NBSIR 77-1298

Power Lawn Mowers: Ease of Pull

V. J. Pezoldt
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Human Factors Section
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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*

Dr. Sidney Harman, *Under Secretary*

Jordan J. Baruch, *Assistant Secretary for Science and Technology*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

Table of Contents

List of Figures

List of Tables

Acknowledgements

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Power Lawn Mowers: Ease of Pull

1.0 Introduction

The Consumer Product Safety Commission (CPSC) estimates that there were 178,000 power lawn mower-related injuries in calendar year 1975. Costs associated with these injuries are estimated to be in excess of 73 million dollars. Over half of the total lawn mower injuries resulted from contact with the mower blade (1). In an effort to reduce the number of these injuries CPSC has accepted the proposal made by Consumers Union (2), the offeror of a proposed lawn mower safety standard, to include a requirement for a "dead-man" control in a mandatory safety regulation (3). The dead-man control must be continuously activated by the mower user in order for the blade to operate. Release of the control stops the blade within a specified time. The blade may be stopped either independently of the mower engine by means of a blade clutch/brake system or in conjunction with engine shut-down. If this latter method is employed to stop the blade, lawn mower users would likely be required to restart their mowers repeatedly throughout a period of use. The CPSC has considered that this inconvenience may encourage consumers to defeat the dead-man control, <u>unless</u> the mower is "easy to restart." This study was designed to provide CPSC with data based on subjective judgments which can be used to objectively define "easy-to-pull" as it relates to restarting power lawn mowers.

Many factors are involved in making a judgment about whether a given lawn mower is easy to restart. Among the more important of these are:

- the force of pull required to start the engine;
- the distance through which a pull must be made;
- the average number of pulls required per engine restart;
- the number of times the engine must be restarted during the mowing period; and
- the time interval between restarts.

In addition to these factors, which are all external to the individual starting the mower, a number of human characteristics are of at least equal importance. To the obvious factors of age, sex and physical condition must be added the kinesthetic and proprioceptive feedback cues experienced when pulling the starting cord and the connotations placed upon the terms "easy" and "hard".

This study did not attempt to explore all of these factors. The data generated by this effort, therefore, cannot be construed as providing a definitive answer to the question "What is easy to restart?" Rather, the present study attempts to define easy to pull under laboratory conditions. In psychological terms, the problem becomes one of determining the relationship between physical stimuli and the psychological responses to such stimuli. In this case the stimuli are the forces which are exerted on a simulated pull-start mechanism and the responses are subjective judgements about the ease or difficulty involved in applying these forces.

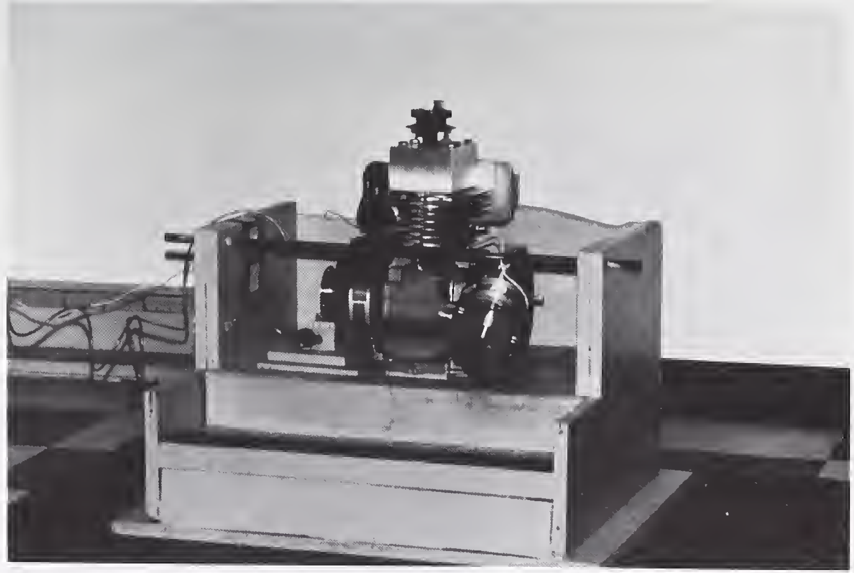
2.0 Methodology

2.1 Subjects

Seventy-four paid volunteers, 38 females and 36 males, participated in the study. The participants ranged in age from 12 to 63 years with a mean age of 33 years (S.D. = 17.7 yr). Subjects ranged in height from 152 to 190 cm (Mean = 169.1 cm, S.D. = 9.1 cm) and in weight from 40.0 to 97.2 kg (Mean = 65.5 kg, S.D. = 13.8 kg). All but three subjects were right-handed. Requirements for subject participation included general good health (no history of cardiovascular trauma or chronic muscle-related incapacity) and experience in pull-starting power lawn mowers. "Experience" was defined as having operated a pull-start lawn mower at least 10 times during the most recent mowing season. Each subject participated in the study for approximately 1.5 hours a day on four consecutive days. Since the distribution characteristics of the lawn mowing population are not known, the sample of subjects tested were chosen to reflect a broad range of mower users.

2.2 Apparatus

Two simulators were designed and built for use in this study. The simulators were operationally identical with the exception of the locus of pull. Pulls on Simulator I (hereafter referred to as the "housing" simulator) were executed from a height typical of several current lawn mower designs, i.e., from a height of 38 cm (15 in). Simulator II ("handle" simulator) was designed to be pulled from a position on the handle, 83 cm (33 in) above the ground. Although most current lawn mowers are similar to the housing simulator, lawn mowers incorporating a dead-man control may have the pull handle located in an area similar to that on the handle simulator. Photographs of the two simulators appear in Figures 1-3.



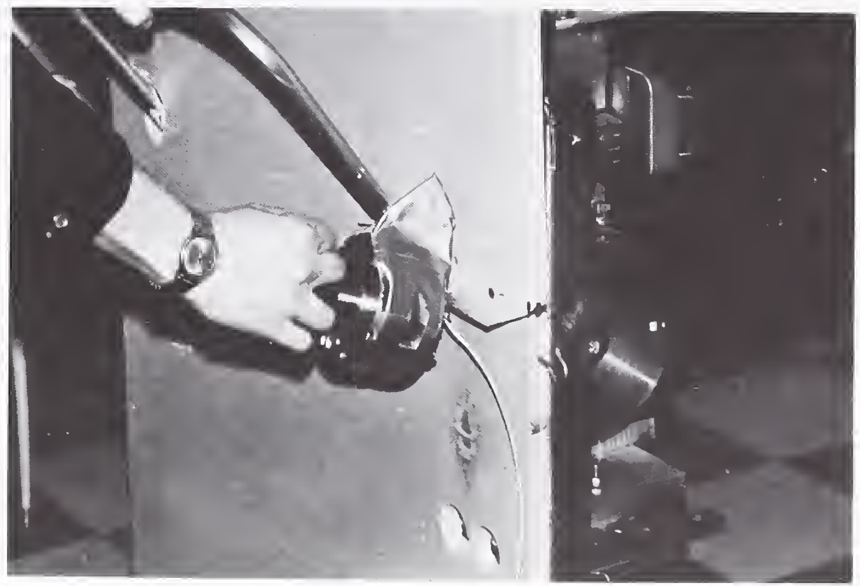


Figure 1 (above) Ease of Pull Test Fixtures

Figure 2 (top, right) Housing Simulator

Figure 3 (bottom, right) Handle Simulator

The heart of each simulator was a modified, general purpose five horsepower, gasoline engine. The automatic compression release mechanism was defeated, increasing the force required to overcome the first compression stroke. The cylinder-head was removed and replaced with a variable displacement cylinder. The piston in this cylinder could be positioned by the investigators in incremental steps, providing a means to vary the compression ratio and, theoretically, the force required to overcome the compression.

The pulleys for winding the pull cords were notched to accept cords of 46, 61, 76, and 91 cm (18, 24, 30 and 36 in) lengths in such a manner that regardless of cord length, and therefore distance of pull, a pull would be initiated from the same place in the compression cycle.

Custom-made pull handles, attachable to any of the cords used, were employed (Figure 4). Measurement of the forces applied when pulling the start cord was accomplished by incorporating a load cell in the pull handles. These load cells were interfaced with a digital readout peak load indicator. Peak force, i.e., the maximum force exerted at any point in the pull was measured to the nearest pound (1 lbf = 4.45 N).

In addition, photocells interfaced with a digital interval timer were mounted on the shaft to permit timing of a pull from initiation through completion of the specified pull distance.

In summary, the simulators permitted pulls similar to those experienced when pull-starting a power lawn mower. Pulls could be made through four distances and the difficulty (resistance) of pulls could be manipulated by the experimenter. Difficulty of pull could only be controlled in a very gross sense, the actual force applied was determined by the participant. The peak force and elapsed time of each pull was measured. Forces required to actually start the engine could not be determined since no gasoline nor spark plugs were present in the simulators.

2.3 Procedure

After the participants signed the required informed consent document (Appendix A) their age, sex, weight, and height were recorded. Each subject was assigned to either the handle or housing simulator for the duration of the study. Assignment to simulator type was random with the constraint that age and sex were distributed approximately equally between the two simulators. Subjects were then instructed as to the specific task they were to perform and the apparatus was demonstrated.

Figure 4

Test Apparatus Pull Handle
Incorporating Load Cell

The subjects' task consisted of making 36 pulls at the appropriate simulator on each of four consecutive days. Each day the subjects were provided with a different length cord which determined the distance through which they were to pull. The distances through which they pulled were approximately 46, 61, 76, and 91 cm (18, 24, 30, and 36 in). The order in which subjects pulled through the various distances was randomly determined. Subjects were instructed to pull the "starting" cord in the same manner they would to start a lawn mower. Immediately following each pull, subjects were requested to judge whether that pull was easy or hard. A forced choice paradigm was employed requiring subjects to judge each pull as either "easy" or "hard". No intermediate responses were allowed. Participants were instructed that the simulators were "perfect lawn mowers", that is, they would start on every pull. In fact, of course, the engine never started. Subjects made six pulls in a five minute test period followed by a rest period of approximately 10 minutes. Six test periods were accomplished each day by each subject.

A modified staircase method was employed to determine compression ratio adjustments to the simulator after each pull. Generally, if a subject judged a pull "easy" the compression ratio of the simulator engine was increased one unit for the next pull. If a pull was judged "hard", the compression ratio was decreased. Some variation in this procedure occurred in an attempt to assure that subjects pulled over a broad range of forces.

After each pull, three measures were recorded: the judgment about the pull, either "easy" or "hard;" the peak force exerted during the pull; and the time from initiation of the pull to completion through the specified pull distance. Peak force, rather than any measure of force over time, was employed for several reasons. First, peak force proved simple to measure. Second, pilot tests showed this measure to be capable of discriminating between pulls judged easy and pulls judged hard. Finally, peak force is the most easily adaptable to test method development.

The experimental plan called for each of 80 subjects (40 using the handle simulator, 40 using the housing simulator) to execute 36 pulls through each of four distances. This array would have resulted in a total of 11,520 pulls. Due to the exigencies of testing (equipment failure, subject availability, etc.) only 74 subjects were tested. Most subjects completed the full complement of 36 pulls at each distance, however, a few subjects did not complete the entire test as scheduled.

3.0 Results

3.1 Data Reduction

The total number of subjects of each sex who pulled on each simulator and the total number of pulls executed at each distance are shown in Appendix B. A total of 5372 pulls were made from the handle position and 5009 pulls from the housing.

The data for each subject consists of a series of approximately 36 judgments (easy or hard) at each pull distance. Each judgment is associated with a peak force and an elapsed time. The peak forces were grouped in 22 N (5 lbf) intervals. All analyses, with the exception of correlations between peak force and elapsed time, were performed on the mid-points of these categories. Thus, for analyses all pulls resulting in a peak force range of 176 - 198 N (39.5-44.5 lbf), for example, were treated as being peak forces of 187 N (42 lbf).

For most analyses, again with the exception of some correlation coefficients, the measures of peak force of primary interest were the maximum forces judged easy ($Easy_{max}$) and the minimum forces judged hard ($Hard_{min}$) for each subject. $Hard_{min}$ and $Easy_{max}$ data are presented in Appendices CI and CII for each subject at each pull distance for the handle and housing simulator respectively.

3.2 Data Analysis

The data presented in Appendices CI and CII were subjected to four two-factor mixed design Analyses of Variance to determine the effects of sex and distance of pull on $Hard_{min}$ and $Easy_{max}$. Separate analyses were performed for the handle and housing data. The analyses are summarized in Appendices D and E.

Analysis of the handle data indicate a significant difference in mean peak force as a function of sex for both $Hard_{min}$[1] and $Easy_{max}$[2]. In both cases the peak forces applied by males are greater than those applied by females. Differences among the mean peak forces as a function of distance of pull are significant for $Easy_{max}$[3] but not for $Hard_{min}$[4].

---

[1] $[F(1,36) = 11.04, p < .01]$
[2] $[F(1,36) = 13.99, p < .01]$
[3] $[F(3,108) = 3.01, p < .05]$
[4] $[F(3,108) < 1, p > .05]$

The mean $Easy_{max}$ peak forces at each pull distance were subjected to a Duncan Multiple Range Test to determine the source of the differences among these means. As indicated in Appendix F, the mean peak force judged easy for the 91 cm (36 in) pull is significantly ($p < .05$) greater than that for any other pull distance. No other significant differences are indicated.

Analysis of the housing simulator data indicates a significant difference in peak force of pull as a function of sex for $Easy_{max}$[5] but not for $Hard_{min}$[6]. No significant differences among the means as a function of distance of pull are evident for either $Easy_{max}$[7] or $Hard_{min}$[8].

Tables I and II show the cumulative distributions (number and percent) of $Hard_{min}$ and $Easy_{max}$ for males and females using the handle and housing simulators respectively for all pull distances combined. These data were employed in constructing Figures 5 through 8. These figures display the cumulative percentages of the peak forces for $Hard_{min}$ and $Easy_{max}$ separately for male and females using the handle and housing simulators.

A series of correlation coefficients (Pearson Product-Moment Correlations, r) were computed to determine the presence of any predictive relationships between peak force of pull and subject variables. Appendix G shows the correlation coefficients between both $Hard_{min}$ and $Easy_{max}$ and subject age, weight and height. Only one of these, the correlation between $Hard_{min}$ and weight of male subjects using the housing simulator ($r = .68$, $p < .05$) is statistically significant. Correlation coefficients were also computed between the measures of $Hard_{min}$ and $Easy_{max}$. These correlations were computed separately for male and female subjects using the handle and housing simulators. All of these coefficients, reported in Appendix G, are significant ($p < .05$) and positive.

A final series of correlations was computed between measured peak force (disregarding judgments of easy or hard) and the time from initiation to completion of pulls through the four distances. Although these correlations were actually computed for only a sample of the subjects, it appears that there is no consistent relationship between these measures in the present data.

---

[5] [$F(1,34) = 6.23$, $p < .05$]
[6] [$F(1,34) = 3.44$, $p > .05$]
[7] [$F(3,102) < 1$, $p > .05$]
[8] [$F(3,102) < 1$, $p > .05$]

Table I

Cumulative Distributions of $Hard_{min}$ and $Easy_{max}$
Handle Simulator, All Pull Distances Combined

Female Subjects

Peak Force N	Peak Force lbf	$Hard_{min}$ Cumulative Number	$Hard_{min}$ Cumulative Percent	$Easy_{max}$ Cumulative Number	$Easy_{max}$ Cumulative Percent
98	22	20	100		
120	27	19	95		
142	32	15	75		
165	37	8	40	20	100
187	42	3	15	18	90
209	47			16	80
231	52			14	70
254	57			11	55
276	62			8	40
298	67			5	25
320	72				
343	77			4	20
365	82				
387	87			1	5

Male Subjects

Peak Force N	Peak Force lbf	Cumulative Number	Cumulative Percent	Cumulative Number	Cumulative Percent
120	27	18	100		
142	32	15	83		
165	37	12	67		
187	42	11	61		
209	47	8	44		
231	52	7	39	18	100
254	57	4	22	14	78
276	62	3	17		
298	67				
320	72			13	72
343	77	2	11	10	56
365	82				
387	87				
409	92			9	50
432	97	1	6	6	33
454	102			5	28
476	107				
498	112				
521	117			3	17
343	122				
565	127			2	11
587	132			1	6

Table II

Cumulative Distributions of $Hard_{min}$ and $Easy_{max}$
Housing Simulator, All Pull Distances Combined

Female Subjects

Peak Force N	Peak Force lbf	$Hard_{min}$ Cumulative Number	$Hard_{min}$ Cumulative Percent	$Easy_{max}$ Cumulative Number	$Easy_{max}$ Cumulative Percent
120	27	18	100		
142	32	17	94		
165	37	16	89		
187	42	15	83		
209	47	12	67		
231	52	9	50		
254	57	5	28		
276	62	4	22	18	100
298	67			17	94
320	72			15	83
343	77	2	11	14	78
365	82	1	6	11	61
387	87			9	50
409	92				
432	97				
454	102			7	39
476	107			4	22
498	112			2	11
521	117			1	6

Male Subjects

Peak Force N	Peak Force lbf	$Hard_{min}$ Cumulative Number	$Hard_{min}$ Cumulative Percent	$Easy_{max}$ Cumulative Number	$Easy_{max}$ Cumulative Percent
120	27	18	100		
142	32				
165	37				
187	42	16	89		
209	47				
231	52	15	83		
254	57	10	56		
276	62	9	50		
298	67	7	39	18	100
320	72	4	22		
343	77			16	89
365	82	2	11	15	83
387	87			14	79
409	92	1	6	13	72
432	97				
454	102			12	67
476	107			11	61
498	112			8	44
521	117			7	39
543	122			6	33
565	127			4	22
587	132			2	11
610	137				
632	142				
654	147			1	6

FIGURE 5

CUMULATIVE DISTRIBUTION OF $HARD_{min}$ AND $EASY_{max}$
HANDLE SIMULATOR, FEMALE SUBJECTS

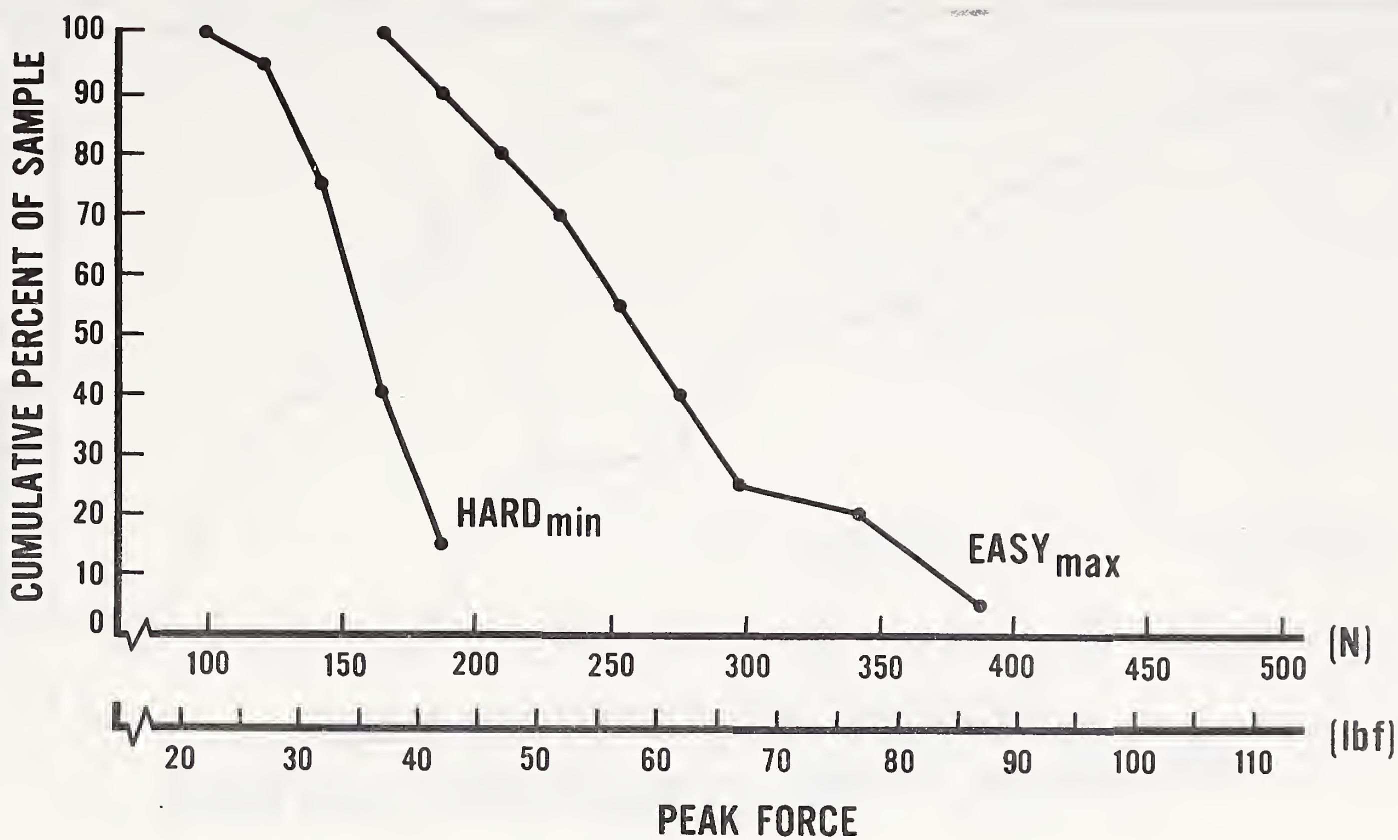


FIGURE 6

CUMULATIVE DISTRIBUTION OF $HARD_{min}$ AND $EASY_{max}$
HANDLE SIMULATOR, MALE SUBJECTS

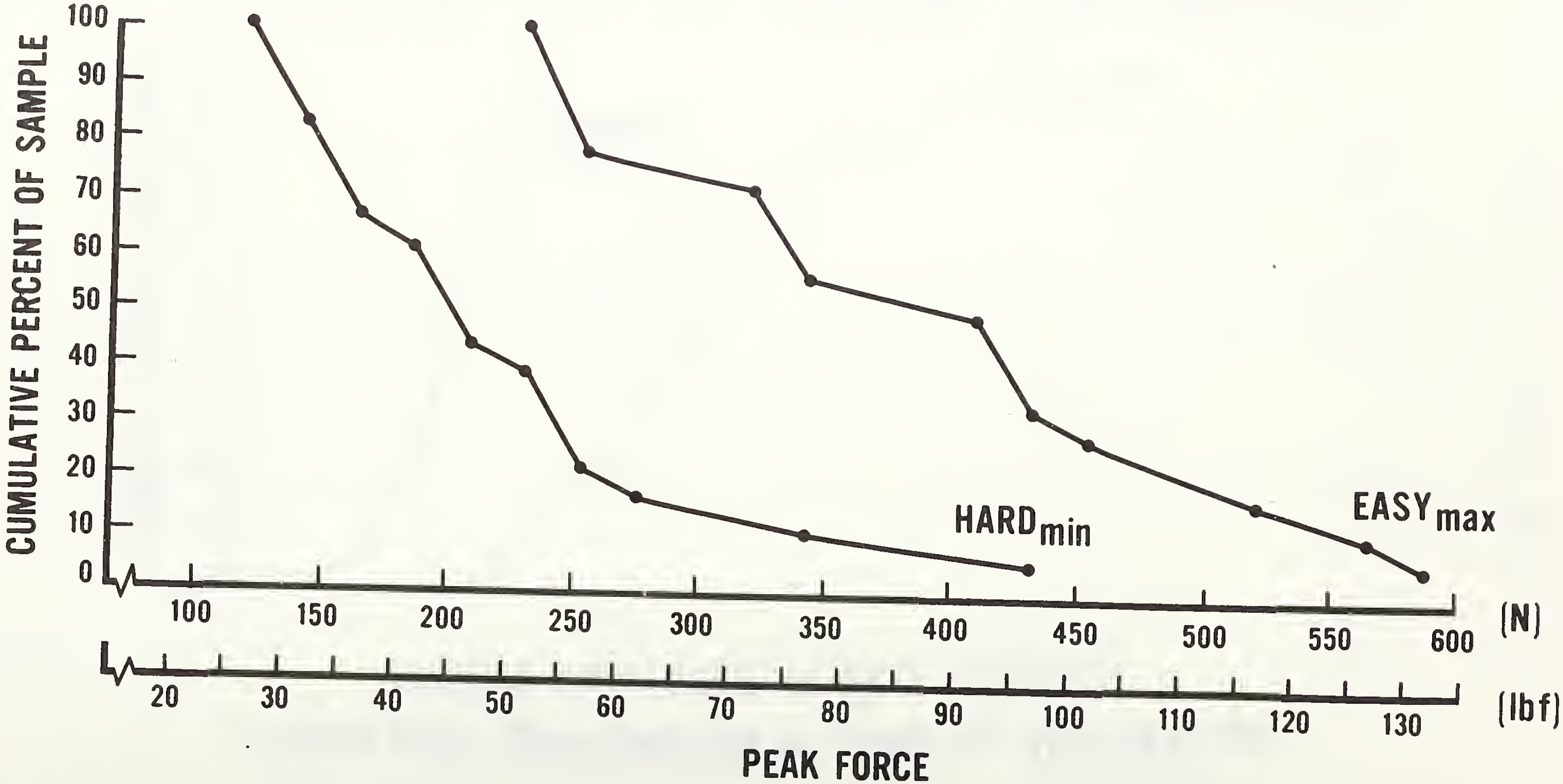


FIGURE 7

CUMULATIVE DISTRIBUTION OF $HARD_{min}$ AND $EASY_{max}$ HOUSING SIMULATOR, FEMALE SUBJECTS

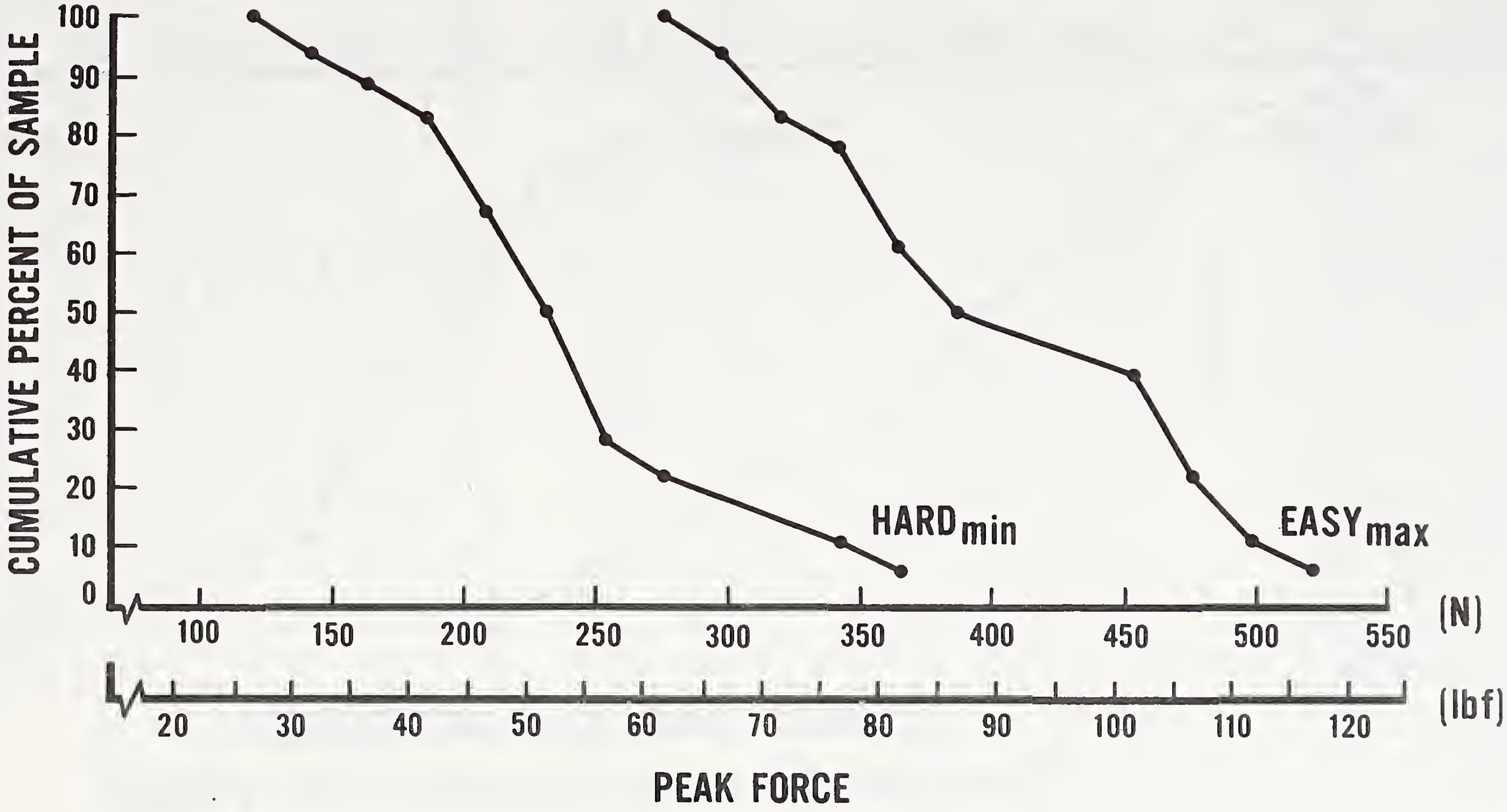
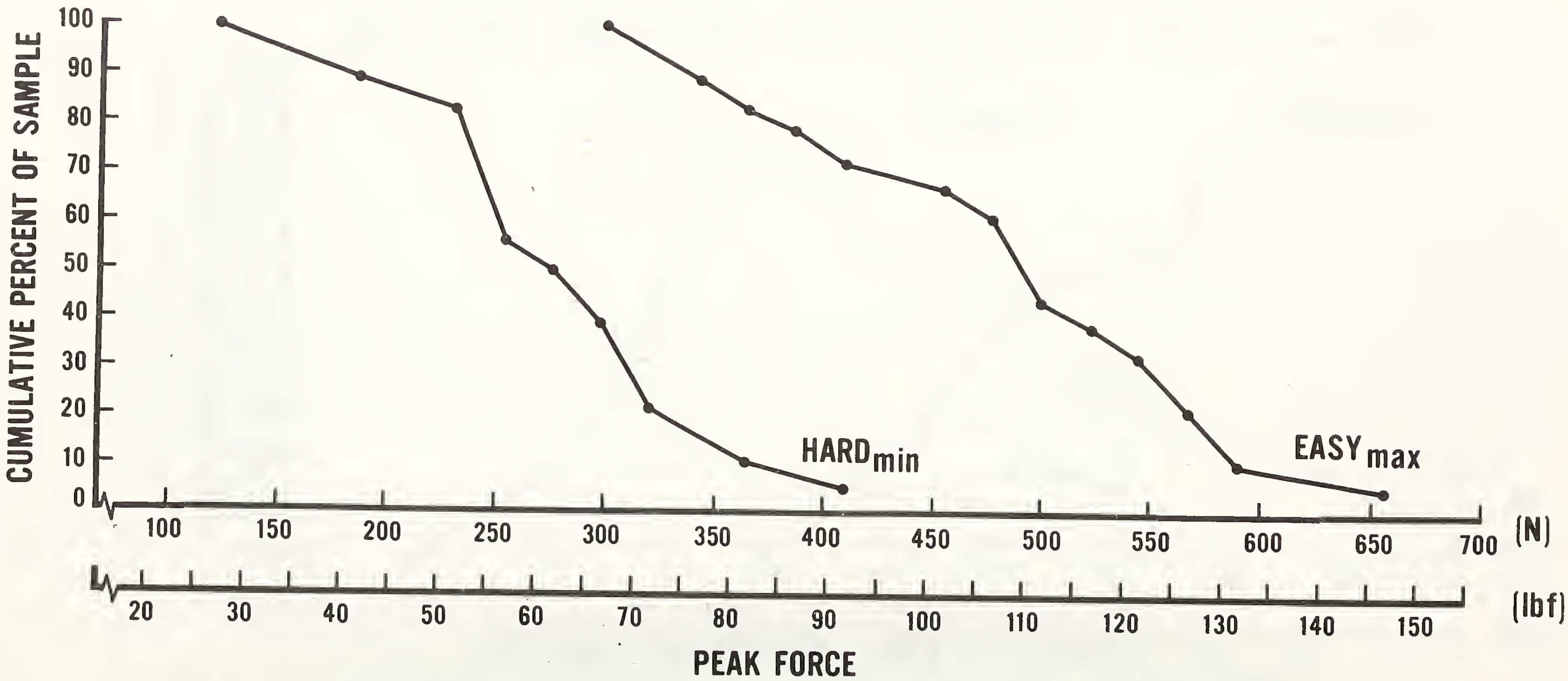


FIGURE 8

CUMULATIVE DISTRIBUTION OF $Hard_{min}$ AND $Easy_{max}$ HOUSING SIMULATOR, MALE SUBJECTS



Appendix H shows the percentage of "double" and "incomplete" pulls at each of the four pull distances. A "double pull" is defined as any pull during which a noticeable pause was observed in the execution of the pull. An "incomplete pull" is any pull in which the pull cord did not come completely off the rewind pulley, i.e., a pull shorter than the specified nominal distance. Many more of these pulls were observed on pulls through 91 cm than any of the shorter pulls.

4.0 Discussion

The results of the analyses of variance suggest that the peak forces for both $Hard_{min}$ and $Easy_{max}$ be collapsed over distance of pull for both housing and handle data since, with one exception, there were no statistical differences among these forces as a function of distance of pull. Although analysis of the handle data indicated a statistically significant difference between pulls of 91 cm and the other pull distances for $Easy_{max}$, this difference is insignificant in practical terms. The largest difference between the mean $Easy_{max}$ for the 91 cm pulls and that for the other pull distances is 20.9 N. This is less than the size of the intervals into which peak forces were grouped for analysis. Although the maximum forces judged easy for pulls through 91 cm were as great or greater than $Easy_{max}$ for the other pull distances, there is some evidence that 91 cm is too long a pull for starting a lawn mower. This is suggested by the much greater percentage of double and incomplete pulls at this distance than any other distance.

Figures 5 through 8 provide the basis for defining "easy to pull" under the conditions of this study. The cumulative percentages of $Hard_{min}$ and $Easy_{max}$ displayed in these figures define the lower limit of "hard to pull" and the upper limit of "easy to pull" respectively. For any given percentage of the sample, the $Hard_{min}$ line defines the minimum peak force which was judged hard. Similarly, the $Easy_{max}$ line defines the maximum peak force which was judged easy for any specified proportion of the sample. These two functions may be viewed as providing conservative ($Hard_{min}$) and liberal ($Easy_{max}$) definitions of the peak forces considered to be easy to pull. Inspection of Figures 5 through 8 reveals the very large difference between the "liberal" and "conservative" estimates of easy to pull. This difference reflects the large variability in judgments of easy and hard both between individuals and within a single individual.

It is recommended that the CPSC adopt a "conservative" stand with regard to determining a force value for ease of pull. This is suggested so that the greatest percentage of the population could "easily" restart lawn mowers and so that the incentive for defeating the dead-man control would be reduced. In practice, this would mean determining the peak force by using the $Hard_{min}$ distribution for females and selecting the sample percentage at 80 percent or greater. That is, based on Figures 5 and 7, the maximum values for pulls from the handle position should be approximately 140 N (31 lbf) and from the housing approximately 190 N (43 lbf).

The lack of significant correlations between peak force of pull and subject age, weight, and height serve to illustrate that judgments about what is easy or hard to pull are not directly related to the pullers' physical characteristics. No measures of physical strength were made in this study; however, it appears that pull judgments in the present context cannot be predicated solely on physical size, strength or age and are probably determined by all of these plus other neuro-muscular cues in some unknown combination.

This study does not, nor was it intended to, answer the question of why one judgment is "easy" and another "hard". Neither does it provide a definitive answer to the question of what is easy to restart. The data generated in the study do, however, provide a practical basis upon which a policy decision regarding the upper limit for "easy to restart" can be made.

References

1. U.S. Consumer Product Safety Commission. Product Profile: Power Mowers, October 1976.

2. Consumers Union of United States, Inc. Proposed Safety Standard for Power Lawn Mowers, Submitted to the U.S. Consumer Product Safety Commission, July 1975.

3. U.S. Consumer Product Safety Commission. Power Lawn Mowers, Proposed Safety Standard and Extension of Time. Federal Register, Vol. 42, No. 87 - Thursday, May 5, 1977, 23052-23072.

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(2-76)

APPENDIX A

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

RESEARCH PARTICIPANT AGREEMENT

3. Cost Center No.

1. Principal Investigator

Val Pezoldt

2. Division, Section

441.02

4. Location

XX Gaithersburg

[ ] Other *(specify)*

5. Experiment Name Code

Ease of Pull

6. Description of Experiment

The purpose of this research is to determine the ease with which power lawn mower users can pull the starting cord on lawn mower engines. It is being done so that maximum force levels can be set for starting lawn mowers. The participants will perform a series of pulls on a simulated engine pull start and make judgements about the ease or difficulty of the pulls.

7. Risks to Participant

Risks to participants are similar to those encountered when pull-starting a lawn mower. They include (1) slips and falls while pulling the simulated lawn mower cord; (2) muscle strains in the arm and back; and (3) cardiovascular trauma due to overexertion. These will be minimized by employing a slip resistant surface and securely anchoring the test device and by scheduling rest periods between series of pulls. The simulator used will have no exposed moving parts and will not use gasoline or any other flammable liquid.

8. Responsibilities of Participant

The participant will arrive promptly at the scheduled test times and, with informed consent, will follow instructions regarding the pull task, answer questions relating to age and lawn mower use, and allow the investigator to make weight and height measurements.

9. Responsibilities of Investigator(s)

The investigator will fully explain the test procedure, explain the purpose of the test, ensure safe testing conditions and keep personal information confidential.

10. IT IS UNDERSTOOD THAT EITHER THE PRINCIPAL INVESTIGATOR, THE PARTICIPANT, OR THE PARTICIPANT'S PARENT OR GUARDIAN MAY TERMINATE THE PARTICIPANT'S INVOLVEMENT IN THE RESEARCH AT ANY TIME WITHOUT INCURRING LEGAL LIABILITY FOR SUCH TERMINATION.

11. I hereby certify that my participation is voluntary and that I have read and accept the terms of this agreement.

Participant, or Parent or Guardian *(Signature)* | Date

12. Principal Investigator *(Signature)* | Date

13. Early Termination by *(Signature)* | Date

USCOMM-NBS-DC

Appendix B

Number of Subjects and Number of Pulls Executed At Each Pull Distance

Handle Simulator Data

No. of Subjects		Pull Distance (cm) 46	61	76	91	Total Pulls
Male	18	630	633	640	654[1]	2557
Female	20	711	700	720	684	2815
Total	38	1341	1333	1360	1338	5372

Housing Simulator Data

No. of Subjects		Pull Distance (cm) 46	61	76	91	Total Pulls
Male	18	622	643	627	603[2]	2495
Female	18	639	632	602	641	2514
Total	36	1261	1275	1229	1244[3]	5009

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[1] One subject made 42 pulls.

[2] 17 subjects

[3] 35 subjects

Appendix CI

Minimum Force Judged Hard and Maximum Force Judged Easy for Subjects Using Handle Simulator (in Newtons)

	$Hard_{min}$				$Easy_{max}$			
	Pull Distance (cm)				Pull Distance (cm)			
Subject No.	46	61	76	91	46	61	76	91
(Female)								
1	276	231	187	209	343	298	276	370
2	165	165	142	142	276	187	187	254
3	165	187	142	142	209	231	209	209
4	165	254	187	209	231	343	254	276
5	187	165	142	165	231	254	231	231
6	209	254	231	231	254	343	276	276
7	142	142	120	142	165	187	165	187
8	142	120	142	120	165	142	165	187
9	320	187	231	298	343	387	320	343
10	165	142	254	209	231	231	276	276
11	165	165	209	187	231	231	231	209
12	187	187	165	231	276	231	209	254
13	231	142	254	231	254	209	298	298
14	165	231	187	209	231	276	254	231
15	120	142	142	165	165	165	165	187
16	142	165	165	142	187	209	187	187
17	120	98	98	98	142	120	165	142
18	142	231	187	209	209	254	231	254
19	165	165	165	165	231	209	231	231
20	120	120	120	142	231	142	165	165
(Male)								
21	187	209	276	231	254	298	320	320
22	209	231	276	254	387	320	320	409
23	209	187	187	165	231	209	231	231
24	142	142	187	187	231	187	254	231
25	187	276	209	142	276	298	320	276
26	231	254	231	276	454	343	343	387
27	231	187	187	254	254	254	320	298
28	343	343	343	454	387	454	432	521
29	387	498	142	409	521	587	343	521
30	142	165	120	142	187	209	187	231
31	276	231	231	254	343	365	343	409
32	231	276	254	298	276	320	343	409
33	276		365	343	387	409	409	432
34	320	187	365	409	432	276	454	454
35	476		498	432	543	565	565	565
36	142	142	142	120	165	187	187	231
37	120	142	120	120	142	231	142	165
38	254	298	254	254	298	298	343	343

Appendix CII

Minimum Force Judged Hard and Maximum Forced Judged Easy for Subjects Using Housing Simulator (in Newtons)

	$Hard_{min}$				$Easy_{max}$			
	Pull Distance				Pull Distance			
Subject No.	46	61	76	91	46	61	76	91
(Female)								
39	187	187	165	187	231	231	298	231
40	231	231	276	276	320	298	320	343
41	231	231	120	142	320	320	387	343
42	187	209	209	231	231	276	254	298
43	409	231	298	409	476	476	365	454
44	298	254	298	209	365	298	320	254
45	231	209	209	209	276	254	231	320
46	231	320	298	231	343	387	343	320
47	187	187	231	254	254	231	276	343
48	298	298	298	276	454	387	409	387
49	365	387	365	343	454	432	432	387
50	365	387	454	454	409	476	454	476
51	298	320	231	276	365	365	320	320
52	298	276	298	254	343	320	343	298
53	387	454	454	276	498	521	498	476
54	187	142	231	231	231	276	276	276
55	343	209	298	320	409	454	365	387
56	409	187	276	409	498	387	432	476
(Male)								
57	231	276	343	343	320	387	432	476
58	454	254	432	476	543	543	521	565
59	343	432	298		454	476	454	
60	254	165	120	120	298	276	276	231
61	142	120	165	276	254	231	365	387
62	343	476	276	498	587	543	587	587
63	365	521	565	476	543	610	587	654
64	298	254	298	231	409	365	365	387
65	365	298	454	343	476	476	543	432
66	387	231	387	343	521	365	454	432
67	409	432	409	432	521	409	565	521
68	276	254	254	231	343	365	298	365
69	387	298	298	276	432	454	387	365
70	320	343	387	298	454	454	543	387
71	365	254	231	254	387	298	343	320
72	320	432	365	387	387	476	454	432
73	387	320	387	409	432	409	498	498
74	254	231	231	187	276	298	298	231

Appendix D

Analysis of Variance: Handle
Minimum Force Judged Hard ($Hard_{min}$)

Source	SS	df	MS	F	p
Total	1,092,651.85	151			
Between	896,483.33	37			
Sex	210,537.01	1	210,537.01	11.04	< .01
Error Between	685,946.12	36	19,054.06		
Within	196,168.52	114			
Distance	5,012.41	3	1,670.80	< 1	> .05
Distance x Sex	1,193.50	3	397.83	< 1	> .05
Error Within	189,962.61	108	1,758.91		

Analysis of Variance: Handle
Maximum Force Judged Easy ($Easy_{max}$)

Source	SS	df	MS	F	p
Total	1,534,013.14	151			
Between	1,380,915.06	37			
Sex	386,489.75	1	386,489.75	13.99	< .01
Error Between	994,425.31	36	27,622.92		
Within	153,098.08	114			
Distance	11,344.06	3	3,781.35	3.01	< .05
Distance x Sex	5,995.60	3	1,998.53	1.59	> .05
Error Within	135,758.41	108	1,257.02		

Appendix E

Analysis of Variance: Housing
Minimum Force Judged Hard ($Hard_{min}$)

Source	SS	df	MS	F	p
Total	1,249,042.69	143			
Between	909,429.81	35			
Sex	83,665.56	1	83,665.56	3.44	> .05
Error Between	825,764.25	34	24,287.18		
Within	339,612.88	108			
Distance	9,158.46	3	3,052.82	< 1	> .05
Distance x Sex	576.85	3	192.28	< 1	> .05
Error Within	329,877.57	102	3,234.09		

Analysis of Variance: Housing
Maximum Force Judged Easy ($Easy_{max}$)

Source	SS	df	MS	F	p
Total	1,415,050.21	143			
Between	1,247,347.79	35			
Sex	193,105.27	1	193,105.27	6.23	< .05
Error Between	1,054,242.33	34	31,007.13		
Within	167,702.42	108			
Distance	1,990.55	3	663.52	< 1	> .05
Distance x Sex	4,657.75	3	1,552.58	< 1	> .05
Error Within	161,054.12	102	1,578.96		

Appendix F

Duncan Multiple Range Test: Handle Maximum Force Judged Easy ($Easy_{max}$)

Distance (cm) of Pull	Mean(N)	76 272.3	46 272.8	61 275.9	91 293.2	Critical Range
76	272.3	-	.5	3.6	20.9*	17.5
46	272.8	-	-	3.1	20.4*	16.7
61	275.9	-	-	-	17.3*	16.1
91	293.2	-	-	-		

* $p < .05$

Appendix G

Correlations Between $Hard_{min}$, $Easy_{max}$ and Subject Variables

Handle

Correlates	Female	Male
$Hard_{min}$ - Age	-.22	.22
$Hard_{min}$ - Weight	.02	.40
$Hard_{min}$ - Height	.10	.15
$Easy_{max}$ - Age	.43	-.01
$Easy_{max}$ - Weight	-.19	.41
$Easy_{max}$ - Height	.19	.30
$Hard_{min}$ - $Easy_{max}$	.85*	.67*

*$p < .05$

Housing

Correlates	Female	Male
$Hard_{min}$ - Age	.13	.26
$Hard_{min}$ - Weight	.22	.68*
$Hard_{min}$ - Height	.20	.07
$Easy_{max}$ - Age	.24	-.23
$Easy_{max}$ - Weight	.33	.41
$Easy_{max}$ - Height	.40	.20
$Hard_{min}$ - $Easy_{max}$	.55*	.75*

*$p < .05$

Appendix H

Percentage of Double and Incomplete Pulls

Handle Simulator

	Pull Distance (cm)			
	46	61	76	91
Female	3.1	4.6	5.5	23.2
Male	5.0	3.1	2.2	11.8
All Subjects	4.1	3.8	3.8	17.7

Housing Simulator

	Pull Distance (cm)			
	46	61	76	91
Female	0.8	1.1	1.9	34.5
Male	0.5	0.6	1.9	14.0
All Subjects	0.7	0.9	1.9	24.4

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15. SUPPLEMENTARY NOTES

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.)*

This study was designed to provide objective information about the subjective judgement of "easy to pull" as it relates to the effort required to restart manual pull-start power lawn mowers. Seventy-four lawn mower users performed a total of more than 10,000 pulls on two simulated pull-start mechanisms. The peak forces applied in the pulls were associated with the subjects' judgements about the ease or difficulty of the pulls. These data were used to generate sample distributions of the maximum forces judged easy and the minimum forces judged hard. While not providing a definitive answer to the question of what is easy to restart, the data generated in the study provide a practical basis upon which an upper force limit for easy to restart can be based.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Consumer products; human factors; human performance; lawn mowers; psychophysics, safety, standards.

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