7	3.9	3.9	4.2	4.1	4.1	3.5
FTML	2.5	2.7	3.1	3.4	3.9	3.6	3.7	4.2	4.3	3.7	3.5
TTMR	2.4	3.0	3.0	3.2	3.8	4.1	4.4	4.4	3.4	5.2	3.7
FTLL	2.7	3.0	2.9	3.8	4.5	3.8	4.1	3.4	4.1	5.1	3.7
FTMR	2.4	3.3	3.4	4.1	4.3	3.8	3.8	3.8	5.2	5.5	4.0
TTLL	2.9	3.1	3.2	3.9	4.4	4.2	4.5	5.3	4.1	2.9	3.9
SQZ1	3.0	3.3	4.5	3.6	4.1	4.7	5.5	5.6	5.3	6.1	4.6
TTLR	3.0	3.0	3.1	3.6	4.2	4.3	5.0	5.6	3.8	3.2	3.9
FTLR	2.8	3.0	3.8	4.3	5.2	4.1	4.5	4.6	5.6	5.3	4.3
SQZ2	5.1	4.8	6.2	4.9	6.3	6.7	8.0	8.6	7.3	7.0	6.5
KPSH	4.3	4.6	6.8	6.6	9.2	10.4	9.5	11.2	9.8	6.8	7.9
RPSH	4.2	4.6	6.0	5.8	8.0	12.2	9.4	11.3	9.9	9.4	8.1
CHPUL	5.7	6.1	7.9	6.7	10.6	11.0	10.5	12.4	8.9	9.7	8.9
KPUL	6.4	7.5	6.9	9.0	11.6	12.1	12.3	12.5	11.0	8.9	9.9
RPUL	7.6	8.1	5.8	10.4	10.6	12.3	10.9	10.7	9.8	8.2	9.4
Average	3.4	3.7	4.3	4.6	5.6	5.9	6.0	6.4	5.8	5.4	5.1

Note: All push, pull and squeeze values are expressed in pounds. All twist values are expressed in inch-pounds.

Table 3. Child Strength Capability Study
Percent Coefficients of Variation Based on a Minimum
50 Children in Each Age and Sex Group

Test \ Group	2F	2M	3F	3M	4F	4M	5F	5M	6F	6M	Average
TTSL	63	57	55	51	46	44	42	48	35	29	47
TTSR	41	39	40	40	32	29	34	27	32	29	34
FTSL	58	55	38	45	33	33	31	29	29	23	37
FTSR	38	37	36	40	31	24	27	25	26	24	31
TTML	43	44	40	35	32	32	30	28	29	23	34
FTML	51	46	40	40	35	29	26	28	27	21	34
TTMR	39	40	34	34	29	29	32	27	24	30	32
FTLL	45	39	33	39	35	26	27	20	22	25	31
FTMR	35	40	36	39	33	27	23	21	28	18	30
TTLL	46	42	34	38	32	29	27	29	21	13	31
SQZ1	51	47	53	38	30	31	29	27	24	23	35
TTLR	38	34	28	31	27	24	28	27	19	14	27
FTLR	37	34	34	38	35	25	23	23	26	22	30
SQZ2	40	34	39	29	26	25	25	26	21	17	23
KPSH	43	36	47	41	38	37	30	30	27	15	34
RPSH	45	40	40	35	33	41	29	30	27	21	34
CHPUL	38	33	38	32	37	36	27	30	21	19	31
KPUL	35	35	32	36	36	33	30	27	24	17	30
RPUL	41	38	24	42	30	33	25	23	20	15	29
Average	44	41	38	38	33	31	29	28	25	21	31

Note: All push, pull and squeeze values are expressed in pounds. All twist values are expressed in inch-pounds.

Table 4. Child Strength Capability Study
95th Percentiles - Based on a Minimum of 50 Children in Each Age and Sex Group

Test \ Group	2F	2M	3F	3M	4F	4M	5F	5M	6F	6M	Average
TTSL	7.0	7.0	8.5	8.5	11.5	11.5	16.0	17.6	15.3	17.6	12.1
TTSR	7.5	9.0	11.9	11.9	14.2	14.8	16.4	17.5	17.1	17.8	13.8
FTSL	8.9	8.9	10.3	12.0	14.2	16.5	16.6	18.0	17.8	19.0	14.2
FTSR	9.2	9.6	11.4	11.8	15.2	16.0	18.8	18.2	20.0	20.7	15.1
TTML	10.3	10.3	13.0	14.8	17.8	18.5	19.8	21.4	22.2	25.0	17.9
FTML	9.3	11.5	14.5	14.5	18.3	20.5	20.4	22.0	22.7	24.8	17.3
TTMR	10.4	13.4	14.3	14.8	20.0	21.5	20.6	25.0	20.8	24.4	18.5
FTLL	10.6	11.8	13.3	17.8	21.4	19.8	22.5	23.5	25.2	29.8	19.6
FTMR	11.8	14.5	15.8	17.0	22.5	19.4	22.5	22.5	29.9	26.4	20.2
TTLL	11.5	13.2	15.5	16.0	22.0	22.0	24.0	24.6	26.2	30.1	20.5
SQZ1	11.0	11.0	15.4	16.5	22.0	24.2	28.6	30.8	30.8	39.6	23.0
TTLR	13.6	14.8	17.8	16.5	22.5	24.0	25.0	29.3	25.0	30.5	21.9
FTLR	12.6	14.4	18.8	19.5	24.5	23.8	27.4	30.5	29.9	31.0	23.2
SQZ2	22.0	19.8	26.4	25.3	34.1	37.4	44.0	48.4	46.2	52.8	35.6
KPSH	17.5	20.5	28.8	28.0	45.3	52.5	50.5	55.0	55.0	55.0	40.8
RPSH	18.3	20.5	28.0	27.0	35.5	55.0	49.0	55.0	55.0	55.0	39.8
CHPUL	25.0	29.0	38.0	31.5	46.0	46.0	58.0	61.3	55.0	65.8	45.6
KPUL	31.5	35.5	38.5	38.5	58.0	60.0	59.5	62.8	63.5	66.5	51.4
RPUL	37.5	38.5	34.0	41.5	58.0	59.5	58.0	63.5	60.5	65.0	51.6
Average	15.0	16.5	19.7	20.2	27.5	29.6	31.5	33.6	34.1	36.7	26.4

Note: All push, pull and squeeze values are expressed in pounds. All twist values are expressed in inch-pounds.

Table 5. Correlation Matrix*

	FTSL	FTSR	FTML	FTMR	FTLL	FTLR	TTSL	TTSR	TTML	TTMR	TTLL	TTLR	KPSH	KPUL	RPSH	RPUL	CHPUL	SQZ1	SQZ2
FTSL	1.0000																		
FTSR	.9972	1.0000																	
FTML	.9988	.9960	1.0000																
FTMR	.9944	.9949	.9969	1.0000															
FTLL	.9979	.9944	.9988	.9946	1.0000														
FTLR	.9944	.9968	.9958	.9969	.9935	1.0000													
TTSL	.9940	.9948	.9935	.9906	.9933	.9971	1.0000												
TTSR	.9835	.9822	.9800	.9770	.9743	.9755	.9743	1.0000											
TTML	.9955	.9904	.9950	.9870	.9943	.9896	.9931	.9843	1.0000										
TTMR	.9814	.9749	.9753	.9666	.9723	.9674	.9725	.9934	.9866	1.0000									
TTLL	.9975	.9969	.9980	.9955	.9973	.9978	.9980	.9814	.9960	.9778	1.0000								
TTLR	.9943	.9888	.9896	.9835	.9887	.9839	.9877	.9887	.9927	.9934	.9909	1.0000							
KPSH	.9913	.9916	.9892	.9869	.9897	.9924	.9954	.9721	.9895	.9763	.9944	.9897	1.0000						
KPUL	.9934	.9943	.9922	.9914	.9922	.9960	.9968	.9677	.9874	.9678	.9950	.9870	.9972	1.0000					
RPSH	.9968	.9954	.9939	.9910	.9931	.9935	.9948	.9819	.9924	.9835	.9962	.9959	.9975	.9965	1.0000				
RPUL	.9943	.9981	.9938	.9950	.9936	.9970	.9956	.9766	.9882	.9708	.9968	.9863	.9951	.9963	.9954	1.0000			
CHPUL	.9822	.9866	.9828	.9823	.9839	.9917	.9946	.9548	.9821	.9549	.9899	.9725	.9939	.9943	.9867	.9922	1.0000		
SQZ1	.9900	.9922	.9910	.9901	.9919	.9954	.9953	.9594	.9853	.9580	.9942	.9787	.9955	.9972	.9923	.9956	.9963	1.0000	
SQZ2	.9914	.9963	.9911	.9913	.9912	.9955	.9942	.9680	.9844	.9626	.9944	.9807	.9943	.9954	.9933	.9981	.9929	.9977	1.0000

*The matrix shows the correlation coefficient between all possible pairs of tests over the 10 age and sex groups.

TABLE 6

Empirical Fit for Averages of Group

$$Y = 0.52 + P_{(A,S)} \cdot Q_{(T)}$$

1. Values of $P_{(A,S)}$

Sex	Age 2	Age 3	Age 4	Age 5	Age 6
F	.456	.661	.972	1.232	1.381
M	.543	.697	1.081	1.363	1.620

2. Values of $Q_{(T)}$

	Top Twister			Front Twister		
	Small	Medium	Large	Small	Medium	Large
Counter-Clockwise	6.31	10.72	13.30	8.33	10.86	12.52
Clockwise	8.04	11.63	14.82	9.69	12.39	15.02

	Knob	Rubber Sleeve	Chain
Push	25.11	25.35	-
Pull	34.10	34.88	30.46

	Squeeze
1 hand	14.24
2 hands	24.46

TABLE 7

Empirical Fit for 95th Percentiles of Groups

$$Z = -0.92 + P'_{(A,S)} \cdot Q'_{(T)}$$

1. Values of $P'_{(A,S)}$

Sex	Age 2	Age 3	Age 4	Age 5	Age 6
F	.584	.754	1.041	1.185	1.280
M	.636	.772	1.118	1.263	1.376

2. Values of $Q'_{(T)}$

	Top Twister			Front Twister		
	Small	Medium	Large	Small	Medium	Large
Counter-Clockwise	12.97	18.77	21.43	15.14	18.23	20.49
Clockwise	14.73	19.44	22.82	16.01	21.15	24.16

	Knob	Rubber Sleeve	Chain
Push	41.73	40.75	-
Pull	52.35	52.52	46.48

	Squeeze
1 hand	23.91
2 hands	36.56

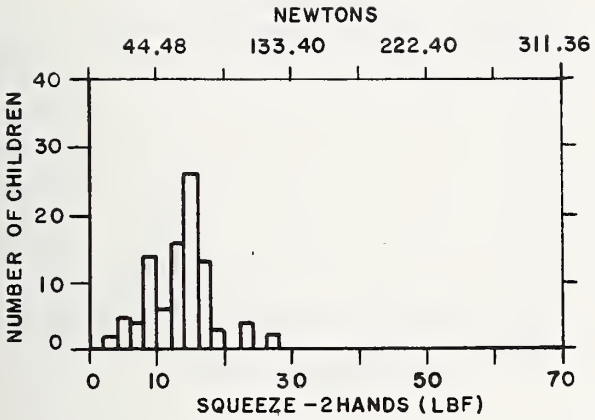
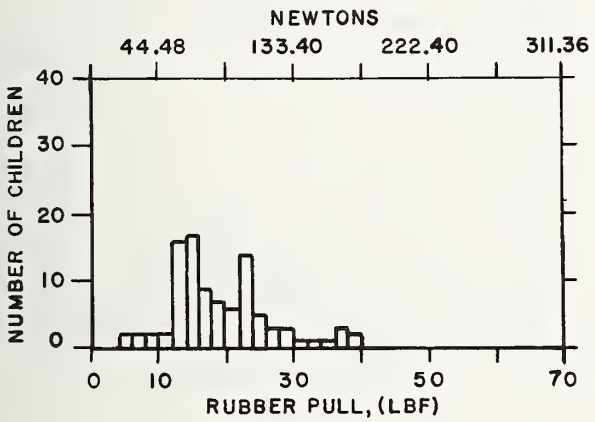
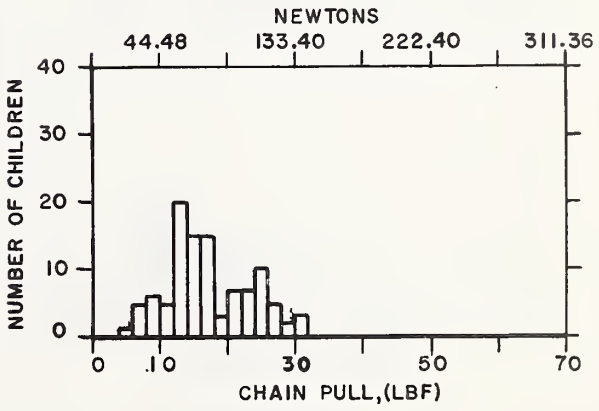


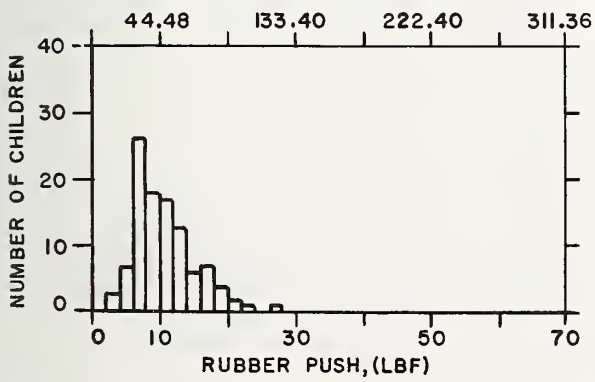
FIGURE 1. FREQUENCY DISTRIBUTION OF CHILDREN'S STRENGTH FOR SELECTED TESTS.

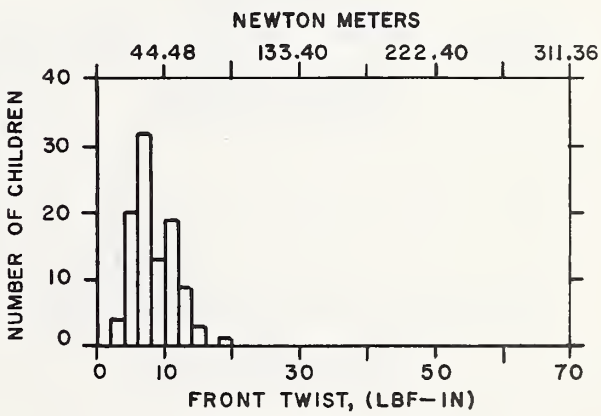
2 YEAR OLD GROUP

(INCLUDES BOTH FEMALE AND MALE CHILDREN)









NOTE: A VALUE OCCURRING AT THE END OF A FORCE INTERVAL IS COUNTED IN THE NEXT HIGHER INTERVAL.

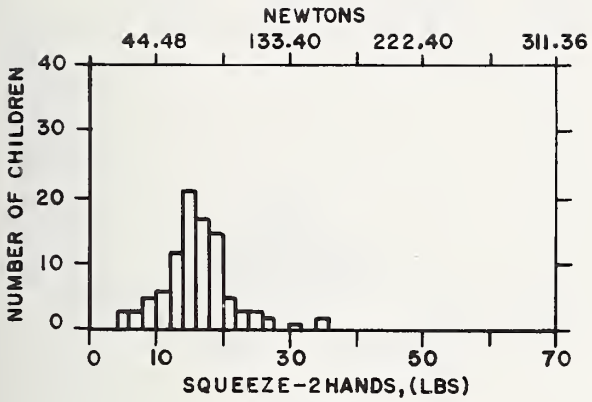
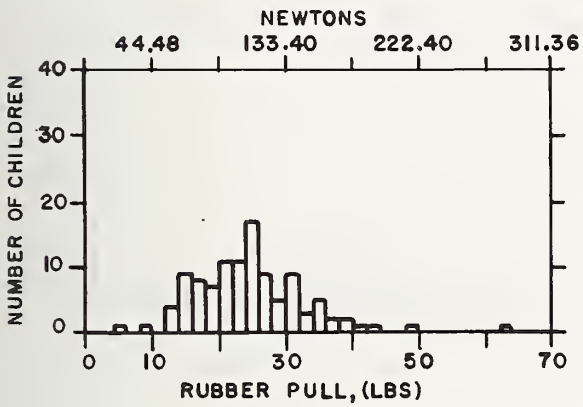
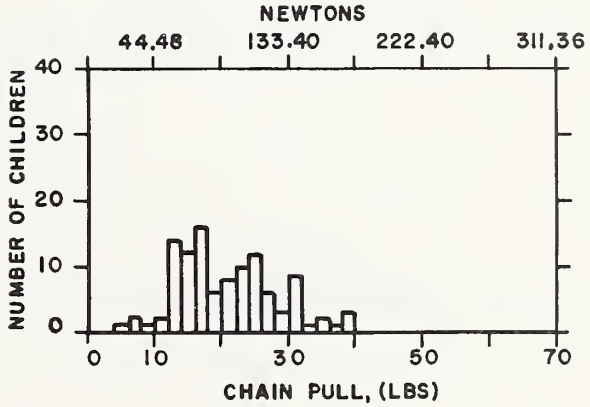


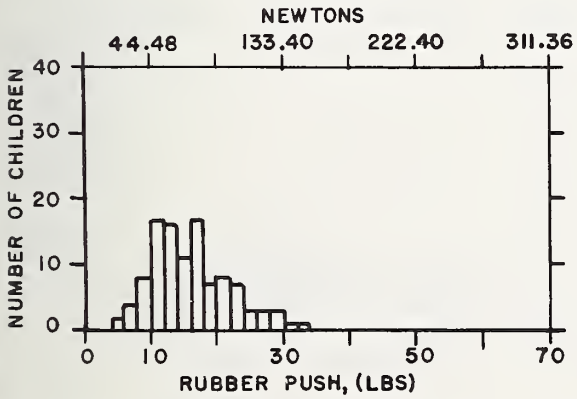
FIGURE 2. FREQUENCY DISTRIBUTION OF CHILDREN'S STRENGTH FOR SELECTED TESTS.

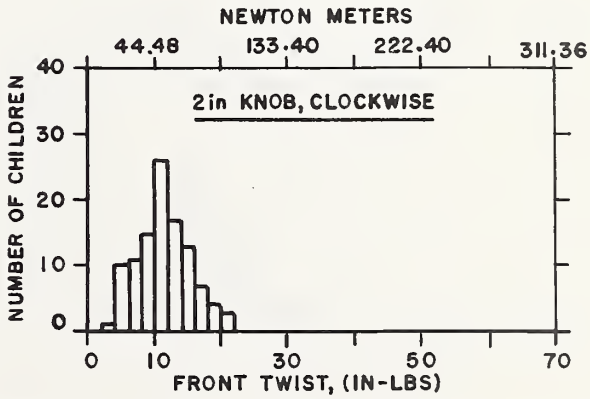
3 YEAR OLD GROUP

(INCLUDES BOTH FEMALE AND MALE CHILDREN)









NOTE: A VALUE OCCURRING AT THE END OF A FORCE INTERVAL IS COUNTED IN THE NEXT HIGHER INTERVAL.

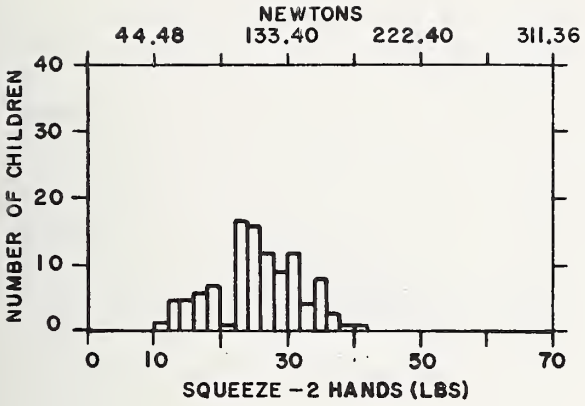
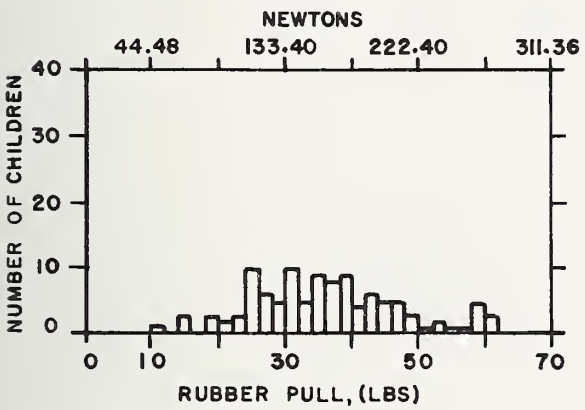
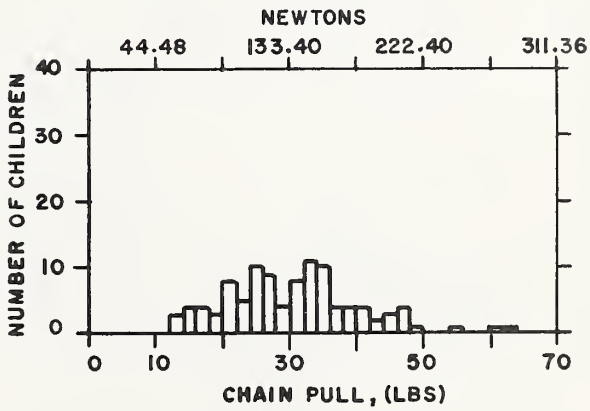


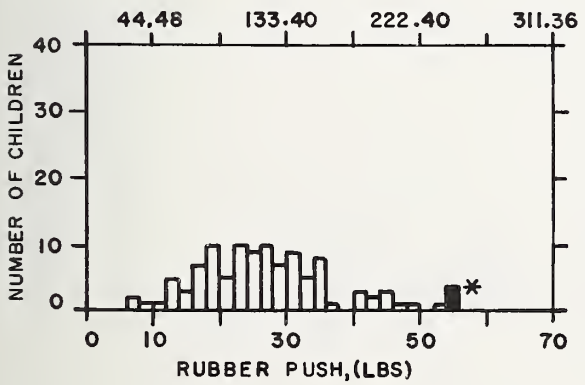
FIGURE 3. FREQUENCY DISTRIBUTION OF CHILDREN'S STRENGTH FOR SELECTED TESTS.

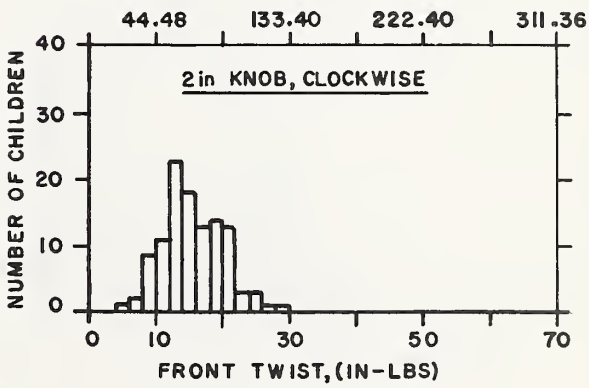
4 YEAR OLD GROUP

(INCLUDES BOTH FEMALE AND MALE CHILDREN)









* 4 CHILDREN EXCEEDED 55 lb. TESTER LIMIT.

NOTE: A VALUE OCCURRING AT THE END OF A FORCE INTERVAL IS COUNTED IN THE NEXT HIGHER INTERVAL.

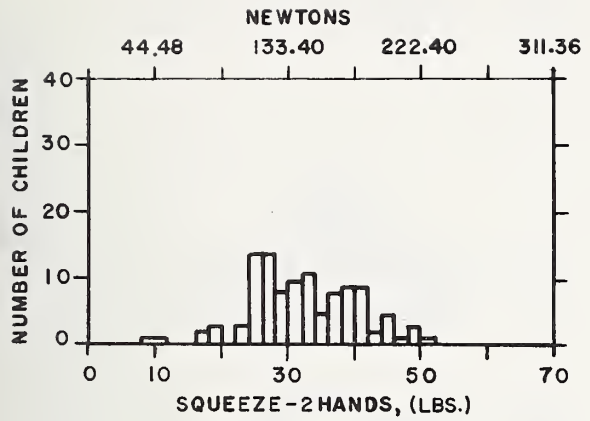
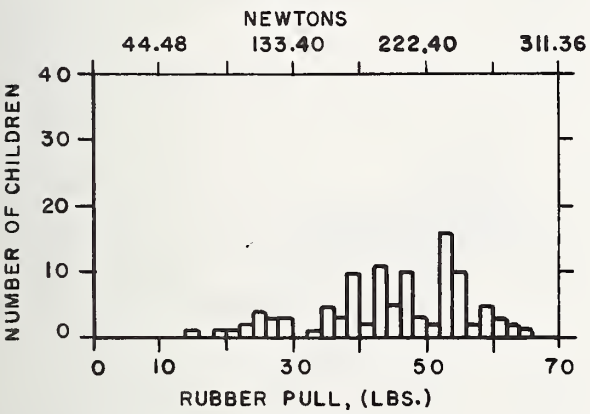
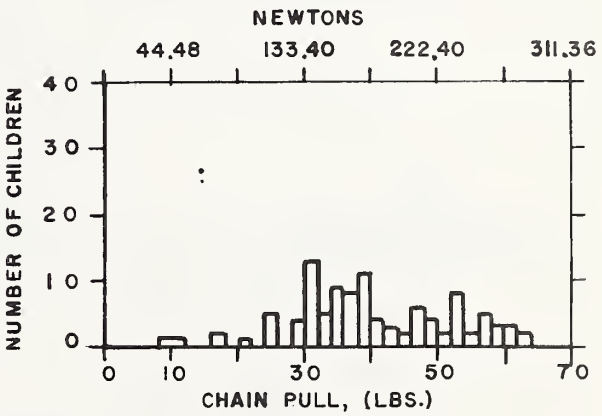


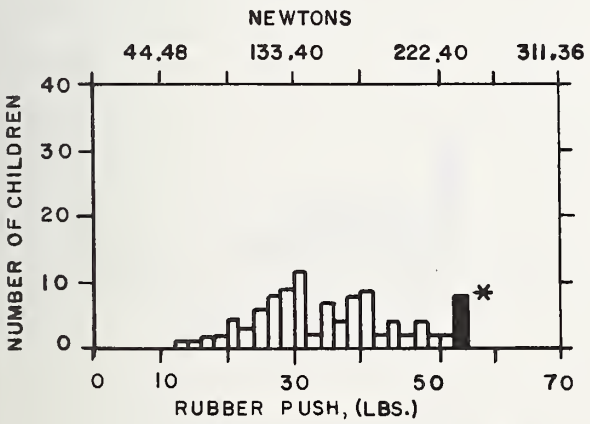
FIGURE 4. FREQUENCY DISTRIBUTION OF CHILDREN'S STRENGTH FOR SELECTED TESTS.

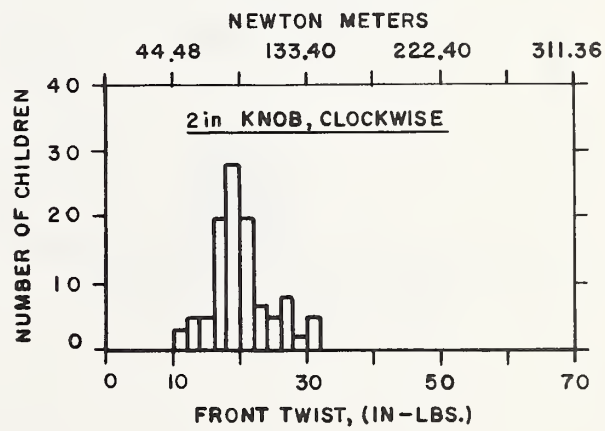
5 YEAR OLD GROUP

(INCLUDES BOTH FEMALE AND MALE CHILDREN)









* 8 CHILDREN EXCEEDED 55lb. TESTER LIMIT

NOTE: A VALUE OCCURRING AT THE END OF A FORCE INTERVAL IS COUNTED IN THE NEXT HIGHER INTERVAL.

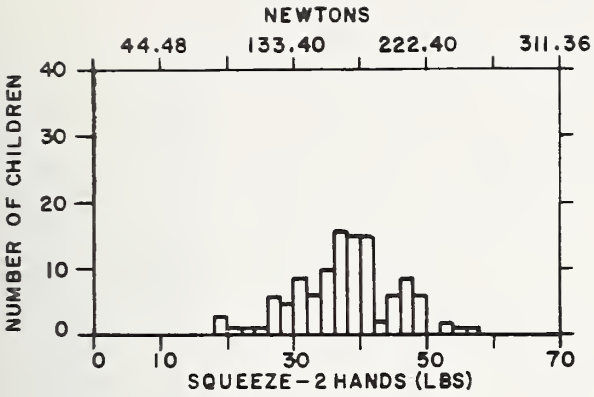
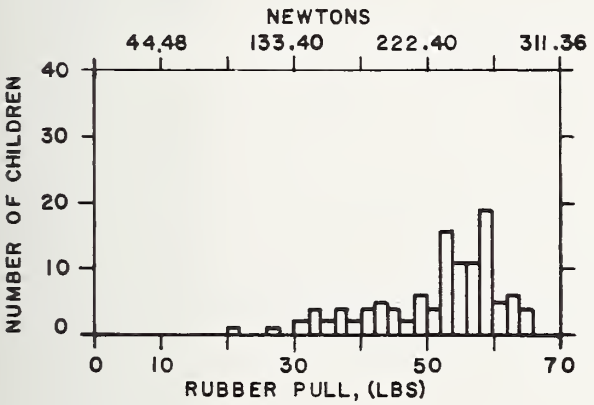
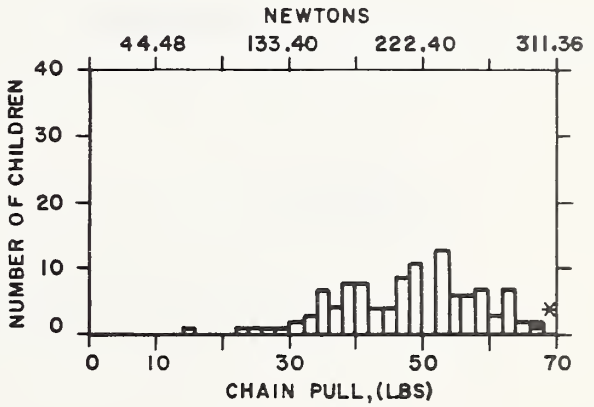


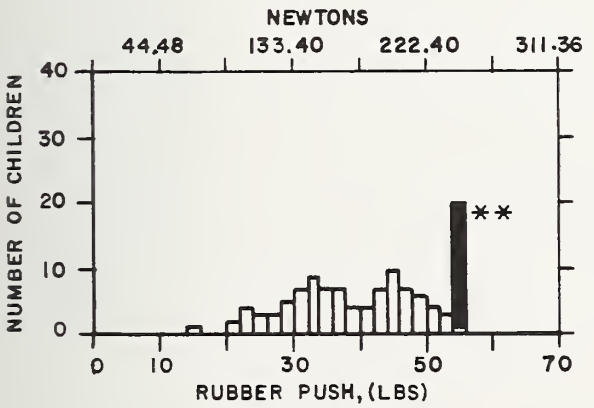
FIGURE 5. FREQUENCY DISTRIBUTION OF CHILDREN'S STRENGTH FOR SELECTED TESTS.

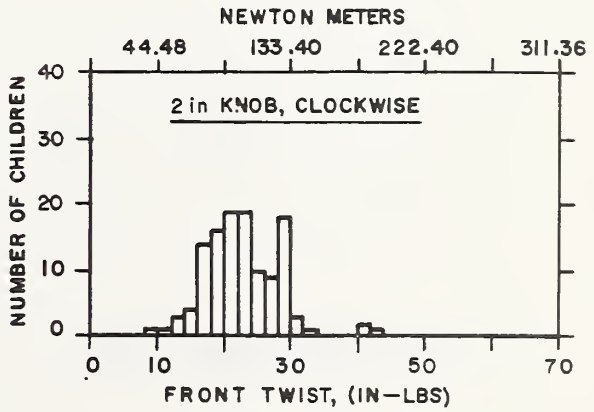
6 YEAR OLD GROUP

(INCLUDES BOTH FEMALE AND MALE CHILDREN)







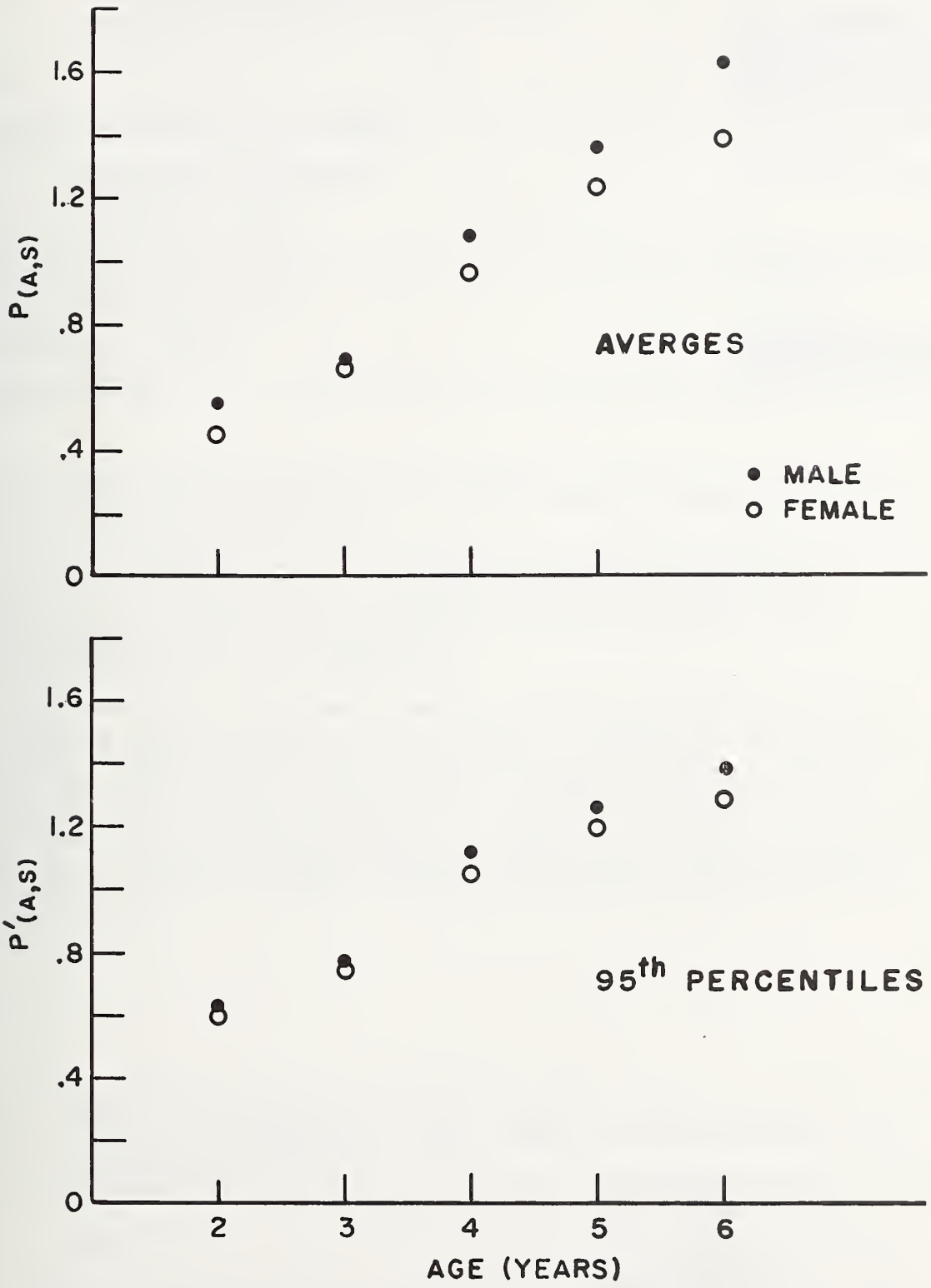


* 1 CHILD EXCEEDED 55lbs. TESTER LIMIT.

** 19 CHILDREN EXCEEDED 55 lb. TESTER LIMIT.

NOTE: A VALUE OCCURRING AT THE END OF A FORCE INTERVAL IS COUNTED IN THE NEXT HIGHER INTERVAL.

FIGURE 6. EFFECT OF AGE AND SEX



NOTE: FOR MEANING OF PLOTTED VALUES, SEE EMPIRICAL EQUATIONS IN THE APPENDIX.

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

The Child Strength Study was conducted to provide information which can be used to develop reliable and realistic standards and test methods for children's toys. The study was conducted on over 550 children in the Washington Metropolitan area, and included both black and white children with varying economic and social backgrounds.

Four test devices were used to measure the forces exerted by children when pushing, pulling, twisting, and squeezing. Quantitative relationships were found to exist between these four types of measurements. The study also provided quantitatively precise and useful information about the effects of age and sex on the strength capability of children two through six years old. The results of the study are exhibited in tables of averages, standard deviations, coefficients of variation, and 95th percentiles for each age and sex group tested. A number of graphs are also included for a quick appraisal of the test results.

17. KEY WORDS (Alphabetical order, separated by semicolons)

Children; Children's Strength; Pull; Push; Safety; Strength; Squeeze; Test Methods; Toys; Toy Safety; Twist

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