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MEDICAL SERIES

Ergonomic Studies of Grip Strength–Literature Review

by Dennis B. Brickman, P.E.[1]

Abstract

The subject of human strength has been addressed for over a century, culminating in an amorphous body of interdisciplinary literature. A thorough study of this literature revealed the need for a single data source which could be easily accessible to many researchers. The published data on one subset of this broad topic, ergonomic grip strength, has been captured and summarized under sixteen factors affecting grip strength. These factors may be broadly categorized as human physical characteristics, physiological features, environmental conditions, and exposure to training. Available data has been charted and documented in a way that will facilitate future reference and use.

I. INTRODUCTION

A literature survey covering the fields of engineering, ergonomics, medicine, physiology, biology, psychology, and anthropology was conducted to develop a database of literature published in the English language on the narrow subject of adult human hand grip strength. A phenomenological critical review of this literature collection focuses on the effects of specific physiological, psychological, environmental, and occupational factors on ergonomic grip strength data. For well over 100 years, scientists and researchers have utilized various spring steel, cable, pneumatic, mercurial, hydraulic, and electrical strain gauge dynamometers to measure human grip strength in units of pounds, kilograms, kilopascals, millimeters of mercury, and kiloponds. Currently, medical, physical rehabilitation, and human factors engineering practitioners typically measure grip strength with instruments such as the Smedley type adjustable spring dynamometer and the Jamar hydraulic dynamometer as shown in Figures 1 and 2 respectively.

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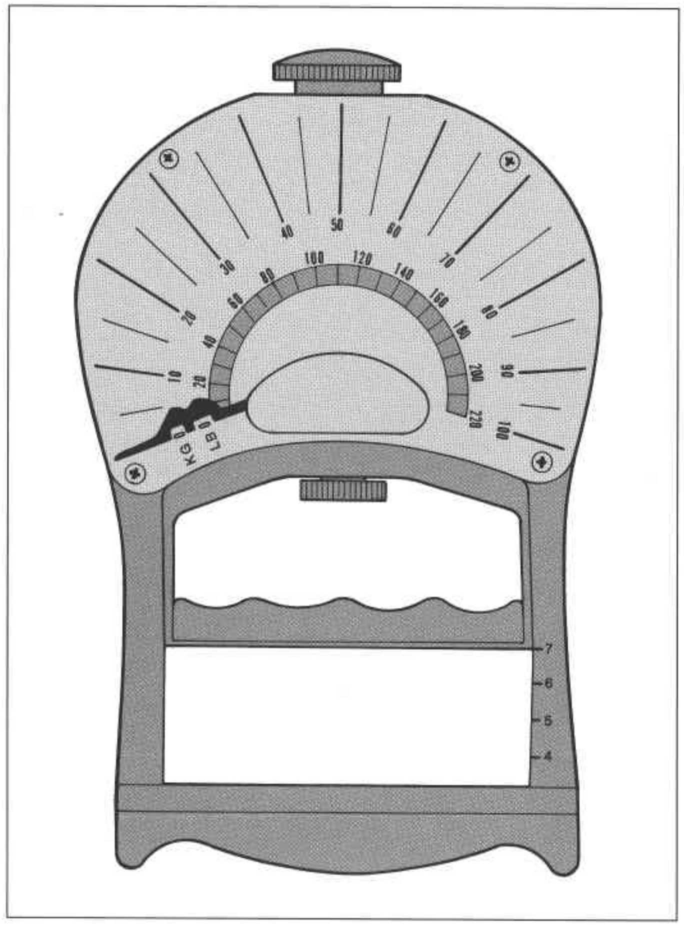
FIGURE 1
Smedley Type Adjustable Spring Dynamometer



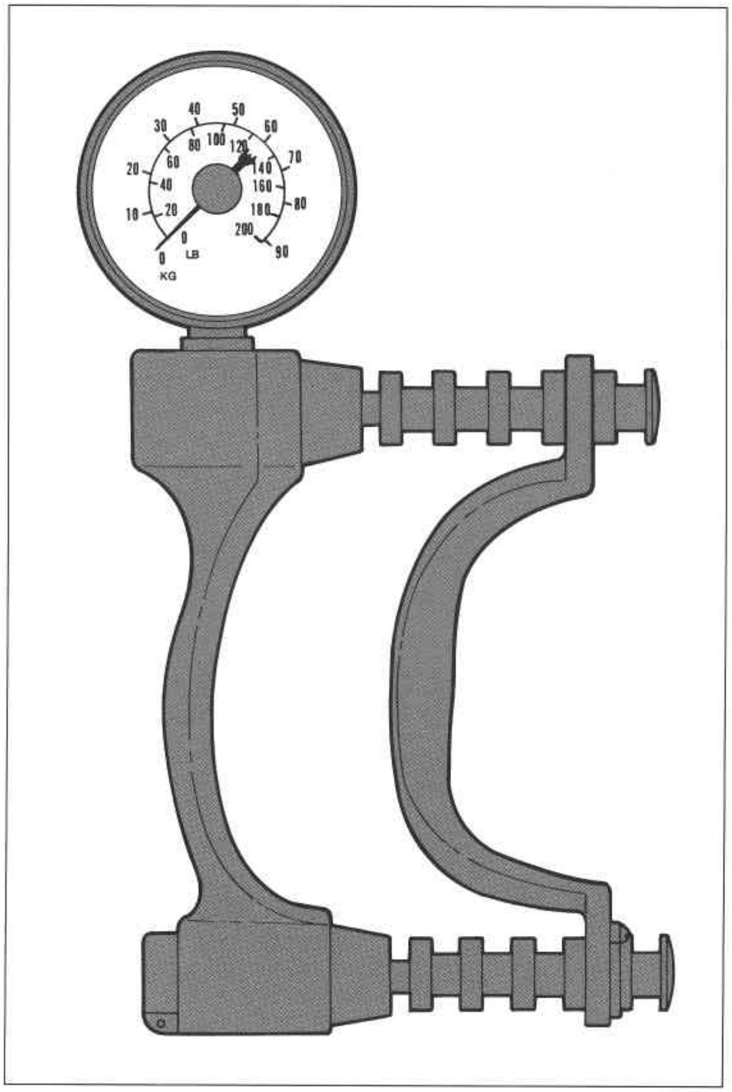


FIGURE 2
Jamar Hydraulic Dynamometer

II. CRITICAL LITERATURE REVIEW

The literature presented in this paper is categorized into the various physiological, psychological, environmental, and occupational factors that affect human hand grip strength. If there exists more than one reference for a particular factor, then a source which exhibits the representative traits of that factor was selected. The scope of the literature is limited to that which is published in the English language and contains data relating to adult subjects. Considerable effort has been made to maintain the integrity of the original data while enhancing its presentation with a uniform format. Finally, each reference is ranked in the bibliography in order of its popularity index, which is defined as the percentage of authors in the bibliography that cite that reference.

A. Age, Sex, and Handedness

The interaction between age, sex, and handedness is one of the most researched topics in the field of human grip strength [2-5, 15, 50, 53, 68, 97]. The relationship between age, sex, and handedness and the mean grip strength of 310 men and 318 women discovered by Mathiowetz is illustrative of that reported in the literature and is presented in Figure 3 [3].

In general, grip strength reaches a maximum value in subjects between 20 to 30 years old and steadily decreases thereafter as the age of the subjects increases. Both the ratio of female to male grip strength and the ratio of left-handed to right-handed grip strength are age dependent and tend to increase with age.

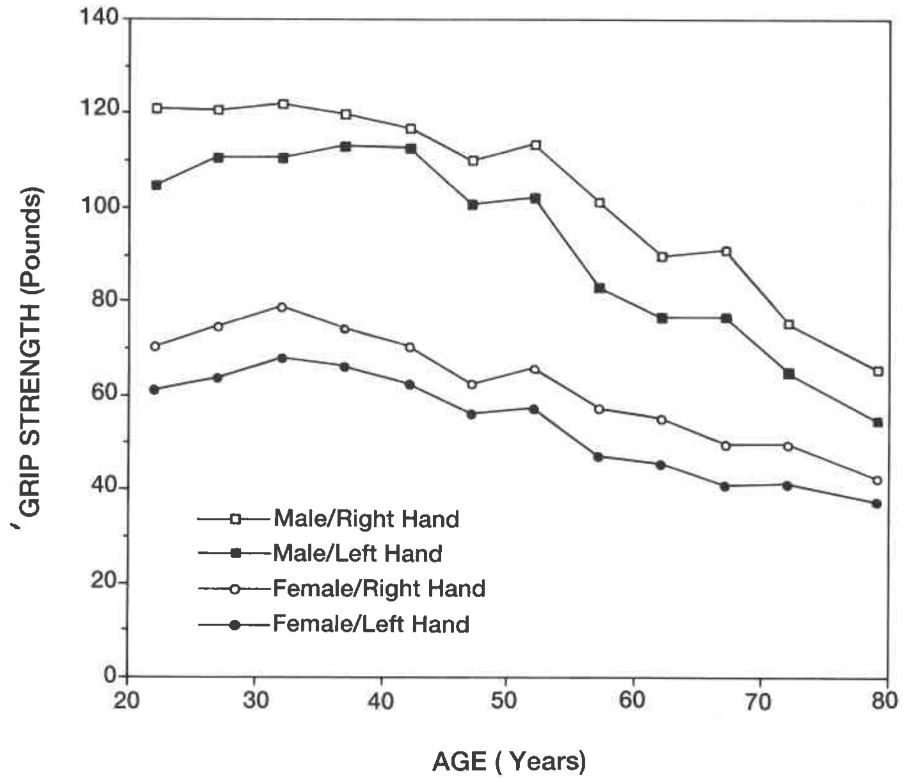


FIGURE 3
Grip Strength Versus Age in Relation to Sex and Handedness.
(Reproduced with permission. *Arch Phys Med Rehabil*, vol. 66, pp. 69-74, 1985.)

B. Time of Day

Grip strength tests performed on subjects at different times of the day have resulted in a diurnal variation in grip strength [15-16, 34, 57, 75, 97]. The daily variation of grip strength in a typical subject has been reported by Wright as shown in Figure 4 [57].

Examining Figure 4, there appears to be a marked increase in grip strength from 6:00 a.m. to 9:00 a.m., a relatively constant strength of grip between 9:00 a.m. and 8:00 p.m., and a great decrease in grip strength from 8:00 p.m. to 4:00 a.m. Repeated testing, beginning tests at different times, and staying awake at night do not alter this daily pattern.

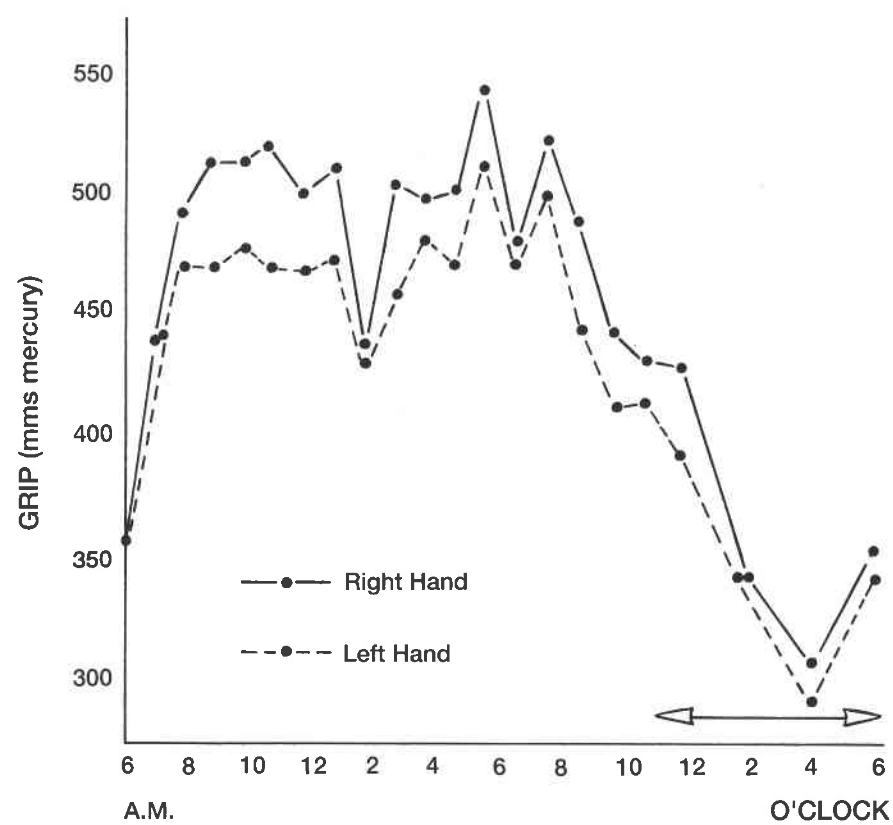
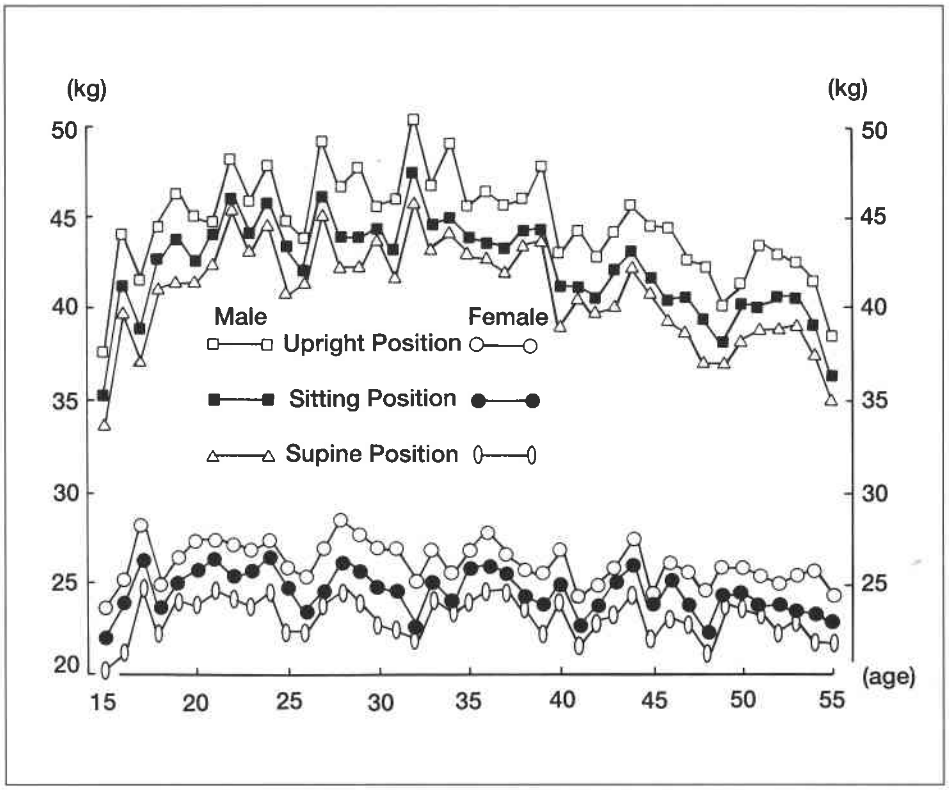


FIGURE 4
Daily Variation of Grip Strength in a Subject over 24 Hours.
(This figure is reprinted with permission from the *Research Quarterly for Exercise and Sport*, March, 1959, p. 113. Research Quarterly is a publication of the American Alliance for Health, Physical Education, Recreation and Dance, 1900 Association Drive, Reston, VA 22091.)



C. Body Position

The position of the human body has a significant effect on hand grip strength [53, 97]. Teraoka has investigated the grip strength of 2,014 subjects in the upright, sitting, and supine (lying on the back) positions, and his findings are given in Figure 5 [53].

It is clear from Figure 5 that grip strength in an upright position is stronger than that of the sitting position and grip strength in the sitting position is stronger than that of the supine position for both males and females in all age groups. Emotional conditions, center of body gravity, circulation, and pulse rate account for the differences in grip strength relative to body position.

FIGURE 5

Grip Strength Versus Age in Relation to Body Position and Sex. Record of each hand is added and averaged. (Source: Teraoka, Toshio, *Kobe Journal of Medical Sciences,* Kobe University School of Medicine, Kobe, Japan, vol. 25, March 1979, p. 7)

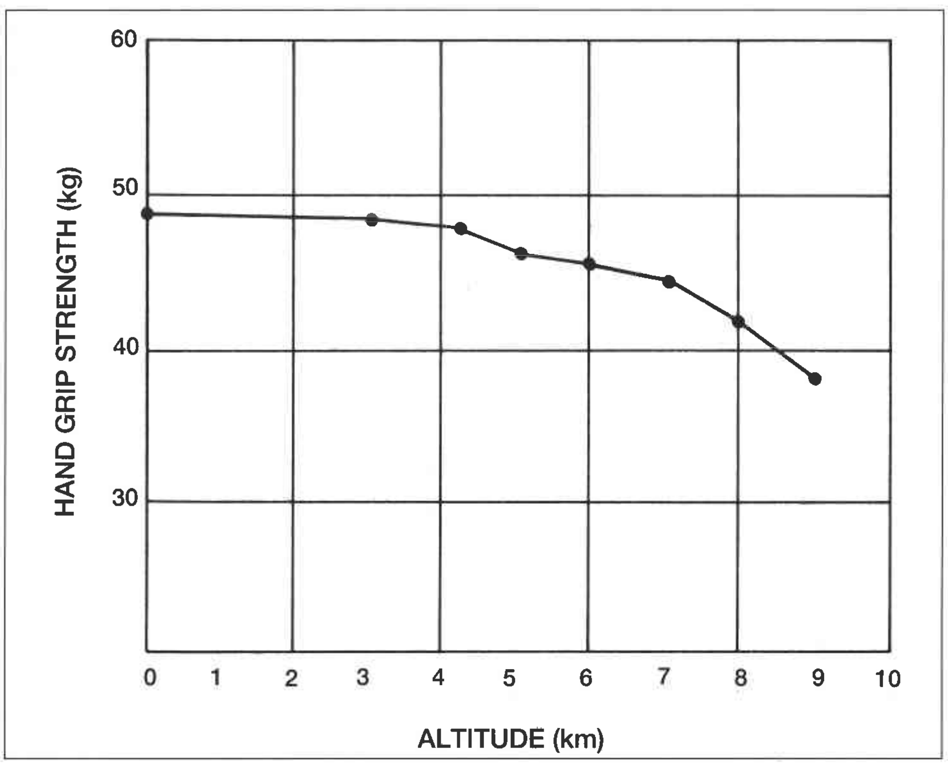


FIGURE 6

Hand Grip Strength Versus Altitude.
(Source: Ruff, Siegfried, and Hubertus Strughold, *Compendium of Aviation Medicine.* Originally reproduced under a License Granted by the Alien Property Custodian, 1942, p. 33.)

D. Altitude

An examination of hand grip strength in relation to altitude has been performed by Ruff and Strughold, and the average values of three experimental subjects are depicted in Figure 6 [80].

The curve in Figure 6 indicates that hand grip strength decreases with increasing altitude in two distinct stages. Grip strength remains relatively constant from 0 m (meters) to 4,000 m, gradually decreases from 4,000 m to 7,000 m, and abruptly drops from 7,000 m to 9,000 m. Grip strength starts to decrease at 4,000 m due to principal circulatory adjustments in the human body. At altitudes above 4,000 m, a lack of oxygen results in retardation of the energy producing chemical processes, and the muscle suffers a distinct decline in its efficiency.

E. Gloves

The consensus held by researchers in industry is that a bare-handed person has a stronger grip than the same person wearing gloves [10, 19, 66, 84, 89, 91]. The decrease in grip strength due to the wearing of gloves is caused by an increased grip span accompanied by an earlier feedback of discomfort [89]. Cochran conducted a study of 5 gloves using 7 male subjects to develop a hierarchy of gloves by comparing the percentage of grasp degradation for each glove with a bare-handed grasp [19]. Cochran's results are displayed in Table 1.

Table 1
Grasp Force Decrement for Different Glove Conditions

Glove Condition	Grasp Force	Percent Decrement
No Glove	21.83	0.0
Cotton	20.24	7.3
Nylon & Steel	19.22	12.0
Leather	19.06	12.7
Steel Mesh	18.37	15.8
Leather & Cotton	18.16	16.8

From *Proceedings of the Human Factors Society 30th Annual Meeting*, 1986. Copyright 1986 by The Human Factors Society, Inc., and reprinted by permission.

Inspecting Table 1, the decrement in grasp force varies from 7.3% for the cotton glove to 16.8% for the leather and cotton glove. Thickness, suppleness, tenacity, and snugness of the glove are the factors which affect the amount of grip strength reduction.

F. Arm Support

Grip strength experiments conducted by Swanson on 50 male and 50 female subjects reveal that the grip is weaker when the arm is supported compared to when the arm is unsupported [15]. Swanson's average grip strength data are presented in Table 2.

Table 2
Supported Grip Versus Unsupported Grip

Subjects	Supported Grasp (kg)	Unsupported Grip (kg)
Male - Major Hand	44.7	47.6
Male - Minor Hand	41.7	45.0
Female - Major Hand	22.3	24.6
Female - Minor Hand	20.1	22.4

Source: Swanson, A.B., et al., *Bulletin of Prosthetics Research*. Department of Medicine and Surgery, Veterans Administration, Washington, D.C., Fall 1970, pp. 147-148.

The reduction in grip strength for the supported arm is due to lost arm strength in keeping the arm stabilized.

G. Grip Size

A plethora of grip strength experiments have been performed by several researchers, utilizing various instruments, in pursuit of finding an optimum grip size [10, 16, 24, 65, 90]. Montoye and Faulkner's experiments consisted of testing the grip strength of 137 male and 63 female subjects grouped into 9 different hand sizes while adjusting the grip size on a Smedley grip dynamometer by 0.5 cm intervals [24]. Montoye and Faulkner's results are displayed in Figure 7.

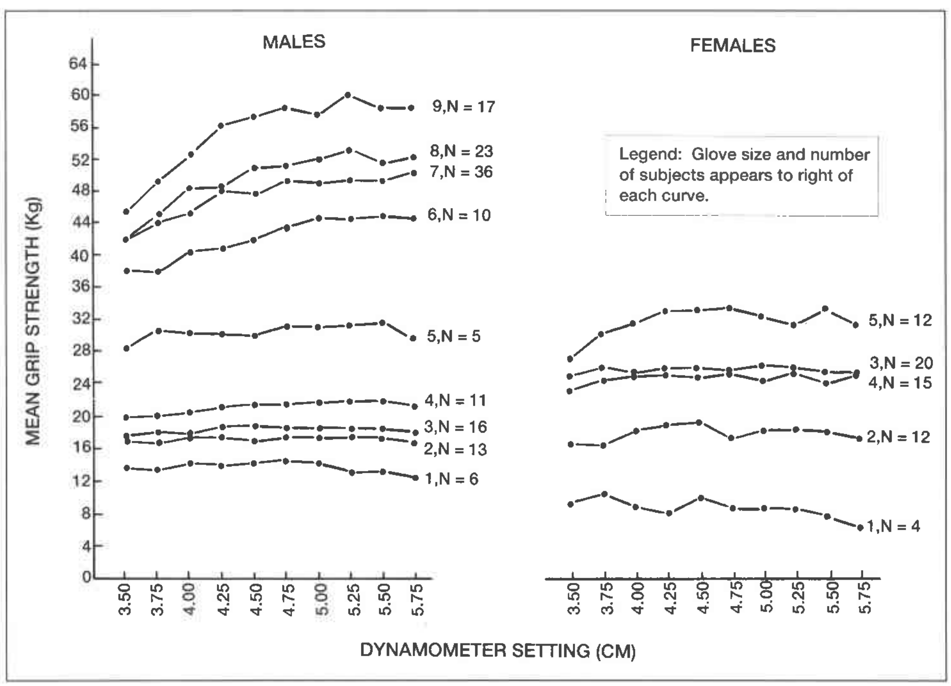
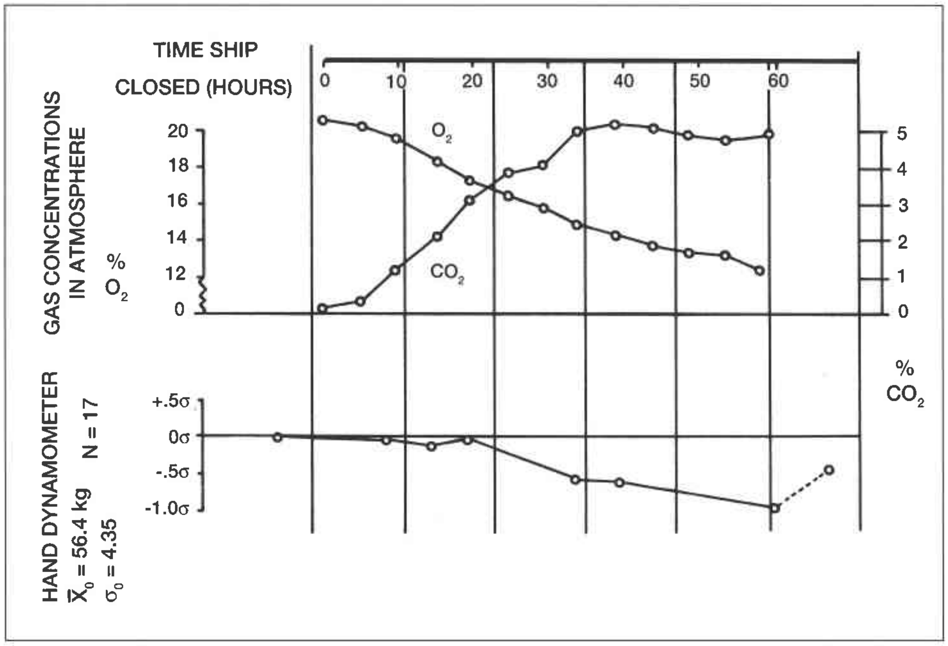


FIGURE 7

Mean Grip Strength at Ten Dynamometer Settings for Subjects of Various Glove Size. (This figure is reprinted with permission from the *Research Quarterly for Exercise and Sport*, March, 1964, p. 32. Research Quarterly is a publication of the American Alliance for Health, Physical Education, Recreation and Dance, 1900 Association Drive, Reston, VA 22091.)

Figure 7 illustrates that there are relatively small differences in performance at the various dynamometer settings. However, performance of subjects with larger hands falls off markedly at the five lowest settings, and subjects with very small hands have distinctly lower results in the largest three settings. At dynamometer settings between 4.50 cm and 5.50 cm, grip strength varies slightly, regardless of hand size. Finally, there is an apparent correlation between grip strength and hand size.



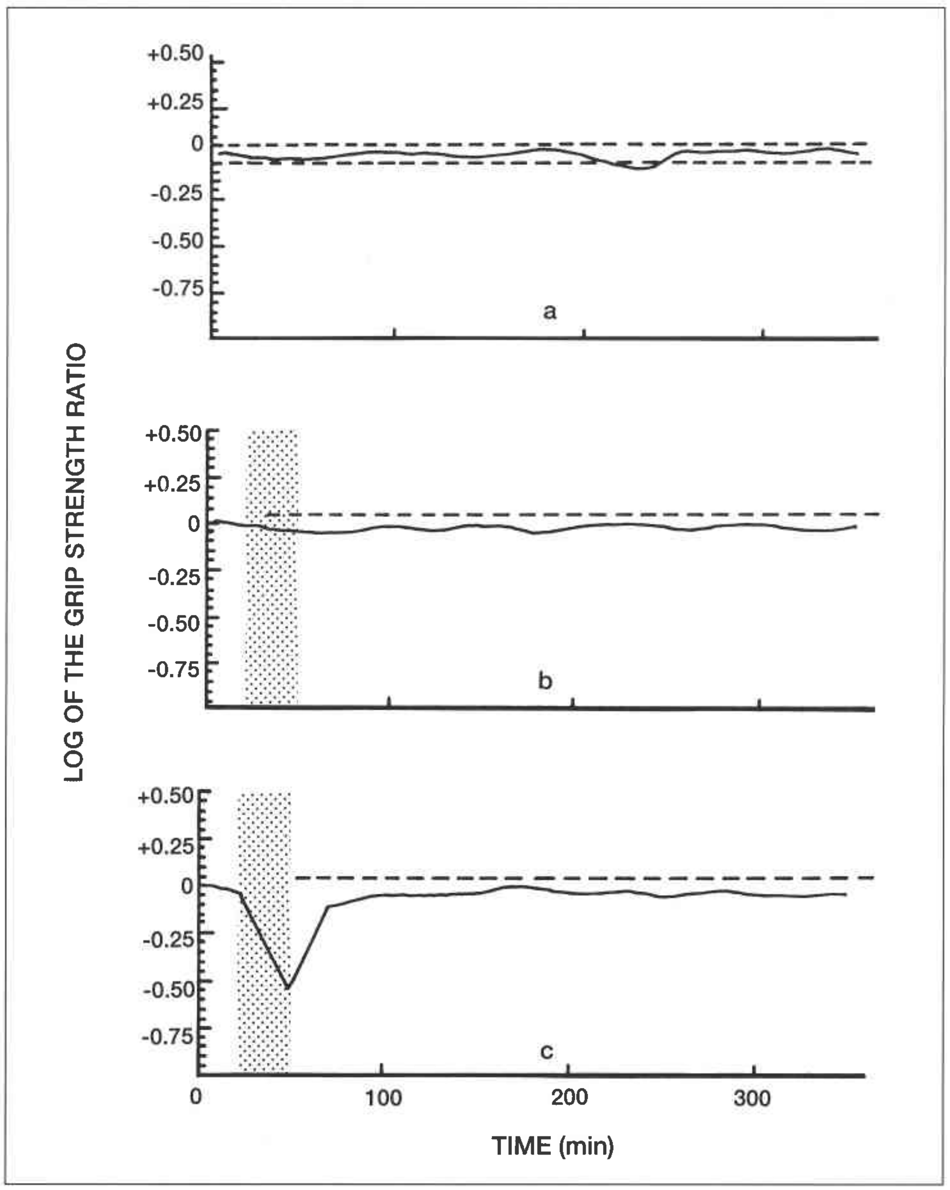
H. Oxygen

Consolazio studied the effects of recirculated air on the grip strength of 17 subjects in a sealed room aboard a Naval submarine for 60 hours while lowering the concentration of oxygen in the atmosphere from 20% to 12% [79]. Consolazio's results are depicted in Figure 8.

Figure 8 exhibits a constant hand grip strength from 0 hours to 20 hours, followed by a steady decline in grip strength from 20 hours to 60 hours as the oxygen concentration in the atmosphere drops.

FIGURE 8

Hand Grip Strength Versus Time in Relation to O_2 and CO_2 Concentrations in Atmosphere.
(Source: Consolazio, W.V., et al., *Research Project X-349*. Naval Medical Center, Bethesda, MD, Sept. 1944 and May 1945, p. 28.)



I. Temperature

Temperature effects on human grip strength have been studied extensively by scientists and medical researchers [21, 59, 84, 106, 111]. Coppin immersed the forearm of 9 male and 4 female subjects into a 10°C water bath for 30 minutes and recorded grip strength values before, during, and after the forearm immersion [106]. Coppin's data for the males' right grip strength versus time are displayed in Figure 9. This figure shows that hand grip strength significantly decreases as the forearm is immersed into the 10°C water bath. Grip strength returns to normal values and does not exceed pre-immersion values 40 minutes after removing the forearm from the cold bath.

FIGURE 9

The males' right hand grip strength values expressed as logarithm of the grip strength ratio (experiment vs. control) as the ordinate vs. time.
a) The control test for the right forearm when neither forearm was immersed into the cold bath. The dotted lines indicate the upper and lower 95% confidence limits only;
b) The right arm's strength values when the left arm was subjected to the cold water treatment. The dotted line indicates the upper 95% confidence limit only; c) The effect of the cold water treatment on the right arm. The dotted line indicates the upper 95% confidence limit only.
(Reproduced with permission. Coppin, E.G., et al., *Aviation, Space, and Environmental Medicine*, vol. 49, Nov. 1978, p. 1324.)

J. Fatigue

Batteries of physical tests have been conducted on various groups of subjects to determine the effect of fatigue on grip strength [9, 30, 34, 37, 94]. Burke had 311 male subjects squeeze a dynamometer for 1 minute to develop a relationship between maximum grip strength and grip strength endurance, which is defined as the average strength for the 1 minute period [30]. Burke's relationship between maximum grip strength and grip strength endurance is displayed in Figure 10.

When comparing maximum grip strength values to grip strength endurance values in Figure 10, the maximum grip strength is approximately twice as much as grip strength endurance for a given age.

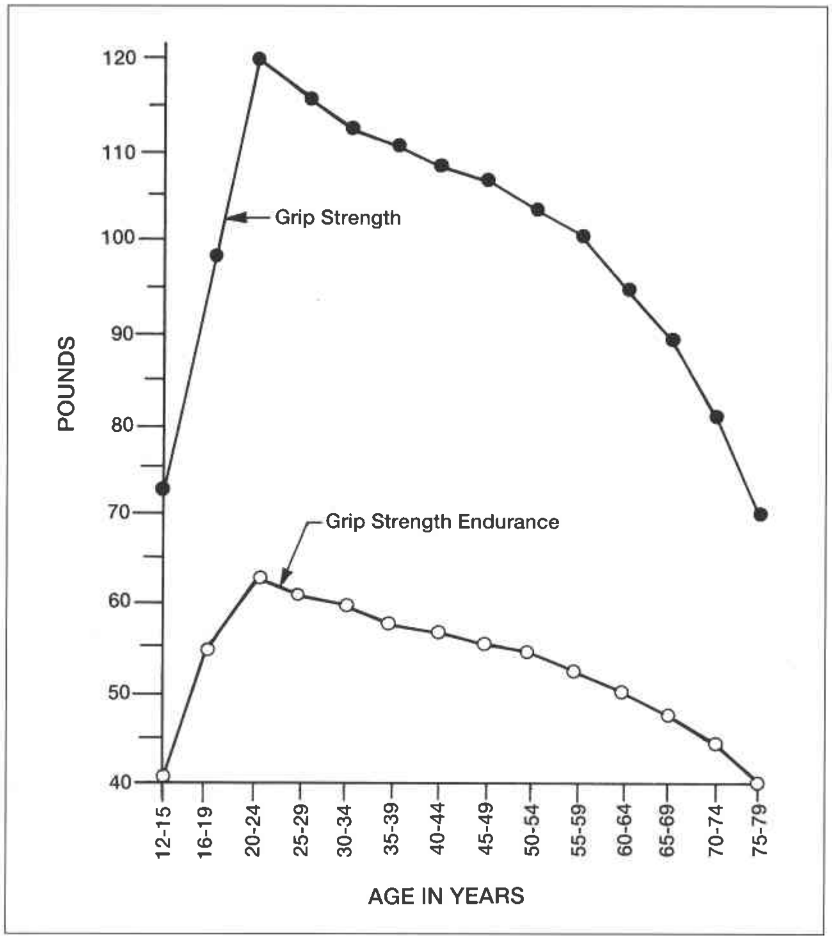


FIGURE 10

Maximum Grip Strength and Grip Strength Endurance in Relation to Age.

(Reproduced with permission of the American Physiological Society. Burke, W.E., et al., *Journal of Applied Physiology*, vol. 5, April 1953, p. 630.)

K. Hypnosis

Psychologists have evaluated the effects of hypnosis on grip strength to determine whether the power of suggestion can overcome physiological limits such as fatigue [66, 83, 112]. Hadfield submitted 3 men to hypnosis to test the effect of mental suggestion on their grip strength [112]. Hadfield's average grip strength results under contrasting hypnotic suggestions are recorded in Table 3.

Table 3 suggests that hypnosis can produce deleterious as well as ameliorable effects on grip strength.

Table 3
Average Grip Strength in Relation to Hypnotic Suggestion

Hypnotic Suggestion	Average Grip Strength (pounds)
Weak	29
Normal	101
Very Strong	142

Extract taken from *The Psychology of Power* by J.A. Hadfield, reproduced by kind permission of Douglas Hadfield.

L. Diet

Keys utilized a hand dynamometer to test 32 subjects under semi-starvation conditions for 24 weeks to evaluate the effects of diet on grip strength [78]. Keys' reported mean values are exhibited in Table 4.

Table 4 demonstrates that starvation causes harmful effects on grip strength which cannot be fully recovered from after a nutritional rehabilitation period.

Table 4
Hand Grip Strength Changes During Semi-Starvation and Rehabilitation

Condition	Hand Grip Strength (kg)
Pre-Starvation	58.2
12 Weeks of Starvation	47.2
24 Weeks of Starvation	41.8
6 Weeks of Recovery	42.3
12 Weeks of Recovery	47.2

Copyright 1950. University of Minnesota, Minneapolis. Reprinted from Keys, Ancel, *The Biology of Human Starvation*, vol. I, p. 705, by permission of University of Minnesota Press.

Arm Condition	Grip Strength Before Training (kg)	Grip Strength After Training (kg)	Relative Difference In Training Effect
Unexercised Arm	28.7	29.11	+1.53%
Exercised Arm	29.22	32.56	+11.43%

Table 5
Influence of Unilateral Training on Grip Strength

Reproduced with permission. *Arch Phys Med Rehabil*, vol. 28, pp. 76-85, 1947.

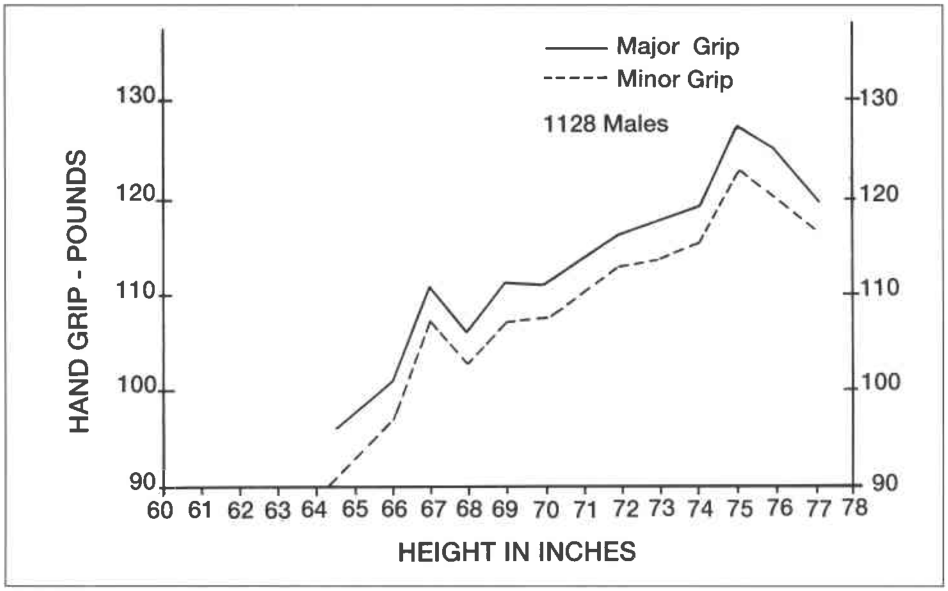


FIGURE 11
Major and Minor Grip Strength Versus Height.
(Reproduced with permission. *Arch Phys Med Rehabil*, vol. 51, pp. 321-327, 1970.)

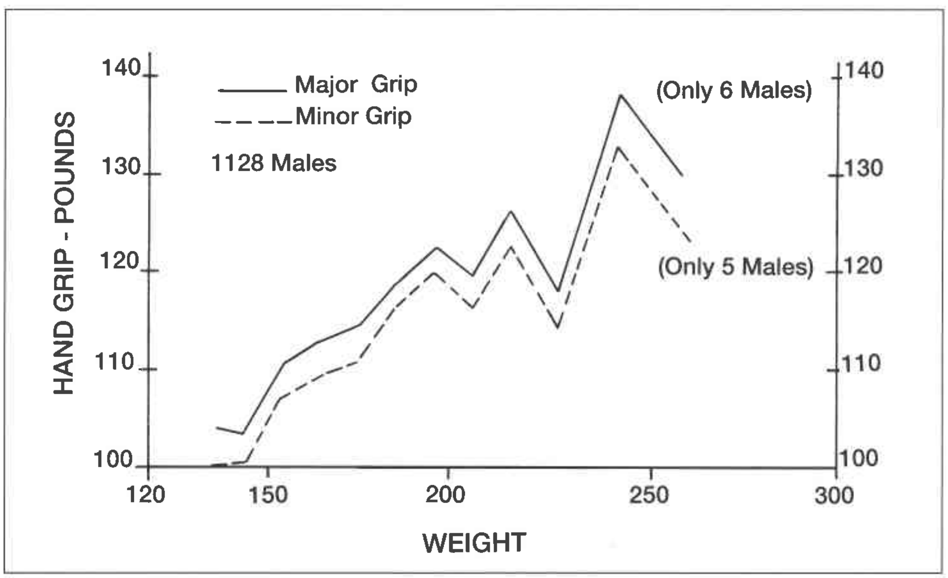


FIGURE 12
Major and Minor Grip Strength Versus Weight.
(Reproduced with permission. *Arch Phys Med Rehabil*, vol. 51, pp. 321-327, 1970.)

M. Training

The effects of physical exercise and training on hand grip strength have been explored by several physiologists and scientists [25, 34, 55, 67]. Hellebrandt tested the grip strength of 6 subjects before and after unilateral right-sided training, and his results are presented in Table 5 [25].

Table 5 illustrates that unilateral training produces a significant improvement in grip strength in the exercised arm, while the unpracticed arm remains virtually unchanged.

N. Height and Weight

Correlating hand grip strength to anthropometric measurements has been a greatly researched topic spanning several interconnected disciplines [2, 13, 29, 41, 49, 51, 58, 62, 65]. Schmidt and Toews tested the grip strength of the major and minor hands of 1128 males with a Jamar dynamometer at a fixed grip setting of 1 1/2 inches and recorded the distribution of major and minor grip strength as compared with height and weight as depicted in Figures 11 and 12 [2].

Figure 11 exhibits a direct association between hand grip and height up to 75 inches, and Figure 12 portrays the correlation between hand grip and weight up to 215 pounds.

O. Wrist and Forearm Position

Researchers in the engineering, human factors, and medical fields have analyzed the relationship between grip strength and wrist and forearm position in applications of hand tool design, manual labor tasks, and physical rehabilitation [12, 65, 105, 108]. Terrell and Purswell designed a special hand dynamometer utilizing the handles of a T-5 Cable Tensiometer to measure grip strength performance in various combinations of 5 wrist and 3 forearm positions [108]. Terrell and Purswell's results are featured in Figure 13.

The decrease in grip strength from the supination (palm up) to pronation (palm down) positions as shown in Figure 13 can be explained by the shortening of muscles in the forearm, which causes a significant decrease in performance. Muscle length in the wrist is also a major factor in grip performance with the neutral wrist position exhibiting the highest grip force.

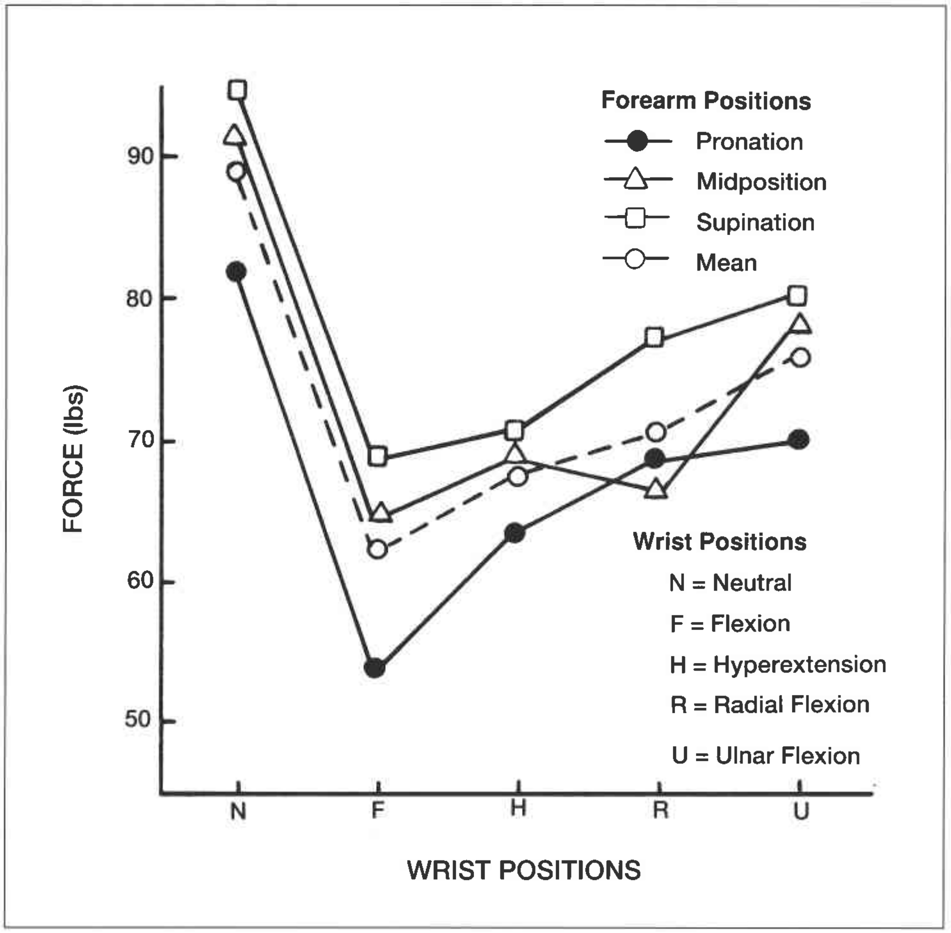


FIGURE 13

Grip Strength Versus Wrist Position in Relation to Forearm Position.
From "*The Influence of Forearm and Wrist Orientation on Grip Strength for Hand Tool Use,* " 1976 by Robert Terrell and Jerry L. Purswell, and used with kind permission of Jerry S. Purswell.

P. Smoking

Parkash and Malik assessed the mean grip strength of 29 age-matched pairs of male smokers and non-smokers using an adjustable hand grip dynamometer, and their results are displayed in Table 6 [85].

Smokers have a relatively lower grip strength than non-smokers due to diminished food intake, decreased activity of the cardiovascular system, and loss in lung function, which reduce muscular performance.

Table 6
Grip Strength of Smokers and Non-Smokers

Subjects	Grip Strength of Right Hand	Grip Strength of Left Hand
Smokers	28.7	25.9
Non-Smokers	33.2	29.8

Source: Parkash, Mohinder, and S.L. Malik, *Indian Journal of Medical Research*, Indian Council of Medical Research, New Delhi, India, vol. 87, May 1988, p. 498.

ACKNOWLEDGMENT

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Rank	Popularity Index	Citation
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What is a Defect?

The definition of defective product in a state may be found in its case law. Triodyne relies on the trial bar for selection of the cases cited.

Maine

Bernier v. Raymark Industries, Inc. 516 A.2d 534 (Me. 1986)

Maine's Strict Liability Statute, 14 M.R.S.A. §221, imposes liability on manufacturers and suppliers who market defective, unreasonably dangerous products. The seller becomes subject to liability if an unreasonably dangerous product causes injury to a foreseeable consumer or user. The product must, however, be in some respect defective before liability will be imposed. See generally *Austin v. Raybestos Manhattan, Inc.,* 471 A.2d 280, 28283 (Me. 1984), *Bernier v. Raymark Industries, Inc.* 516 A.2d 534 (Me. 1986).

In defining the terms "design defect" Maine follows a "danger utility test". *Stanley v. Schiavi Mobile Homes, Inc.,* 462 A.2d 1144 (Me. 1983). "In actions based upon defects in design, negligence and strict liability's theories overlap in that under both theories the Plaintiff must prove that the product was defectively designed thereby exposing the user to an unreasonable risk of harm. Such proof will involve an examination of the utility of its design, the risk of the design and the feasibility of safer alternatives." *Stanley,* 462 A.2d @ 1148, See also *St. Germain v. Husqvarna Corp.,* 544 A.2d 1283 (Me. 1988).

When the strict liability defect is a failure to warn, the reasonableness of the manufacturer's conduct is a factor in determining whether the manufacturer had a duty to warn. "The conduct should be measured by knowledge at the time the manufacturer distributed the product. Given the scientific, technological and other information available when the product was distributed, did the manufacturer know or should he have known of the danger. In other words, did he have actual or constructive knowledge of the danger. A product related danger may be regarded as knowable if the available scientific data gave rise to a reasonable inference that the danger is likely to exist". See *Bernier v. Raymark Industries, Inc.* 516 A.2d 534 (Me. 1986).

Contributed by Frederick F. Costlow, Richardson & Badger, 82 Columbia Street, Bangor, ME 04401

Maryland

Valk Manufacturing v. Rangaswamy, 537 A.2d 622 (Md. App. 1988)

A 1982 fatal collision involved Dr. Rangaswamy and a Montgomery County dump truck with a snowplow hitch mounted on its front. No snowplow was attached to the hitch, which contained a lift arm protruding 29 inches beyond the bumper of the truck. Dr. Rangaswamy, driving a Toyota automobile, was attempting to enter an intersection, the full view of which was blocked by a C & P Telephone Company truck. Rangaswamy purportedly looked both left and right, then drove into the intersection into the path of the County dump truck. When the vehicles collided, the lift arm penetrated the Rangaswamy vehicle and Dr. Rangaswamy died of massive head and chest injuries shortly thereafter.

The survivors filed suit against several different parties: C & P Telephone Company and Montgomery County were sued under theories of negligence. Valk Manufacturing Company, manufacturer of the snowplow hitch, was sued under theories of negligence and strict liability in tort. Valk, in turn, filed a cross-claim against Montgomery County.

The case against C & P Telephone Company was settled prior to trial. At the conclusion of the case, a motion for judgment was granted in favor of Montgomery County; a motion for judgment was also granted in favor of Montgomery County on the cross-claim of Valk Manufacturing. The trial judge ruled that the deceased was contributorily negligent as a matter of law. The case proceeded to the jury against the sole remaining defendant, Valk Manufacturing. A $2,500,000 verdict was returned against Valk and a motion for a new trial was denied. Valk Manufacturing appealed, arguing that Montgomery County was negligent in failing to disconnect the snowplow hitch and should be held for contribution and that recovery was barred the survivors because deceased had assumed the risk, as opposed to being contributorily negligent.

The Maryland Court of Appeals adopted the theory of strict liability as set forth in the Restatement (2nd) of Torts, Sec. 402A (1965) *[Phipps v. General Motors, 278 Md. 337, 363 A.2d 955 (1976)]*. To succeed on such a theory, the plaintiff must establish that the product with its defect was unreasonably dangerous to the user/consumer. To determine whether a defect is unreasonably dangerous, two tests have been employed: The Consumer Expectation Test (for manufacturing defect claims) and the Risk Utility Test (for design defect claims). The Risk Utility Test requires that Maryland Courts weigh "the utility of the risk inherent in the design against the magnitude of the risk." This test was used in *Valk Manufacturing v. Rangaswamy*, 537 A.2d 622 (Md. App. 1988).

On appeal, the Court of Special Appeals ruled in favor of the Rangaswamy survivors, stating that the motorist was protected under the doctrine of strict liability in tort, although he was a mere bystander. The judgement in favor of Montgomery County was reversed and remanded for new trial as to Valk's cross-claim for contribution, with costs to be divided equally between Falk and Montgomery County.

Case selection by Francis X. Quinn of Anderson & Quinn, 25 Wood Lane, Rockville, MD 20850

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Triodyne Safety Briefs

Volume 1 No. 1
On Classification of Safeguard Devices (Part 1): Intrinsic Classification of Safeguarding Systems
by Ralph L. Barnett and Peter Barroso Jr.

Scientists and legislators set safeguarding standards for individual machines and specific processes. The courts, on the other hand, produce general rules which they apply to all machines thereafter. Since no *valid* general rules exist, the legal system is producing irrational tenets at odds with other intellectual disciplines.

Engineers can provide guidelines to help the courts make more reasonable decisions. The first step is to stop looking at safety devices as a homogeneous lump. Safety devices differ in the amount of safety that they provide and the amount of harm that they can do. This article presents a classification system which breaks down safety devices into mutually exclusive and jointly exhaustive catagories.

Volume 1 No. 2
On Classification of Safeguard Devices (Part II): Functional Hierarchy of Safeguarding Systems
by Ralph L. Barnett and Peter Barroso Jr.

Part II examines the relationships among individual safeguarding devices. The approach was to establish a pecking order which would allow safeguarding devices to be ranked according to the type of protection offered. However, important safety problems seemed to fall outside of its scope. For example, it did not explain why a knife is not unreasonably dangerous, or account for the very low injury frequency rate associated with the press brake compared to the mechanical punch press.

Proper account of a system's safety profile requires the introduction of a category which deals with those safety characteristics inherent in a system. These characteristics, which include simplicity, obviousness, slow motion, and wisdespread user training, are ranked under Zero Order Systems in the function hierarchy of safety devices and concepts.

Volume 1 No. 3
Zero Obstruction Repair Overpass

Professor Ralph Barnett, his students, and Triodyne are introducing a new concept in highway construction which enables roadways to be repaired without interrupting normal traffic flow. The concept is called Z.O.R.O, Zero Obstructing Repair Overpass. Z.O.R.O. is a movable, prefabricated hill which cars drive over while construction proceeds underneath. Z.O.R.O.'s lightweight, resusable modular design incorporates techniques developed for military bridge construction.

Volume 1 No. 4
Philosophical Aspects of Dangerous Safety Systems
by Ralph L. Barnett and Beth A. Hamilton

One of the unfortunate trends developing in the product liability movement is the promotion of dangerous safeguarding devices. Such devices arise principally from insufficient research, judicial coercion, and liability proofing. The safety literature presents an unequivocal mandate against the use of safeguarding systems that sometimes present hazards themselves.

Volume 2 No. 1
On Safety Codes and Standards
by Ralph L. Barnett

This article posits that 1) compliance, or non-compliance, with safety codes is presently the only rational way to judge whether a design is safe or defective, and 2) safety codes cannot properly protect the public interest unless they define both lower and upper bounds, or limits, on the conduct of designers. Engineers are introduced to the doctrine of "rebuttable presumption" relative to safety standards. Further, a semantic problem concerning the use of the term "minimum safety standards" is addressed.

Volume 2 No. 2
Safety and Product Liability Considerations in Farm Machinery Equipment
Only Photocopies Available

In December 1982, the American Society of Agricultural Engineers gathered at the Palmer House in Chicago for its Winter Meeting, celebrating its 75th anniversary as an organization. The meeting consisted of a variety of educational seminars, forums, and presentations. Professor Ralph L. Barnett presented a seminar entitled "Product Liability Considerations in Designs."

In March, April and May 1983, *Implement and Tractor*, the farm and industrial equipment industry trade magazine, published a series of articles inspired by Professor Barnett's presentation. These articles are reprinted in this ***Triodyne Safety Brief***.

Volume 2 No. 3
The Dependency Hypothesis (Part I)
by Ralph L. Barnett, Gene Litwin, and Peter Barroso Jr.

This article discusses the types of changes in the man/machine interface which accompany the incorporation of safety systems into a machine. Safety systems introduced to meet narrowly defined safety objectives may give rise to broad secondary effects that subtly or profoundly influence the machine's overall safety and function. Designers and lawmakers alike must understand these secondary effects so they can weigh them against prevailing value systems to determine the overall desirability of safety devices. Some new criteria are described to aid in the evaluation of proposed safeguards.

Volume 2 No. 4
On the Safety of Motorcycle Side Stands
by Dror Kopernik

When a motorcycle is banked to the left with its kickstand down, or in the park position, the contact between the kickstand and the pavement can cause the driver to lose control. Some kickstand designs retract during such a turn without interfering with the driver's control. A reprint of Dror Kopernik's SAE Paper (No. 840905) is presented which explores the design parameters affecting kickstand retraction.

Drill Press Guards
by William G. Switalski and Ralph L. Barnett

An investigation into the safety of drilling machines has revealed a number of shortcomings of drill press safety guards. The results of Triodyne's research have been reported by the National Safety Council in *National Safety News*. The article is reprinted here. It is significant that the National Safety Council has withheld recommendation of the subject guards in all of their subsequent publications.

Volume 3 No. 1
The Dependency Hypothesis (Part II) — Expected Use
by Ralph L. Barnett, Gene D. Litwin, and Peter Barroso Jr.

Safeguarding systems may be introduced to perform specific safety tasks, to comply with some code or standard, or to liability-proof a machine. Whatever the case, the device itself may be perceived to define a safety function and users will expect the device to perform that function. Moreover, one may argue, users have a right to such expectations.

Volume 3 No. 2
Safety Hierarchy
by Ralph L. Barnett and Dennis Brickman

Outside of the judicial oath, the most popular litany heard in a product liability trial is "the safety hierarchy." It is associated with a number of misconceptions which are explored in this paper. First, there is no such thing as **the** safety hierarchy; there are many hierarchies. Second, "it" is not a scientific law but rather a useful rule of thumb whose genesis is consensus. Finally, its complete form is broader than reported in any single reference.

Volume 3 No. 3
Trailer Hitches & Towbars
by William G. Switalski and Ralph L. Barnett

A survey of trailer hitch requirements in the 50 United States has highlighted problems of uniformity, communication, suitability, and design specificity.

Volume 3 No. 4
The Meat Grinder Safety Throat
by Ralph L. Barnett, Gene Litwin, and Gary M. Hutter

Every engineered system represents a tradeoff among at least three criteria: cost, safety, and function. For a meat grinder with a safety feed throat and stomper, common sense tells us that operator safety will increase as the throat diameter gets smaller and its length gets longer. It is just as apparent that the feed throat capacity will decrease accordingly. This paper quantifies the relationship among the throat parameters, the capacity, and the stomper force.

Volume 4 No. 1
Mechanical Power Presss Safety Bibliography
by Beth A. Hamilton, Joyce E. Courtois, and Cheryl Hansen

The safety literature on mechanical power presses (punch presses) is characterized by publications more practical than scholarly. It has not been subjected to the more exact bibliographic control of other technical literature, thereby inhibiting research on safety matters relating to power presses. The aim of this bibliography is to promote better control of, and to facilitate access to, the literature on mechanical power press safety.

Triodyne maintains a database on mechanical power press literature for scholarly purposes, with the intention of building the most comprehensive collection available on the subject. The scope of the bibliography is limited to coverage of the safety literature of mechanical power presses; pneumatically and hydraulically-powered press and press brake documents are excluded. Patents, manufacturers' literature, medical and legal literature, and student theses and dissertations have also been excluded. The time period covered is 1902 to Jan. 3, 1986.

Volume 4 No. 2
On Rubber Augers — Failure Modes and Effects
by Dennis Brickman and Ralph L. Barnet

Contrary to reported notions, the flexible flight auger gives rise to a new set of hazards and risks without fulfilling its promise of eliminating the amputation hazard. Increased jamming, elevated temperatures, grain damage, and rubber flight damage are among the failure modes observed.

Volume 4 No. 3
Mandatory Seat-Belt Usage Laws: Exemptions to the Rule
by Gary M. Hutter and Cheryl A. Hansen

The legislators of twenty-seven states have passed mandatory seat-belt usage laws, all of which provide a variety of exemptions to mandatory seat-belt usage. The categories and distribution of these exemptions provide an interesting examination of the perceived need and utility of vehicular seat-belts.

Volume 4 No. 4
A Proposed National Strategy for the Prevention of Severe Occupational Traumatic Injuries

The Association of Schools of Public Heatlh, under a cooperative agreement with the National Institute for Occupational Safety and Health (NIOSH), recently developed and published a proposal for minimizing traumatic injuries in the workplace. Contributing to this effort were over five hundred participants representing industry, government, business, trade unions, voluntary organizations, the professions, and academia. The resulting position paper, reprinted here, establishes a national strategy for the advancement of workplace safety.

Volume 5 No. 1
Principles of Human Safety
by Ralph L. Barnett and William G. Switalski

This paper describes selected concepts from safety and human factors engineering. Important philosophical tools that affect designs are summarized.

Volume 5 No. 2
Deadman Controls on Lawn Mowers and Snowblowers
by Ralph L. Barnett and Dennis B. Brickman

By exercising their rights under the Freedom of Information Act, the authors obtained the Consumer Product Safety Commission data on injuries sustained with lawn mowers and snowblowers equipped with deadman controls. The associated failure modes and effects verify the predictions contained in the literature. All of the failure modes involve ergonomic considerations. "Bypass" incidents are characterized using the Compatibility Hypothesis and "reliability" accidents are explored with the Dependency Hypothesis. There is also a discussion of the zero mechanical state (ZMS) concept and its relationship with the current approach to lawn mower and snowblower maintenance.