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TWO-HANDED RETENTION ON VARIOUS HANDLE CONFIGURATIONS

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Foreword

This report was prepared by the Anthropology Branch, Behavioral Sciences Laboratory, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. This research was performed in support of Project 7184, "Human Performance in Advanced Systems," Task 718408. "Anthropology for Design."

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This technical report has been reviewed and is approved.

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Abstract

This report presents data on the manual grip-retention capability of seated persons. Nine male subjects, grasping experimental ejection actuators located forward of an ejection seat pan, were required to maintain their grasp against force loadings of 50 to 500 pounds. Grip retention at various increments of time to a maximum of 30 seconds are compared for each of the four handles: a T-bar, Twin grips, a standard D-ring and a flexible Gemini-type loop. Test results indicated that the T-bar provides the greatest grip-retention capability. Potential applications of these performance data are discussed.

List of Figures

SECTION I.
Introduction

Man's capability for manual grip-retention provides him with a positive deterrent to accident or injury in certain situations. A pilot ejecting from his aircraft, an astronaut clinging to a life line or stanchion, even a worker holding onto a jackhammer must grasp an object with one or both hands and retain that grasp within certain force levels or risk injury. His grip-retention capability is directly affected by two important considerations: his own strength and the configuration of the object to be grasped. The experiment described below was designed to determine the maximum force which could be manually resisted by a man's grasp on four distinct handle configurations.

Investigations of human grip-strength capability are profuse in the literature but are generally limited to situations where the forces are applied by an individual to either a tension measuring device or to weights. Hunsicker (1955) presents an excellent summary of the development of strength testing since the early 19th century. The present study utilized the application of known dynamic forces against the subject through pneumatic controls.

Maximum grip for up to 30-second retention was determined on each of four basic handle shapes. These data provide basic biomechanical-strength information which may be used in designing any equipment where grip retention against a known force is necessary. However, the specific purpose of the experiment was to compare handles that could be considered for use in nonencapsulated high-speed ejection systems where grip retention against the sudden application of high aerodynamic forces is essential to prevent arm flailing and subsequent injury. Data are presented in the appendix for grip-retention performance by the same subjects on differently shaped handles. These data all reflect the effect that handle shape has on grip-retention capability.

SECTION II.
Test Apparatus

The test apparatus, designed to simulate downward ejection from an aircraft, consisted of a 60-inch high platform upon which was affixed a Stanley B-47E downward ejection seat (figure 1).

The seat's D-ring, or substitute experimental handle, was attached to the end of a variable length shaft that was movable up and down within a 17-inch range through an opening in the wooden platform in front of the ejection seat. This shaft was activated by a Bellows-Valvaire air cylinder with a solenoid-controlled 4-way valve system. The air cylinder was mounted on a

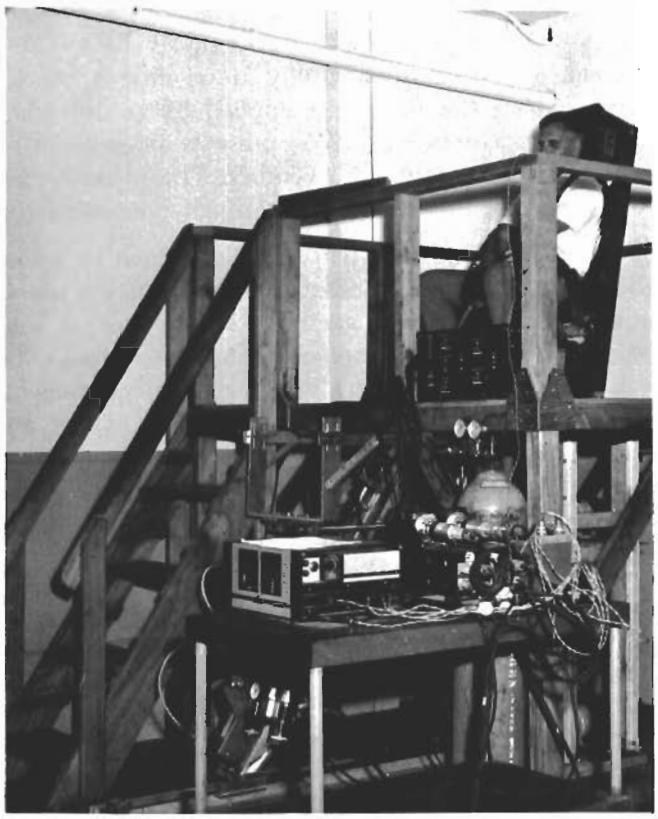


Figure 1. The Experimental Apparatus and Test Stand

mechanized carriage to provide angular changes of the shaft. The shaft, when fully extended, could be restrained by a metal locking block to permit the application of a predetermined 0-500 pound force through the shaft to the handle. When the lock was released by the subject pulling on the grip, the predetermined force was instantaneously transmitted to the subject's hands.

Instrumentation for measuring the magnitudes of the force consisted of two strain gauges mounted on the shaft. A potentiometer measured the displacement of the shaft. The outputs from the instrumentation were transmitted through amplifiers to four channels of an oscillograph which recorded the force, displacement, and time values.

The four handle configurations used in the experiment are illustrated in figures 2-5.

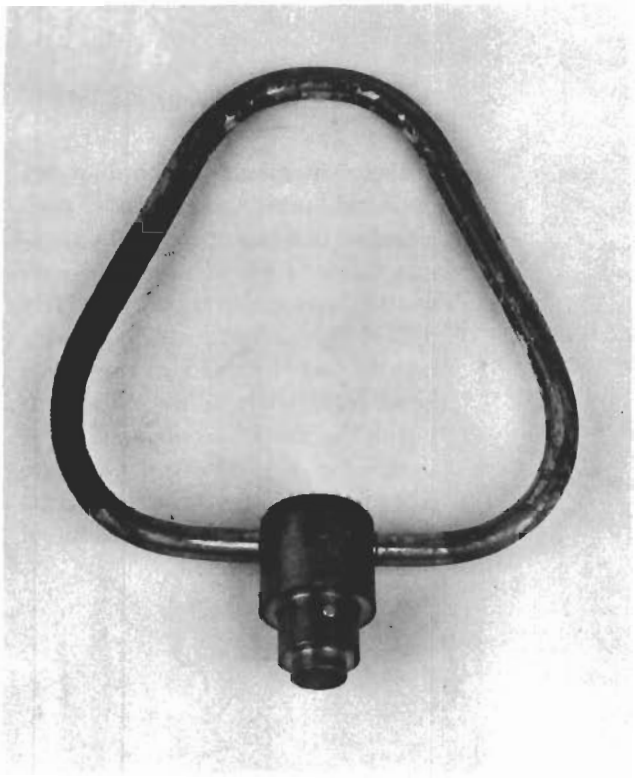


Figure 2 (left)
Standard D-ring

A metallic triangular handle with the apex towards the subject when in the grasping position. Fabricated of $\frac{5}{16}$-inch diameter steel tubing, the sides are 5 inches long, the base is 4 inches long with a rod reinforcement at the middle of the base to support the center mount. The apex has a $1\frac{1}{16}$-inch radius, each of the side angles has a $1\frac{1}{8}$-inch radius.

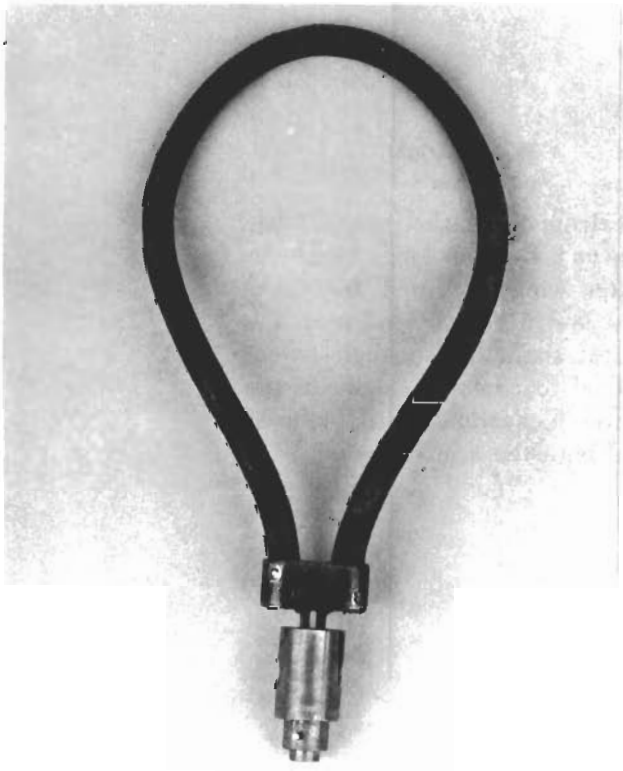


Figure 3 (right)
Gemini Flexible Loop

An 11-inch long, flexible loop formed by 24 inches of fabric-wound, metal-cored, ½-inch diameter composite wire. (This handle was provided by the Crew Stations Branch, National Aeronautics and Space Administration for inclusion in our experimental program.)

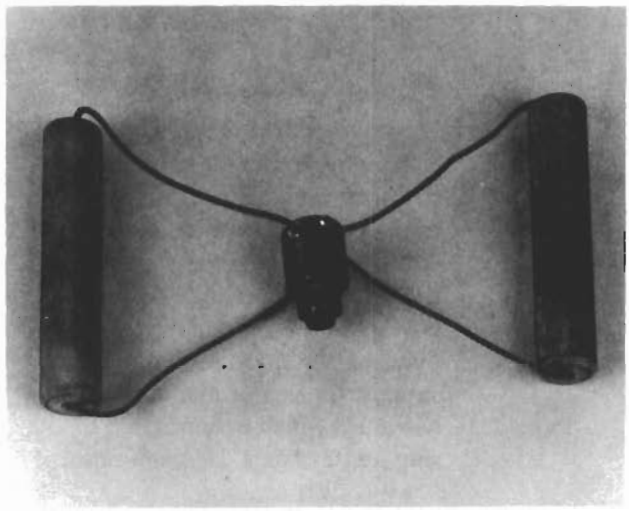
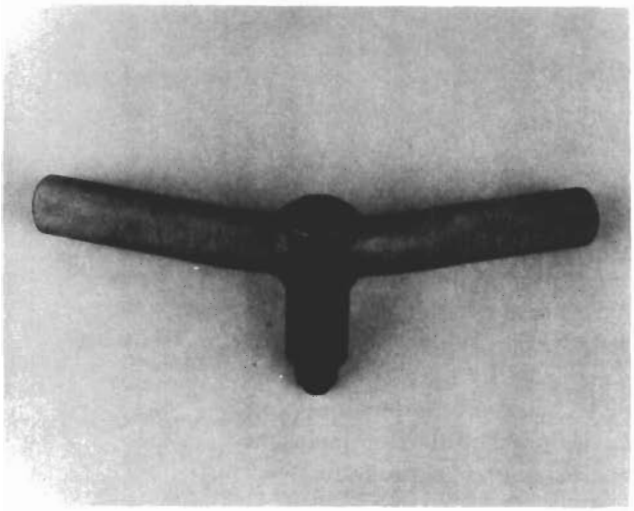


Figure 4 (left)
Twin Grip

Two 5-inch long, 1-inch diameter diamond-knurled metal rods, each attached to a center mount by separate loops of 14-inch long, $\frac{1}{8}$-inch wire passing through an axially drilled $\frac{5}{32}$-inch diameter bore. This handle was designed to provide a nondeformable handle sized according to the design recommendations in Human Engineering Guide to Equipment Design (ref. 2), section 6.4, with independent freedom of motion for each hand.

Figure 5 (right)
T-bar

A diamond-knurled metal T-bar with two $4\frac{1}{2}$-inch long, 1-inch diameter wings inclined 20° backward and 5° downward from the vertical shaft. These angles were selected to conform closely to the natural inclination of the relaxed hand with the arm extended.



SECTION III.
Subjects

The subjects were nine males; three were members of the Aerospace Medical Research Laboratories and six were undergraduate students. The nature and duration of the experiment necessitated accepting available and willing subjects with minimal regard to their physical resemblance to the USAF population. Selected anthropometric measurements were taken on all subjects. The age, stature, and weight for each subject and comparative data with the corresponding parameters of the USAF population (Hertzberg et al., 1954) are given below.

Subject No.	*Age (yr)*	*Stature (in.)*	*Weight (lb)*
1	37	65.55	142
2	35	66.77	140
3	28	74.21	227
4	24	67.59	153
5	21	71.77	157
6	21	72.32	161
7	21	67.05	173
8	20	72.32	175
9	19	66.30	137

COMPARATIVE DATA

	Study Sample N=9		*USAF N=4000+*	
	Mean	*S.D.*	*Mean*	*S.D.*
Age in Years	25.11	6.75	27.87	4.22
Stature in Inches	69.32	1.72	69.11	2.44
Weight in Pounds	161.67	27.65	163.66	20.86

SECTION IV.
Procedure

When a subject expressed his willingness to participate, he first read a statement outlining the nature of the experiment and its potential hazards (appendix I). After being measured, he was seated in the ejection seat and fitted with shoulder harness, lap belt, and leather gloves. The shaft was fully extended and adjusted so that the handle rested immediately in front of the top forward edge of the seat cushion. The trigger-lock mechanism was then activated. The subject grasped the handle affixed to the end of the shaft and the mechanical carriage was adjusted until the shaft formed a straight line with the subject's extended arms, wrists, and hands. Next, the air cylinder was loaded to a preselected pressure. The subject was told to pull up on the handle, thereby releasing the lock transferring the force to the grip. He attempted to maintain his grasp on the handle as long as possible for a maximum of 30 seconds, at which time he was told to relax his grip.

Force loadings began at either 50 or 100 pounds and were increased by increments of 25 pounds until the oscillograph tracing showed that the subject was unable to stop completely the downward thrust of the shaft and handle. An arbitrary decision was made to differentiate between actual stoppage of the shaft and merely a slowed descent as the handle pulled away from the subject's grasp. Progression from low to high force loadings rather than the reverse or a random sequence eliminated the surprise of unexpected forces which, we felt, might lead to injury.

It became obvious during nonrecorded, preexperimental trials that the retention against the standard D-ring and Gemini loop handle configurations at moderate to heavy force levels (150 to 500 pounds) would cause some subject pain which would not be present for the T-bar and Twin handles. Therefore, each subject was restricted to two trials per day beyond a force loading of 125 pounds; the first on a "nonpainful" handle and then, after a rest period of approximately 2-5 minutes, a trial on a "painful" handle. The T-bar and D-ring were always paired as were the Twin and Gemini loop handles, but the presentation of pairs to the subject was alternated. This method was followed throughout the entire experiment to minimize the effects of fatigue and pain on the subjects' performance.

Each subject returned on subsequent days for additional trials at increasingly higher force levels until he could no longer retain his grip on any of the four handles used in the experiment, or until he reached 500 pounds on each handle. Depending upon his performance and availability, approximately 20-25 sittings were required at varying intervals over a maximum period of 3 months.

Shortly after the first nine subjects had concluded their trials, one of a second series of subjects sustained a hernia while attempting to retain a force loading of 250 pounds. Although the experiments were suspended at that point, the basic information obtained on the first nine subjects is sufficiently consistent to be useful to the design or selection of ejection handles and other grip devices.

While the experimental situation had been designed to simulate one aspect of an aircraft ejection situation, no attempt was made to simulate an actual ejection. Motivational and other factors would be expected to influence performance drastically, but not differentially.

Results

Graphs of each of the nine subjects' performance on the four basic handles are presented in appendix II (figures 7-10). Figure 6 summarizes these results, showing the highest and lowest absolute forces retained on each handle, irrespective of subject.

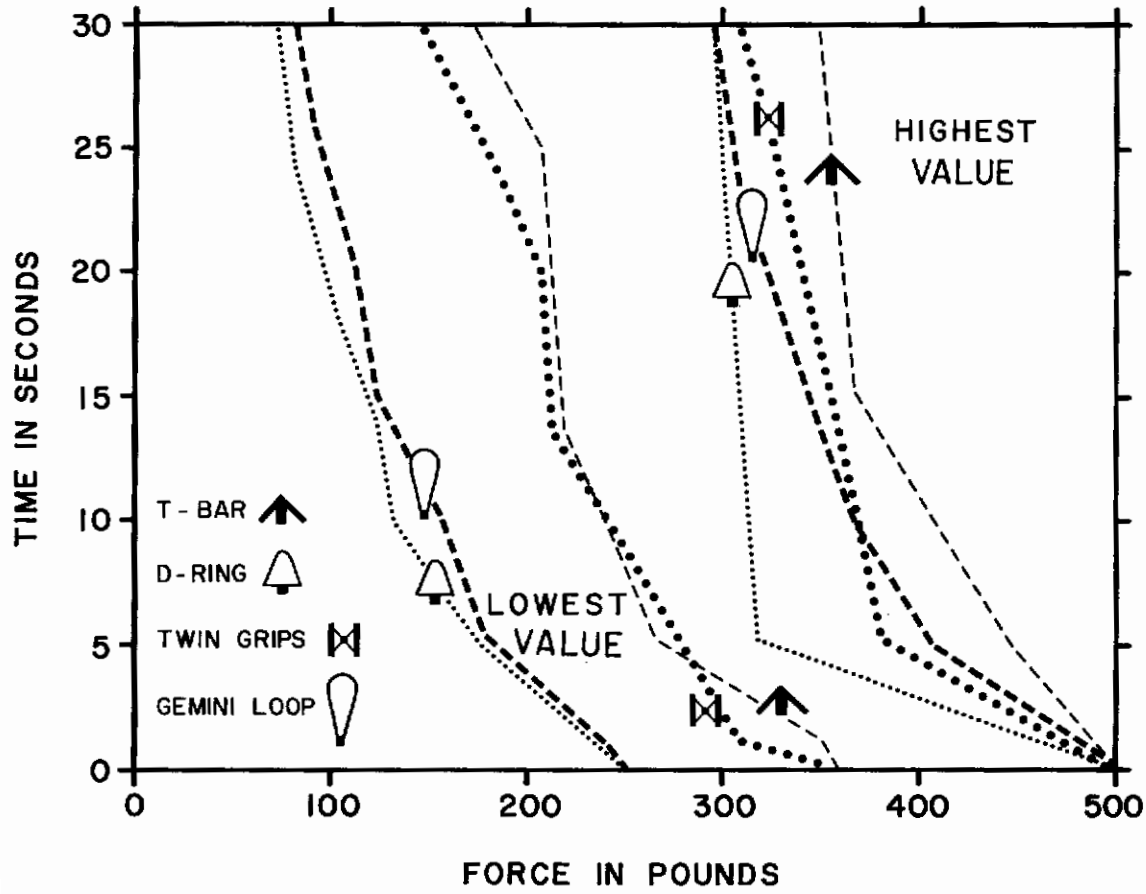


Figure 6. Summary of Force Data

Table I presents the data on a 30-, 5-, 1-second and no grip retention capability for lowest, median, and highest performance, irrespective of subject. The values for highest performance at 1-second and no retention do not necessarily indicate maximum grip-retention capability because of the 500-pound force limitation. Note that the lowest performance reflects a retention capability of approximately 100 additional pounds on the T-bar handle over the D-ring at each of the four time intervals.

TABLE I.

SUMMARY OF GRIP-RETENTION DATA

Performance Level	*Force Retained for 30 Seconds*	*Force Retained for 5 Seconds*	*Force Retained for 1 Second*	*Force Loading at Point of Nonretention*
	lb	*lb*	*lb*	*lb*
Lowest	TB 175	TB 270	TB 355	TB 360
	TW 145	TW 265	TW 310	TW 350
	GL 85	GL 180	GL 235	GL 250
	DR 75	DR 180	DR 240	DR 250
Median	TB 200	TB 365	TB 425	TB 425
	TW 235	TW 315	TW 350	TW 450
	GL 155	GL 220	GL 290	GL 325
	DR 150	DR 220	DR 330	DR 330
Highest	TB 350	TB 445	TB 500+	TB 500+
	TW 310	TW 385	TW 470	TW 500+
	GL 295	GL 410	GL 500+	GL 500+
	DR 295	DR 320	DR 465	DR 500+

TB—T-bar handle
TW—Twin handle
GL—Gemini Loop handle
DR—Standard D-Ring handle

Discussion and Summary

In general, our data indicated the T-bar and Twin handles are quite comparable and both superior to the Gemini loop and D-ring handles, which are also quite comparable. Certain explanations for the performance differential on the various handle configurations may be advanced from the authors' observations and from the subjects' reactions. Maximum grip retention in all cases was greatest on the T-bar and Twin handles, the T-bar having a slight advantage, especially at the lower range of performance. The 1-inch diameter of these handles permitted a greater distribution of the force over the surface of the hand. This reduced the pain caused by the thinner diameter handles of the D-ring and Gemini loop, which cut or pinched under high-pressure loads. Each subject's hands showed welts and evidence of possible superficial tissue damage after grasping the D-ring and to a lesser degree with the Gemini loop. None showed a similar effect from the 1-inch diameter of the T-bar and Twin handles.

Another factor may have been the wedging, hence compression, of the knuckles of the index fingers against the apex of the triangle on the D-ring handle and similar compression against the Gemini loop as it deformed with higher loads. On the T-bar and Twin handles, the subject's hands were kept separate.

The performance differential between the D-ring and the Gemini loop handles was affected by the subject's ability or willingness to ignore pain for longer periods. The subject with the greatest grip-retention capability on these handles was heavily calloused on both hands and admitted to little pain even though at the highest forces tested he was unable to extend fully his fingers and unzip his gloves for several minutes after the test.

Although these data strictly apply only to the specific situation of a seated man grasping a particular handle between his knees, applicability to general situations is possible. In an ejection situation where the pilot may be exposed to high aerodynamic forces we recommend, on the basis of the data obtained in this experiment, that a D-ring or Gemini loop arm-hand restraint system not require a grip-retention capability of over 250 pounds and even that for only a matter of a few seconds at most.

Bulk, weight and stowage considerations do limit handle design in particular situations. While it is not the purpose of this report to design future nonencapsulated ejection restraint systems, the experiments tend to show that improved handle configurations over the standard rigid, thin diameter D-ring or the flexible Gemini loop handle may permit a significantly higher grip-retention capability, hence a greater safety factor, for the aircrewman.

APPENDIX I.

INSTRUCTIONS

Instructions Read by Subject

Preliminary: Thank you for volunteering to help during this grip-retention capability experiment.

Why the Experiment: Several injuries have occurred because pilots have failed to retain their grip on the D-ring or ejection handle during ejection from a disabled airplane. This experiment is an attempt to determine the maximum force a man can withstand while holding on to variously shaped handles during a simulated ejection situation.

The Equipment: We are using a mounted Stanley B-47E downward ejection seat with the ejection handle attached to a pneumatically controlled shaft. We will use different force levels and differently shaped handles. Results are recorded on an oscillograph and gauges.

What You Will Do: After a preliminary series of body measurements, you will be seated on the downward ejection seat upon the platform and secured by a standard shoulder harness and safety belt. You will grasp, with *both* hands, the ejection release handle positioned at the front of the seat between your knees. The handle is attached to a shaft which is moved up or down by compressed air. When you initially grasp the handle, the shaft will be locked in an upward position.

What Will Happen: Your sharp pull on the handle will release the lock, causing the shaft to move rapidly downward at various, pre-set, force levels. This sudden jerk will simulate the force against the ejected pilot's hands which are still grasping the handle when he strikes the windblast along the bottom of his aircraft. Failure to retain hold of the handle during *actual ejection* would cause the arms to flail and be injured. In this *experiment,* the handle will merely travel down with the shaft and your arms and hands will remain in a normal position.

You will be required to hold onto the handle for a maximum of 30 seconds during each test. The force against the handle will be increased during various runs until you can no longer retain your grip. This force, then, will be greater than you can hold with both your hands on the particular handle.

Precautions and Safety: This experiment has been reviewed and certified as non-hazardous by a medical panel. However, although the shaft can be halted instantly by the operator, please do not attempt to hold onto the handle beyond your own strength limits.

Feel free to ask questions at any time.

APPENDIX II.

DETAILED PERFORMANCE DATA

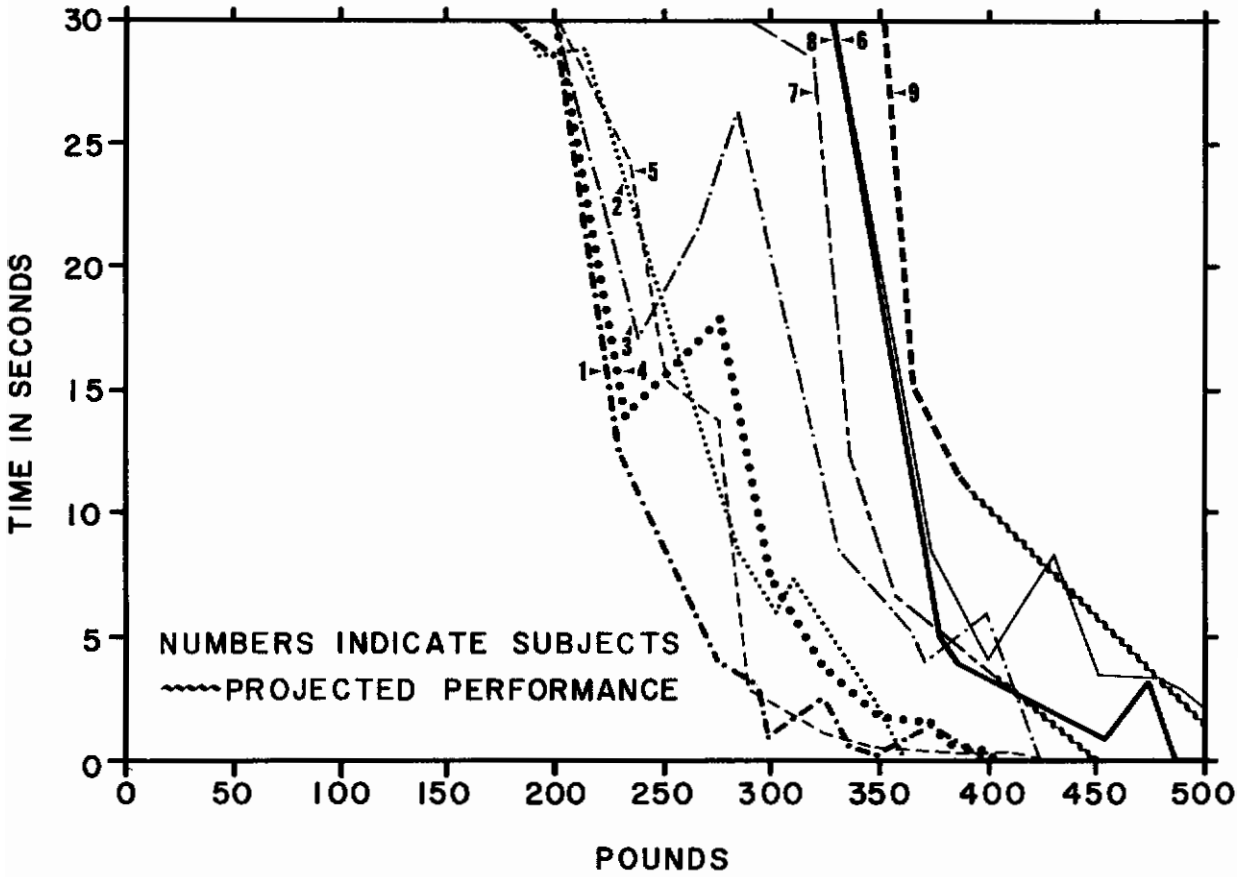


Figure 7. Grip Retention on T-bar

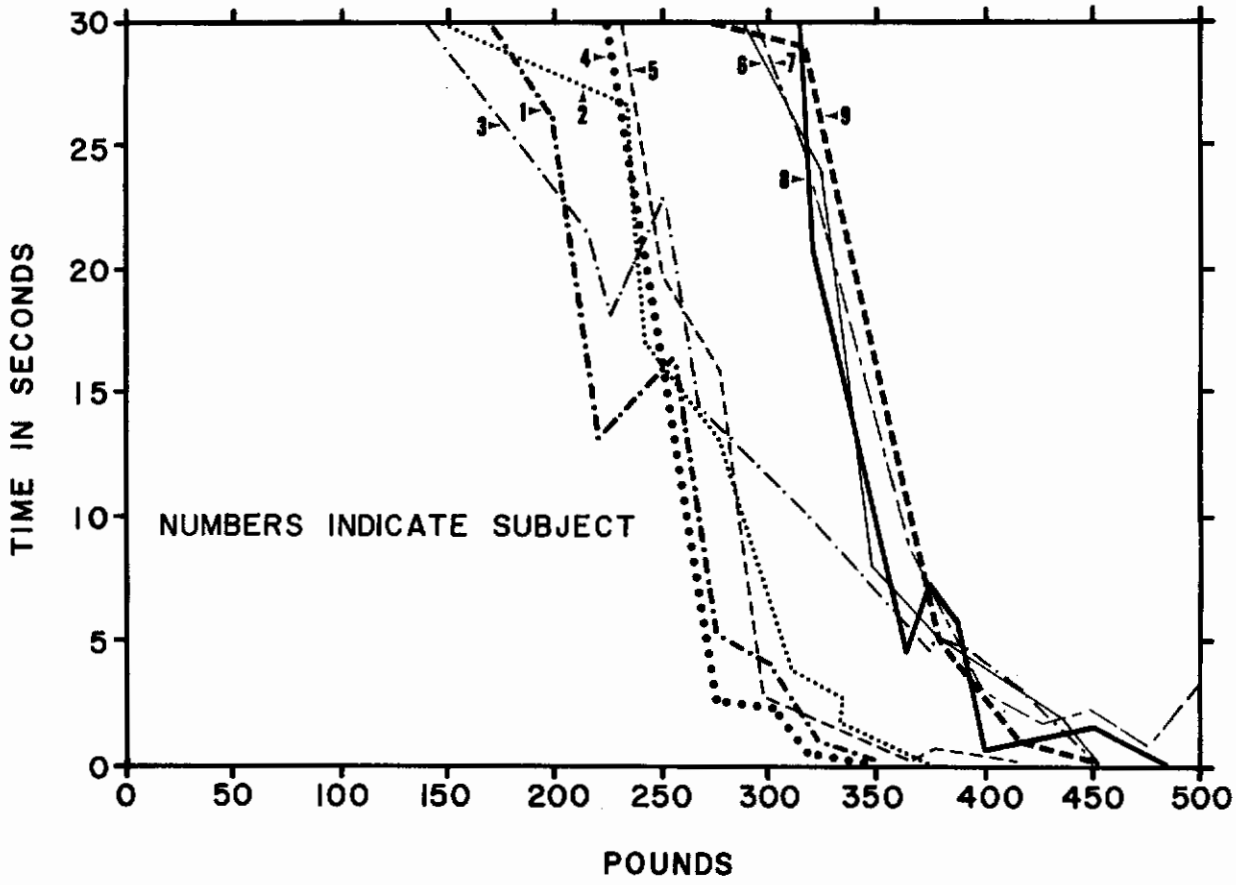


Figure 8. Grip Retention on Twin Grip

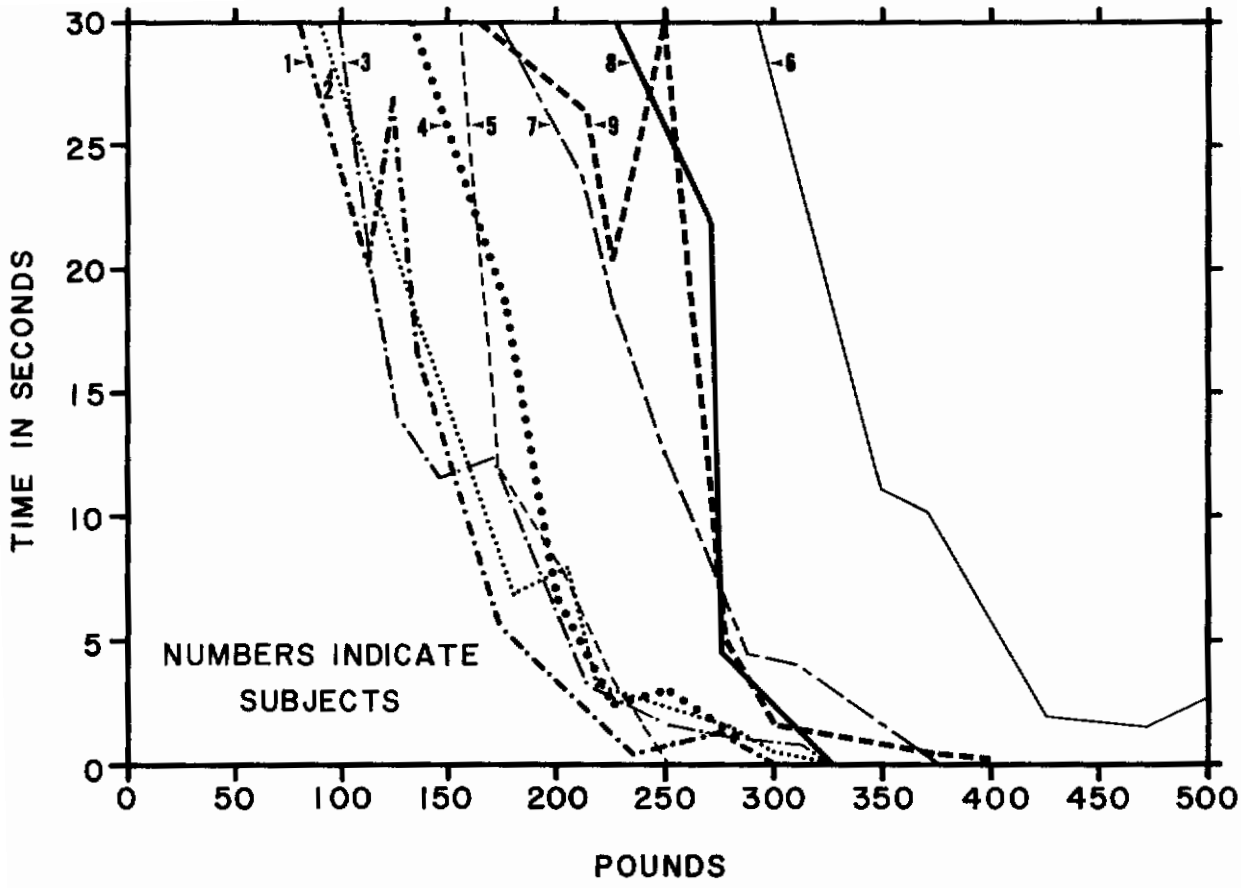


Figure 9. Grip Retention on Gemini Loop

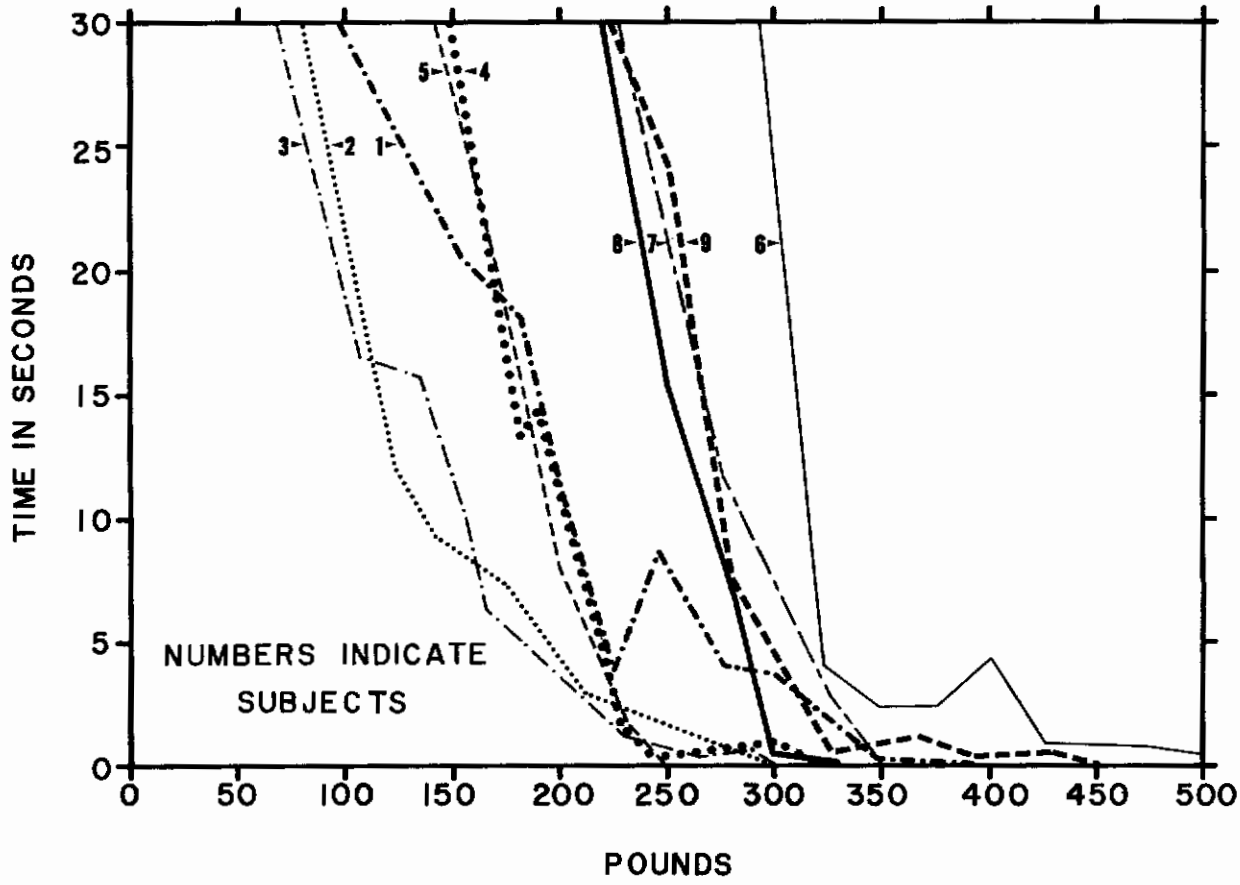


Figure 10. Grip Retention on D-ring

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13. ABSTRACT

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