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A Study of Young Children's Pull-Apart Strength (An Addendum to NBSIR73-156 - A Study of the Strength Capabilities of Children Ages Two Through Six)

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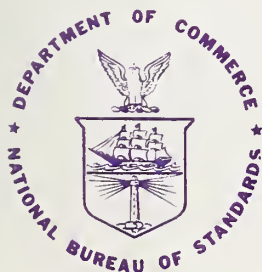
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This is a final report



U. S. DEPARTMENT OF COMMERCE
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154

**A STUDY OF YOUNG CHILDREN'S PULL-APART
STRENGTH (AN ADDENDUM TO NBSIR73-156-A
STUDY OF THE STRENGTH CAPABILITIES OF
CHILDREN AGES TWO THROUGH SIX)**

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

Introduction

Each year, thousands of young children are injured as a result of playing with unsafe or potentially hazardous toys. In order to aid in developing reliable and realistic test methods for use in establishing standards for children's toys, a study was conducted by members of the staff at the National Bureau of Standards to determine the strength capabilities of children. The main objective of the Child Strength Study was to determine what forces young children ages 2 through 6 are capable of exerting when pulling, pushing, twisting and squeezing. The results of this study are found in a report "A Study of the Strength Capabilities of Children Ages Two Through Six (NBSIR73-156)". Another phase of the child strength study involved an investigation of the forces exerted by children when attempting to pull objects apart. It is important to have some knowledge of these forces in order to establish design parameters and select appropriate materials for the manufacture of safe toys. Many accidents result when toys and other objects are pulled apart and expose hazards, such as sharp points and jagged edges which would normally be inaccessible.

The child pull-apart strength study was conducted with approximately 500 children, ages two through six.* The children participating in the study attended rural, suburban and inner-city schools which were selected at random from the various child institutes in the Washington Metropolitan area.

*Definition of age groups studied are given in "A Study of the Strength Capabilities of Children Ages Two Through Six", page 2.

The test device used to measure the forces exerted by the children was a prototype instrument, designed and constructed at the National Bureau of Standards.

Prior to beginning the Child Pull-Apart Strength Study, consultations were held with psychologists from the National Bureau of Standards and the National Institute of Child Health and Human Development, National Institutes of Health. These discussions were instrumental in designing the test procedures used in this study.

Instrumentation Description

The pull-apart tester (Figure 1) was designed to measure the force that children can exert when pulling an object apart. The tester consisted of an instrumented cylinder, with a T-shaped handle protruding from each end, and a display box, which housed a series of multi-colored lights. These lights lit up sequentially as increasing tension was applied to the T-shaped handles. The lights served as a motivational tool to induce the children to perform to the maximum capability.

One of the T-shaped handles was attached to an extension spring and coupled to a rotary potentiometer. When the T-shaped handles were pulled apart, the change in the resistance of the potentiometer, which had a constant voltage applied across it, resulted in an electrical output proportional to the force exerted. This output was recorded on a strip chart recorder and later converted to units of force.

The pull-apart tester and recording system was calibrated to an accuracy of 2.2N (0.5 lb). The calibration was checked periodically to insure that the data collected was as accurate as possible throughout the testing period.

No attempt was made to adapt the instrumented cylinder to correspond to the size of each child tested.

Test Description

Prior to being tested, the children were divided into small groups according to age. Each group of children was tested separately and a brief demonstration of the procedure to be used during testing was presented by the test instructor.

Two pull-apart methods were used in the Child Pull-Apart Strength Study. The first method consisted of holding the instrumented cylinder parallel to the shoulders at chest height, and pulling the T-shaped handles apart. The second pull-apart method consisted of holding the instrumented cylinder approximately perpendicular* to the shoulders, at chest height, and pulling the T-shaped handles apart with either the left or right hand extended forward.

A minimum of nine trials was allowed in the child pull-apart strength tests. Three trials were allowed when using the "chest pull-apart" method and six trials (three with the left hand extended and three with the right hand extended) were allowed when using the "perpendicular pull-apart" method. The children were encouraged to watch the multicolored lights illuminate sequentially as they tried to pull the handles apart as far as possible.

*During testing the children were allowed to vary slightly from the perpendicular plane to a position most comfortable for them. The amount of variation did not exceed $\pm 45^\circ$ right or left and up or down.

Test Results

The results of the pull-apart strength tests are presented in Tables 1 through 4. Tables 1a and 1b contain averages, 95th percentiles+ and 5th percentiles for each age and sex group tested in both the chest pull-apart and perpendicular pull-apart modes. Table 2 contains standard deviations, showing the variability among children within each group, and coefficients of variation expressed in percentages.

In terms of the ultimate purpose of the child strength study, the distinction between chest pull-apart strength measurements and perpendicular pull-apart strength measurements is of secondary importance. Therefore, the data were condensed in the following way. For each child, the maximum pull-apart force value was selected, regardless of whether exerted in the chest pull-apart mode or perpendicular pull-apart mode. A compilation of the averages, 95th and 5th percentiles was then made, for each age and sex group tested, from the condensed pull-apart strength data. The results of the condensed pull-apart strength data are summarized in Figure 2. It can be seen that for the 4 through 6 year old children, the males exerted greater forces than the females. The reverse situation observed for 2 and 3 year old children may be the result of sampling fluctuations.

A comparison of the pull-apart forces exerted in the two performance modes, by children of various age groups, leads to an interesting observation. These results are presented in Table 3 which shows the percentage

+The 95th percentile 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 pull-apart strength capability less than or equal to this value. The definition of the 5th percentile is determined by interchanging the numbers 95 and 5 in the preceding definition.

difference of the averages in the two performance modes in each age and sex group. Children in the 2 through 4 year age groups exerted significantly greater force, overall, when pulling the handles apart in the perpendicular pull-apart mode as opposed to the chest pull-apart mode. This result contrasted markedly with the performance of the 6 year old children whose pull-apart strength test results were just the opposite (i.e. the 6 year old children exerted greater pull-apart force in the chest rather than perpendicular mode). The 5 year old pull-apart strength performance was essentially the same for either pull-apart mode.

Correlation coefficients (Table 4) were calculated to show the relationship between the two modes of the pull-apart test, as well as the relationship between either of these modes and the strength tests described in the report on initial phases of the child strength study (Reference 1).

Conclusions

1. As was the case with the previous child strength study which dealt with twist, pull, push, and squeeze forces, the pull-apart strength study yielded useful results on the strength capability of children. These are summarized in tables of averages, 95th percentiles, and 5th percentiles for children ages 2 through 6, of both sexes.
2. With the exception of the 2 and 3 year old children, males showed higher strength than females. The reversal for the lower age groups is statistically not significant, i.e. it might be due to sampling fluctuations.

3. An unexpected result was obtained in the relation between the two modes of performing the test. For children of the lowest age group (2 years old) the test result was significantly smaller when the pull was exerted parallel to the shoulders than when it was exerted perpendicular to the chest. The difference decreased, however, as the ages of the children increased, and reversed for children of age 6, for which the direction parallel to the chest yielded larger values than the perpendicular direction. We have no explanation for this observation.
4. The correlation between the two modes of the pull-apart tests is very high (correlation coefficient of 0.99), and the correlations between either of the two modes with the strength tests carried out in the previous child strength study (Reference 1) are all high (correlation coefficient 0.92 or better). While these large correlation coefficients reflect in part the increase in the strength of a child with an increase in age, they lend support to the hypothesis that all the tests included in the child strength study measure the basic characteristic of physical strength. Thus the strength characteristic measured by the pull-apart test appears to be closely related to the strength characteristics measured by the other tests.

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Table 1a. Force Values for Pull-Apart Test
Expressed in Newtons

95th Percentiles

Age (years)	Chest		Perpendicular	
	Female	Male	Female	Male
2	54.7	42.7	54.7	42.7
3	54.7	48.9	60.0	60.0
4	70.3	81.8	68.1	79.2
5	87.2	92.5	81.8	84.5
6	112.1	122.8	94.3	100.1

Averages

Age (years)	Chest		Perpendicular	
	Female	Male	Female	Male
2	24.9	21.4	31.1	28.9
3	34.2	33.8	42.3	41.8
4	46.7	49.8	51.6	53.8
5	59.6	67.2	60.5	67.6
6	81.8	85.8	73.8	79.2

5th Percentiles

Age (years)	Chest		Perpendicular	
	Female	Male	Female	Male
2	10.7	10.7	13.3	15.6
3	17.8	22.2	22.2	22.2
4	27.6	22.2	27.6	35.1
5	35.1	42.7	45.8	45.8
6	54.7	54.7	54.7	52.0

Table 1b. Force Values for Pull-Apart Test
Expressed in Pounds

95th Percentiles

Age (years)	Chest		Perpendicular	
	Female	Male	Female	Male
2	12.3	9.6	12.3	9.6
3	12.3	11.0	13.5	13.5
4	15.8	18.4	15.3	17.8
5	19.6	20.8	18.4	19.0
6	25.2	27.6	21.2	22.7

Averages

Age (years)	Chest		Perpendicular	
	Female	Male	Female	Male
2	5.6	4.8	7.0	6.5
3	7.7	7.6	9.5	9.4
4	10.5	11.2	11.6	12.1
5	13.4	15.1	13.6	15.2
6	18.4	19.3	16.6	17.8

5th Percentiles

Age (years)	Chest		Perpendicular	
	Female	Male	Female	Male
2	2.4	2.4	3.0	3.5
3	4.0	5.0	5.0	5.0
4	6.2	5.0	6.2	7.9
5	7.9	9.6	10.3	10.3
6	12.3	12.3	12.3	11.7

Table 2. Standard Deviations and Per Cent Coefficients of Variations for Child Pull-Apart Strength Test Data

Standard Deviations (Newtons)

Group	2 yrs. old		3 yrs. old		4 yrs. old		5 yrs. old		6 yrs. old	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Chest Pull	7.6	11.1	9.8	11.1	14.7	13.8	14.7	12.9	19.6	16.9
Perpendicular Pull	7.1	10.7	10.2	10.2	10.7	11.1	12.0	9.8	12.9	12.5

Standard Deviations (Pounds Force)

Group	2 yrs. old		3 yrs. old		4 yrs. old		5 yrs. old		6 yrs. old	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Chest Pull	1.7	2.5	2.2	2.5	3.3	3.1	3.3	2.9	4.4	3.8
Perpendicular Pull	1.6	2.4	2.3	2.3	2.4	2.5	2.7	2.2	2.9	2.8

Per Cent Coefficients of Variation

Group	2 yrs. old		3 yrs. old		4 yrs. old		5 yrs. old		6 yrs. old	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Chest Pull	36	45	30	33	30	30	22	22	23	20
Perpendicular Pull	24	34	25	24	20	23	18	16	16	17

Table 3. Effect of Performance Mode

<u>Age Group</u>	<u>Percent Difference*</u>	
	<u>Male</u>	<u>Female</u>
2	-29.5	-22.1
3	-21.2	-21.7
4	-8.2	-5.6
5	-0.9	-1.3
6	8.2	10.2

*Chest pull apart strength minus perpendicular pull apart strength, expressed as a percent of the average of 2 modes.

Key for Table 4

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

Table 4. Correlation Matrix for Pull-Apart Test*

	<u>Chest Mode</u>	<u>Perpendicular Mode</u>
FTSL	.98	.99
FTSR	.98	.98
FTML	.98	.99
FTMR	.98	.99
FTLL	.98	.99
FTLR	.98	.99
TTSL	.98	.99
TTSR	.93	.95
TTML	.96	.98
TTMR	.92	.94
TTLL	.98	.99
TTLR	.96	.97
KPSH	.96	.98
KPUL	.98	.99
RPSH	.97	.98
RPUL	.98	.98
CHPL	.98	.98
SQZ1	.98	.99
SQZ2	.98	.98
Chest Mode	1.00	.99
Perpendicular Mode	.99	1.00

*This matrix shows the correlation coefficients between the chest and perpendicular pull-apart tests and all other tests in the child strength study for the 10 age and sex groups studied.

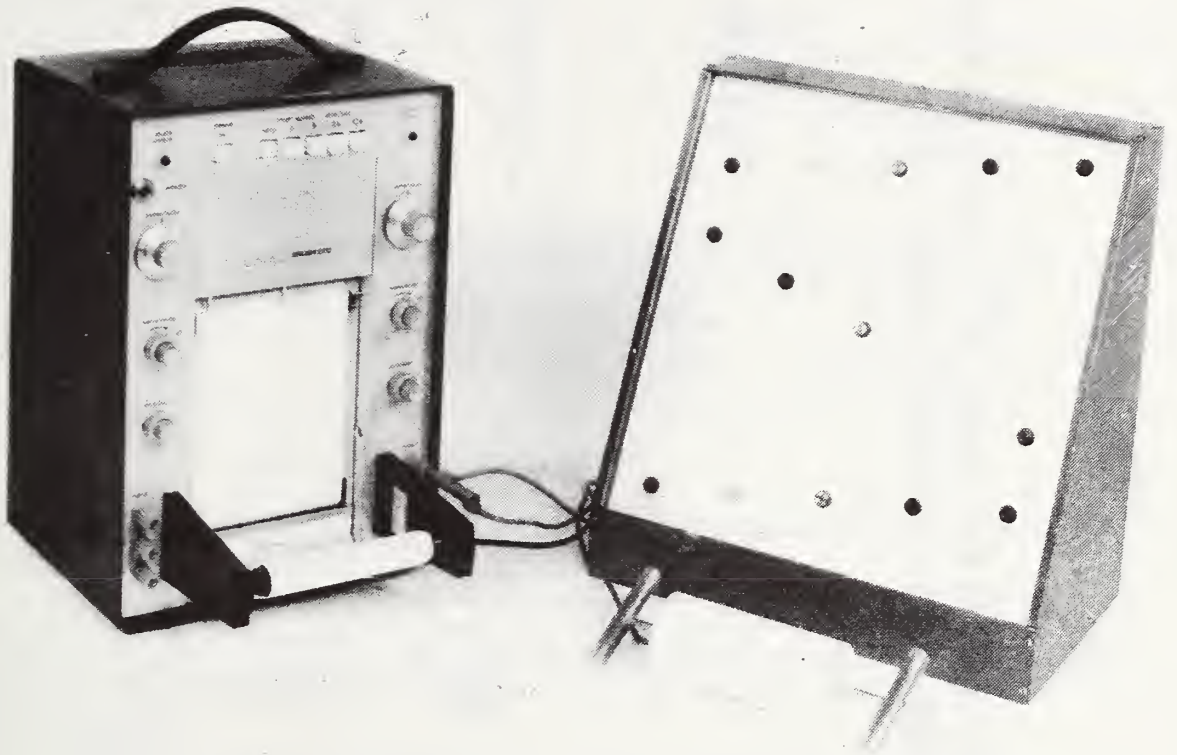
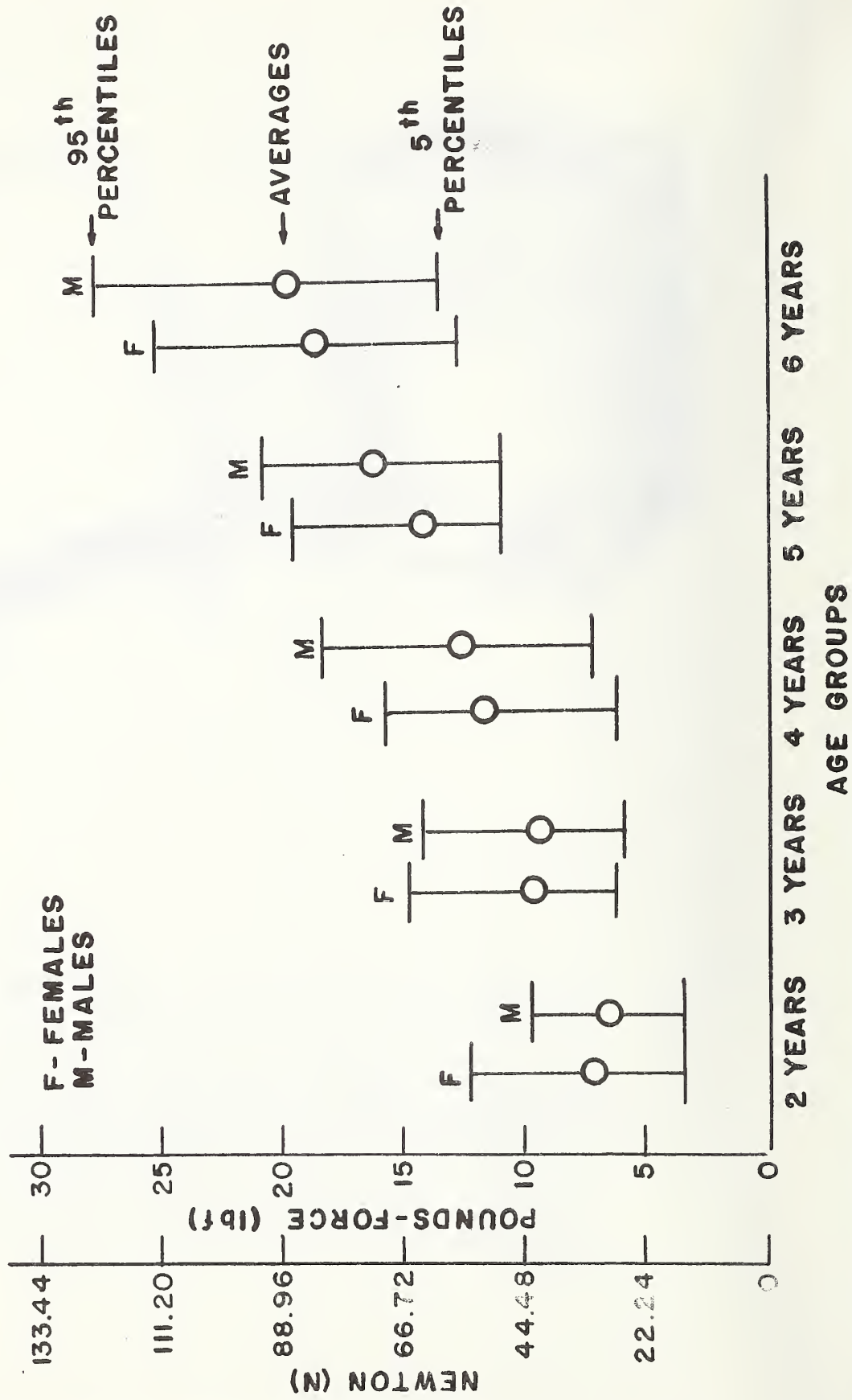


Figure 1. Pull Apart Tester. This device is used to measure the pulling forces that children are capable of exerting when pulling an object apart. The pull apart tester (unit on the right front) features a "T" shaped handle, which can be pulled and twisted simultaneously, located at each end of an instrumented cylinder. A series of lights, mounted on a display box (unit at right rear) illuminate sequentially as increasing force is applied to the handles. These lights serve to motivate the test subject to perform to his maximum capability. A strip chart recorder (unit on the left) provides a permanent record of the forces exerted by the test subject.

FIGURE 2. AVERAGES, 95th PERCENTILES AND 5th PERCENTILES OF CONDENSED PULL-APART DATA



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<p>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.)</p> <p>The Child Pull-Apart 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 with over 500 children in the Washington Metropolitan area, and included both black and white children from varying economic and social backgrounds.</p> <p>The pull-apart test device used is a prototype model designed and constructed at the National Bureau of Standards. This test device was designed to measure the force that children can exert when pulling an object apart.</p> <p>The results of the pull-apart strength study are consistent with those obtained in the previous child strength study which dealt with twisting, pulling, pushing, and squeezing (NBSIR73-156). The study provided quantitatively precise and useful information about the effects of age and sex on the pull-apart strength capability of children ages two through six. The results are exhibited in tables of averages, standard deviations, coefficients of variation, and 95th and 5th percentiles.</p>			
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