

# **USER'S GUIDE**

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## **ENGINEERING DATA COMPENDIUM**

**Human Perception and  
Performance**

**19990604 011**

# USER'S GUIDE

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# ENGINEERING DATA COMPENDIUM

## Human Perception and Performance

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*Integrated Perceptual Information for Designers Program*



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*“Engineers have been aware of the desirability of designing equipment to meet the requirements of the human operator, but in most cases have lacked the scientific data necessary for accomplishing this aim.”*

In honored memory of

PAUL M. FITTS

We dedicate this work to the past and future achievements  
of the organization he founded

The Human Engineering Division  
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## Acknowledgments for the *User's Guide*

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In particular, we are indebted to Herschel Self (Armstrong Aerospace Medical Research Laboratory) for his tireless efforts in aiding the development of the design checklist. His assignment was to assess and document the relationship of Compendium data to design-related issues by identifying specific human performance questions for which answers might be derived from individual Compendium entries. Over a period of several years, Hersch authored many thousands of questions based on an in-depth review of entry content. These questions were then edited and sorted into meaningful categories linked to an equipment-related taxonomy. Accomplishing this task required detailed scrutiny and extensive technical support by Herschel Self, by Ed Martin, Engineering Technical Advisor for the project, by Barbara Palmer and Sarah Osgood of Systems Research Laboratories, and by Anita Cochran, Jeffrey Landis, and Patrick Hess of the University of Dayton Research Institute.

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# About the *Engineering Data Compendium*

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## Claims and Disclaimers

The concept underlying the *Engineering Data Compendium* was the product of a research and development program (Integrated Perceptual Information for Designers project) aimed at facilitating the application of basic research findings in human performance to the design of military crew systems. The principal objective of this effort was to develop a workable strategy for (a) identifying and distilling information of potential value to system design from the existing research literature, and (b) presenting this technical information in a way that would aid its accessibility, interpretability, and applicability by system designers. The present volumes of the *Engineering Data Compendium* represent the first implementation of this strategy.

Ultimately, the success of this effort depends critically on the reception given to these initial volumes by both the R&D and design communities. To ensure the technical credibility of the present work and the feasibility of extending the treatment to other topical domains, it is essential that the R&D community be comfortable with this selection and representation of research findings. Of equal or greater importance, the functional utility of the Compendium must be fully demonstrated in design practice. Feedback from these user communities regarding working experience with the Compendium will shape future refinements to the project's basic strategy as well as revisions of the present Compendium. As one means of facilitating the interaction that is so vital to the continued success of the project, reader service cards have been provided at the back of the *User's Guide* on which users are encouraged to comment regarding the value of the Compendium in their work and improvements that would increase its utility and applicability.

Though the existing volumes provide system designers with a wealth of relevant human performance and perceptual data, coverage does not extend to all topics of potential value, nor is the depth of treatment uniform across subject areas. The Compendium was originally conceived as a demonstration project, and its scope paralleled that of the *Handbook of Perception and Human Performance* (edited by K. Boff, L. Kaufman, and J. Thomas, 1986). Because of concerns over limitations of the Handbook, we selectively and somewhat arbitrarily extended the treatment to include selected topics (vibration and large-amplitude motion, target acquisition, warnings and attentional directors, person-

computer dialogue, etc.) that rounded out the coverage we felt was essential for the Compendium. In addition, during the development of the Compendium, we continually modified the scope and depth of treatment of different subject areas based on the many suggestions of outside peer reviewers.

In general, the depth of treatment for any given topic area was determined by the availability of useful data and by the editorial necessity to limit coverage within reasonable bounds. Data were chosen through a multi-step process of evaluation and review by subject-matter experts, human factors specialists, and design engineers (see Preface and Acknowledgments in Volumes I-III for a detailed description of this development stage). No doubt some data were overlooked or misunderstood in this process. In a few instances, the paucity of entries in a given topic area occurs partly as an artifact of the organizational scheme of the Compendium. For example, relatively few entries are included in Section 4.0, "Information Storage and Retrieval," in part because entries dealing with memory and learning in the context of specific human perception and performance functions are distributed throughout the Compendium. It was not appropriate to repeat these entries in Section 4.0. However, neither was it appropriate to exclude the topics of memory and learning entirely from this section. We recognize that our treatment of these topics is by no means complete. Indeed, entire volumes may eventually be set aside for the subjects of memory and learning. Therefore, in these and other areas of the Compendium, we decided to include a few key entries as place holders, with the intention of fleshing out these areas in future editions.

Though we spared no effort in our attempts to ensure accuracy, in any project of this scale, errors and omissions are bound to slip through. The reader service cards at the back of this Guide may be used to communicate suggestions and concerns regarding entry content. We would be equally interested in hearing about specific circumstances in which the Compendium proved particularly valuable to you.

We urge you, as a Compendium user, to register your copy of the Compendium using the card provided; this will help us keep you informed about updates, revisions, and related products that may be of interest.

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## Entry Format

One of the major innovations of the Compendium is the development of a specialized format for presenting complex technical information on human perception and performance to designers with little or no knowledge in the given subject area. The format evolved over several years through the study of past efforts in the area, critical thinking on the problem, discussions with sponsors and consultants, and feedback from members of the user population. We attempted, in addition, to devise a typographic style and layout that would complement the organizational format and enhance the usability of the material.

### General Specifications

Information in the *Engineering Data Compendium* is organized as a series of brief entries dealing with narrow, well-

defined topics. There are eight different classes of entry, based on the general type of information each contains. Most entries present basic research data regarding human perceptual and performance characteristics.

The general specifications for individual Compendium entries are given below:

**Length:** two printed pages

**Layout:** single spread of two facing pages

**Writing style:** clear, concise style to minimize length; technical terminology is avoided when possible

**Format:** series of modular text elements (subsections) containing specific classes of information

**Mode of communication:** information presented in the form of figures or tables when possible

**Type of information:** Eight classes of information are included in the *Engineering Data Compendium*:

1. *Basic and parametric data* (e.g., dynamic range of the visual system, spatial and temporal contrast sensitivity functions, physical response constants of the vestibular system, receiver operating characteristic curves).

2. *Models and quantitative laws* (e.g., CIE spaces, probability summation, operator control models). A model or law had to meet two criteria to be included: (a) it had to provide a way of interpolating or extrapolating existing data and relating them to a specific application, either to answer a design question directly or to specify the research needed to answer the question; and (b) it had to have a well defined and well documented domain of reliable application.

3. *Principles and nonquantitative or nonprecise formulations* that express important characteristics of or trends in perception and performance (e.g., Gestalt grouping principles, interrelationship between size and distance judgments, depth and distance cues).

4. *Phenomena* that are inherently qualitative or that are general and pervasive, although quantitatively described in specific instances (e.g., simultaneous brightness contrast, visual illusions, motion aftereffects).

5. *Summary tables* consolidating data derived from a body of studies related to a certain aspect of sensation, perception, or performance (e.g., table showing different acuity limits as measured with Landolt rings, grating patterns, etc.; table summarizing the effects of various factors known to affect stereoacuity).

6. *Background information* necessary for understanding and interpreting data entries and models (such as rudimentary anatomy and physiology of sensory systems, specialized units of measurement or measurement techniques; specific examples are anatomy of the ear, geometry of retinal image disparity, colorimetry techniques).

7. *Section introductions* to topical areas that describe the topic and set out its scope, explain general methods used in the given area of study, note general constraints regarding the application of data in the area, and provide references for further general information.

8. *Tutorials* containing expository material on general topics such as psychophysical methods, signal detection theory, etc., included both to help the user fully understand and evaluate the material in the Compendium, and to support research and evaluation studies in engineering development.

To make pertinent information more accessible to the user, graphic modes of presentation are used wherever possible. The Compendium contains over 2000 figures and tables, including data graphs, models, schematics, demonstrations of perceptual phenomena, and descriptions of methods and techniques. Other features of the Compendium include indicators of data reliability, caveats to data application, and the use of standardized units of measurement (Système International).

Each Compendium entry is subdivided into a series of standard elements that convey specific types of information about the entry topic, such as areas of application, constraints in applying the data under different circumstances, etc. The particular subsections included in a given entry vary depending upon entry category. However, the type

of information contained in each subsection is consistent across entries, so that users can readily locate the particular item of information they need.

Individual entry subsections vary in style as well. Some are discursive paragraphs, others are series of bulleted items, etc., depending on the specific content.

### Graphic Design

The typographical design of entries for the *Engineering Data Compendium* had four goals:

1. To conserve space while preserving readability.

2. To signal the important elements in the entry so that they can be located and perceived rapidly.

3. To differentiate entry subsections visually to make it easy for readers to pick out information of interest and skip information irrelevant to their particular needs.

4. To present a pleasing overall appearance that is balanced, consistent, and cohesive.

Based on empirically validated design principles for promoting the readability of textual material, a graphic design was developed that fulfills these aims and enhances the usability of the Compendium.

In the current design, page arrangement signals at a glance what is important and what is less so. Figures generally appear at the top of the first page immediately following the title. The bold rule under figures and tables emphasizes the importance of this graphic and tabular information. The grid system which provides for either two or four columns within subsections also aids in differentiating material of greater and less import. Major discussion of the entry topic and information of general interest appear in the larger-type, two-column format. Text printed in the smaller type and four-column format is more technical information provided for the interested user. Two features of the design make it easy to scan an entry and locate the desired subsection: (1) subsections are clearly separated from one another by rules that cross the entire page; and (2) subsections are signalled by large headings in bold type.

A key element in promoting efficient communication of complicated information is to reduce the complexity of its presentation. Design guidelines incorporated into the entry design to simplify the presentation and enhance readability include:

1. Use of a limited number of type sizes and a limited number of weights and styles within a typeface family. This avoids the visual chaos that ensues when too many text elements compete for the user's eye.

2. Manipulation of weights and sizes of type to selectively emphasize or de-emphasize entry text elements. Optimum boldness enhances visibility and readability (Ref. 1).

3. Use of lower-case letters with initial capitals for titles and headings. Text set in this fashion is read more quickly than similar material set in all capitals (Ref. 2).

4. Establishing typeset line length at approximately one and one-half to two alphabet widths. Readability is reduced when lines are significantly shorter or longer (Refs. 3, 4, 5).

5. Use of ragged (unjustified) rather than even (justified) right-hand margins. Irregularities of word spacing that occur with justified text, particularly in narrow columns of type, can result in poorer reading comprehension than with unjustified text (Ref. 6).

6. Control of white space to create optimal visual scanning patterns.

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# How to Use the *Engineering Data Compendium*

Any data compendium is only as useful as the strategies for accessing the information it contains. This "how-to" guide describes the features incorporated into the *Engineering Data Compendium* to enable you, the user, to locate relevant information quickly and easily.

The perceptual and performance information contained in the Compendium is organized into a series of short entries dealing with narrow, well-defined topics. Within each

individual entry, information is further subdivided into a set of standardized text modules or subsections.

The first part of this guide describes how the Compendium is structured and how you can locate the specific Compendium entry containing the information you need. The second part of the guide explains where within an individual entry you will find a specific item of information.

## How to Locate Information in the Compendium

The Compendium consists of 12 main sections subdivided into more than 75 different topic areas. Each topic area contains a number of individual Compendium entries treating narrow subjects within that broader topic.

A numbering scheme has been developed that reflects this organization and makes apparent the relative position of any given entry within the Compendium. This scheme uses a decimal number of up to 4 digits to identify a particular section, topic area, or entry. The digit to the left of the decimal point identifies the Compendium section; the first digit to the right of the decimal represents the topic area number within that section; and the last two digits identify the individual entry within that topic area. For example:

- 5.0 Spatial Awareness
- 5.9 Depth Perception
- 5.918 Factors Affecting Stereoacuity

Here, "5.0 Spatial Awareness" is the fifth of the 12 major subject area divisions of the Compendium; "5.9 Depth Perception" is the ninth topic area within this section; and "5.918 Factors Affecting Stereoacuity" is entry no. 18 in topic area 5.9.

Each data volume of the Compendium contains 3 to 5 major subject area sections. These sections can be located easily in the Compendium by means of labeled tabbed dividers. The section title and topic area are also repeated at the top of each individual entry.

You can locate a specific entry several different ways. These are described below, along with an example of how you might employ each if you were interested in locating information on the legibility of displays under vibration conditions.

### Volume Table of Contents

At the front of each data volume of the Compendium is a Table of Contents listing each main section in that volume as well as individual topic areas under that section. The Table of Contents thus provides a quick overview of the information contained in the volume and can be used to identify the broad subject area in which a particular item of information is likely to be found. For example, if you are interested in display legibility during vibration, you would scan the contents to locate section "10.0 Effects of Environmental Stressors," under which is found the subsection "10.4 Vibration." You can then browse through section 10.4 to see which entries may be of interest, or you can consult the detailed Table of Contents at the beginning of section 10.0.

### Sectional Table of Contents

At the beginning of each Compendium section is a detailed Table of Contents listing each entry in that section by topic area. This sectional Table of Contents is printed on a tabbed

card immediately following the tabbed divider for that section. If you desire information on display legibility during vibration, you would scan the Table of Contents for section "10.0 Effects of Environmental Stressors," to locate topic area "10.4 Vibration." Under this topic area, the Table of Contents lists several entries on the subject of interest, such as "10.414 Display Legibility: Effect of Character Spacing."

### Complete Table of Contents

A cumulative, detailed Table of Contents listing every entry in the Compendium by section and topic area can be found at the front of the *User's Guide*.

### Tabbed Divider Cards

The section of the Compendium containing the information of interest can be located quickly by means of the tabbed dividers imprinted with section titles (for sections 1.0, 5.0, and 7.0, tabbed dividers are also provided for topic area divisions). For quick access to the group of entries dealing with display legibility under vibration, you would locate the tab labeled, "10.0 Effects of Environmental Stressors."

### Logic Diagrams

Printed on the tabbed divider card for each Compendium section is a schematic diagram showing the relationship among the entries in that section and referencing specific entries by number. To locate information on a given topic, such as display reading during vibration, you would find the box in the diagram that relates most closely to the topic of interest and consult the entries cited in the box. In the logic diagram for section "10.0 Effects of Environmental Stressors," the box marked "Effect of Vibration on Performance" lists a number of individual entries where information on display legibility during vibration might be found.

### Design Checklist

The *User's Guide* contains a design checklist to aid in identifying and accessing human factors data relevant to specific equipment needs. The checklist takes the form of questions focusing on specific aspects of human performance that should be considered in the design of control and display system components. The questions are grouped according to a hierarchy of equipment-related issues and are indexed to the specific Compendium entries that provide information on the given topic. The checklist questions pertinent to a given design issue can be located from the contents listing at the beginning of the checklist. For example, the contents subsection "1.f Vibration" under the heading "I.A. Visual displays" cites the pages containing design questions relevant to display legibility during vibration.

## Key Term Indices

The Key Terms section of each Compendium entry lists terms relating to the topic discussed in the entry. At the beginning of each major Compendium section is an alphabetical index of these key terms referenced to the appropriate entries. The index is printed on a tabbed card following the tabbed divider for that section. Information on specific topics within the given section can be located by looking up the relevant terms. For example, the entries listed under *display vibration* or *legibility* in the Key Terms index for section 10.0 will direct you to entries discussing the effects of vibration on display legibility.

## General Index

The *User's Guide* contains a high-resolution index in which you can look up selected terms to locate information on a particular topic. Following each index listing is the number of the Compendium entry or entries containing information on the given topic. On looking up the terms *vibration* and *display legibility*, for example, you will be directed to entries 10.411 to 10.416, which deal with display legibility under vibration conditions.

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## How to Locate Information in Individual Compendium Entries

Each entry in the *Engineering Data Compendium* is a self-contained treatment of a specific narrow topic. In almost all cases, the complete entry is contained on two facing pages of the Compendium.

There are eight categories of entry, classified according to content. The majority of entries present basic/parametric data. Other entry classes include tables summarizing a body of data in a given topic area, models and quantitative laws, principles and nonquantitative laws, perceptual phenomena and demonstrations, background information, tutorials on technical topics, and introductions to topical areas.

Compendium entries generally feature a figure or table, with supporting text presented as a set of modular elements or subsections. This modular format has been adopted to promote uniformity of presentation and usability of the data. There are ten standard entry subsections. Not every subsection will appear in each entry—some are pertinent only for particular categories of entry and will not be used in other entry classes. When specific subsections are present, however, they are consistent in content from entry to entry to allow confident access to the type of information desired.

The content and function of each of the standard subsections are described below. The figure on pages 8 and 9 illustrates these sections for an entry presenting basic perceptual data.

### Title

The title provides a concise description of the entry content.

### Key Terms

This section lists terms that relate to the topic discussed in the entry. Along with key words in the entry title, these key terms can be used to verify entry content and serve as access terms in an index search for related information.

### General Description

In entries presenting basic data, this section summarizes the general findings, conclusions, and trends in the data. For entries presenting perceptual/performance models, laws, or principles, it provides a precise description or definition and indicates the general purpose for which the model, law, or principles was developed.

## Key Terms

Scanning the Key Terms section of individual entries will help you judge the relevance of an entry to a specific purpose. For example, one of the key terms for entry 10.414, "Display Legibility During Vibration: Effect of Character Spacing," is *panel-mounted displays*. If you are seeking information about the legibility of panel-mounted displays during vibration, this entry should be of value. The key terms can also serve as entry points for an index search to locate additional information related to the topic treated in the entry.

## Cross References

Cross references in each entry guide you to other entries in the Compendium that contain information on related subjects or provide pertinent background information to aid the understanding of the topic. For example, in reading entry 10.414, "Display Legibility During Vibration: Effect of Character Spacing," you will be directed by the Cross Reference section to entry 10.411, "Display Legibility: Effects of Vibration Frequency," as well as to several other entries treating the topic of display legibility during vibration.

## Applications

This section describes general areas of application for the information in the entry; specific types of displays, control systems, task environments, etc., for which the information might be useful; and, where pertinent, general procedures for application.

## Methods

Entries presenting basic data contain a Methods section that describes how the data were collected. The section is divided into the following two subsections.

*Test Conditions.* This subsection specifies the physical and psychophysical characteristics of the stimulus and the conditions under which the testing was carried out.

All measurements are given in units of the Système International (SI). When units in the original data source did not conform to the SI, measurements have been converted to SI units. Values in the original units are given in parentheses after the first such conversion. For example, specification of target diameter as "15.24 cm (6 in.\*)" indicates that size was given in inches in the original data source and has been converted to SI units for the Compendium.

*Experimental Procedure.* This subsection lists, in order: (1) the experimental method, paradigm, and design (such as method of constant stimuli, two-alternative forced-choice paradigm, randomized design); (2) the stimulus dimensions that were varied (independent variable); (3) the response or effect measured (dependent variable); (4) the subject's task; and (5) the number and characteristics of subjects. Other pertinent procedural details may also be included.

Unless otherwise specified, subjects are assumed to have normal vision, normal hearing, etc., and no prior practice on the experimental task. Results represent data averaged across all subjects and all trials within a given condition unless indicated otherwise.

## Experimental Results

When an entry reports findings of a research study, it contains an Experimental Results section that provides a more detailed discussion of the data than the General Description. The Experimental Results includes graphic or tabular presentation of the data, an enumeration of the major findings

and trends in the data, and an indication of their meaning or significance.

When statistical tests have been used to assess the effects of an experimental manipulation or treatment, the significance level ( $p$  value) may be reported in the Experimental Results section. The significance level indicates the probability that differences between experimental groups occurred by chance alone (rather than because of experimental manipulation); for example, a level of  $p < 0.01$  indicates that the difference in the measured variable observed between groups would occur by chance less than 1% of the time if in fact the groups did not differ.

**Variability.** This subsection indicates how performance or sensitivity differed from subject to subject (between-subject variability) or from session to session for the same subject (within-subject variability). Generally, variability is expressed in terms of the standard deviation from the mean or the standard error of the mean. The Variability subsection also cites any statistical test performed to evaluate the significance of the experimental findings.

**Repeatability/Comparison with Other Studies.** This subsection describes the findings of other studies that conducted similar research and suggests reasons for any discrepant results.

### Empirical Validation

This section is found in entries that treat a model, law, or principle. It includes a description of the methods used in empirical tests of the model, law, or principles and reports the results and scope of the validation studies.

### Constraints

This section describes features or limitations of the information in the entry that may affect its application; stimulus or subject characteristics, environmental conditions, etc., that may influence the results or effect reported; criteria that must be met for proper application; and limits on the class of response, stimulus, task environment, etc., to which the information can be applied.

### Key References

This section provides full bibliographical data for several reference sources that contain more detailed information on the entry topic. The original source of the data, model, etc., presented in the entry is marked with an asterisk. References are listed alphabetically and numbered consecutively.

### Cross References

This section cites Compendium entries that treat related topics or provide pertinent background information useful in understanding or interpreting the information in the entry. Also listed are sections of the *Handbook of Perception and Human Performance*, companion volume to the Compendium, where fuller technical treatment of the topic may be found. (See K. Boff, L. Kaufman, and J. Thomas, eds., *Handbook of Perception and Human Performance*. Vol. I: *Sensory Processes and Perception* and Vol. II: *Cognitive Processes and Performance*. New York: John Wiley and Sons, 1986).

### Other Text Reference Aids

Four other reference aids can also help you derive maximum benefit from the material and locate additional information on the topic of interest.

**1. Page headings.** Headings located at the top of entry pages help to pinpoint the relative position of the entry in the Compendium. At the top of the left page is the number and title of the topic area of which the entry is a part. At the top of the right page is the number and title of the section—the broad subject area under which the entry falls.

**2. Glossary terms.** Each major Compendium section contains its own Glossary, located on the third tabbed card following the section divider. An expanded, cumulative Glossary is also found in the *User's Guide*. All terms printed in bold type in the entry text are defined in the sectional glossaries. Some additional technical terms *not* boldfaced in the entries (for example, specialized measurement units, experimental methods, statistical terms) as well as common abbreviations are also defined in the sectional glossaries or in the cumulative Glossary.

**3. Text cross references.** Other Compendium entries dealing with a specific topic mentioned in the entry text may be referenced by number in the text body using the following type of notation:

(CRef. 3.216)

A full citation for the given cross-reference (number and title of the entry to which reference is made) can be found in the Cross References section at the end of the entry.

**4. Text reference citations.** Sources supporting a particular point or providing additional information may be cited by number in the body of the text, e.g.,

(Ref. 1)

Full bibliographic information for the reference source can be found in the citation of the same number in the Key References section at the end of the entry.

### Selective Search

The modular construction of the entry allows you to focus on the information of interest at a depth commensurate with your needs by selectively reviewing specific entry subsections. For example, the General Description section provides a concise summary of the information contained in the entry. In some cases, this summary alone may satisfy your need regarding the given topic. In other cases, you will wish to continue to other entry sections, such as the Experimental Results, that expand and deepen the discussion.

The Methods sections describing data-collection procedures is included for the benefit of those who require a more detailed examination of the experimental data for replication or analysis, or a close comparison of original testing conditions with the application environment. If you do not require this level of technical detail, you may skip this entry section. Similarly, the Key References and Cross References sections are provided for those who wish to pursue further the topic of the entry.

Topic area to which entry belongs

5.11 Adaptation of Space Perception

Entry number

5.1116 Adaptation to Visual Tilt: Acquisition and Decay

Entry title

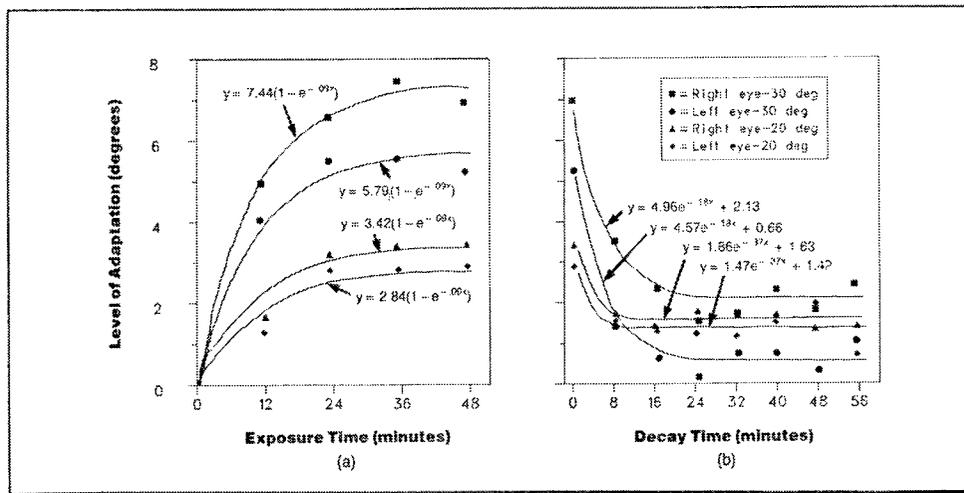


Figure 1. Mean level of adaptation to 30 and to 20 deg of optical tilt in the exposed (right) and unexposed (left) eye as a function of exposure time while prisms are worn, and decay time in the dark after prism removal. Adaptation is measured as the amount by which observers' postexposure verticality judgments depart from apparent vertical as measured before prism exposure. (From Ref. 2)

Terms related to entry topic

**Key Terms**

Altered visual orientation; interocular transfer; prismatic rotation; tilt adaptation; visual field rotation

Concise summary of entry topic

**General Description**

Observers who wear prisms that tilt the visual field adapt rapidly to the distortion. Tilt adaptation reaches a peak after 12-15 min of prism exposure and is higher for 30-deg than for 20-deg tilt rotation. When prisms are removed,

adaptation declines to a low level after 15 min in the dark. If only one eye is exposed to the rotating prisms, postexposure judgments of target verticality show adaptation effects regardless of which eye is tested—exposed or unexposed.

General and specific areas of application of entry content

**Applications**

Environments subject to optical distortion.

Methods used in collecting data presented

**Methods**

**Test Conditions**

• The observer's right eye covered by Dove prisms mounted in tandem and affixed by headset; left eye occluded  
• Prisms tilted visual field by 20 or 30 deg; visual field 10 deg in diameter

• During exposure period observer walked in hallway; observer wore black cloak that covered body and was instructed not to touch walls; after prism removal, observer sat in dark  
• Test stimulus: luminous vertical line 30-cm long by 0.4-cm wide; viewing distance 121.92 cm; tests made without prisms in dark room

**Experimental Procedure**

• Independent variables: magnitude of tilt, duration of exposure, time since prism removal, test eye (exposed versus covered)  
• Dependent variable: level of adaptation, defined as difference between mean pre-exposure and post-exposure verticality settings.

determined separately for exposed and unexposed eyes  
• Observer's task: set a luminous vertical line to upright position prior to, and at various times during and after adaptation  
• 16 observers, undergraduates, males and females, 8 tested at each tilt magnitude

Physical and psychophysical characteristics of stimulus, conditions for data collection

**Experimental Results**

• Adaptation to visual field rotation is significantly greater for 30-deg tilt (mean = 5.83 deg) than for 20-deg tilt (mean = 2.71 deg). (Mean scores are for both eyes combined.)

• Adaptation is greater in the exposed eye than in the unexposed eye, but the difference is significant only when the exposed eye is tested first.  
• Magnitude of adaptation to tilt levels off after ~ 12-15 min of prism exposure.

Major experimental findings and trends in the data, and their significance

1212

Bolf, K. R., & Lincoln, J. E. *Engineering Data Compendium: Human Perception and Performance*. AAMRL, Wright-Patterson AFB, OH, 1988

Experimental method and design, stimulus and response variables, subject's task, subject characteristics

Boldface type indicating term defined in Glossary

Major section of which entry is a part

**Spatial Awareness 5.0**

- Decay of adaptation is more rapid for 20-deg than for 30-deg tilt, i.e., for a smaller tilt. Decay reaches an asymptote after 8 min for 20-deg tilt, and after 16 min for 30-deg tilt.
- Decay is not complete for either tilt magnitude after 56 min in dark.
- The smoothed curves in Fig. 1a are negatively accelerated exponential growth functions of the form adaptation level =  $a(1 - e^{-bt})$ , where  $a$  is the estimated asymptote of adaptation and  $b$  estimates the rate at which adaptation approaches the asymptote as a function of exposure time  $t$ . Curves were fit by the method of least squares for both left (occluded) and right (exposed) eye.
- The smoothed curves in Fig. 1b are negatively decelerated exponential decay functions of the form adaptation level =  $ae^{-bt} + c$ , where  $a + c$  is the adaptation level at the beginning of the decay period.  $b$  estimates the rate of

**Variability**

Two subjects (one in each tilt magnitude group) failed to show at least 1 deg of adaptation after 48 min of exposure and were replaced. One observer showed unusually large negative values (anti-adaptive shift) in left eye during tests of decay.

**Repeatability/Comparison with Other Studies**

Difference in adaptation level for the two eyes found in this study is probably an experimental artifact due to the order in which the eyes were tested. Other studies have shown complete **interocular transfer** of tilt adaptation (Ref. 1).

**Constraints**

- Adaptation will decay completely (performance will return to preadaptation levels) if the observer is re-exposed to normal conditions.
- Even when prisms are not worn, viewing a physically tilted edge for a few minutes will lead to a small but reliable reduction in its perceived tilt.

**Key References**

1. Hajos, A., & Ritter, M. (1965). Experiments to the problem of interocular transfer. *Acta Psychologica*, 24, 81-90.

\*2. Rodding, G. (1975). Decay of visual adaptation to tilt and displacement. *Perception & Psychophysics*, 17, 203-208.

**Cross References**

5.1115 Factors affecting adaptation to visual tilt.

5.1117 Adaptation to visual tilt: effect of rotation magnitude.

*Handbook of perception and human performance*, Ch. 24, Sect 3.2

**1213**

Performance differences within and between subjects

Findings of other studies conducting similar research

Citation of source in Key References

Cross-reference to pertinent Compendium entry

Features or limitations of the data that affect their application

Sources of more detailed information on entry topic

Relevant sections of the Handbook of perception and human performance, edited by K. Boff, L. Kaufman & J. Thomas (NY: Wiley, 1986)

Compendium entries on related topics

Primary source of the data in this entry

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## Glossary

- Abduction.** The outward rotation of an eye away from the midline.
- Absolute threshold.** The amount of stimulus energy necessary to just detect the stimulus. Usually taken as the value associated with some specified probability of stimulus detection (typically 0.50 or 0.75).
- Acceleration magnitude.** Time rate of change of velocity, reflecting a change in either the speed or direction component of velocity.
- Accommodation.** A change in the thickness of the lens of the eye (which changes the eye's focal length) to bring the image of an object into proper focus on the retina. (CRef. 1.222)
- Achromatic.** (1) Characterized by an absence of chroma or color. (2) In optics, corrected to have the same focal length for two selected wavelengths.
- Acoustic reflex.** Contraction of two small muscles attached to the conducting bones of the middle ear in response to a high-intensity sound; the contraction dampens sound pressure by increasing acoustic impedance and serves to protect the ear from damage by very loud sound. (CRef. 2.202)
- Active movement.** Movement of a limb or body part by the individual under his or her own volition.
- Adaptation.** (1) A change in the sensitivity of a sensory organ to adjust to the intensity or quality of stimulation prevailing at a given time (also called **sensory adaptation**); adaptation may occur as an increase in sensitivity (as in dark adaptation of the retina) or as a decrease in sensitivity with continued exposure to a constant stimulus. (2) A semipermanent change in perception or perceptual-motor coordination that serves to reduce or eliminate a registered discrepancy between or within sensory modalities or the errors induced by this discrepancy (also called **perceptual adaptation**). (CRef. 5.1101)
- Adaptometer.** An instrument for determining the amount of retinal adaptation or the time course of adaptation by measuring changes in the observer's threshold for light. Adaptometers are most frequently designed to measure dark adaptation.
- Afferent.** Conveying neural impulses toward the central nervous system, as a sensory neuron; sensory, rather than motor.
- Alpha wave.** Oscillations in the electrical potential of the cortex of the brain that have a frequency of 6-14 Hz and characteristically occur when the individual is awake and relaxed. The waves are generally measured between one electrode taped to the scalp on the back of the head and another, more distant electrode attached, e.g., to the mastoid.
- Alveolar.** Articulated with the tip of the tongue placed against part or all of the ridge behind the upper teeth (as in [t], [s], [n]).
- Amblyopia.** Low or reduced visual acuity not correctable by refractive means and not attributable to detectable structural or pathological defects. Clinically judged present if Snellen acuity is 20/30 or worse after refractive correction, or if acuity is significantly less in one eye than in the other.
- Amplitude modulation.** Modulation of the amplitude of a (usually) constant-frequency carrier in accordance with the strength of a second signal, generally of much lower frequency than the carrier; AM radio utilizes amplitude modulation.
- Analysis of variance.** A statistical test in which the variance (average squared deviation from the mean) among scores within experimental groups is compared with the variance among means across groups to assess whether the means of the experimental groups are significantly different from one another.
- Anechoic room.** A room in which all surfaces are covered by large wedges of sound-absorbing material to minimize reflections and provide an essentially echo-free or free-field environment.
- Aqueous humor.** The clear, watery fluid that fills the front chamber of the eye (the space between the cornea and the crystalline lens) and supplies oxygen and nutrients to the cornea and lens. (CRef. 1.201)
- Arousal.** Increased attention to and awareness of the environment, rendering the organism better prepared for mental or physical action.
- Articulator.** A moveable organ such as the tongue, lips, or uvula, that is used in the production of speech.
- Artificial pupil.** An aperture (smaller than the eye pupil in diameter) in a disc or diaphragm mounted in front of the eye and used to control the amount of light entering the eye. A small artificial pupil (2 mm) provides the eye with a virtually infinite depth of field.
- Astigmatism.** In the eye, refractive error due to unequal refraction of light in different meridians, caused by nonuniform curvature of the optical surfaces of the eye, especially the cornea. (CRef. 1.201)
- Asymmetric convergence.** Fixation on a target to one side rather than directly ahead of the observer. (CRef. 1.808)
- Atlanto-occipital joint.** A joint in the vertebral column at the juncture of the first cervical vertebra and the posterior part of the skull; permits flexion, extension, and lateral flexion of the head.
- Attention operating characteristic.** A curve showing how performance on one task varies as a function of performance on a second task when the two are carried out concurrently and the allocation of attention between the two tasks is varied; that is, a performance trade-off function describing the improvement in the performance on one task due to any added resources released by lowering the level of performance on (by decreasing the level of attention to) another task with which it is time-shared.
- Backward masking.** Masking in which the masking stimulus occurs after the test stimulus. (See **masking**.)
- Bang-bang control.** System control in which the operator moves the control stick rapidly from maximum deflection in one direction to maximum deflection in the opposite direction in a series of motions timed to bring the error to zero in a minimum time; used only when time constants are long or in acceleration (second-order) control systems (i.e., when the system is sluggish in responding to a control input). (CRef. 9.524)

- Basocentric axes.** Axes with an origin in the contacting surface through which vibration is transmitted to the body.
- Beats.** Periodic fluctuations in amplitude produced by the superposition of sound waves of slightly different frequencies.
- Békésy tracking procedure.** A procedure for measuring auditory thresholds in which the listener presses a switch to reduce the signal level as long as the signal is heard and releases it to increase the signal level when the signal becomes inaudible. When the procedure is continued over several minutes, a zigzag pattern of increasing and decreasing signal levels is produced on a chart recorder designed for the purpose. Threshold is usually calculated as the average of the median points between successive peaks and valleys in this pattern.
- $\beta$ .** In signal detection analysis, the index of response bias representing the ratio of the height (ordinate) of the signal-plus-noise distribution to the height of the noise distribution. In practice,  $\beta$  may be derived from the hit and false alarm rates. (CRef. 7.420)
- Between-subjects design.** An experimental design in which each subject or group of subjects is tested under only one level of an independent variable. The performance of the difference groups is then compared to assess the effect of the experimental manipulation.
- Bimodal.** Pertaining to, affecting, or impinging simultaneously upon two sensory modalities (such as vision and touch).
- Binaural.** Pertaining to, affecting, or impinging upon both ears; sometimes used to imply identity of the signals to the two ears. (*See also* **diotic**; **dichotic**.)
- Binocular.** (1) Pertaining to, affecting, or impinging upon both eyes; sometimes used to imply the identity of both eyes' views (*see also* **dichoptic**). (2) Employing both eyes at once, with each eye's view contributing to the final percept.
- Binocular disparity.** *See* **lateral retinal image disparity**.
- Binocular suppression.** Decrease or loss of visibility of a portion or all of one eye's view due to stimulation of the same portion of the other eye. Binocular suppression is most clearly demonstrated when the two eyes are presented with conflicting information (such as different colors or different orientation of contours) in corresponding parts of the retinas. (CRef. 1.804)
- Blackbody radiator.** An ideal surface that completely absorbs all radiant energy of any wavelength incident upon it (and therefore appears black) and emits radiant energy of a spectral distribution that varies with absolute temperature according to Planck's radiation formula; also known as a **Planckian radiator** or an **ideal radiator**. (CRef. 1.107)
- Blackbody source.** *See* **blackbody radiator**.
- Blind spot.** The region of the retina where the optic nerve exits the eye; this region contains no visual receptors and is therefore insensitive to light; also known as the optic disc.
- Bloch's law.** A law stating that, for brief targets (less than  $\sim 100$  msec), the threshold intensity for detecting a target varies inversely with exposure duration; i.e.,  $I = k/T$ , where  $I$  is the light intensity of the target,  $T$  is exposure duration, and  $k$  is a constant. In other words, target lights with equal energy (or equal numbers of quanta) are equally detectable ( $I \times T = k$ ).
- Blocked design.** An experimental design in which only one value (or set of values) of the experimental variable(s) is tested in each group or block of trials to reduce uncertainty and maximize the subject's performance.
- Bode plot.** A plot in rectangular coordinates showing the magnitude of the input-output ratio of a system (in decibels) and the magnitude of the phase lag as a function of the logarithm of frequency.
- Brain potential.** Electrical voltage generated by the activity of nerve cells in the brain, usually measured from electrodes placed on the scalp or in contact with brain cells.
- Brightness.** The subjective attribute of light sensation by which a stimulus appears to be more or less intense or to emit more or less light. Brightness can range from very bright (brilliant) to very dim (dark). In popular usage, brightness implies higher light intensities, dimness the lower intensities.
- Brightness induction.** *See* **induction**.
- C.** Celsius (formerly **Centigrade**).
- Candela (cd).** A unit of luminous intensity equal to the luminous intensity in a direction perpendicular to the surface of  $1/60$  of 1 square centimeter of a blackbody radiator at the solidification temperature of platinum. Sometimes also called **candle** or **new candle**.
- cd.** Candela.
- cd/m<sup>2</sup>.** Candelas per square meter, a unit for measuring luminance;  $1 \text{ cd/m}^2 = 0.292 \text{ fL} = 0.314 \text{ mL}$ . (*See also* **candela**.)
- Choice reaction time.** The time from the onset of a stimulus to the beginning of the subject's response to the stimulus in conditions where there is more than one stimulus alternative and more than one response alternative. (CRef. 9.101)
- Chroma.** (1) The attribute of color perception representing the degree to which a chromatic color differs from an achromatic (gray) color of the same lightness. (2) The dimension of the Munsell color system corresponding most closely to saturation.
- Chromatic.** Having hue; colored; i.e., appearing different in quality from a neutral gray of the same lightness value.
- Chromatic aberration.** Image degradation in an optical system resulting from unequal refraction of light of different wavelengths; commonly manifested in simple optical systems as colored fringes on the border of an image. (CRef. 1.212)
- Chromatic induction.** *See* **induction**.
- Chromaticity.** The quality of a color characterized by dominant or complementary wavelength (hue) and purity (saturation) but not brightness or lightness.
- Chromaticity coordinates.** The proportions of each of the three standard primaries required to match a given color, expressed as the ratio of the amount of one primary to the total amount of all three. The chromaticity coordinates are designated as  $x$ ,  $y$ , and  $z$  in the colorimetric system of the CIE (Commission Internationale de l'Eclairage).
- Chromaticity diagram.** The two-dimensional diagram produced by plotting two of the three chromaticity coordinates ( $x$ ,  $y$ ,  $z$ ) against one another. The most widely used is the ( $x$ ,  $y$ ) diagram of the CIE (Commission Internationale de l'Eclairage), plotted in rectangular coordinates. (CRef. 1.722)
- CIE.** Commission Internationale de l'Eclairage (International Commission on Illumination), an international organization devoted to the study and advancement of the science of illumination; the commission has developed a number of international standards in photometry and colorimetry.

- CIE observer.** A hypothetical observer with standard color vision defined by the color-matching behavior embodied in the RGB and XYZ systems of the CIE (Commission Internationale de l'Éclairage).
- Circularvection.** Illusory self-rotation induced by rotating scenes.
- Closed loop.** A system in which the output (or some function of the output) is fed back and used to manipulate an input quantity so as to stabilize the system or achieve the desired control. Closed-loop systems are frequently called feedback control systems. (CRef. 9.506)
- Closure.** Perception of a series of pattern elements as a single large unit rather than a number of apparently unrelated parts. (CRef. 6.301)
- cm.** Centimeter, a unit for measuring length; 1 cm = 10 mm.
- Color assimilation.** A form of chromatic induction in which the difference between adjacent colors diminishes and it appears as though the color of one field spreads into and combines with the color of another field. Also known as Bezold spreading effect. (CRef. 1.718)
- Color temperature.** The temperature of a blackbody radiator (in degrees Kelvin) that has the same chromaticity as a given color sample or source. (CRef. 1.107)
- Color wheel.** A colored disk consisting of two or more disks of different colors cut along a single radius, then interleaved and overlapped to provide any desired ratio of exposure; the composite disk is rotated rapidly to produce a perceptual mixture of the colors.
- Colorimetric purity.** The ratio of the luminance of the spectrally pure component of a mixture to the luminance of the mixture itself. (CRef. 1.703)
- Combination tone.** A secondary tone not present in the stimulus that is heard when two primary tones of widely differing frequencies are presented simultaneously and that is thought to be due to nonlinearity in the response of the human auditory system to sound waves. Combination tones are heard at frequencies that represent the sum and differences of the frequencies of the two primary tones, or the harmonics of the primary tones. They may also occur at frequencies that bear a more complex relation to the primary-tone frequencies.
- Command input.** The motivating input signal to the system. An ideal tracking system will perfectly follow the command input.
- Comparison stimulus.** A variable stimulus presented along with a fixed or standard stimulus in an experiment designed to determine the difference threshold or just noticeable difference between the two. The value of the comparison stimulus is varied along a given dimension, while the value of the standard remains fixed, and the subject must indicate the relation between the two (e.g., the comparison is "greater than," "less than," or "equal to" the standard).
- Compensatory display.** A display that shows the direction and magnitude of tracking error, but not the position of the input or system response independently of each other. (CRef. 9.528)
- Compensatory tracking.** Tracking in which the operator's display shows only the direction and magnitude of tracking error and does not independently present the command input and system position. The task is to compensate (correct) error.
- Complementary wavelength.** The wavelength designated by the point on the spectrum locus of a chromaticity diagram that lies on the opposite side of the achromatic point, in a straight line with the wavelength in question; i.e., the wavelength that, when mixed with the wavelength in question, yields white.
- Complex conjugate.** A quantity that has the same real part as a secondary quantity but an imaginary part with the opposite sign; e.g.,  $a - ib$  is the complex conjugate of  $a + ib$ , where  $i = \sqrt{-1}$ .
- Complex sound.** A sound comprising more than one frequency, i.e., a sound that is not a pure sine wave.
- Compound task.** The combining of two or more component tasks in such a way that each trial consists of a single stimulus drawn randomly from one of the component tasks and a response drawn from one of the component tasks.
- Conditioning (classical).** Learning in which a neutral stimulus comes to elicit a given response after being paired repeatedly with a second stimulus that previously elicited the response.
- Cone.** A cone-shaped photoreceptor in the retina of the eye; cones are the only receptors in the fovea and their density falls off rapidly with distance from the fovea. Cones function only at photopic (daylight) levels of illumination; they are responsible for color vision and fine visual resolution. (CRefs. 1.201, 1.301)
- Conjoint scaling.** A technique that enables several variables to be combined such that the order of their joint effects is preserved by a composition rule (e.g., an additive rule) resulting from various axiom tests (e.g., transitivity, cancellation) specified by conjoint measurement theory. Conjoint scaling procedures are applied subsequent to the axiom testing, and specify actual numerical scale values for the joint effects that fit the combination rule derived from the conjoint measurement technique. When an additive combination rule is specified by the axiom tests, a number of scaling procedures can be applied to seek interval-scaled values for level of the variables based on the ordinal constraints imposed by the data.
- Contactactor.** In studies of cutaneous sensitivity, a device that generates vibrotactile stimulation by moving alternately against and away from the skin by force transmitted to it from an electromechanical vibrator. (CRef. 3.105)
- Contralateral.** Pertaining to, occurring on, or acting in conjunction with a similar part on the opposite side of the body.
- Contrast.** The difference in luminance between two areas. In the research literature, contrast is expressed mathematically in several nonequivalent ways (CRef. 1.601). (See also **contrast ratio**; **Michelson contrast**.)
- Contrast attenuation.** A reduction in contrast. Divided attention. A task environment in which the observer or operator must attend to two or more stimuli, input channels, or mental operations that are active simultaneously, and must respond appropriately to each.
- Contrast ratio.** A mathematical expression for contrast (luminance difference between two areas); defined in this way, the contrast of one area with respect to a second is given as  $L_1/L_2$ , or as  $(L_2 - L_1)/L_2$ , where  $L_1$  is the luminance of the first area and  $L_2$  is the luminance of the second area. (CRef. 1.601)
- Contrast sensitivity.** The ability to perceive a lightness or brightness difference between two areas; generally measured as the reciprocal of the contrast threshold. Contrast sensitivity is frequently measured for a range of target patterns differing in value along some dimension such as pattern element size and portrayed graphically in a contrast sensitivity function in which the reciprocal

- of contrast threshold is plotted against pattern spatial frequency or against visual angle subtended at the eye by pattern elements (such as bars).
- Contrast threshold.** The contrast associated with the minimum perceptible difference in luminance between two areas, often measured in terms of the luminance difference detectable on some specified proportion of trials (generally 0.50).
- Control condition.** In experimental design, the no-treatment condition; subjects are not exposed to any experimental manipulation.
- Control/display ratio.** For continuous control, the ratio of the movement distance of the control device to the movement distance of the display indicator (i.e., pointer or cursor).
- Convergence.** An inward rotation of the eyes to fixate on a point nearer the observer. (CRef. 1.808)
- Convergence angle.** The angle formed between the lines of sight of the two eyes when the eyes are fixated on a point in space. (CRef. 1.808)
- Convergent disparity.** Lateral retinal image disparity associated with a point in the visual field that is closer than the fixation point; also known as crossed disparity. By convention, convergent disparity is given a negative value when expressed in terms of visual angle.
- Convergent lateral retinal disparity.** *See* convergent disparity.
- Cooper-Harper Aircraft-Handling Characteristics Scale.** A widely used rating procedure designed for use by test pilots in evaluating aircraft ease of control. Although the scale deals primarily with aircraft handling, several empirical studies have demonstrated a relation between scale ratings and subjective workload.
- Cornea.** The transparent structure forming the front part of the fibrous coat of the eyeball and covering the iris and pupil. (CRef. 1.201)
- Corollary discharge.** That component of an internally generated command (outflow) signal (such as a signal to move the eyes) that is theoretically used for comparison with the inflowing sensory signal in determining perception.
- Course frequency.** *See* input frequency.
- Crest factor.** The ratio of the frequency-weighted peak of vibration acceleration to the frequency-weighted root mean square acceleration; indicates the importance of the peak values in a motion.
- Critical band.** That frequency bandwidth at which the subjective response to a sound changes abruptly; as measured by loudness, it is the frequency band within which the loudness of a sound of constant total sound pressure remains unaffected by the bandwidth of the sound; as measured by masking, it is the frequency band within which varying the bandwidth of narrow-band masking noise of constant power density does not affect the threshold for a pure tone located at the center frequency of the noise band.
- Critical flicker frequency.** The modulation frequency of an intermittently illuminated target at which the target ceases to appear flickering and appears steady.
- Cross-modality matching.** A procedure in which the subject adjusts the magnitude of a stimulus in one sensory modality to match the apparent magnitude of a stimulus in a different modality. For example, the loudness of a tone might be adjusted until it seems equal in magnitude to the brightness of a light.
- Cutaneous.** Pertaining to the skin or receptors in the skin, or to sensation mediated by receptors in the skin.
- Cyclofusional eye movements.** Disjunctive rotational eye movements around a horizontal axis through the pupil; such movements are generally made to bring differentially rotated left and right images into alignment on the two retinas.
- d'.** In signal detection analysis, a statistical measure of the subject's sensitivity (or signal strength) that estimates the psychological distance between the mean of the noise distribution and the mean of the signal-plus-noise distribution. In practice, d' can be calculated from the hit and false alarm rates. (CRef. 7.420)
- Dark adaptation.** Adjustment of the eye to low levels of illumination which results in increased sensitivity to light.
- Dark focus.** The distance to which the eye is focused in the dark.
- dB.** Decibel, a unit for expressing the ratio of two powers used mainly in acoustics and telecommunication. (*See* decibel.)
- dB(A).** The relative sound pressure level of a sound in decibels measured using the A weighting network of a sound level meter. (CRef. 2.104)
- Decibel (dB).** (1) In audition, the standard unit used to express the ratio of the power levels or pressure levels of two acoustic signals. For power, one decibel =  $10 \log P_1/P_2$  (where  $P_1$  and  $P_2$  are the powers of the first and second signals, respectively). For pressure, one decibel =  $20 \log p_1/p_2$  (where  $p_1$  and  $p_2$  are the sound pressure levels of the two signals). In most applications, the power or pressure of a signal is expressed relative to a reference value of  $P_2 = 10^{-12} \text{ W/m}^2$  for power and  $p_2 = 20 \text{ } \mu\text{Pa}$  (or  $0.0002 \text{ dynes/cm}^2$ ) for pressure. (2) In vision, the decibel is sometimes used to express the ratio between two stimulus magnitudes, such as the threshold luminance contrast for a given target under two different experimental conditions. One decibel is taken to be  $10 \log I_1/I_2$  (where  $I_1$  and  $I_2$  are the magnitudes of the two stimuli). (3) In cutaneous studies, the decibel is sometimes used to denote the ratio between two stimulus intensities and is taken to be  $20 \log I_1/I_2$  (where  $I_1$  and  $I_2$  are the intensities of the two stimuli in the dimensions of force, amplitude of displacement, or pressure).
- Dependent variable.** The response to a stimulus presentation measured by the investigator to assess the effect of an experimental treatment or independent variable in an experiment; for example, the investigator might measure the auditory threshold (dependent variable) for several tones that differ in sound frequency (independent variable). (*Compare* independent variable.)
- Describing function.** An engineering-mathematical description of a nonlinear system element as an equivalent element in which the relationships between some, but not necessarily all, pertinent measures of the input and output signals have "linear-like" features despite the presence of nonlinearities. This approach leads to a quasi-linear characterization of nonlinear elements that can be approximated by an equivalent linear element (the describing function) plus an additional quantity called the remnant.
- Detection threshold.** *See* absolute threshold; threshold.
- Dichoptic.** Referring to viewing conditions in which the visual displays to the right and left eyes are not identical but differ with respect to some property (such as luminance or placement of contours).
- Dichotic.** Pertaining to listening conditions in which the sound stimulus to the left and right ears is not identical but differs with respect to some property (such as frequency or phase).

**Difference threshold.** The least amount by which two stimuli must differ along some dimension (such as sound pressure level or luminance) to be judged as nonidentical. Usually taken as the difference value associated with some specified probability of detecting a difference (typically 0.50 or 0.75).

**Diopter.** (1) A measurement unit expressing the refractive power of a lens and equal to the reciprocal of the focal length in meters. (2) A measurement unit expressing the vergence of a bundle of light rays equal to the reciprocal of the distance to the point of intersection of the rays in meters (taking a positive value for diverging rays and a negative value for the converging rays); the unit is often used to express the distance to an object being viewed, since it indicates the amount of eye accommodation necessary to bring the object into proper focus on the retina. (3) A measurement unit expressing the strength of a prism and equal to 100 times the tangent of the angle through which light rays are bent (generally called prism diopter).

**Diotic.** Pertaining to listening conditions in which the sound stimulus to both ears is identical.

**Diphthong.** A gliding, monosyllabic vowel sound that undergoes a shift in vowel quality from start to finish, such as the vowel combination at the end of the word "boy".

**Diplacusis binauralis.** A condition in which a tone of given frequency is perceived as having a different pitch in the left and right ears; most normal listeners show at least some degree of diplacusis.

**Diplopia.** See **double vision**.

**Distal.** Away from the point of attachment or origin; e.g., the finger is distal to the wrist. (*Compare proximal.*)

**Disturbance input.** An undesired input signal that affects the value of the controlled output. In manual control, a signal arising from sources other than the operator's input or the command input track to be followed that affects the controlled output (e.g., turbulence or wind shear acting on an aircraft).

**Divergence.** An outward rotation of the eyes to focus on a point further from the observer.

**Divergent disparity.** Lateral retinal image disparity associated with a point in the visual field that is further than the fixation point; also known as uncrossed disparity. By convention, divergent disparity is given a positive value when expressed in terms of visual angle.

**Divergent lateral retinal disparity.** See **divergent disparity**.

**Dominant wavelength.** The spectral wavelength that will match a given sample of color when mixed with a suitable proportion of white and adjusted appropriately in intensity.

**Dorsal.** Pertaining to the back or denoting a position toward the back surface; also, on the limbs, the side opposite the palm or sole.

**Double vision.** A condition in which a single object appears as double because the images of the object in the left and right eyes do not fall on corresponding portions of the retinas; also called **diplopia**.

**Dove prism.** A prism such as that invented by J. W. Dove with two slanted faces and a mirrored base. A ray entering parallel to the base is refracted, then internally reflected, and then refracted again, emerging parallel to its incident direction. When the prism is rotated about its longitudinal axis, the image formed rotates through twice the angle of the prism rotation. (CRef. 5.1102)

**Dwell time.** The length of time the eye is fixated on a given point.

**Dynamometer.** An instrument for measuring the force exerted by muscular contraction.

**Dyne.** The force that will accelerate 1 gram by 1 cm/sec<sup>2</sup>.

**Effective pilot time delay.** Time delay due to processing of sensory information by the pilot.

**Efferent.** Conveying neural impulses away from the central nervous system, as a motor neuron serving a muscle or gland; motor, rather than sensory.

**Electrocutaneous.** Pertaining to electrical stimulation of the skin.

**Electroencephalogram.** A graphic recording of changing electrical potentials due to the activity of the cerebral cortex, measured from electrodes located on the scalp.

**Electromyography.** The recording and study of the electrical properties of the skeletal muscles.

**Electro-oculography.** The recording and study of the changes in electrical potential across the front and back of the eyeball that occur during eye movements; generally measured using two electrodes placed on the skin at either side of the eye. The electrical potential is a function of eye position, and changes in the potential are caused by changes in the alignment of the resting potential of the eye with references to the electrodes.

**Emmetropia.** Optically normal vision; i.e., the refractive condition of the normal eye in which an object at infinity is brought accurately to a focus on the retina when accommodation is relaxed. (*Compare farsightedness; nearsightedness.*)

**Entrance pupil.** The image of the aperture stop formed by the portion of an optical system on the object side of the stop. The dark aperture seen when looking into a person's eye is the entrance pupil of the eye, which is larger and closer to the cornea than the real pupil.

**Equalization.** In control system design, the introduction of compensatory lead (prediction) and/or lag (smoothing) elements to achieve desired system response and stability.

**Ergograph.** An instrument for recording the amount of work done by muscular exertion.

**Esophoria.** A tendency for one or both eyes to turn inward in the absence of adequate fusion contours. (CRef. 1.809)

**Exophoria.** A tendency for one or both eyes to turn outward in the absence of adequate fusion contours. (CRef. 1.809)

**Extended source.** A light source that, unlike a point source, subtends a non-zero angle at the observer's eye. In practice, considered to be any source whose size is larger than one-tenth the distance from the observer to the source.

**Extorsion.** Cyclorotational eye movements away from the midline; from the observer's viewpoint, the right eye rotates clockwise and the left eye counterclockwise. Extorsion usually occurs in response to orientation disparity between the right and left eyes' views.

**F. Fahrenheit.**

**Factorial design.** An experimental design in which every level or state of each independent variable is presented in combination with every level or state of every other independent variable.

**False alarm.** In a detection task, a response of "signal present" when no signal occurred.

**Farsightedness.** An error of refraction in which parallel rays of light from an object at infinity are brought to a focus behind the retina when accommodation is relaxed. In some individuals with this condition, accommodative power may be sufficient to achieve good focus of objects at all distances; others may require corrective lenses to achieve proper focus of very near objects. Also known as hyperopia or hypermetropia. (CRef. 1.204)

**Fatigue-decreased proficiency boundary.** One of a series of boundaries defined in International Standard 2631 (1978). Exceeding this boundary for one minute is said to carry a significant risk of impaired working efficiency in many kinds of tasks, particularly those in which time-dependent effects are known to worsen performance as, for example, in vehicle driving.

**fc.** Footcandle, a unit for measuring illuminance; 1 fc = 10.76 lx. (See **footcandle**.)

**Feedback.** In a closed-loop system, the return of a part of the output of the system or mechanism to the input, so that dynamic response is made to the difference between input and output (i.e., the discrepancy between intended and actual operation) rather than to the input itself.

**Feedback loop.** See **feedback**.

**First-order control.** A system in which the response is proportional to the first time integral of the control input; also known as velocity control.

**First-order dynamics.** See **first-order control**.

**First-order system.** See **first-order control**.

**Fixation disparity.** Convergence of the eyes to a plane in front of or behind the intended plane of fixation.

**Fixation distance.** The distance to which the eyes are converged.

**Fixation point.** The point in space toward which one or both eyes are aimed. In normal vision, the image of the fixation point falls on the fovea.

**fL.** Foot lambert, a unit for measuring luminance; 1 fL = 3.426 cd/m<sup>2</sup> = 1.076 mL. (See **foot lambert**.)

**Foot candle (fc).** The illuminance of a surface 1 foot from a point source of light of one international candle and equal to 1 lumen/ft<sup>2</sup>; 1 foot candle = 10.764 lux.

**Foot lambert (fL).** A unit of luminous intensity equal to the luminance of a surface that emits or reflects 1 lumen/ft<sup>2</sup>; 1 fL = 3.426 cd/m<sup>2</sup> = 1.076 mL.

**Formant.** One of several bands of frequencies apparent in the spectrum of a vowel sound that are associated with resonance of the vocal tract and determine the phonetic quality of the vowel.

**Fourier analysis.** The representation of a complex periodic waveform as the superposition of a series of single sinusoidal components according to Fourier's theory.

**Fovea.** A pit in the center of the retina (approximately 1-2 deg of visual angle in diameter) where the density of cones is highest and visual acuity is greatest.

**Frame.** (1) In CRT displays, one complete scan of the image area by the electron beam. (2) In motion-picture film, a single image of the connected multiple images.

**F-ratio.** A ratio between the variances (average squared deviations from the means) of two samples calculated to determine if two different distributions have been sampled.

**Free field.** A sound field in free space produced by a source that is far enough away from all objects so that they cause no reflections or other disturbances to it.

**Frequency domain specifications.** For dynamic systems, expression of important system properties (i.e., speed of response, relative stability, and system accuracy or allowable error) as functions of frequency.

**Fricative.** A consonant produced by frictional passage of air moving through a narrowing at some point in the vocal tract; it may be either voiced (as in [v] and [z]) or voiceless (as in [f] and [s]).

**Frontal plane.** The plane passing vertically through the body from side to side, perpendicular to the medial plane and dividing the body into front and back, or any plane parallel to this plane.

**Functional stretch reflex.** A reflexive contraction of the leg muscles in response to passive longitudinal stretching that aids in maintaining postural stability.

**Fundamental frequency.** For a complex periodic waveform, the repetition rate of the waveform; i.e., the harmonic component that has the lowest frequency (and usually the greatest amplitude). Also called **first harmonic**.

**Gain.** The ratio of output to input in a system; typically employed to specify, for example, the relation between control movement and display movement or system response. In the human describing function, it may also describe the relation between perceived error and controlled response.

**Ganzfeld (uniform field).** A uniformly lit, homogeneous, structureless visual field; no surface is seen, just a fog that appears to fill the space. (CRef. 1.239)

**Gaussian distribution.** A probability density function that approximates the frequency distribution of many random variables in biological or other data (such as the proportion of outcomes taking a particular value in a large number of independent repetitions of an experiment where the probabilities remain constant from trial to trial).

The distribution is symmetrical, with the greatest probability densities for values near the mean and decreasing densities at both larger and smaller values, and has the form

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

where  $f(x)$  is the probability density for the value  $x$  in the distribution,  $\mu$  is the mean value, and  $\sigma$  is the standard deviation. Also called normal distribution or normal probability distribution.

**Gaussian noise.** Noise that is the result of random processes and whose spectral level (power density) is uniform over the frequency band where it occurs; also called white noise.

**Glide.** A speech sound generally classified as between a vowel and a consonant, which is produced by movement or gliding to or from an articulatory position to an adjacent sound (generally a vowel); in English, the glides include /w/ and /y/ and, in some classification systems, /l/ and /r/.

**gm.** Gram, a unit of mass; 1 gm = 10<sup>-3</sup> kg = 0.0352 oz.

**Go/no-go reaction.** A reaction time task in which the subject must respond ("go") when a given stimulus is presented but must not respond ("no go") on trials on which any other (or no) stimulus occurs.

**Half-field.** The view of one eye only; most commonly used to refer to one of the two parts of a stereogram.

**Haploscope.** A stereoscope in which the arms holding the displays for the left and right eyes can be rotated to produce a wide range of symmetric and asymmetric convergence angles.

**Haptic.** Pertaining to or arising from tactual perception based on both cutaneous and kinesthetic information.

**Haversine pulse.** A single cycle of a sine wave, the zero axis of which is shifted to the minimum value to yield the appearance of a unidirectional displacement.

**Head-down display.** A display located on the control panel of a cockpit or some other location that requires downward movement of the head to locate information. In contrast, a head-up display puts the most important display information where it can be seen with the head up, as on the windshield or helmet visor.

- Head-up display.** A display in which information is viewed superimposed on the outside world (as by displaying on a windscreen or visor) so that the information can be read with the head erect and with the outside world always in the field of view.
- Hearing threshold level.** The amount (in decibels) by which the level of a sound exceeds the average threshold of audibility of normal listeners as established in national and international standards.
- Hertz (Hz).** A unit of frequency equal to 1 cycle/sec.
- Heterochromatic brightness matching.** A procedure in which a fixed-radiance reference light of known luminance is presented adjacent to a comparison field with a different wavelength composition. The observer adjusts the radiance of the comparison field until both appear of equivalent brightness. The procedure is used to measure relative sensitivity to light of different wavelengths. (CRef. 1.109)
- Heterochromatic flicker photometry.** A procedure in which a reference light of fixed luminance is alternated in time with a coextensive comparison light with a different wavelength composition. The observer adjusts the radiance of the comparison light to eliminate or minimize the sensation of flicker. The procedure is used to measure relative sensitivity to light of different wavelengths. (CRef. 1.109)
- Heteromodal.** Pertaining to or affecting more than one sensory modality.
- Homatropine.** An alkaloid (oxytoluyl-tropeine) applied topically to the eye to dilate the pupil and paralyze eye accommodation.
- Homograph.** A word identical in spelling with another, but different in origin, pronunciation, or meaning.
- Horizontal axis of Helmholtz.** In representing eye position, the horizontal axis connecting the centers of rotation of the two eyes; eye elevation is specified in terms of rotation about this axis.
- Horizontal disparity.** See lateral retinal image disparity.
- Huddleston font.** A display font developed by H. F. Huddleston; based on the ASCII font, with certain arms of letters widened to make the letters more distinguishable.
- Hz.** Hertz, a unit of frequency equal to 1 cycle/sec.
- Ideal radiator.** See blackbody radiator.
- Illuminance.** The luminous flux incident per unit area of a surface at any given point on the surface. The most commonly used units of measurement are lux (lumens per m<sup>2</sup>) and foot candles (fc, or lumens/ft<sup>2</sup>). (CRef. 1.104)
- Increment threshold.** See difference threshold.
- Independent variable.** The aspect of a stimulus or experimental environment that is varied systematically by the investigator to determine its effect on some other variable (i.e., the subject's response). For example, the investigator might systematically alter the frequency of a tone (independent variable) to assess the effect of these changes on the observer's auditory threshold (dependent variable). (Compare dependent variable.)
- Induced effect.** In stereoscopic vision, apparent tilting of the visual field about the vertical axis caused by vertical magnification differences between the left and right eyes' views. The magnitude and direction of perceived tilt depend on which eye's image has greater magnification, as well as on the amount of magnification difference between right and left eyes, viewing distance, and interpupillary separation. (CRef. 5.909)
- Inducing field.** The portion of the visual field acting on and modifying the perception of another portion of the visual field (the induced field or test field).
- Induction.** Alteration of perception by indirect stimulation. Lightness or brightness induction is the alteration of the perceived lightness or brightness of a given area due to the presence of a nearby area of different lightness or brightness. Chromatic or color induction is the alteration of the perceived hue of a colored area due to the presence of a nearby area with differing chromaticity.
- Inferior oblique muscle.** One of the six voluntary muscles that move the eyeball. (CRef. 1.901)
- Infradian.** Pertaining to a rhythm with a period considerably longer than 24 hours.
- Innervation.** The distribution or supply of nerves to a body part.
- Input frequency.** The frequency of the changes a system is supposed to follow; the frequency of the forcing function or desired path when only one frequency (a pure sine wave) is present.
- Inside-out display.** A display (as of aircraft attitude) that uses the vehicle as a frame of reference, so that the display reflects the way the environment appears to the operator inside the vehicle looking out. For example, when the aircraft banks, the horizon in the attitude display tilts. (Compare outside-in display.) (CRef. 9.529)
- Integrated error.** Tracking error that is summed over the tracking task.
- Interaural phase.** The relative phase of a tone in the left and right ears, generally taken to imply a time in the mechanical activity of the middle ear.
- Intermanual transfer.** Transfer of the change in performance due to practice or exposure from one hand or limb to the other.
- Interocular transfer.** Transfer of the change in performance due to practice or exposure from one eye to the other.
- Interphalangeal.** Situated between two contiguous joints of the fingers or toes.
- Interpupillary distance.** The distance between the centers of the pupils of the eyes when the eyes are parallel (converged to optical infinity); also known as interocular distance. (CRef. 1.208)
- Interstimulus-onset interval.** The time between the onset of one stimulus and the onset of a second stimulus. Also called stimulus-onset interval.
- Intervocalic.** Occurring between vowels. Labial. Articulated using one or both lips (as in [b], [w]); sounds articulated using both lips are frequently termed bilabial.
- Intorsion.** Cyclorotational eye movements toward the midline; from the point of view of the observer, the right eye rotates counterclockwise and the left, clockwise. It usually occurs in response to orientation disparity between the right and left eyes' views.
- Intra-modal matching.** A procedure in which the subject matches the magnitude of a stimulus along some dimension with the magnitude of another stimulus in the same sensory modality that is presented as a standard. (Compare cross-modal matching.)
- Inverse power function.** An exponential function with a negative exponent, e.g.,  $x^{-2}$  or  $1/x^2$ .
- Inverse square law.** (1) A law stating that the illuminance or irradiance from a point source varies as the inverse square of the distance from the source to the observer. (2) A law stating that the intensity (power) of a sound source is inversely proportional to the square of the distance of the listener from the sound source. (Because intensity is proportional to the square of the sound pressure level, sound pressure is inversely proportional to the distance of the sound source.)

- Iris.** The circular, pigmented membrane that surrounds the pupil of the eye, located between the cornea and the crystalline lens. (CRef. 1.201)
- Isometric.** Referring to contraction of a muscle against resistance in which there is little shortening of the muscle but muscle tone increases.
- Just-noticeable difference.** The least amount by which two stimuli must differ along a given dimension to be perceived as nonidentical.
- K.** Kelvin.
- kHz.** Kilohertz, a unit of frequency equal to 1000 ( $10^3$ ) Hz.
- Kinesthesia.** The sense of movement and position of the limbs or other body parts, arising from stimulation of receptors in joints, muscles, and tendons.
- km.** Kilometer, a unit for measuring length; 1 km = 1000 m.
- Labiodental.** Articulated with the lower lip touching the upper central incisors (as in [f], [v]).
- Lag time constant.** For first-order (exponential) lag, the time required for the output to reach 63% of its final value in response to a step input. It generally describes the "responsiveness" of the system, with sluggish systems having long time constants.
- Landolt C.** An incomplete ring, similar to the letter C in appearance, used as a test object for visual acuity. The thickness of the ring and the break in its continuity are each one-fifth of its overall diameter. The ring is rotated so that the gap appears in different positions and the observer is required to identify the location of the gap. Also called a **Landolt ring** or **Landolt C-ring**. (CRef. 1.602)
- Landolt ring.** *See* Landolt C.
- Laplace domain.** *See* Laplace transform.
- Laplace operator.** *See* Laplace transform.
- Laplace transform.** A transformation technique relating time functions to frequency-dependent functions of a complex variable.
- Latency.** The time between the onset of a stimulus and the beginning of the individual's response to the stimulus; also called reaction time or response time.
- Lateral disparity.** *See* lateral retinal image disparity.
- Lateral inhibition.** Inhibitory interactions between neural units serving spatially separated regions; evidenced as a reduction in the sensation or response to stimulation of one area due to stimulation of a nearby area, usually on the skin or on the retina.
- Lateral rectus muscle.** One of the six voluntary muscles that move the eyeball. (CRef. 1.901)
- Lateral retinal image disparity.** The difference in the relative horizontal position of the visual images of an object on the left and right retinas due to the lateral separation of the eyes. (CRef. 5.905)
- Lateralization.** Localization of a sound presented (usually dichotically) via earphones in terms of its apparent spatial position along an imaginary line extending from the right to the left ear.
- Lead time constant.** The time constant of a lead element placed in a dynamic control loop to increase high-frequency stability. It determines the frequency above which the system responds with lower order.
- Least-squares method.** A mathematical method of fitting a curve to a set of quantitative data points in which the sum of the squares of the distances from the points to the curve is minimized.
- Lens.** A transparent, biconvex, lens-shaped body located immediately behind the iris of the eye; through the action of the ciliary muscle, the shape of the semi-elastic lens can be changed to alter its refractive power and bring the images of objects at different distances to a sharp focus on the retina. (CRefs. 1.201, 1.222)
- Lexical decision task.** A task in which the subject must judge whether a given letter string is a word.
- Light adaptation.** The adjustment of the visual system to an increase in illumination in which sensitivity to light is reduced (threshold for light is increased) as illumination is increased.
- Lightness.** The attribute of visual perception according to which a visual stimulus appears to emit more or less light in proportion to a stimulus perceived as "white." Lightness can range from very light (white) to very dark (black). The physical correlate of lightness is reflectance.
- Lightness induction.** *See* induction.
- Liminal contrast threshold.** The contrast associated with the minimum perceptible difference in luminance between two areas, often measured in terms of the luminance difference detectable on some specified proportion of trials (generally 0.50).
- Linear regression.** A statistical technique for predicting the value of one variable from the value of another variable when the two variables bear a linear relation to one another.
- Line-spread function.** A mathematical description of the relative intensity of light in the optical image of an infinitesimally narrow bright line as a function of distance from the center of the image in a direction perpendicular to the line's length. (CRef. 1.215)
- Linguadental.** Articulated with the tip of the tongue placed on the upper front teeth (as in the [th] sound of thin).
- Loudness level.** The loudness level of a sound (in phons) is the sound pressure (in decibels re 20  $\mu$ Pa) of a 1000-Hz tone judged equal in loudness to the sound being measured.
- Lumen (lm).** A unit of luminous flux equal to the light emitted within a solid angle of unit size by a point source of light with a luminous intensity of 1 candela; i.e., 1 candela per steradian.
- Luminance.** Luminous flux reflected or transmitted by a surface per unit solid angle per unit of projected area in a given direction. The most commonly used units of measurement are candelas per meter<sup>2</sup> (cd/m<sup>2</sup>), footlamberts (fL), and millilamberts (mL). (CRef. 1.104)
- Luminosity.** The luminous efficiency (brightness-producing capacity) of radiant energy.
- Luminous efficiency.** The ratio of the total luminous flux radiated by a source (i.e., radiant flux weighted by the standard spectral luminous efficiency function of the eye) to the radiant flux from the source; usually expressed in terms of lumens/watt. (CRefs. 1.104, 1.110)
- Luminous efficiency function.** The function describing the relative sensitivity of the eye to light of different wavelengths. (CRef. 1.110)
- Luminous flux.** The radiant flux from a source weighted by the luminous efficiency function of the eye (i.e., the response of the eye to each wavelength present); usually expressed in terms of lumens. (CRefs. 1.104, 1.110)
- Luminous intensity.** The light-giving power of a source, measured as the luminous flux per unit solid angle in a given direction and usually expressed in terms of candelas (cd, or lumens/steradian). (CRef. 1.104)
- Lux (lx).** A unit of illuminance equal to the illumination on a surface 1 meter from a point source of light with a

luminous intensity of 1 candela, or 1 lumen per square meter (1 candela per steradian per square meter); 1 lux = 0.0929 foot candle.

**lx.** Lux.

**m.** Meter, a unit for measuring length; 1 m = 100 cm = 1000 mm.

**mA.** Milliampere, a unit for measuring electric current; 1 mA =  $10^{-3}$  A.

**Macula lutea.** The central region of the retina, approximately 6-10 deg of visual angle (2-3 mm) in diameter. Marked by yellow pigmentation, it is the region of greatest visual acuity; the fovea is at its center.

**Macular.** Of or pertaining to the macula lutea.

**Mann-Whitney U test.** A powerful, non-parametric statistical test used with rank-order data to determine the significance of the difference between two experimental groups.

**Mask.** See **masking**.

**Masking.** A decrease in the detectability of one stimulus due to the presence of a second stimulus (the mask) which occurs simultaneously with or close in time to the first stimulus.

**Massed practice.** Extended practice without interspersed rest or recuperation periods.

**Maxwellian view.** A uniformly luminous field obtained when a light source is focused on the pupil of the eye. Very high luminances are achievable and the amount of light entering the eye is not affected by pupil size.

**Mean.** The average value of a set of numbers or data points; the sum of the values divided by the number of values.

**Mechanoreceptor.** A neural structure that responds to mechanical stimuli such as a change in pressure, shape, or tension; the mechanical stimulation may be internal (such as the mechanical events associated with limb movement) or external.

**Medial plane.** The vertical plane passing through the middle of the body from front to back and dividing the body into left and right. Sometimes called **sagittal plane**.

**Medial rectus muscle.** One of the six voluntary muscles that move the eyeball. (CRef. 1.901)

**Median.** The middle value in a series of values arranged in order of magnitude. For an even number of values, the median is the arithmetic mean of the two middle values.

**Mel.** A subjective unit of pitch such that a pure tone of 1000 Hz has a pitch of 1000 mels.

**Mesopic.** Pertaining to a luminance range intermediate between photopic and scotopic levels at which both the rods and cones function.

**Metameric pair.** Two lights or targets of different spectral composition that nevertheless appear identical in color.

**Method of adjustment.** A psychophysical method for determining a threshold in which the subject (or the experimenter) adjusts the value of the stimulus until it just meets some preset criterion (e.g., just appears visible or just appears flickering) or until it is apparently equal to a standard stimulus.

**Method of constant stimuli.** A psychophysical method of determining a threshold in which the subject is presented with several fixed, discrete values of the stimulus and makes a judgment about the presence or absence of the stimulus or indicates its relation to a standard stimulus (e.g., more or less intense).

**Method of limits.** A psychophysical method of determining a threshold in which the experimenter varies a stimulus in an ascending or descending series of small steps and the observer reports whether the stimulus is detectable or not or indicates its relation to a standard stimulus.

**Michelson contrast.** A mathematical expression for specifying contrast of periodic patterns; defined as  $(L_{\max} - L_{\min}) / (L_{\max} + L_{\min})$ , where  $L_{\max}$  and  $L_{\min}$  are the maximum and minimum luminances in the pattern. Michelson contrast ranges between 0 and 1. (CRef. 1.601)

**μm.** Micrometer, a unit for measuring length; 1 μm =  $10^{-6}$  m.

**μPa.** Micropascal, a unit for measuring pressure or stress; 1 μPa =  $10^{-6}$  Pa.

**Microsaccade.** Very small movements or tremors of the eye (2-28 min arc of visual angle) occurring at a variable rate and most typically seen when observers attempt to fixate very accurately.

**Millilambert (mL).** A unit of luminance equal to 0.001 times the luminance of a surface of 1 lumen/cm<sup>2</sup>; 1 mL = 3.183 cd/m<sup>2</sup> = 0.929 fL.

**Minimum angle of resolution.** The minimum distance (measured in minutes of arc of visual angle) by which two targets (such as lines or points) must be separated to be distinguished as two targets rather than one. (CRef. 1.602)

**Minimum visibility.** The smallest perceivable target size, typically measured as the width of the narrowest dark line that can be detected at a given distance and luminance level. (CRef. 1.602)

**Mirror stereoscope.** A device using a system of mirrors to present separate images of an object or scene to the left and right eyes; for appropriately constructed stereograms, the result is a single, fused image appearing to have depth or three-dimensionality. Sometimes called a **Wheatstone stereoscope**.

**mL.** Millilambert, a unit for measuring luminance; 1 mL = 0.929 fL = 3.183 cd/m<sup>2</sup>. (See **millilambert**.)

**mm.** Millimeter, a unit for measuring length; 1 mm =  $10^{-1}$  cm.

**Modulation transfer function.** The function (usually graphic) describing the ratio of the modulation of the input to the modulation of the output over a range of frequencies; for an image-forming system, the ratio of the modulation in the image to that in the object. Also called **sine-wave response function** and **contrast transfer function**.

**Modulus.** The numerical value assigned to a standard stimulus (e.g., 1.00); other stimuli are judged by the subject in comparison to this modulus and assigned a value in relation to it.

**Monaural.** Pertaining to, affecting, or impinging upon only one ear.

**Monocular.** Pertaining to, affecting, or impinging upon only one eye.

**Monte Carlo method.** A technique for obtaining a probabilistic approximation to the solution of problems in mathematics, science, and operations research by the use of random sampling.

**Motion parallax.** Changes in the projective relations among objects in the visual field due to the relative motion of the observer. (CRef. 5.902)

**Motor.** Pertaining to structures or functions connected with the activation of muscles or glands.

**msec.** Millisecond, one-thousandth of a second ( $10^{-3}$  sec).

**Multidimensional scaling.** A family of statistical techniques designed to uncover the underlying structure in data that consist of measures of relatedness among a set of objects (e.g., stimuli). Multidimensional scaling uses a matrix of proximities among the objects as input and produces an  $N$ -dimensional configuration or map of the

- objects as output. The configuration is so derived that the distances between the objects in the configuration match the original proximities as closely as possible. The locations of particular clusters of objects are said to reflect whatever dimensions might underlie the proximity measures.
- Munsell color system.** A method of ordering and specifying object color in terms of hue, lightness, and saturation. The system is embodied in a set of color samples arranged to represent perceptually equal steps in Munsell hue, Munsell value, and Munsell chroma. (CRef. 1.724)
- Munsell value.** The dimension of the Munsell color system corresponding to lightness; it ranges from 1 (black) to 10 (white) and is approximately equal to the square root of the reflectance expressed in percent. (CRef. 1.724)
- mW.** Milliwatt, a unit for measuring power;  $1 \text{ mW} = 10^{-3} \text{ W}$ .
- Myopia.** See **nearsightedness**.
- Myotatic stretch reflex.** A reflexive contraction of a muscle in response to passive longitudinal stretching.
- N.** Newton, a unit for measuring force; it is the force required to accelerate  $1 \text{ kg}$  by  $1 \text{ m/sec}^2$ .
- n, N.** Number, as in number of subjects or number of observations.
- Nearsightedness.** An error of refraction in which parallel rays of light from an object at infinity are brought to a focus in front of the retina when accommodation is relaxed. An individual with this condition will see close objects clearly, but distant objects will not be in sharp focus unless corrective lenses are worn. Also known as **myopia**. (CRef. 1.204)
- Negative aftereffect.** The occurrence of a perceptual effect in response to a stimulus that is opposite to the original effect elicited by a stimulus that preceded it. For example, after a heavy weight is lifted, a second weight appears lighter than if the first had not been lifted.
- Negative feedback loop.** A feedback loop in which a signal from a part of the system following the control is fed back to the system input with a polarity opposite to that of the control output, thus tending to decrease output and helping to stabilize the system by avoiding progressively increasing error. Also called **negative feedback servoloop**.
- Neutral density.** See **neutral density filter**.
- Neutral density filter.** A light filter that decreases the intensity of the light without altering the relative spectral distribution of the energy; also known as a gray filter.
- Newton (N).** A unit of force equal to the force required to accelerate  $1 \text{ kg}$  by  $1 \text{ m/s}^2$ ;  $1 \text{ N} = 10^5 \text{ dynes}$ .
- nm.** Nanometer, a unit for measuring length;  $1 \text{ nm} = 10^{-9} \text{ m}$ .
- Nodal points.** The points in a lens system, such as the eye, toward which and from which are directed corresponding incident and transmitted rays that make equal angles with the optical axis.
- Noise spectral level.** The average noise power in a 1-Hz band of noise (in decibels re  $10^{-12} \text{ W/m}^2$ ); also called **noise-power density**.
- Nonius markers.** A pair of lines or other contours presented, one to each eye, which are in vernier alignment in the combined (binocular) view when left and right stereoscopic half-fields are in proper registration on the retinas. Nonius markers are used in stereoscopic displays to facilitate proper fixation as well as to assess convergence (fixation distance), vertical eye rotation, and image size differences between the eyes.
- Normal distribution.** See **Gaussian distribution**.
- Nystagmus.** Involuntary rhythmic movements of the eyes, which generally take the form of a slow drift alternating with a quick movement in the opposite direction.
- Octave.** A band of frequencies whose upper and lower limits have a 2:1 ratio.
- Open loop.** A system in which there is no feedback of information about an output to an earlier stage of the system. (CRef. 9.506)
- Optacon.** From OPTical-to-TACTile CONverter; a reading aid for the blind that converts printed or optical patterns (such as letters) into a corresponding tactile pattern presented to the skin of the index finger pad by means of an array of 144 small vibrators covering an area of approximately  $2.7 \times 1.2 \text{ cm}$ .
- Optic node.** The optical center of the compound lens system of the eye (center of curvature of the cornea in the simple lens equivalent).
- Optokinetic nystagmus.** Nystagmus induced by viewing a moving object.
- Optometer.** An instrument for measuring the refractive power and range of vision.
- Order.** See **system order**.
- Orientation disparity.** Rotation of the image in one eye with respect to the image in the other eye. This causes corresponding image points to fall on noncorresponding (disparate) retinal locations for all points in the binocular field except a point at the center, provided optical axes are parallel. (CRef. 5.908)
- Orthogonal.** Completely independent or separable.
- Otolith organs.** Two small sack-shaped organs (the utricle and the saccule) that are embedded in the temporal bones on each side of the head near the inner ear and are sensitive to gravity and linear acceleration of the head.
- Outside-in display.** A display (as of aircraft attitude) that uses the outside world as the frame of reference, so that the display reflects the way the aircraft would appear to someone facing the windscreen from the outside. For example, when the aircraft banks, the aircraft in the attitude display tilts while the horizon of the display remains horizontal. (*Compare inside-out display.*) (CRef. 9.529)
- Overtone.** A constituent of a complex tone whose frequency is an integral multiple of the fundamental frequency; also called harmonic or upper partial.
- p.** In statistical analysis, the probability that the observed difference between experimental groups is due to sampling effects (i.e., occurred by chance) rather than to the experimental manipulation. In most experimental psychology research, the significance level is set at  $p = 0.05$  or  $p = 0.01$ . If the value of the analytical statistic calculated for the data (such as Student's  $t$  or Mann-Whitney  $U$ ) is greater than the value associated with  $p = 0.05$  (or  $p = 0.01$ ), then the observed difference between experimental groups is assumed to be real (i.e., the data samples are assumed to be drawn from different populations rather than from the same population).
- Pa.** Pascal, a unit of pressure or stress equal to a force of  $1 \text{ N/m}^2$ .
- Palatal.** Articulated with the tongue on or near the hard palate (as in [r], [ž]).
- Panum's fusional area.** A small area surrounding the fixation point (or any point on the horopter [CRef. 5.910]) in which objects are seen as single, even though corresponding image points may not fall on precisely corresponding locations of the two retinas. (CRef. 5.911)
- Parafovea.** A region of the retina covering approximately 4 deg of visual angle (0.5 mm), immediately surrounding the fovea.

**Pascal (Pa).** A unit of pressure or stress equal to a force of 1 newton/m<sup>2</sup>.

**Passive movement.** Movement of a subject's limb or body by a device or by the experimenter while the subject keeps the moved part as relaxed as possible.

**Perceptual adaptation.** *See adaptation* (2).

**Performance operating characteristic.** A curve showing how performance on one task varies as a function of performance on a second task when the two are carried out concurrently and the relative emphasis on one task or the other is varied; that is, a performance trade-off function describing the improvement in the performance on one task due to any added resources released by lowering the level of performance on another task with which it is time-shared. (CRef. 7.205)

**Peripheral nervous system.** The nervous system excluding the brain and spinal cord.

**Peripheral vision.** Vision in the peripheral (non-foveal) region of the visual field.

**Phase droop.** The increased phase lag at very low frequencies that is sometimes observed in the human operator manual control response.

**Phon.** A unit of loudness equal to the number of decibels (re 20  $\mu$ Pa) of a 1000-Hz tone that is equal in loudness to the sound being measured. Loudness in phons is termed the loudness level of a sound.

**Phone.** The smallest discriminable unit of sound in speech. (CRef. 8.206)

**Phoneme.** The smallest meaningful unit of speech; i.e., the shortest segment of speech that, if altered, alters the meaning of a word. (CRef. 8.206)

**Photometric unit.** A unit for measuring radiant energy in terms of its effect on vision, as contrasted with radiometric units, which measure energy and power without regard to biological effect.

**Photometry.** The measurement of light in terms of its effects on vision.

**Photopic.** Pertaining to relatively high (daytime) levels of illumination at which the eye is light-adapted and vision is mediated by the cone receptors. (CRef. 1.103)

**Photoreceptor.** A receptor such as a rod or cone cell of the eye that is sensitive to light.

**Plane of fixation.** The plane parallel to the front of the observer's body that contains the point of convergence (or fixation) of the eyes.

**Point source.** A light source (such as a star) that subtends an extremely small angle at the observer's eye. In practice, considered to be any source whose diameter is less than one-tenth the distance of the observer from the source.

**Position control.** A control system in which the output position is directly proportional to the input position. (*See also zero-order control.*)

**Postrotary nystagmus.** Nystagmus caused by decelerative stimulation of the vestibular system after the cessation of head rotation; the eye movements are opposite in direction to the nystagmus induced by the head rotation itself.

**Power spectral density.** The average power of a time-varying quantity within a band 1-Hz wide, as a function of frequency.

**Power spectrum.** A plot of the distribution of intensity as a function of frequency (with frequency usually given in logarithms). Also called power density spectrum and frequency spectrum.

**Primary line of sight.** The line connecting the point of fixation in the visual field with the center of the entrance pupil (and center of the fovea) of the fixating eye.

**Primary task.** The principal task of the operator, whose performance is critical or most important. (*Compare secondary task.*)

**Proactive inhibition.** Interference of responses learned earlier with the performance of responses learned at a later time.

**Probability summation.** The increase in the probability of detecting a stimulus due to an increase in the number of independent opportunities for detection on a given trial (as by viewing with two eyes or processing by multiple independent sensory mechanisms). (CRef. 1.814)

**Probit analysis.** A regression-like maximum-likelihood procedure for finding the best-fitting ogive function for a set of binomially distributed data. Originally developed in connection with pharmacological and toxicological assays to compute the lethal or effective dose (dosage affecting 50% of treated organisms); the procedure has also been applied in psychophysical studies in analyzing all-or-nothing (yes/no) responses to compute the 50% threshold (stimulus level eliciting a given response on 50% of trials) and its confidence limits.

**Proprioception.** The sensing of movement and position of the body or its parts.

**Proximal.** Near the point of attachment of a limb or body part; near the body; e.g., the wrist is proximal to the fingers. (*Compare distal.*)

**Psychometric function.** A mathematical or graphical function expressing the relation between a series of stimuli that vary quantitatively along a given dimension, and the relative frequency with which a subject answers with a certain category of response in judging a particular property of the stimulus (e.g., "yes" and "no" in judging whether a given stimulus is detected, or "less than," "equal to," and "greater than" in comparing the stimulus with a standard stimulus). (CRef. 1.657)

**Pulfrich effect.** Apparent motion in depth of a laterally moving target when the retinal illumination of one eye is lower than that of the other eye. A pendulum target appears to move in an elliptical path in a plane perpendicular to the frontal plane and parallel to the floor. (CRef. 5.933)

**Pure tone.** A tone of a single frequency produced by sinusoidal vibrations and without overtones.

**Pursuit tracking task.** Tracking in which the operator's task is to keep a marker or cursor on a moving target symbol or command input; the operator chases or pursues the target with the target position always displayed and the size and direction of tracking error available from the positions of the target and marker or cursor.

**Quickening.** A display technique in which the higher derivatives of the error (or system state) are added directly onto the error position with some relative weighting; that is, the rate at which error is changing, and higher derivatives as well, are represented as additions to the deviation of a cursor from a reference position in the display. Quickening is used to reduce the difficulty of controlling higher-order systems. (CRef. 9.525)

**r.** Pearson product-moment correlation coefficient, a statistic that indicates the degree of linear relationship between two variables.

**rad.** Radian.

**Radian.** A unit of angular measure equal to the angle subtended at the center of a circle by an arc the length of which is equal to the radius; 1 radian = 57.3 deg.

**Random-dot pattern.** Matrix pattern of light and dark cells, usually computer-generated, in which the probabil-

- ity that any given cell will be light or dark is determined by a random function. Such patterns are used in the study of stereoscopic vision because they allow the construction of stereograms containing no depth cues except lateral retinal image disparity. Thus only those with intact stereopsis mediated by retinal disparity can perceive the patterns.
- Random walk model.** A model of the perception and decision response components in reaction time tasks. According to the model, an ideal detector accumulates information about the identity of the stimulus from the start of a trial; when the information exceeds some preset threshold (response boundary), the appropriate response is made. Each new increment of information takes a constant time and is assumed to be somewhat unreliable so that the cumulative balance of all the information waivers (i.e., executes a random walk) between the alternatives.
- Randomized design.** An experimental design in which the various levels of the independent variable are presented in random order within a given block of trials or experimental session.
- Rate-aided system.** A position control system to which a rate control system has been added.
- Rate control.** See **first-order control**.
- Rate order.** See **second-order control**.
- Re.** Relative to the reference value given.
- Reaction time.** The time from the onset of a stimulus to the beginning of the subject's response to the stimulus by a simple motor act (such as a button press).
- Receptive field.** For cutaneous neural units, the area of the skin within which stimulation (as by pressure, vibration, etc.) influences the activity of a given sensory neuron. (CRef. 3.103)
- Reflectance.** The ratio of reflected radiant flux to incident flux; the portion of incident light reflected.
- Regression line.** A line on a graph or an equation of a line for predicting the value of one variable from the value of another; the line is derived by statistical methods as representing the relationship between the two variables that best describe a given set of data.
- Remnant.** In a quasi-linear characterization of a nonlinear system, the component that represents the difference between the response of the actual nonlinear system and the equivalent linear element (the describing function); called "remnant" because it is left over from the portion of the system response represented by the linear element.
- Resolution threshold.** A measure of the ability to resolve fine detail; determined in a variety of ways, e.g., as the minimum separation between two lines required for them to be seen as double rather than single, or as the smallest width of bars in a bar pattern that allows the patterns to be distinguished from a uniform field.
- Retina.** The membranous structure lining the inside of the eyeball which contains the photoreceptors (rods and cones) that mediate vision.
- Retinal disparity.** See **lateral retinal image disparity; vertical retinal image disparity**.
- Retinal eccentricity.** Distance from the center of the fovea to an image on or to an area of the retina generally expressed in angular terms; corresponds to the distance in the visual field from the fixation point to a given object or point in the field.
- Retinal illuminance.** The luminous flux incident on the retina per unit area; typically specified in trolands, where retinal illuminance in trolands is equal to the luminance of the source (in  $\text{cd}/\text{m}^2$ ) times pupil area (in  $\text{mm}^2$ ).
- Retinal image disparity.** See **lateral retinal image disparity; vertical retinal image disparity**.
- Ricco's law.** A law stating that, for small targets, the threshold intensity for detecting a target varies inversely with the size of the target; i.e.,  $I = k/A$ , where  $I$  is the light intensity of the target,  $A$  is the target area, and  $k$  is a constant. In other words, target lights with equal energy (or equal numbers of quanta) are equally detectable ( $I \times A = k$ ). (CRef. 1.308)
- Risley prism.** A prism assembly comprised of two thin wedge prisms (generally identical) arranged in series. Rotating the two prisms in opposite directions alters the magnitude of off-axis beam deviation but not azimuth, while rotating them in the same direction changes deviation azimuth but not deviation angle.
- ROC analysis.** Signal detection theory maintains that performance in a detection task is a function of both the sensitivity or resolution of the operator's detection mechanism and the criterion or response bias adopted in responding to signals. A receiver operating characteristic (ROC) graphically depicts the joint effects of sensitivity and response bias on operator performance. It is defined by the locus of points on a graph obtained by plotting the probability of correct target detection (or "hits") versus the probability of false detections (or "false alarms") in a detection task. By requiring observers to vary their response criteria under identical stimulus conditions, points along a curve that represent equivalent sensitivity but different degrees of response bias can be generated. Given hit and false alarm rates from a detection experiment, ROCs can be plotted to compare the detection performance of observers under different conditions, and analyses conducted to specify the signal detection theory indices of sensitivity to the signal ( $d'$ ) and criterion or response bias ( $\beta$ ).
- Rod.** A rod-shaped photoreceptor in the retina of the eye; rods are distributed only outside the fovea and are responsive at low levels of illumination. (CRefs. 1.201, 1.301)
- Roll angle.** The angle of rotation about the longitudinal (nose-to-tail) axis of an aircraft.
- Saccade.** A short, abrupt movement ("jump") of the eyes, as in shifting fixation from one point to another (such as occurs in reading).
- SAE pad.** Device of the Society of Automotive Engineers for measuring translational vibration on a seat beneath the human body.
- Sagittal plane.** The vertical plane passing through the body from back to front, and dividing it into left and right (i.e., the medial plane), or any plane parallel to it.
- Saturation.** The attribute of color perception representing the degree to which a chromatic color differs from an achromatic color regardless of their lightnesses. For example, a red with low saturation is pink.
- Schema.** A nonconscious adjustment of the brain to the afferent impulses indicative of body posture that is a prerequisite of appropriate bodily movement and of spatial perception.
- Scotopic.** Pertaining to relatively low (nighttime) levels of illumination at which the eye is dark adapted and vision is mediated by the rod receptors. (CRef. 1.103)
- SD.** Standard deviation from the mean. (See **standard deviation**.)
- SE.** Standard error.
- Second-order control.** A system in which the response is proportional to the second time integral of the control input; also called **acceleration control**.
- Second-order system.** See **second order control**.
- Secondary task.** A task the operator is asked to perform in addition to the primary task; performance on the

secondary task provides an estimate of primary task workload. Secondary tasks may be "non-loading" (the operator attends to the secondary task when there is time) and "loading" (the operator must always attend to the secondary task).

**Selective attention.** A task environment in which the observer or operator must attend selectively to some stimuli or input channels while ignoring others that are active simultaneously.

**Semi-circular canals.** Three fluid-filled tubes oriented roughly at right angles to one another that are embedded in the temporal bones on each side of the head near the inner ear and that aid in maintaining body equilibrium. (CRef. 3.201)

**Sensation level.** The amount (in decibels) by which the level of a sound exceeds the threshold of audibility of the sound for a given listener.

**Sensitivity.** In a general sense, the ability to detect stimulation; in psychophysical studies, refers in particular to the ability to be affected by and respond to low-intensity stimuli or to slight stimulus differences; commonly expressed as the reciprocal of measured threshold.

**Sensory adaptation.** See **adaptation**.

**Signal detection theory.** A theory which holds that performance on a detection task is a function of both the detectability of the signal (or the sensitivity of the observer) and the observer's criterion or response bias in reporting the signal. (CRef. 7.420)

**Signal-to-noise ratio.** The ratio of the intensity of a signal to the intensity of noise in the absence of the signal. In most auditory studies, the signal-to-noise (S/N) ratio is measured as the relative sound pressure level of the signal and noise in decibels re 20  $\mu$ Pa, so that an S/N ratio of zero indicates that signal and noise are of equal amplitude, while positive and negative values indicate that the signal is of greater or lesser amplitude than the noise, respectively.

**Simultaneous contrast.** Alteration in the appearance of one stimulus due to the simultaneous presence of another nearby stimulus that differs from it along some dimension (such as lightness or color), in such a way that the difference between the two stimuli is accentuated. **Simultaneous lightness contrast:** alteration in the lightness of one stimulus due to the presence of a nearby stimulus of different lightness (CRef. 1.714). **Simultaneous color contrast:** alteration in the perceived hue of one stimulus due to the presence of an adjacent stimulus of different hue. (CRef. 1.717)

**Sine wave.** A periodic waveform in which the amplitude at each point across time or space varies according to a sine function.

**Sine-wave grating.** A bar pattern in which some property (generally luminance) varies with spatial position according to a sine function in a direction perpendicular to the bars. (CRef. 1.601)

**Single vision.** The perception of a single object from the separate images of the object in each eye. (CRef. 5.911)

**Sinusoidal.** Varying according to a sine function.

**SIT-bar.** Seat interface transducer bar; device for measuring the translational or rotational vibration on a seat beneath the human body.

**Sloan letter chart.** (1) A chart for measuring visual acuity that contains ten capital letters graded in size in equal logarithmic steps and chosen to be equal in difficulty to each other and to the Landolt ring. There is one chart for testing vision at 20 feet and another for testing at 16 inches. (2) A set of nine cards containing samples of

discursive text that is used to test individuals with subnormal vision to determine the magnification required to read newsprint.

**Snellen acuity.** Visual acuity measured using a standard chart containing rows of letters of graduated sizes and expressed as the distance at which a given row of letters is correctly read by a specific individual compared to the distance at which the letters can be read by a person with clinically normal eyesight. For example, an acuity score of 20/50 indicates that the tested individual can read only at a nearer distance of 20 ft the letters read by a normally sighted person at 50 ft. (CRef. 1.602)

**Snellen letter chart.** A chart for measuring visual acuity consisting of a standard set of letters in rows of graduated size. (CRef. 1.602)

**Sone.** A subjective unit of loudness equal to the loudness of a 1000 Hz tone presented binaurally at an intensity of 40 dB above the listener's threshold (or 40 dB SPL for the "average" listener).

**Sound pressure level.** The amount (in decibels) by which the level of a sound exceeds the reference level of 20  $\mu$ Pa (or 0.0002 dynes/cm<sup>2</sup>).

**Spaced practice.** Practice in which practice periods are interspersed with rest intervals.

**Spatial frequency.** For a periodic target, such as a pattern of equally spaced bars, the reciprocal of the spacing between bars (i.e., the width of one cycle, or one light bar plus one dark bar), generally expressed in cycles per millimeter or cycles per degree of visual angle.

**Spatial summation.** The combining of the visual response to light impinging simultaneously on different regions of the retina. (See also **Ricco's law**.)

**Spectral radiant power distribution.** The radiant power at each wavelength along a given portion of the electromagnetic radiation spectrum.

**Spectral sensitivity.** The relative sensitivity of the eye to light of different wavelengths.

**Spectrogram.** A graphic record of speech in which the intensity of acoustic energy at a given frequency is plotted as a function of time. (CRef. 8.202)

**Spectrum locus.** The line on a chromaticity diagram on which fall the chromaticities of all wavelengths of the visible spectrum.

**Spherical aberration.** Image degradation in an optical system that occurs when light rays passing through the central and outer zones of a lens are brought to a focus at different distances from the lens. (CRef. 1.211)

**Split-half reliability method.** A method of measuring test-retest reliability in which, for speed and convenience, the coefficient of correlation is calculated between performance on the first half of a test and performance on the second half of the test for a group of subjects, rather than between performance on two separate repetitions of the test. (See **test-retest reliability**.)

**Square wave.** A rectangular waveform whose amplitude periodically shifts instantaneously between two discrete values.

**Stabilized vision.** Vision in which, through optical or other means, the image of a target is made to move exactly with the eye so that the same portion of the retina is always stimulated, that is, the image does not move on the retina when the eye moves.

**Staircase procedure.** A variant of the method of limits for determining a psychophysical threshold in which the value of the stimulus on a given trial is increased or decreased, depending on the observer's response on the previous trial or group of trials.

- Standard deviation (SD).** Square root of the average squared deviation from the mean of the observations in a given sample. It is a measure of the dispersion of scores or observations in the sample.
- Standard error of estimate.** The standard deviation of the sampling distribution of a population statistic (such as the mean, median, or variance); it is a measure of the variability of the statistic over repeated sampling.
- Standard error of the mean.** The standard deviation of the sampling distribution of the mean; mathematically, the standard deviation of the given data sample divided by the square root of one less than the number of observations. It describes the variability of the mean over repeated sampling.
- Standard luminous efficiency.** Luminous efficiency as defined by the CIE (Commission Internationale de l'Eclairage).
- Standard normal deviate.** A test score or experimental measurement or datum point expressed in terms of the number and direction of standard deviation units from the mean of the sample distribution. Also called **standard score** or **z-score**.
- Standard stimulus.** A fixed stimulus presented along with a variable or comparison stimulus in an experiment designed to determine the difference threshold or just noticeable difference between the two. The value of the standard stimulus along a given dimension remains fixed, while the value of the variable stimulus is altered, and the subject must indicate the relation between the two (e.g., the comparison is "greater than," "less than," "or equal to" the standard).
- Stereoacuity.** The ability to discriminate depth or distance solely on the basis of lateral retinal image disparity; usually expressed as the smallest detectable difference in depth of two targets (in seconds of arc of visual angle).
- Stereogram.** A pair of two-dimensional drawings, photographs, etc., presented separately to the right and left eyes by a stereoscope or other means; generally, each half of the stereogram represents the same scene from a slightly different viewpoint, so that their fusion by the visual system gives rise to a single impression characterized by relief, depth, or three-dimensionality.
- Stereopsis.** Visual perception of depth or three dimensionality; commonly used to refer specifically to depth arising from lateral retinal image disparity.
- Stereoscope.** An instrument used to present a separate visual display to each eye. Typically utilizes a system of mirrors, prisms, or lenses to present two specially constructed flat pictures (one to each eye) that, when combined by the visual system, give the impression of solidity or three-dimensionality.
- Stereoscopic.** Of or pertaining to stereopsis.
- Stiles-Crawford effect.** The decrease in the apparent brightness (luminous efficiency) of a narrow beam of light entering the eye near the edge of the pupil relative to the brightness of an identical beam entering in the center of the pupil. (CRef. 1.111)
- Stop.** A consonant sound (such as [b] or [t]) whose articulation requires complete closure of the vocal tract at some point.
- Subjective vertical.** The orientation the observer perceives (indicates) as being vertical, which may or may not be true (gravitational) vertical.
- Superior oblique muscle.** One of the six voluntary muscles that move the eyeball. (CRef. 1.901)
- Suppression.** See **binocular suppression**.
- System dynamics.** The patterns of interactions occurring in an interdependent group of components that serve a common function or form a functional unit.
- System order.** For a control system, the highest power of the Laplace operator,  $S$ , that appears in the denominator of the transfer function. Equivalently, the order of the highest-order derivative of the differential equation describing the system element. (CRef. 9.519)
- Tachistoscope.** An apparatus for presenting visual material for a very brief exposure time; the simplest type uses a falling screen or shutter, with an aperture that momentarily reveals the visual stimulus.
- Tactile.** Of or relating to tactual perception (touch) mediated by the cutaneous (skin) sense.
- Tactual.** Of or relating to the sense of touch, as mediated by the cutaneous (skin) sense and/or kinesthesia.
- Td.** Troland, the retinal illuminance produced by a surface having a luminance of  $1 \text{ cd/m}^2$  when the area of the pupil of the eye is  $1 \text{ mm}^2$ .
- Telestereoscope.** A device for producing an appearance of exaggerated depth in scenes by increasing effective interpupillary distance (and thus lateral retinal image disparity). It permits depth judgments for objects otherwise too distant to judge. (CRef. 5.1102)
- Temporal summation.** The integration over time of the tactile response to a stimulus falling on a given region of the skin or the combining of the response to two or more stimuli impinging consecutively on the same region of the skin.
- Test-retest reliability.** Consistency in yielding the same or similar scores on repeated administrations of a given test, measured by computing the coefficient of correlation between performance on two successive presentations of the same test for a group of subjects.
- Third-order control.** A system in which the response is proportional to the third time integral of the control input.
- Third-order system.** See **third-order control**.
- Threshold.** A statistically determined boundary value along a given stimulus dimension which separates the stimuli eliciting one response from the stimuli eliciting a different response or no response (e.g., the point associated with a transition from "not detectable" to "detectable" or from "greater than" to "equal to" or "less than"). (CRef. 1.657) (See also **difference threshold**.)
- Time constant.** See **lag time constant**; **lead time constant**.
- Transfer function.** A complex function describing a dynamic system as a function of frequency that specifies the ratio of output to input amplitude and the phase difference between input and output.
- Transmission lag.** Pure time delay, i.e., a delay (expressed in time units) in transmitting input to output that leaves all other aspects of the signal unchanged.
- Trasonic speed.** Speed approximating the speed of sound in air (738 mph at sea level); often refers to speed in the range a little below to a little above the speed of sound in air, i.e., 600-900 mph.
- Tristimulus colorimeter.** An instrument for measuring color which allows a given test color to be specified in terms of the relative proportions of three primary colors (e.g., red, green, and blue) which, when additively mixed, give the same hue sensation as the test color.
- Troland (Td).** A unit expressing light intensity at the retina equal to the illumination produced per square millimeter of pupil area by viewing a surface with a luminance of 1 candela per square meter. Originally called photon. (CRef. 1.106)
- T-test.** A statistical test used to compare the mean of a given sample with the mean of the population from which the sample is drawn or with the mean of a second sample in order to determine the significance of an experimental

- effect (i.e., the probability that the results observed were due to the experimental treatment rather than to chance). Also known as **Student's t-test**.
- Two-alternative forced-choice paradigm.** An experimental procedure in which the subject is presented on each trial with one of two alternative stimuli and must indicate which stimulus occurred; a response must be made on each trial even if the subject must guess. Commonly referred to as a "criterion free" method of determining sensitivity.
- Two-interval forced-choice procedure.** An experimental procedure in which a subject is presented a stimulus during one of two time intervals and must indicate during which of the two intervals the stimulus was presented even if the subject must guess.
- Two-point threshold.** The smallest separation between two punctate stimuli applied to the skin that can be discriminated as two stimuli rather than one.
- Ultradian.** Pertaining to cyclical variations with a period of less than 12 hr. (CRef. 10.709)
- Uniform chromaticity scale.** A chromaticity diagram on which all pairs of just-noticeable different colors of equal luminance are represented by pairs of points separated by approximately equal distances.
- Vehicle dynamics.** The relationship between the output of a vehicle control device and the resulting motion of the vehicle.
- Velar.** Articulated with the tongue on or near the soft palate (velum) (as in [g], [k]).
- Velocity control.** See **first-order control**.
- Vernier acuity.** The ability to discern the alignment (colinearity) or lack of alignment of two parallel lines placed one above the other, as in reading a vernier scale; frequently expressed in terms of the smallest detectable misalignment in seconds of arc of visual angle. (CRef. 1.602)
- Vernier adjustment.** Adjustment of the lateral position of one of two vertical lines placed one above the other until the two appear vertically aligned. The procedure is used to measure vernier acuity.
- Vertical retinal image disparity.** The difference in the relative vertical position of the visual images of an object on the left and right retinas.
- Vestibular nystagmus.** Nystagmus produced by stimulation of the vestibular system (as by head rotation) or by disease of or damage to the vestibular apparatus.
- Vestibular sense.** The sense mediated by the otolith organs and semi-circular canals that is concerned with the perception of head position and motion and is stimulated by acceleration associated with head movements and changes in the pull of gravity relative to the head. (CRef. 3.201)
- Vestibular system.** The system comprised of the otolith organs and the semi-circular canals that mediates the perception of head position and motion. (CRef. 3.210)
- Vestibulo-ocular reflex.** Reflexive eye movements initiated by stimulation of the vestibular system during head movements whose purpose is to stabilize the eyes with respect to the object being viewed so that the image of the object on the retina will be stationary and will not be blurred by motion.
- Vibrotactile stimulation.** A mechanical vibration applied to the skin by an electromechanical transducer such as a modified loudspeaker or electrodynamic mechanical shaker, resulting in a periodic displacement of the skin.
- Visual acuity.** The ability of an observer to resolve fine pattern detail. Acuity is usually specified in terms of decimal acuity, defined as the reciprocal of the smallest resolvable pattern detail in minutes of arc of visual angle. "Normal" or average acuity is considered to be 1.0 (a resolution of 1 min arc), although many young adults have a decimal acuity slightly better than this. (CRef. 1.602)
- Visual angle.** The angle subtended at the eye by the linear extent of an object in the visual field. It determines linear retinal image size. (CRef. 1.240)
- Visual axis.** A line from the point being fixated to the center of the fovea; in the eye, the optical axis and visual axis do not coincide.
- Visual capture.** The tendency for visual information to dominate in determining perception when visual information and information from some other sensory modality (such as touch) are discrepant.
- Visual direction.** (1) The physical direction of the line of sight of the eye. (2) The relative direction in subjective visual space associated with a given point on the retina.
- Visual field.** The portion of the external environment that is visible to the eye in a given position; usually measured in degrees of visual angle.
- Visual noise.** A random array of images or pattern elements; frequently used as a camouflage in visual masking paradigms.
- Visual position constancy.** The tendency for the visual field to appear stable and motionless when the observer moves his or her eyes or head, despite the image motion on the retina caused by such movements.
- Vitreous humor.** The transparent, jelly-like substance that fills the back chamber of the eye (the space between the crystalline lens and the retina). (CRef. 1.201)
- Voicing.** Vibration of the vocal cords during the production of a phoneme. Phonemes accompanied by vibrations of the vocal cords (such as /b/) are voiced, and phonemes not accompanied by vibrations (such as /p/) are unvoiced.
- Von Frey hair (filament).** Hairs of various thicknesses and lengths calibrated to exert a constant force when pressed on the skin.
- Weber ratio.** See **Weber's law**.
- Weber's law.** A law which holds that the smallest detectable change in the magnitude of a stimulus along some dimension is always a constant proportion of the stimulus magnitude from which the difference is noted. The law is expressed mathematically as  $\Delta I/I = k$ , where  $I$  is the magnitude of the stimulus,  $\Delta I$  is the smallest detectable change in magnitude, and  $k$  is a constant which is often called the **Weber fraction** or **Weber ratio**.
- Wheatstone mirror stereoscope.** A stereoscope of the type invented by physicist Charles Wheatstone which utilizes a system of mirrors to present a different visual display to each eye; when the displays for the two eyes are appropriately constructed to represent the same object or visual scene from slightly different viewpoints (or positions in space), the result is the perception of a single image apparently having depth or three-dimensionality.
- White noise.** Random noise whose noise spectral level (noise-power density) is uniform over a wide frequency range; termed "white noise" by analogy with white light.
- Within-subjects design.** An experimental design in which a single group of subjects is tested under all levels of the independent variable. Each subject serves as his or her own control, and the performance of the subjects under one condition is compared with their performance under the other conditions to determine the effect of the experimental manipulation.
- Zero-order control.** A system in which the position (or zero time derivative) of the response is proportional to the control input position; also called **position control**.

# Design Checklist

This Design Checklist is provided to help you identify and locate human factors data in the Compendium. It is made up of human performance questions selected for their potential relevance to the design of control and display system components. The questions are sorted into categories keyed to a hierarchy of equipment-related factors. Each question is indexed, in turn, to specific entries within the Compendium that provide information pertinent to the question raised. To use the checklist, locate the topic of interest in the outline contents below, then turn to the indicated page for questions relating to that topic.

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## Visual Displays

### Resolution

#### Imaging Properties of the Eye

How large is the human eye? (1.201)

What is the fovea and how large is it in angular terms? (1.201)

How does the density of rods (which mediate night vision) vary with distance from the fovea? (1.201)

How can retinal image size be calculated from target linear size and distance for distant objects? (1.240)

What is the blind spot? (1.201)

Where, in the eye, is the yellowish macular pigment, and how large an angle does it subtend? (1.202)

What is the distance from the cornea to the nodal point of the eye? (1.240)

Where is the eye's center of rotation with respect to the front of the cornea and with respect to the eye's entrance pupil? (1.207)

#### *Visual optics*

What are the eye's four major refracting surfaces? (1.210)

What is the approximate refraction index of the optical elements of the eye? (1.203)

What two processes in the eye, other than focusing, change the amount and spectral distribution of light reaching the retina? (1.202)

Where is two-thirds of the eye's focusing power located? (1.201)

What are the approximate focal lengths of the eye for very near and very far distance? (1.201; 1.203; 1.240)

#### *Astigmatism*

With astigmatism, what will be the appearance of a radial pattern of lines? (1.205)

How is astigmatism specified? (1.205)

In astigmatism, what is declination error? (1.205)

What type of lens is required to correct astigmatism? (1.205)

#### *Retinal image distribution*

What is the Fourier transform of the aperture function? (1.219)

How can the optical transfer function be obtained from the pupil aperture function? (1.218)

How is retinal image modulation obtained from the modulation transfer function of the eye's optics and the light distribution of the object? (1.219)

What is done to a modulation transfer function to obtain an intensity point-spread function? (1.218)

In general, what happens to the modulation transfer function as spatial frequency increases? (1.219)

For extended light sources to be treated, with small error, as point sources, how much greater than their diameter must their distance be from illuminated surfaces? (1.104)

On the retina, what shape is the image of a point of light? (1.214)

What is the major factor contributing to the point-spread function of the eye? (1.214)

How does point spread vary with errors of focus? (1.214)

Which spatial frequencies are most affected by eye focus error? (1.639)

What characteristic of an optical system sets an upper limit to the spatial frequency that can be imaged by the system, no matter how well its aberrations are corrected? (1.218)

As the point-spread function increases, what happens to visual acuity? (1.214)

Under what luminance conditions is it likely that spherical aberration of the eye has little influence on visual acuity? (1.211)

How can the light distribution on the retina be calculated for the image of complex objects? (1.215)

What is the shape of the cross-section of a line-spread function? (1.215)

Over how wide a central region of the retina does the line-spread function remain relatively constant, and what happens to it at greater off-axis angles? (1.216)

For calculating the spread of light in an optical image, what is simpler than using diffraction equations? (1.218)

What is the major reason the eye does not image an edge as sharply as it appears in the object? (1.217)

For the image of an extended source of white light, where are colored fringes seen? (1.217)

#### *Pupillary Aperture*

What is the numerical aperture of an optical viewing device? (1.105)

What is the effectivity ratio of the eye pupil? (1.106)

Over what range of diameters may pupil size vary with illumination changes? (1.203)

What is the relationship between the real pupil and the entrance pupil of the eye? (1.209)

Why must an artificial pupil be carefully centered on an observer's natural pupil? (1.111)

What does the rotation of the eye about a point well behind the pupil do to image illuminance on the retina for devices whose exit pupil is not larger than the eye's pupil? (1.207)

#### *Effects on retinal light distribution*

To minimize spherical aberration, what should pupil size be? (1.211)

How does the size of the blur patch on the retina for a point light source vary with pupil size? (1.211)

What happens to the line-spread function as pupil diameter increases? as focus error increases? (1.215)

How does pupil diameter affect the size of the blur patch on the retina and the depth of focus of the eye? (1.221)

With large pupils, what is the cause of resolution loss at longer wavelengths? (1.606)

At what eye pupil diameter does visual acuity reach its maximum? (1.614)

#### *Effects of luminance level*

What happens to pupil diameter as scene illumination increases, and what happens at very low and very high luminance levels? (1.232)

How does the time taken for the pupil to stabilize in size compare to the time taken for the eye to light or dark adapt? (1.233)

How does pupil diameter when only one eye is illuminated compare to that when both eyes are illuminated? (1.232)

When visual acuity test patterns are viewed through small pupils, what wavelength yields the best acuity? (1.606)

When one eye is closed, how does its pupil diameter compare with the pupil diameter of the open eye? (1.106)

#### *Effects of target distance*

At distances less than one meter from an object, what happens to pupil size? (1.234)

When fixation is changed from a distant scene to an equally bright display nearby (<1 meter), by how much might the pupil contract? (1.106; 1.234)

### Visual Accommodation

How many diopters of accommodation are present when the eye is in a resting state? (1.223; 1.238)

Are differences between individuals in resting accommodation large or small? (1.223)

What happens to eye accommodation with steady fixation on a stationary target? (1.224)

For what distance is the eye accommodated when an unstructured target is all that is visible? (1.226)

What happens to accommodative accuracy with decreasing luminance? (1.228)

In dim light, what happens to the farthest and nearest distances to which an object can be focused? (1.226; 1.227)

How low must luminance levels be before night myopia occurs? (1.227)

What is the relationship between the diameter of Airy's disc and accommodation accuracy? (1.213)

For what spatial frequencies is accommodation most accurate? (1.226)

For which end of the spectrum, red or blue, does the eye have the shortest focal length? (1.212)

#### *Effects of distance*

Under conditions of low luminance, what changes in accommodation occur with change in distance? (1.226; 1.227; 1.228)

What happens to eye focus as an observer attempts to hold focus as constant as possible on a near object? (1.225)

Is fluctuation in eye focus greater for a fixated target or in the absence of a target? with a near or a far target? with monocular or binocular viewing? with large or small pupils? (1.224)

How do near-to-far and far-to-near accommodation times compare? (1.228; 1.230)

About how long does the eye take to accommodate to a slow change in object distance? (1.229; 1.230)

When a target distance changes, what is the ratio of accommodation change to distance change? (1.230)

As oscillation in distance of a far target increases in amplitude, what happens to the accommodative response relative to target position? (1.229)

If the observer must focus an object as close to the eye as possible, what color should be used? (1.212)

In an otherwise uniformly empty visual field, upon what does the apparent distance of an object depend? (1.239)

#### *Effects of monocular vs. binocular viewing*

When the eyes are fixated on a near object, how do the focus fluctuations of the two eyes compare? (1.225)

How does accuracy in accommodation compare for monocular and binocular viewing? (1.230)

#### *Effects of age*

What is the maximum range of accommodation in the young and in the very old? (1.222)

Why does the range of accommodation decrease in older people? (1.204)

#### *Relation between accommodation and convergence*

What is the ratio of accommodative convergence to accommodation (AC/A ratio)? How much larger, on average, is the observed AC/A ratio than the AC/A ratio called for by stimulus conditions? (1.231)

In the general population, how much does the AC/A ratio vary per diopter of accommodation? (1.231)

What effects on an observer may occur when accommodation and convergence are decoupled? (1.808)

### Visual Acuity

What is the assumed or nominal angular resolution in minutes of arc for normal vision? (1.602; 1.608)

Where, on the retina, is visual acuity highest, and what is the angular extent of this area? (1.201)

Excluding the blind spot, where in the eye is visual sensitivity lowest? (1.305)

For what range of pupil sizes is visual acuity highest? (1.603)

What is the common measure of visual acuity that increases in numerical value with better acuity? (1.602)

What vertical separation of lines, in arc minutes, yields best vernier acuity with natural pupils and binocular vision? (1.608)

What are some of the factors, other than observer acuity, that influence minimum separable visual acuity with resolution test patterns? (1.602)

How does visual acuity vary with viewing distance? (1.603)

At what line orientations is vernier acuity most precise? (5.801)

What is the effect of practice on visual acuity tasks? (1.603)

At what age does visual acuity peak, and at what age does acuity for intermediate and high spatial frequencies begin to decline? (1.603)

Up to what exposure time, in msec, can static visual acuity increase? (1.603; 1.613)

How does visual acuity vary with luminance for light targets on a dark background? For dark targets on a light background? (1.603)

At high levels of luminance with narrow-band illumination, how does wavelength influence visual acuity? (1.603)

Does monochromatic light or narrow-band light yield appreciably better visual acuity than white light? (1.603; 1.606)

Is visual acuity improved by using lenses that correct the chromatic aberration of the eye? (1.203; 1.212)

At what retinal location is visual acuity the greatest at low illumination levels? (1.603)

### Dynamic Visual Acuity

Is there an appreciable correlation between static and dynamic visual acuity? (1.621)

Is the fovea or the retinal periphery more sensitive to target motion? (5.203; 5.204)

How does dynamic visual acuity vary as the angular velocity of a target increases? (1.617)

How does dynamic visual acuity change with angular target velocity for horizontal and vertical target movement? (1.619)

Up to what target illumination does dynamic visual acuity improve, and how does this compare with the illumination required for good static visual acuity? (1.619)

For what angular velocities does increased illumination provide the greatest benefit? (1.619)

When an observer can anticipate the direction of motion of a resolution test pattern, what happens to visual acuity: (a) as target velocity increases, (b) as exposure time lengthens, and (c) as anticipatory tracking time increases? (1.621)

In testing dynamic acuity with a television display, how important are direction of motion and image velocity? (11.105; 11.106)

With practice, does dynamic acuity improve more for low or for high angular velocity? (1.622)

In detecting moving vehicles, how does identification vary with number of resolved scan lines per vehicle and with image velocity? (11.105)

### Spatial Frequency Resolution

What is meant by channel bandwidth in human vision, and what are three pattern characteristics for which information channels are selective? (1.652)

What range of spatial frequencies, in cycles/deg, is easiest to detect? (1.628)

As spatial frequencies become more closely spaced, what happens to ability to identify spatial frequency? (1.649)

What are three major techniques for estimating channel bandwidths for pattern orientation and spatial frequency? (1.652)

### Central vs. Peripheral Field of View

Which part of the retina provides maximum visual acuity? (1.202)

What is the fovea and how large is it in angular terms? (1.201)

Which part of the retina most effectively detects motion? (1.637; 5.203; 5.204)

When visual fixation is required, what happens to detection probability for peripheral signals? (7.406)

Is peripheral vision good for detecting small or stationary targets? (11.204)

In the retinal periphery, are slowly moving or rapidly moving stimuli more easily detected? (5.205)

In the visual periphery, is reduced visual acuity due to retinal structure or to optical image quality on the retina? (1.214)

How does contrast required for detection in the visual periphery compare with that required for foveal viewing? (7.609)

In what part of the visual field is performance best for a visual message? (11.409)

How important in display reading is semantic information from the visual periphery? (8.116)

### *Size of visual field*

What part of the total field of view can be seen by both eyes? (1.235)

What is the size and shape of a normal observer's field of view? (1.235)

Over what range of visual angle, measured from the center of the visual field, does field of view for color fall off? (1.237)

In addition to reducing the angular field of view, what are some of the undesirable effects of viewing through tubes attached to the head? (5.1102)

How does the apparent size of the visual field change as a function of background color? (1.237)

## **Luminance**

### Sensitivity to light and contrast

If a surface is inclined to incident light by an angle  $A$ , by what factor will illuminance be reduced, relative to illuminance of a perpendicular surface? (1.104)

What is the luminance profile of a visual pattern? (1.601)

What is the approximate absolute threshold of the eye in candelas per square meter? (1.013; 1.109)

What is the approximate sensitivity range of the human eye for electromagnetic radiation, in nanometers? (1.101)

What is the approximate dynamic range of rods and of cones, in candelas per square meter? (5.1001)

What limits target visibility for very dim backgrounds? (1.502)

If the luminance of a small, dim target cannot be increased, how can it be made more detectable? (1.308)

To maximize detectability of luminance increments and decrements, what should be the target size, target duration, and background illuminance? (1.403; 1.404)

In designing a system for finding and attacking ground targets from the air, what are the factors that must be considered when estimating the probability that targets will be detected? (7.607; 7.608)

In general, as viewing angle decreases, what happens to contextual information, and what does this do to the ability to separate luminance from reflectance? (11.221)

Given the display background luminance for an instrument, what amount of instrument luminance plus reflected illumination is required to obtain a working preference level for contrast and legibility? (11.102)

For medium and large surrounds, what is the preferred (most visually comfortable) surround luminance for viewing broadcast television? (11.103)

In a television display, does a small surround require more or less luminance for visual comfort than a medium or large surround? (11.103)

For small surrounds and a mean display luminance of 86 cd/m<sup>2</sup>, what is the preferred average surround luminance? (11.103)

Does loss of visibility due to glare increase or decrease with increase in ambient illumination? with decrease in glare source luminance? (10.501)

#### *Lightness and brightness*

What is the luminance factor of a surface? (1.705)

What is the difference between brightness and lightness? (1.720)

What are some of the factors that complicate brightness predictions? (1.720)

For two identical gray surfaces combined with black surfaces, which appears lighter, a gray figure with a dark background or the gray background with a dark figure? (1.714)

In general, do illusory contours or figure appear to have the same brightness as their backgrounds? (6.314)

Is the distinctness of the border between a chromatic field and an achromatic field of unequal luminance affected by the direction of the luminance contrast (i.e., by which field appears brighter)? (6.313)

When the exit pupil of an optical viewing device is larger than the entrance pupil of the eye, how does scene brightness compare with and without using the viewer? What is the case when the exit pupil of the eye is larger than the instrument's exit pupil? (1.105)

#### *Mach bands*

For a very steep luminance gradient, how short an exposure will produce Mach bands? (1.716)

For what values of the luminance gradient from dark to light do Mach bands not appear? (1.716)

#### *Contrast sensitivity*

In what part of the visible spectrum is the lowest luminance contrast required to obtain a minimally distinct border between two adjacent chromatic areas? (6.313)

What happens to contrast sensitivity with increase in ambient illumination, and at what illumination does sensitivity become relatively constant? (1.403; 6.313)

What is amplitude resolution (minimum discriminable luminance difference) for vision? (5.1001)

About what contrast is required between two adjacent areas to perceive a minimally distinct border? (6.313)

What is the formula for modulation or Michelson contrast? (6.313)

For what two types of periodic luminance pattern is Michelson contrast inappropriate? (1.601)

For a fixed target luminance, how does contrast sensitivity vary with increases in background luminance? (1.502)

When inherent (or zero range) target contrast and meteorological range are known, how can detection probability be estimated? (7.508)

What are some constraints on using nomograms derived from laboratory contrast detection data to estimate target detection range in real-life situations? (7.508)

In television display systems, what are the effects on target requisition performance of image quality measures, such as display resolution, resolved lines/target height, signal/noise ratio, etc.? (7.614)

How does target contrast affect reaction time? (9.108)

#### *Contrast sensitivity with flickering targets*

Regardless of average luminance, how does contrast sensitivity vary with flicker rate? (1.503; 1.509)

For what frequency range does temporal contrast sensitivity peak for a large uniform field? (1.505)

What happens to the peak of the temporal contrast sensitivity function for large uniform fields as luminance level decreases? (1.505)

What happens to contrast sensitivity when temporal frequency is decreased while spatial frequency is high? (1.508)

### Color

#### *Specification*

What two systems are used to define the CIE standard observer? (1.110)

How many standard deviation units on the CIE diagram correspond to a just noticeable difference in color? (1.704)

Usually, what conditions are required for good correlation between purity and saturation? (1.703)

How is color characterized when the dominant wavelength does not fall on the spectrum locus? (1.703)

#### *Sensitivity*

What is the approximate wavelength region to which the human eye is sensitive? (1.101; 1.102; 5.1001)

Over the range of visible wavelengths at high luminance, how many hues can be discriminated? (5.1001)

What can be said about the color of objects viewed under low (scotopic) light levels? (1.103; 1.301)

What limits visual sensitivity at the short wavelength end of the visible spectrum? What limits it at the long wavelength end? (1.101)

Over what range of visual angles measured from the center of the visual field does field of view for color fall off? (1.237)

In what region of the CIE chromaticity diagram are observers least sensitive to color differences? (1.704)

What percentage of males and what percentage of females have color deficiencies? (1.707)

#### *Color discrimination*

About what is the critical luminance level above which color discrimination is relatively stable? (1.705)

At very high retinal illuminance levels, at which end of the spectrum is color discrimination poor? (1.705)

As luminance decreases, for which color does color discrimination become poor first? (1.304; 1.705)

For practical work, how short can exposure be before significant loss in color discrimination occurs? (1.705)

Up to what age does color discrimination improve? (1.707)

For normal observers, a mixture of no more than how many primary colors is needed to match any hue? (1.702)

Over what range, in trolands, do color matches between metameric fields hold? (1.705)

To obtain maximum sensitivity in color matching small visual fields, what should be the chromaticity of the field surrounding the test lights? (1.705)

How do judgments of the color of textured papers compare in consistency (repeatability) with those for colored lights? (1.710)

What may happen to the distinctiveness of a border in the presence of a chromatic difference? (1.237; 1.701)

To appear equally bright, must an achromatic (gray) sample have a higher or a lower luminous reflectance than a chromatic sample? (1.303)

When adjacent to a white standard, how do yellow (560 nm) and deep red (620 nm) compare in equivalent achromatic contrast? (6.313)

In chromatic induction configurations with red/green and yellow/blue fields, as redness (yellowness) of the surrounding (inducing) field increases, what happens to the perceived redness (yellowness) of the central test area? (1.701)

What is the approximate shape of the visual field for different colors? (1.237)

How do green, blue, and yellow compare for field of view and response times? (11.204)

How much misregistration of colors in a CRT is permissible before identification performance becomes significantly poorer? Which symbol colors are best and which are worst with color misregistration? (11.126)

#### Dark Adaptation

After a period of exposure to very high levels of light, how much time is required in total darkness for complete dark adaptation to occur? (1.409; 1.411)

With increasing time in the dark, how does improvement in target detectability compare for large and small targets? (1.406)

With square-wave gratings, how long after the start of dark adaptation does resolution of coarse details continue to improve? (1.410)

#### Afterimages

After a single primary stimulus exposure, can various types of afterimages occur in sequence? (1.309)

How long, typically, do negative and complementary afterimages last? (1.309)

#### **Flicker and Temporal Changes**

How is sensitivity to rapid flicker measured? (1.501)

With a flickering sinusoidal grating, how does flicker sensitivity vary with duration? (1.501)

At what luminance level can the highest flicker rate be detected? (1.501)

In barely detectable targets, how well can flicker rate be discriminated? (1.510)

If the observer's task is to detect the fine details of a pattern, what flicker rate is least detrimental to performance? (1.509)

If the contrast of a flickering target is increased from zero, which is detected first, target pattern or target flicker? (1.509)

In what two ways can flicker sensitivity be improved when the observer views a large uniform field flickering at a slow rate? (1.506)

What happens to critical flicker frequency with time in the dark for nonfoveal targets of relatively high luminance? (1.504)

With sine-wave modulation and a flash rate  $>15$  Hz, is flicker more or less easily seen at high luminances than at low? For rates  $<15$  Hz, how does flicker visibility vary with luminance? (11.120)

For CRT displays, below what refresh rate is it generally agreed that flicker is usually quite annoying? (11.122)

What undesirable effects may occur with observers when refresh rates are between 7 and 15 Hz? (11.122)

How high must luminance be on a CRT for a user to notice flicker with a 60-Hz refresh rate? (11.122)

To eliminate flicker perception in the fovea in most electronic displays, how high should the refresh rate be? (11.122)

To eliminate flicker in the visual periphery, how high a refresh rate is required? (11.122)

How does target flicker affect fixation stability? (1.909)

## **Distortion**

### Prismatic Displacement

What are "negative aftereffects" following adaptation to a distorted presentation of the environment? (5.1101)

After adaptation to prismatic displacement has occurred, how do negative aftereffects decay? (5.1101; 5.1104)

Is adaptation to prismatic displacement both rapid and complete when error-corrective feedback is provided? (5.1101)

How quickly do observers adapt to prisms that laterally displace the visual field? (5.1103)

Is adaptation to prism displacement of the visual field ever complete? (5.1104)

Must an observer be consciously aware of prismatic displacement for adaptation to occur? (5.1104)

With prism-induced retinal image disparity, what may happen to apparent target size as the target appears to recede? (1.950)

What are typical tolerances for prism-induced image disparity? (1.950)

How rapidly does adaptation to loss of visual position constancy decay after removal of the source of distortion? (5.1120)

### Underwater Effects

What color is poorest for color coding under water? (5.1124)

What colors are most visible in turbid (muddy) water? cloudy water? clear water? (5.1124)

What happens to stereoacuity under water? (5.1124)

Is motion across the line of sight under water underestimated or overestimated? (5.1124)

At and beyond what underwater distance are distances overestimated? (5.1124)

What happens to apparent size of both far and near objects under water? (5.1124)

What type of image displacement occurs when objects are viewed through a face mask at an angle other than 90 deg? What different displacement occurs because the index of refraction of water is about a third higher than that of air? (5.1124)

Upon entering the water wearing a facemask, do experienced divers initially judge object size, curvature, and distance more accurately than do novices? Is initial judgment due to adaptation? (5.1125)

Why is visual position constancy lost under water? (5.1124)

With head and eye movement under water, does the environment appear stationary, as it does in air? (5.1124)

### Adaptation to underwater distortion

Under what condition does adaptation occur to underwater viewing with a face mask? (5.1101)

With underwater viewing through a face mask, how quickly does an observer adapt to distortion of perceived size, distance, and curvature caused by the mask? (5.1125)

Is adaptation to underwater distortion as rapid with massed practice as with spaced practice? (5.1126)

Is adaptation to underwater distortion as rapid with free swimming as with underwater games? (5.1126)

How does amount of adaptation to underwater distortion compare for terminal exposure and concurrent exposure? (5.1126)

Do novices show as much adaptation as experienced divers? (5.1126)

### Magnification/Minification

In designing an optical system to be used in tasks where little distortion can be permitted, will a horizontal or vertical distortion of 1% or less be noticed by an observer? (6.311)

What does overall (or uniform) magnification in one eye do to relative image orientation? (5.907)

Under what conditions may spectacles cause aniseikonia? (5.909)

What problems can be caused by magnification differences in the two eyes? (5.909)

Along what directions does vertical magnification in one eye produce spurious horizontal disparities? (5.907)

Is there adaptation to the optical minification of objects viewed in a convex mirror? (5.1122)

With either a rotation or a magnification difference between the eyes, what happens to angular misalignment as off-axis angle increases? (1.813)

### Visual Aftereffects

What are the potential aftereffects of exposure to visual displays? (6.320)

Typically, do contingent aftereffects require short or long adaptation periods, and are they difficult to produce? (6.320)

With long exposure to periodic targets, such as gratings, does the spatial frequency of a test target that is lower in frequency than the inducing target appear to be raised or lowered? (6.319)

### Subjective Contours

Are subjective contours more or less apparent with low-pass spatial frequency filtering? (6.314)

Can subjective contours mask real contours? (6.314)

## **Eye/Head Movement Dynamics**

### Visual Fixation

#### *Spatial factors*

How far, in degrees of visual angle, does the foveal area of the retina extend around the visual fixation point? (8.116)

Can an observer maintain eye position with ease in the absence of a visual signal? (1.915)

About how many microsaccades occur per minute during fixation? (7.505)

What is the optimum angular subtense of a display for most efficient eye fixations? (7.315)

For displays with less than what angular subtense does the percentage of eye fixations falling outside of the display markedly increase? (7.315)

#### *Temporal factors*

Does drift (excursion) of eye position from a fixation point increase with time? (1.912)

What is the approximate length of the shortest eye dwell time in real-life situations? (7.313)

What happens to the duration of the average eye fixation as the size of a visual display increases? (7.315)

In fixating a remembered target location in the dark, does fixation error increase with time in the dark, and does variability increase? (1.911)

What is average eye fixation duration for all signal bandwidths? (7.317)

How does target flicker affect stability of eye fixation? (1.909; 1.915)

#### *Effects of luminance and wavelength*

How does the eye behave if a fixated target is too dim to be perceived in the fovea but not in the periphery? (1.909)

How should an observer fixate on a light that is too dim to be seen clearly? (1.916)

When an observer attempts to fixate a static point, what three types of unintentional eye movement may occur? (1.914)

When illumination is below the photopic (daylight vision) level, what happens to voluntary control of eye movements? (1.915)

What is the maximum effect (in arc min) of color on eye fixation? (1.915)

Maladaptive (fovea-centering) eye movements generally occur with light too dim to be seen clearly; for what color of light does this not happen? (1.916)

For both dim and very dim target discs, do the majority of intersaccadic drifts move away from or toward the fovea? (1.916)

#### *Effects of target information content*

What three factors affect fixation region? (7.505)

Are eye fixations more frequent on display areas containing higher information density? (7.505)

In reading, what is the average duration of eye fixations? (8.116)

### Vergence

What is the formula for convergence angle? (5.905)

What, in degrees, is resting convergence for most people? (1.808)

How is convergence in diopters obtained from convergence in radians? (1.808)

Beyond what distance does convergence change very little with object distance? (1.808)

With normal viewing conditions, do the eyes sometimes diverge past parallel? (1.808)

Does the parallelism or convergence of the eyes change during vergence/conjugate eye movements? (1.905)

Do both eyes always move in the same direction (conjugate motion) for abrupt eye motions? (1.906)

Up to what frequency do slow vergence movements increase with changing (oscillating) retinal disparity? (1.949)

With identical targets in each eye, up to how large a lateral target disparity elicits vergence eye movements? (1.950)

In the disparity range of 0.5-1 deg, how rapidly are vertical compared to lateral disparities corrected by vergence eye movements? (1.950)

In the peripheral retina, do vertical and lateral disparities cause symmetrical or asymmetrical vergence responses of the two eyes? (1.954)

Can target lines of disparate length elicit vergence movements? (1.952)

Can target lines of unequal luminance elicit vergence movements? (1.952)

How small a vertical target disparity will be corrected by vergence eye movements? (1.950)

Can a vertical disparity too small to induce diplopia (0.5 min arc) initiate vergence eye movements? (1.955)

### Tracking Eye Movements

Is pursuit motion of the eyes dependent upon perception of motion? (1.947)

In general, are eye movements in tracking highly efficient? (1.946; 1.959)

Under what conditions is motion seen during pursuit eye movements? (5.202)

Can an observer easily engage in smooth pursuit when no target is present? (1.915)

Are involuntary anticipatory pursuit eye movement responses suppressible? Can they be produced under conditions of no target motion? Do they improve with practice? (1.948)

### *Latency*

With unpredictable target movement, what is the approximate lag between major changes in target velocity and changes in tracking velocity? (1.906)

How soon before target motion do anticipatory eye movements begin? (1.939)

Can anticipatory eye movements during eye tracking be voluntarily suppressed, and does their occurrence vary with experience on the task? (1.939)

When an observer expects a target to move, is there a small lag after target movement before the eyes begin to move? (1.948)

When a previously stationary target begins to move horizontally at a constant velocity, by how many milliseconds will pursuit eye movement lag behind the target? (1.942)

### *Accuracy*

When tracking a target, for what target speed (in deg/sec) can observers not accurately match or exceed a required fraction of actual target velocity? (1.945)

When observers are asked to match eye to target velocity, what percentage of target velocity will eye velocity actually be? (1.945)

Does quality of smooth pursuit tracking differ when observers actively control target movement and when they do not? (1.946)

What type of eye movements occur with unpredictable target movement? (1.906)

With increased target predictability, does phase lag increase or decrease? (1.959)

Do synchronization of the two eyes and fixation stability change as excursion and movement frequency increase? (7.505)

How does eye tracking proceed with a constant target velocity within a range of 25-30 deg/sec, and what may be required for velocities >30 deg/sec? (1.906)

How does overall gain in smooth-pursuit tracking compare for between foveal targets and targets 5-7 deg below the line of sight? (1.941)

### *Effects of luminance*

Does a change in the contrast of predictable moving targets cause a change in smooth-pursuit velocity? (1.915)

What effect does target luminance have on the gain of tracking eye movements, and what happens to phase lag as target luminance decreases? (1.941)

For clearly visible targets, does the relationship of eye movement to target displacement vary much with target luminance? (1.959)

When target luminance is too low for foveal detection, what happens to visual tracking? (1.959)

### *Effects of practice*

Is tracking of targets below the line of sight difficult without practice, and do subjects perform well? (1.941)

Does training readily improve performance on a task in which observers must move their eyes in a direction opposite to target movement? (1.937)

How do errors compare for tasks in which eye movements must be in the same direction and in the opposite direction as target motion? (1.937)

## *Saccadic Eye Movements*

### *Latency*

What are some factors that affect differences among observers in latency of saccadic eye movements? (1.906; 1.932; 1.935)

About how many milliseconds are there between the termination of a saccade and the "point of no return" for the next saccade? (8.115)

How long before initiation of a saccade must it be programmed, and how long thereafter can it be modified? (8.116)

Does wavelength (color) affect saccadic latency? (1.915)

What happens to saccadic latency as contrast increases? (1.915)

Do righthanded people respond more quickly with rightward or leftward saccades? (1.932)

What is the minimum interval between light onset and the initiation of abrupt saccadic movement? How long do eye movements persist after cessation of target motion or the disappearance of a light? (1.906)

### *Accuracy*

During active search, what purpose is served by saccadic eye movement? (7.505)

Is there a systematic relationship between saccade speed and accuracy? (1.935)

At the end of each saccade, with what velocity, in arc minutes/sec, do the eyes drift toward the primary position? (1.931)

Do normal voluntary saccades generally overshoot or undershoot their mark? (1.933; 1.935)

If a target disappears late in the course of the first saccade, does the eye next move to the intended (or predicted) target position? (1.932)

Can successive saccades be executed with reasonable accuracy based on remembered target locations? (1.931)

When a target appears during free search of a visual field, is one or more than one saccade usually required to center the target on the fovea? (1.935)

In reading, what is the average length of a saccade? (8.116)

Generally, does the number of different targets have an effect on saccade initiation? (1.932)

When visual fields have no fixation positions, are saccades between remembered target points similar for dark versus illuminated fields? (1.931)

In making saccades between remembered target positions, how do movement durations and velocities with eyes closed compare with those in the dark? (1.931)

### *Effects of fatigue*

Are large saccades more fatiguing than small ones? (1.908)

After how many very large (50-deg) or large (30-deg) saccades will an observer be incapable of making normal saccades? (1.908)

Do changes from smaller to larger saccades temporarily restore saccade accuracy when the observer is visually fatigued? (1.908)

With visual fatigue, do more or fewer saccades have a dynamic overshoot, and are more saccades present with abnormally large dynamic overshoot? (1.908)

### *Effects of practice*

Does initial eye movement latency improve with practice in fixating an object on a retinal area other than the fovea? (1.909)

Does practice reduce overall saccadic latency or errors? (1.935)

### *Predictability*

For a given observer, are the angular size and duration of saccades predictable? (1.935)

What happens to secondary saccades when a spot to be fixated disappears before the primary saccade ends? (1.935)

If observers are cued in advance to locations where targets may appear, do speed and accuracy of initial saccades increase relative to no cueing? What happens to speed and accuracy if cues are not accurate? (1.935)

For both normal saccades and the small corrective saccades which generally follow them, how does peak velocity of a saccadic eye movement vary as a function of saccade length? (1.933)

With step motion of a target, is the response always saccadic eye movement? (1.906)

Is proximity a more powerful factor than contour and movement in determining the first saccade? (1.934)

### *Microtremors*

During search of a display, what is the amplitude in arc sec and velocity in deg/sec of microtremors? (7.505)

### *Rotational Eye Movements*

When the eye moves, where is its center of rotation? (1.206)

How many of its three degrees of rotational freedom does the eye use, i.e., how many parameters fully describe eye position? (1.903)

With optically unaided (naked eye) viewing, about how many degrees from straight ahead may the eye rotate with comfort? (1.207)

With head tilt, how does average amplitude of ocular torsion compare with average horizon displacement? (5.803)

What two distinct types of rotational eye movement occur when an observer tilts the head laterally in a steady, uniform manner? (1.959)

Do cyclofusional eye movements completely compensate for a difference in tilt of left- and right-eye images? (1.956)

### *Eye-Head Movement Coordination*

At all vibration frequencies, how do mean eye-in-space displacements compare with head-in-space displacements? (10.418)

Why may head translation induce eye rotation? (10.418)

Up to what vibration frequency is translational eye vibration nearly the same along all three axes as head vibration? (10.418)

What must occur with head rotation for the retinal image to be stabilized? (1.928)

When observers rotate their heads while fixating a distant target with both eyes, up to how many deg/sec does retinal image position between the eyes change? What is the average retinal image speed within each eye? (1.913)

Is eye movement compensation for head rotation the same for both eyes, and is it accurate when observers rotate their heads while fixating a distant target with both eyes? (1.913; 1.958)

What is suggested by the fact that the amplitude of ocular countertorsion is a function of the sine of the angle of head tilt? (1.957)

What type of eye movement accompanies neck rotation? (1.958)

When the head is tilted in a gravitational field, why do the eyes undergo torsional movements? (1.959)

What happens to visual position constancy when optical or other devices disrupt the normal relationship between head (or eye) motion and the resultant retinal image motion? (5.1120)

### *Optokinetic Response*

In a normal environment, are vestibular and optokinetic nystagmus congruent in direction and magnitude? (1.918)

What happens to the velocity of a pursuit eye movement with sudden exposure to a moving surround? (1.924)

How do the gains of optokinetic nystagmus and optokinetic after-nystagmus compare? (1.924)

What are the approximate values of the rise and fall time constants of optokinetic after-nystagmus? (1.924)

### *Vestibulo-Ocular Response*

#### *Dynamics*

What is the gain of the vestibulo-ocular reflex? (1.917)

What is the time constant of the primary vestibular input to vestibular nystagmus? (1.918)

How are the directions of head and eye movement related in the vestibulo-ocular reflex? (1.917)

For what vibration frequencies does the vestibulo-ocular reflex stabilize the eye in space? (10.418)

Above what head rotational velocity is compensation for velocity rather poor? (1.917)

At low frequencies ( $<3$  Hz), does predictability of motion aid eye compensation for motion? (1.917)

What, approximately, is the maximum slow-phase velocity of the vestibulo-ocular reflex? (1.922)

For head rotation velocities of  $>200$  deg/sec, what happens to quick-phase velocity? How long does the quick phase last? (1.922)

When an observer in the dark is not alert, what happens to the gain of compensatory eye movements? (1.926)

During rotation, are changes in gain specific to the plane within which visual information is distorted? (1.926)

For active rotational oscillations of the head that require a 36% change in gain, how long does it take for complete gain adaptation? (1.926)

Why must the gain of compensatory eye movements be varied when the head rotates? (1.926)

How does the amount of compensatory eye rotation (or gain of vestibular nystagmus) required to stabilize retinal image motion compare for near and distant objects? (1.928)

What is the mean adaptive time constant underlying the time course of declining nystagmus under constant acceleration (adaptation) and secondary nystagmus? (1.930)

What eye movement accompanies ferris-wheel rotation of the head and body about a horizontal axis? (1.958)

#### *Visual suppression of vestibular nystagmus*

Will visual suppression of vestibular nystagmus increase or decrease when continuous illumination is made intermittent? (1.918)

Is visual suppression of nystagmus greater in the pitch plane for forward or backward pitch? (1.918)

How does visual suppression of vestibular nystagmus in the yaw plane vary with frequency? (1.918)

Should the target image be moved to the retinal periphery to lessen visual suppression of vestibular nystagmus? (1.918)

What visual problems are caused by incomplete suppression of vestibular nystagmus? (1.920)

Is visual suppression of vestibular nystagmus greater when leaning the head forward or leaning it backward while rotating about a vertical axis through the head? (1.919)

When the head rotates sinusoidally about a vertical axis at a sinusoidal frequency of 0.2 Hz, does an observer have difficulty reading digits on a display? (1.920)

#### *Effects of attention*

Does relaxed attention weaken or strengthen vestibular nystagmus? (1.929)

Does increased mental alertness affect the duration of nystagmus? (1.923)

If a target must be visually fixated, is vestibular nystagmus weakened or strengthened during a mental arithmetic task? (1.929)

#### *Reverse nystagmus*

In an aircraft, when may reverse nystagmus occur? (1.921)

Is there a large discrepancy between actual and required angular eye velocity for retinal image stabilization in the roll plane, and how does the discrepancy change during rolling? (1.921)

How can a pilot minimize the effects of rotation in the roll plane? (1.921)

During aircraft spin, how well can the pilot visually follow in the pitch plane? (1.921)

At the time of aircraft recovery from a roll, what happens to angular eye velocity in the roll plane? (1.921)

How much reverse nystagmus occurs in the yaw plane on recovery from aircraft spin, and what is the presumed reason? (1.921)

What probably counteracts the reverse nystagmus for pitch and yaw after aircraft spin? (1.921)

Is roll after-nystagmus counteracted, is it substantial, and what may it cause the pilot to do? (1.921)

#### *Postrotary nystagmus*

How long must the head be rotated at a constant velocity for postrotary nystagmus to occur on cessation of rotation? What is the result of this nystagmus on compensation? (1.923)

How does duration of postrotary nystagmus vary as a function of angular head velocity? (1.923)

Is duration of postrotary nystagmus appreciably decreased by fixating a stationary target? (1.923)

Does tilting the head to the side after rotation of the body increase or decrease the duration and gain of postrotary nystagmus? (1.923)

Does practice reduce nystagmus intensity? Do subjective measurements of its duration change? (1.923)

## **Vibration**

### *Transmission of Vibration*

Over what frequency range is vertical transmission of vibration through the torso greatest? (10.406)

How do seating conditions affect transmission of vibration to the body? (10.401)

At frequencies  $>5$  Hz and  $<60$  Hz, what does contact with seat back and shoulder strap do to head motions? (10.401; 10.406; 10.407; 10.408)

What is the frequency range containing significant motion in vibration environments? (10.402)

With atmospheric turbulence, for which frequencies do particularly high vibration acceleration amplitudes occur? (10.403)

The translational cockpit vibration spectrum typically compromises what frequency range? (10.403)

With ships, how many z-axis frequencies are typical? (10.426)

For frequencies below 4 Hz, is vertical transmission of vibration to the head increased or decreased by a relaxed posture? (10.406)

Above 5 Hz, is vertical transmission of vibration to the head increased or decreased by a stiff upright posture? (10.406)

In what frequency range does seat vibration cause the maximum vertical head vibration? (10.406; 10.407)

By how much may the amplitude of pitch head vibration be increased by x-axis seat vibration? (10.408)

At which frequencies do fore-and-aft seat back vibrations induce significant pitch-axis head vibration? (10.408)

Below what frequency is the head well isolated from lateral (y-axis) seat motion? (10.408)

### Effects on Visual Performance

How do sinusoidal and random vibrations of the same root mean square amplitude compare in effects on visual performance? (10.409)

What is the effect on visual performance of vibration of the display compared with vibration of the observer? (10.409)

Will collimating a display reduce effects on vision of translational motion of eye or image? (10.409)

Above what frequency is visual detection of target vibration independent of vibration frequency? (10.410)

At a constant viewing distance, how does average vibration acceleration for perceiving blur vary with vibration frequency? (10.410)

During whole-body vibration, what causes reduced visual performance? (10.417)

Above what frequency of vibration will display collimation not be beneficial? (10.417)

With a collimated helmet-mounted sight or display, are the vibration amplitudes in pitch and yaw of the helmet in an aircraft sufficient to affect observer performance? (10.419)

### Effects on Visual Display Legibility

Under conditions of vibration, upon what does reading performance depend? (10.402)

When luminance contrast is high ( $> 90\%$ ), what may happen to reading performance during vibration? (10.409)

Under vibration conditions, does increased angular display size aid vision? (10.409)

For observer-only vibration at high frequencies, in what frequency range is display legibility loss greatest? (10.411)

What is the form of the functional relationship between vibration magnitude and reading errors for all but characters of large angular subtense? (10.413)

During vertical whole-body vibration, by how many horizontal character widths should small-subtense characters be separated to optimize display legibility? (10.409; 10.414)

Do a large number of pixels in a symbol aid reading speed, with or without vibration? (10.415)

With and without vibration, are Huddleston and Lincoln Mitre fonts read equally fast? (10.415)

What luminance contrast and symbol size yield minimum reading errors during vibration? (10.416)

What is the mathematical relationship between reading errors and luminance contrast with vibration? (10.416)

Under vibration conditions, do reading errors increase for characters with larger amounts of high-spatial-frequency information? (10.435)

## **Visual Information Representation and Coding**

### Size

What is the advantage of using visual angle or angular subtense rather than linear measurements to describe the size of objects? (1.240)

When the line of sight is not along the optical axis of a spectacle lens, what happens to image size and apparent location of objects? (1.206)

What two elements provide a means of specifying the size, shape, and distance to any object in a scene? (5.105)

Does the height of the horizon, relative to an observer, influence size perception? (5.108)

Under reduced viewing conditions, does the subtended visual angle of an object influence size and distance judgments? (5.104)

Do observers tend to underestimate, accurately estimate, or overestimate objective and projective size? (5.104)

In a diving attack on vehicles, how does target detection vary with target image size (or distance) and aircraft speed? (11.106)

What is the effect of element size in reading alphanumeric with pixel element displays? (11.114)

### Shape and Slant

In judging perceived slant, do observers make judgments that appear to obey the rules of projective geometry? (5.113)

In estimating the slant of surfaces with texture, do observers underestimate, accurately estimate, or overestimate slant? (5.116)

With a constant element spacing on a textured surface, how does perceived slant vary as element size increases? (5.116)

Is slant judged more accurately for surfaces with regular or irregular texture? (5.116)

What is the magnitude of the correlation between perceived slant and perceived shape? (5.113)

Does shape discrimination vary systematically with area and illumination of forms? (6.311)

## Orientation

Does target detection vary with target orientation? (1.624; 1.634)

What is one reason why patterns that differ only in orientation may not be readily identifiable? (6.309)

How precisely can an observer set a luminous line in the dark to the vertical or horizontal? (5.801)

What happens to the visual vertical as the head is tilted backward? (5.801; 5.802; 5.803)

How is the visual vertical influenced by returning the tilted head or body to an erect position after prolonged tilt? How do head and body tilt effects compare? (5.801)

How long after tilting the head for a prolonged time and then returning to vertical does the effect on the perceived vertical increase? (5.802)

What is the maximum advisable tilt from perpendicular to the line of sight of a television display screen when alphanumerics have to be read? (11.109)

## Grouping

With familiar versus unfamiliar groupings, how do speed and accuracy in determining number of objects in view change? (7.523)

What are five Gestalt principles for predicting which elements of a display will be perceived as figure and which as ground? (6.301)

How does the size of an area influence preference for seeing it as figure, rather than ground? (6.301)

## Color

By how many degrees do the optical and visual axes of the eye differ? What does this angular deviation do to the apparent distances of objects of different color? (1.209)

When display density is high, what is the advisable maximum number of color code levels? (7.513; 11.329)

In a system that displays television imagery of terrain, symbols are to be overlaid on the scene via computer to represent objects of various types. For these conditions, will the use of colored symbols enhance operator speed in finding targets? (7.519)

For what color stimuli is the visual field widest and response time shortest? For what color is the field narrowest and response time longest? (11.204)

As ambient illumination level increases, what happens to reaction time and color-naming errors for signal lights? (11.406)

How does reaction speed to red and green signals compare with that to yellow and white signals? (11.406)

What are recommended colors for alerting or advisory signals? (11.401)

How do response times compare for compatible and incompatible control-display arrangements? Is color coding of lights and switches recommended for either condition? (11.206)

In an alphanumeric display for use in a high ambient light environment, how do red LED characters compare with green ones of equal luminances in accuracy of character identification? How do larger, less luminous elements compare with smaller, more luminous ones? (11.123)

In selecting pointer, background, and panel lighting colors, which color combinations yield highest accuracy in reading with various lighting conditions? (11.125)

In designing a circular dial, is it useful to add color contrast to a dial of a given achromatic contrast when using (1) light symbols on a dark background and (2) dark symbols on a light background? (11.124)

(See Also: Color Sensitivity)

## Depth

*Cues to depth*

How good a depth cue is eye convergence? (1.808)

What factors can characterize perspective structure in a display? (5.105)

How does vertical position influence distance perception? (5.901)

When a moving observer is attempting to judge relative distances by using motion parallax, what is the function of visual fixation point? (5.902)

With central vision, what distance cue is dominant up to 6.4 meters? (5.904)

How do highlights and shading, respectively, indicate the surface configuration of objects? (5.901)

How can surface texture aid in depth discrimination? (11.221)

With a moving target, what happens to apparent position of the target in depth when luminance is different in the two eyes? (5.931)

For static peripheral viewing, up to what distance are stereoscopic cues effective? What is the dominant cue at longer distances? (5.904)

What are the response limits for lateral disparity? (1.952)

For observers with excellent stereoacuity and widely spaced eyes, up to what distance is retinal image disparity an effective depth cue? (5.905)

Under what natural viewing conditions do vertical retinal image disparities arise? (5.906)

How high can retinal disparity be, when eye movement is restricted, before judged target depth departs from predictions based on parallax geometry? (5.916)

At large retinal image disparities where targets are seen as double and accurate depth judgments are not possible, what judgments can be made, provided stereoscopic depth perception is still possible? (5.930)

Are hysteresis effects as pronounced for vertical disparity as for horizontal disparity? (5.937)

*Stereoacuity*

What stereoacuity tests are commonly available? (5.917)

Above what illumination level is stereoacuity at a maximum? (5.918; 5.919)

How rapid can motion in depth be before reducing stereoacuity? (5.918)

What effect on stereoacuity is caused by the presence of depth reference cues? (5.922)

Are results similar for stereoacuity when measured with stereoscopic targets and with real objects? (5.917; 5.929)

## **Motion**

### *Motion detection*

How does sensitivity to vertical-axis movement compare with sensitivity to horizontal-axis movement? (5.206)

In general, is motion detection improved more by increasing illumination or by increasing target exposure time? (5.207)

When a moving pattern has no unique parts, what may be the effect upon detection of motion direction? (6.316)

### *Apparent motion*

What conditions of flash duration, temporal separation, and spatial separation induce apparent motion? (1.938; 5.401; 5.402; 5.403)

Is there a consistent tendency to see apparent motion between elements of like configuration? (5.402)

In apparent motion where several paths are possible, how important to path selection are feature properties of stimulus elements? (5.402)

In stroboscopic motion, how does critical sampling frequency vary with velocity? (5.404)

### *Relative motion*

What is the least discriminable angular velocity difference between two moving objects? (5.203)

Does the presence of reference stimuli improve detection of object-relative motion? (5.203)

For a target moving against a textured background, what is the minimum detectable angular velocity and how does it compare with that against a featureless or dark background? (5.201)

For target paths of equal length, can observers accurately match target velocities? (5.203; 5.210)

When optical flow arises from observer motion, how does an object's flow vary with its distance from the observer? (5.502)

From what point does the optical flow appear to expand outward? (5.502)

For simulated aircraft landings, how much assistance in determining aim point is provided by the optical flow pattern? (5.102)

In simulated aircraft landings, what pilot judgment (distance, height, or glideslope angle) is affected by amount of detail in visual scenes? Is judgment better with more scene details? (5.103)

Can linear motion of the visible environment, such as a moving or swinging room, induce self-movement? (5.501)

### *Collision prediction*

When an object is approaching from straight ahead, does amount of error in estimating collision time vary with approach velocity? (5.214)

When observers must judge the probability of collision of two objects on intersecting paths, and one path is occluded before the intersection point: (a) What type of object motion yields the most accurate prediction? (b) Is prediction accurate when one object rapidly slows down? (c) When one target is slowing down or speeding up, how is predicted collision time affected? (5.213)

When two small aircraft are on a collision course, does the probability of one aircraft's detecting the other increase or decrease as crossing angle increases? (7.613)

## **Text**

### *Dialogue design*

What are some special recommendations for the design of formal query languages relative to (1) layering, (2) semantic confusion, and (3) term specificity? (11.315)

In designing a query language, what are some general recommendations for (1) data organization, (2) quantifiers, (3) query feedback, (4) abbreviations, and (5) dialogue transaction? (11.315)

What are some special recommendations for the design of informal query languages relative to dialogue clarification and use of quasi-natural language? (11.315)

What are some considerations in designing sequence control for dialogue? (11.319)

What are some guidelines for error detection, message design, and error correction? (11.320)

In presenting data in person-computer dialogue, what are some recommendations for (1) display of text data, (2) display of alphanumeric data, (3) multicolumn displays, and (4) grammatical style? (11.326)

In presenting numeric data, what are some recommendations for formatting numerical information to facilitate comprehension and comparison of the data by the user? (11.325)

In presenting tabular data, what are some guidelines for (1) formatting data into lists, and (2) justification of lists? (11.327)

### *Character font size and spacing*

What is the probability of correctly reading alphanumeric and geometric symbols on CRT and large-screen projected displays with different modular organizations, exposure times, and visibility? (7.109)

Do 5x7 and 7x9 pixel symbols produce an equal number of errors and equal reading speed? (10.415)

What is the minimum vertical symbol resolution, in TV lines, required for high accuracy in character recognition and how does accuracy vary with angular size of characters? (11.108)

For CRT alphanumerics, what is the maximum allowable off-axis viewing angle? the recommended minimum number of TV lines per character? the recommended minimum angular subtense of characters? How does bandwidth influence legibility? (11.109)

What is the preferred resolution for television-displayed characters in terms of scan lines per symbol height? (11.111)

What stroke widths relative to character width of symbols on television are best for legibility (accuracy) and reading speed? (11.112)

On fixed displays of alphanumeric characters, what range of active area (i.e., element size/inter-element spacing), is acceptable in unstressed conditions? What range is acceptable in difficult viewing conditions? (11.115)

With dot-matrix displays, how does text reading rate vary with the ratio of element size to element spacing? (11.116)

With and without vibration, are Huddleston and Lincoln Mitre fonts read equally fast? (10.415)

Do a large number of pixels in a symbol aid reading speed, with and without vibration? (10.415)

### *Reading*

How does the shape of elements (dots) in a pixel display influence search time and reading time, and what shape is best? (11.207)

What are the characteristics of eye fixations and saccades text reading? (8.101)

In reading, what is the average duration of eye fixations? (8.116)

During reading, as viewing distance increases, what happens to fixation duration? (8.111)

In reading, how does eye fixation duration compare for long and short words? (8.113)

In reading, does average number of eye fixations per word increase with word length? (8.114)

When reading, do saccades generally fall on blank spaces? (8.116)

### *Pictures vs. words*

How do pictures and words compare as to speed with which they can be categorized? (8.106)

On the average, can a presented picture be named as rapidly, as a presented printed word can be pronounced? (8.106)

### **Numeric Representation**

For scales with various spacing between numbers, what is the approximate number of graduation marks above which reading errors no longer appreciably decrease? (11.212; 11.214)

For a circular dial, is accuracy maximized during interpolation by a large number of minor graduation marks? (11.215)

How much time is required to read semi-circular scales and what accuracy can be expected? (11.216)

How much time is required to read counters and what accuracy can be expected? (11.217)

What are the design guidelines for graphic presentation of (1) labels, (2) axis subdivisions and scales, (3) displayed values, (4) symbols? (11.328)

## **Binocular Displays**

### **Binocular vs. Monocular Vision**

What is probability summation in vision, and what does it imply? (1.801)

How do contrast sensitivity, detection of weak lights, visual acuity, and form recognition (in simple displays) compare for binocular versus monocular vision? (1.801)

Under binocular rather than monocular viewing conditions, how much does contrast sensitivity improve? (1.802)

When the luminances in the two eyes' visual fields are very different, what is the effect upon binocular brightness? (1.803)

How do monocular approaches to landing an aircraft compare in height and in steepness to binocular landings? (5.101)

How does workload compare for monocular and binocular aircraft landings? (5.101)

How does relative accommodation compare for monocular and binocular viewing with a target oscillating in depth? (1.229)

How does pupil size with both eyes stimulated compare with pupil size when only one eye is stimulated? (1.232)

### **Geometrical Considerations**

What is the range of interpupillary distances (IPD) found in the adult population? (1.208)

What happens to interpupillary distance when looking into an instrument whose optical axes diverge so that the eye axes must converge? (1.208)

In using an optical device with an exit pupil, where should the exit pupil of the device be located relative to the eye? (1.209)

What is the formula for convergence angle? (5.905)

How is convergence in diopters obtained from convergence in radians? (1.808)

### **Image Alignment**

What conditions produce binocular rivalry? (1.804)

Under what conditions may binocular suppression occur? (1.807)

When the images in the two eyes are too far out of alignment to permit fusion, what may happen to target appearance? (1.813)

What are the maximum recommended tolerances, based on comfort in use, for vertical and horizontal misalignment? for eye convergence and divergence? (1.813; 5.911)

With axial misalignment of a binocular device, how does alignment vary over the field of view? (1.813)

What is the largest recommended vertical disparity for displays? (5.906)

Is double vision (diplopia) due to vertical disparity more disturbing and uncomfortable with complex or real scenes than when backgrounds are homogeneous? (5.906)

When targets appear double due to large image disparity, does ability to accurately localize targets in depth cease? (5.930)

How does the maximum tolerable rotational misalignment of a stereoscopic display compare for displays with almost no details and for displays with considerable detail? (5.913)

In a stereoscopic display, how does tolerance for rotational misalignment vary with target size? (5.913)

Can the two eyes rotate relative to each other to compensate for rotational misalignment of stereoscopic displays? (5.913)

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## Auditory Displays

### Speech Intelligibility

#### Message Context

In a noisy situation, can context aid message reception? (7.208)

Under difficult listening conditions, why are sentences more intelligible than isolated words? (8.301)

In noise, does the recognition of common words exceed that of rarely used words? (8.308)

Are effects of the recognizability of words due to commonality and to word length independent or dependent? (8.308)

#### Speech Interruption

What happens to the intelligibility of interrupted speech as the speech-time fraction increases? (8.402)

#### Age

At what age does speech perceptibility begin to markedly decline? (8.401)

#### Speech Level and Playback Speed

For a high-quality communication system, how much dynamic range is needed, and how much is sufficient for practiced talkers and listeners? (8.203)

What is the speed range over which recorded speech can be played back with little effect on intelligibility? (8.404)

#### Signal-to-Noise Relationships

What happens to speech intelligibility when speech level exceeds 100 dB? (8.305)

How does recognition of speech vary with signal-to-noise ratio? (8.305)

For speech in noise, how much improvement in intelligibility can be expected with increased vocal force? (8.312)

#### *Phase*

Putting speech out of phase in the two ears without altering noise is equivalent to increasing speech power by what amount? (8.314)

Up to how much is word intelligibility improved by having signal or noise 180 deg out-of-phase in the two ears rather than in phase? (8.314)

#### *Spatial Separation*

What spatial separation of signal and noise sources yields best intelligibility? (8.314)

How does accuracy in responding to one of two simultaneous auditory messages vary with spatial separation of the messages? (7.210)

How does speech intelligibility compare when speech and noise appear to arise from the same location and when they seem to arise from different locations? (8.314)

#### *Masking characteristics of noise*

What kind of noise is the best masker for speech? (8.306)

In general, does high-frequency noise mask the low-frequency components of speech? (8.306)

When noise is more intense than speech, which is the better masker, low-frequency or high-frequency noise? (8.306)

When noise is less intense than speech, which is more effective as a masker, low-frequency bands, or midrange to high-frequency bands? (8.306)

For a speech message, is a speech distractor more or less effective than noise? (8.307)

#### Earplug Use

For very high noise levels, do earplugs aid intelligibility? (8.312)

For noise that raises the signal threshold at least 60 dB, do earplugs increase speech intelligibility? (8.316)

For relatively quiet conditions, do earplugs decrease intelligibility of speech? (8.316)

How much can earplugs designated for a specific noise spectrum aid intelligibility? (8.316)

At all signal-to-noise levels in a reverberating room, at what noise level do earplugs aid rather than hinder speech intelligibility? (8.316)

### Techniques for Improving Speech Intelligibility

What are seven methods to improve the intelligibility of speech in noise? (8.304; 8.312)

Does use of a smaller set of words (vocabulary or alternatives) increase intelligibility in noise? (8.309)

For speech in noise, how much improvement in intelligibility can be expected with repetition? (8.312)

Is intelligibility affected when speech is clipped after it is mixed with noise? (8.313)

How much of the speech wave can be clipped off before listeners fall below 90% correct identification of isolated words? (8.313)

In quiet conditions, up to how much peak clipping can occur without decreasing intelligibility? (8.313)

Does having the noise and speech come from different locations aid intelligibility? (8.315)

## **Speech Processing**

### Characteristics of Speech Signals

What are two ways of describing a spectrum envelope of speech? (8.201)

In speech analysis, which acoustic invariants are sought? (8.201)

Can individual components of speech be isolated by a spectrum envelope? (8.201)

In speech, most of the energy falls below what frequency? (8.201)

At frequencies over 600 Hz, what happens to speech energy as frequency increases? (8.204)

What is the frequency range in which the intensity of human speech is greatest and in which 300 Hz band is speech energy concentrated? (8.204)

At 1 m from a talker, what is long-term RMS speech pressure in dB for whispering and for shouting? (8.203)

At 1 m from a talker, what is the dB range from minimum normal level to maximum normal level for peak instantaneous levels, and how much does it vary across talkers? (8.203)

Which sounds are on the average the loudest, vowels or consonants? (8.203)

On the average, how much less are measured speech intensities for females than for males? How do they compare in the 100- 1000 Hz range? above 1000 Hz? (8.204)

Why do analyses of speech spectrograms usually concentrate on consonants? (8.201)

What is the range of duration of vowels/sec and consonants/sec in speech? (8.201)

In normal speech, what is the range of phonemes/sec? (8.201)

Which have rapidly changing aperiodic elements, vowels or consonants? (8.201)

How do glides compare with vowels in length and in intensity? (8.205)

### Speech Production

At normal rates of speech, about how many times a second do lips and tongue change position? (8.201)

What is the usual rate of laryngeal pulses/sec for males and for females? (8.201)

How do fricatives and stops compare in manner of production? (8.205)

What are the joint effects of the number of words in the response and the number of syllables per word in a reaction time task? (8.208)

How much does response time increase for each additional word required in a response? (8.208)

## **Non-speech Signals**

### Signal Detectability

For a 1000 Hz tone at 20 dB or above, what is amplitude resolution (minimum perceptible intensity difference) in dB? (5.1001)

For a reference of 0 dB = 0.0002 dyne/cm<sup>2</sup>, what is the dynamic range in dB of hearing? (5.1001)

For what pure tone frequency is sensitivity greatest? (2.301)

From 20-1000 Hz and above 1000 Hz, respectively, what is auditory frequency resolution? (5.1001)

With earphone listening, does reversing the phase of the noise or of the signal greatly enhance signal detection in noise? (2.314)

How does the minimum audible pressure compare for tones above and below 6000 Hz with free-field versus earphone listening? (2.302)

Does signal detectability vary when signal and noise come from different locations? (8.301)

### *Effects of duration*

How does discrimination of the duration of noise bursts vary with signal bandwidth, amplitude, and waveform? (2.503)

Which is more easily integrated into a single percept, simultaneous signals from two locations? signals from a single location? signals separated in time? (6.401)

By how large an interval can two sequential auditory stimuli be separated and still be heard as a single, fused sound rather than as two sounds? (6.407)

How short must the interval be between two brief sounds for the sounds to be heard as distinctly separate? (6.408)

Does slowing presentation rate aid in hearing a sequence of tones as a single coherent series? (6.403)

#### *Effects of interaural phase*

Are interaural phase effects more pronounced at higher or at lower signal-to-noise ratios? (8.314)

About how much lower are binaural thresholds than monaural ones? How does this difference vary with frequency? (2.301)

How can interaural phase differences between signal and mask affect signal detection? (2.306)

Does monaural or binaural noise increase more rapidly with sound pressure level? (2.608)

In listening for a signal with noise present, under what conditions do interaural phase effects occur? (2.609)

Does increasing the interaural phase difference of a signal and a distractor affect intelligibility? (8.301)

#### *Underwater listening*

How do absolute underwater sound thresholds compare with those in air? (2.301)

What happens to the difference between underwater and in-air hearing thresholds as frequency increases? (2.304)

#### **Masking and Interference**

Up to how much attenuation at one ear, relative to the other ear, can be caused by the sound shadow of the head? (2.801)

How does pressure on the ears from earphones induce low-frequency masking noise? (2.302)

Which masks more effectively, a sound lower or higher in frequency than the sound to be masked? (2.306; 2.309; 8.301)

How does masking by narrow-band masks and wide-band masks vary with signal delay? (2.306)

How wide apart can two tones be and still produce strong beats with each other? What does this do to detectability? (2.309; 8.301)

To increase signal masking in noise, should wide-band noise (200-400 Hz) be used, or is a low-frequency band of the same power better? (8.306)

How much masking may be obtained when signal and mask are presented to opposite ears? (2.309)

For signals affected by a mask, how does threshold vary with signal frequency? (2.308)

How do pulse and steady-state masks compare in effectiveness? (2.313)

What is interaural masking, and where does the mask interfere with the signal? (2.313)

Does interaural masking show symmetry with frequency? (2.313)

For how long after mask presentation does masking continue? How does it decay within that time? (2.313)

#### *Echoes*

In normal rooms, by how much time do echoes follow original sounds and how much are they attenuated from the original signal? (2.817)

By how much time must an echo follow a sound for it to be heard as a separate or independent sound? (2.817)

#### **Environmentally Induced Shifts in Listener Sensitivity**

What does exposure to sounds do, temporarily, to sensitivity to nearby frequencies? (10.311)

For what signal frequency relative to the noise center frequency, does maximum temporary threshold shift (TTS) occur? (10.311)

How does temporary threshold shift vary with exposure duration? (10.311)

How does degree of temporary threshold shift vary with sound pressure level (SPL) of sounds such as white noise, pulsed tones, clicks, or gunshots? (10.312)

Exposure to low-frequency (<2000 Hz) noise may cause a permanent loss in sensitivity for what range of frequencies? (10.313)

What three factors should be considered in assessing the risk of permanent damage to hearing from sound exposure? (10.313)

Does broadband or narrow-band noise produce more temporary threshold shift? (10.313)

Below what frequency do pure tones increase temporary threshold shift? (10.313)

How does noise-induced permanent threshold shift vary with exposure intensity and with years of exposure? (10.314)

How does hearing loss vary with the frequency and bandwidth of the noise inducing it? (10.314; 10.315)

Exposure to what kind of noise produces the greatest hearing loss? (10.314)

After how many years of noise exposure may hearing loss level off? (10.315)

#### *Recovery*

How quickly does recovery from temporary threshold shifts begin after noise stops, and what is the time course of recovery? (10.311)

About how many hours may be required for complete recovery from long-term exposure to 4.0 Hz-centered noise? (10.313)

#### *Susceptibility*

Does degree of an individual's hearing loss at one frequency permit prediction of susceptibility to loss at another frequency? (10.315)

#### **Localization of Signals**

What are the two main cues for localizing sounds? (2.810)

What is the shape of the region within which sound source localization is confusing? (2.805)

Where in the sound spectrum are front-back localization errors most common? (2.813)

Under free-field conditions, where on the horizontal plane are sound localization errors smallest? (2.813)

What does occluding one ear do to the perceived locus of sounds? (2.810)

For wide-band noise and for narrow-band signals, how does localization error compare for both ears versus one ear? (2.810)

Do echoes normally interfere with localization of sound sources? (2.817)

When visual and auditory information on localization is contradictory, how much can vision bias hearing? (5.1006)

When optical devices produce visual field displacement, causing a discrepancy between visual and auditory localization, do sounds then seem to come from the apparent visual sound source? (5.1127)

Does it aid accuracy of reception of one of two simultaneous auditory displays to give visual cues to message source location? (7.210)

With the head fixed in position, how does sound source localization change when listeners are blindfolded? (2.815)

How do earphones affect the perceived location of sounds? (8.314)

Is there any perceptual adaptation to an artificially reversed auditory space? (5.1127)

#### *Intensity cues*

For what sound frequencies is interaural intensity difference an important cue to sound localization? (2.803)

Above what sound frequency does the human head provide an effective shadow so that interaural intensity differences can serve as a primary cue for sound localization? (2.804)

#### *Temporal cues*

What is the maximum possible difference in time of arrival to the two ears of sounds from a small sound source? (2.801)

Up to what frequency is interaural time-of-arrival difference an important cue in locating a pure tone? (2.801)

What is the minimum duration of sounds for which head movements can aid localization? (2.801)

For a pure 3900 Hz tone with only interaural time differences as a cue, how well can listeners locate sound sources? (2.808; 5.1006)

What can be done to high-frequency complex stimuli so that a listener can extract time-of-arrival differences to determine the location of a sound source? (2.808)

#### *Pitch (Signal Frequency)*

Other things being equal, how does pitch vary with changes in frequency? (2.701)

#### *Loudness (Signal Intensity)*

How does loudness depend on bandwidth? (2.606)

How does loudness of tones heard in the two ears compare with loudness when only one ear is used? (2.601; 2.608)

For what repetition rates does a pulse train sound louder than a continuous sound of equal total energy? (2.610)

What is loudness adaptation, and how does it differ from fatigue and habituation? (2.612)

In an aircraft, at which noise level in dB does noise change from acceptable to uncomfortable? (10.302)

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## **Vestibular Displays**

### **Vestibular Sensitivity**

What is the absolute threshold of the vestibular sense? (5.1001)

What is the range of input frequencies for which cupula displacement is a function of head velocity? (3.203)

By how many degrees may cupula displacement lead or lag head velocity? (3.203)

What illusion may be produced by linear acceleration? (3.210)

How well can people detect constant velocity in the absence of visual cues? (3.210)

### **Vibration**

Below how many  $m/sec^2$  are vibration magnitudes not perceptible? (10.401)

Between 2 and 100 Hz, for both seated and standing observers, what is the approximate threshold in  $m/sec^2$  root mean square for perception of whole-body vibration? (10.427)

Are seated subjects more or less sensitive to horizontal (x- and y-axis) vibration than standing subjects? (10.427)

Approximately how much does vibration frequency have to change to be noticeable 50% of the time? (5.1001)

What vibration magnitude and duration will generally cause severe discomfort? (10.401; 10.402; 10.426; 10.428; 10.430)

At and above what level are vibration magnitudes assumed to be dangerous? (10.401; 10.402)

Does sustained normal acceleration affect vibration transmission through the torso? (10.406)

At what frequencies are local vibrations to the hands associated with circulatory, bone, joint, muscle, and nerve injuries? (10.402)

(See also Visual displays: Transmission of vibration)

## Acceleration

As positive (toe-to-head) accelerations increase from 1-4 g do both the fovea and the periphery become less sensitive to contrast? (10.901)

What happens to contrast sensitivity as either longitudinal acceleration (toe-to-head) or transverse acceleration increases? (10.904)

For the seated subject, are physiological limits lower for vertical or transverse acceleration? (10.903)

With vertical acceleration of a seated subject, what happens to vision? (10.903)

At what acceleration level is reading of aircraft instruments potentially affected? (10.905)

Under high illumination (150 cd/m<sup>2</sup>), what happens to errors in reading aircraft instruments as acceleration increases up to 4 g? (10.905)

If acceleration lasts more than 6-7 seconds, how much does acceleration tolerance increase? (10.906)

With positive g acceleration of 4-6 seconds, at what levels does (a) loss of peripheral vision occur, (b) blackout occur, and (c) unconsciousness occur? (10.406)

During tolerance testing for positive g acceleration, up to how many multiples of g have been used for short durations with live human subjects? (10.906)

How do thresholds for direction of motion and sensation of tilt compare? (3.206)

What is the best method for exposing subjects to forces in excess of one  $g_n$  for long periods of time? (3.206)

## Body Rotation

If an observer's head is tilted forward, while rotating around a vertical axis, what will be experienced? (3.204)

What sensation is perceived with deceleration following prolonged rotation? (3.210)

Under what condition may body tilt not be perceived? (3.210)

Can an illusion of self-motion be induced in the absence of a visual input? (5.503)

As gravitational-inertial forces along an observer's long body-axis increase, what do stationary objects appear to do? (5.504)

If the observer in a centrifuge faces toward or away from the axis of rotation, in what plane do vertical visual objects appear to tilt? (5.505)

*Perceived vs. gravitational vertical*

What happens to the visual vertical as the head is tilted backward? (5.801)

How is the visual vertical influenced by returning the tilted head or body to erect after prolonged tilt? How do head and body tilt effects compare? (5.801)

What does tilting the head do to perceived tilt of vertical lines? (5.802; 5.803)

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## Cutaneous (Tactile) Displays

### Cutaneous Sensitivity

What is an adequate stimulus for pressure on the skin? (3.101)

How widely spaced must two points be on the thigh or on the fingertips to discriminate one point from two points? (two-point resolution) (3.101)

For which frequencies of a vibratory signal is the base of the thumb most sensitive? (3.108)

How long should tactile pulses be to optimize detectability for cueing purposes? (3.116)

When two tactile pulses are physically separated and must be perceived as discrete, how close in time can they occur? (3.118)

### Pattern Discrimination

Is the skin capable of acute spatial resolving power? (3.101)

For vibrotactile pattern perception how does accuracy of perception compare for static presentation versus other modes? (6.502; 6.503)

How does identification accuracy compare for equal-sized characters for Braille and vibrotactile presentation? (6.502; 6.506)

How does identification accuracy for vibrotactile letter patterns vary with intensity for short and for longer presentation times? (6.504)

When vibrating pins present letters to the fingertips, how does accuracy compare using one finger versus spreading the pattern over two fingers? (6.507)

In discrimination learning of vibrotactile patterns that vary in locus, duration, and intensity, how much practice is required to attain ~90% accuracy? (6.510)

In discriminating two-dimensional shapes, how well can alphabet characters be discriminated by active fingertip motion versus touching without motion? How well are geometric outline shapes discriminated by moving the palm over the surface? twisting an object in the palm? with target resting on the palm? (6.607)

What is the effect on perceived roughness as skin temperature changes? (6.604)

How does the judged roughness of a surface of constant texture vary as the shear force parallel to the surface decreases? (6.605)

## Thermal Sensitivity

How long can a sensation of cold continue to increase? (3.101)

How quickly does adaptation to warmth reach an asymptote? (3.101)

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## Controls

### Feel

#### Use of Gloves

If controls are used while wearing gloves, what effects may be expected on operator performance with various types of controls? (12.426)

When speed of operation is important, how do different types of gloves compare for different types of controls? (12.427)

How do gloves influence the maximum torque that can be applied to rotary controls with various control orientations and knob diameters? (12.428)

When keyboard data entry is required while wearing gloves, how important is auditory feedback? What key travel and resistance should be considered when both speed and accuracy are important? (12.429)

How does glove-wearing influence the discriminability of fluted knobs? How well can a glove wearer discriminate knob rim surface textures? (12.430)

#### Coding of Controls

What are the major coding methods used for controls, and what are their advantages and disadvantages? (12.424)

When pushbutton controls are used, are there known shapes for developing coding sets that have high discriminability by touch alone? (12.425)

When felt by hand, (1) how is the curvature of a convex object's horizontal edge judged relative to its true curvature, and (2) how is the curvature of a concave object's edge judged relative to its true curvature? (6.609)

When continuous control rotary knobs are used, how much must they differ in diameter to avoid confusion between them? (12.417)

When rotary selector controls are used under conditions where they must be identified and adjusted without looking at them, is a wide range of shapes available that require little or no learning? In terms of total operating time, are there significant differences between coded and non-coded controls? (12.418)

When a rotary control is used under conditions where it cannot be seen, how do straight-sided and tapered knobs compare in setting accuracy? (12.419)

### Control Placement and Grouping

As a practical rule, how far apart should controls be spaced

in front of the operator? in areas to the back and sides of the operator? (9.208)

In designing a workstation, what are the principles for grouping and arranging controls for optimizing operator performance? (12.301)

In designing a system that has both displays and controls, how should controls be arranged to ensure unambiguous associations of controls with their displays and predictable display movements with system response? (12.302)

In a system containing multiple controls of various types, what are the recommended minimum separations between them by type of control? (12.303)

In designing workspaces for standing and for seated operators, what are the reach envelopes for placement of controls? (12.304)

### Hand-activated Controls

#### Pushbuttons/Legend Switches

When pushbutton controls are used, how does error rate vary with the diameter and orientation of the pushbuttons and the space between them? (12.401)

What are the human design factors for legend switches, and what are the specific design requirements for them? (12.403)

In designing transilluminated pushbutton indicators to be used in low ambient illumination where rapid reading is essential, how do white or red colors compare with green or amber for speed of response? (12.402)

#### Keyboards/Keysets

How important are word arrangement and keyboard position in data entry? (11.318)

In terms of operator speed and accuracy in data entry, how do calculator keyboard and telephone arrangements compare? (12.406)

How do conventional and membrane keyboards compare in terms of operator speed and accuracy? (12.407)

In selecting among different keyboard arrangements, what arrangements will be expected to yield best performance in terms of speed and accuracy? (12.408)

What range of keyboard slope is acceptable? (12.409)

In designing keyboards for data entry, how do speed and accuracy of use vary with key size, required activation force, key displacement, and feedback that indicates activation? (12.410)

What are some of the design considerations for computer-driven control/display panels and multi-function keyboards? (12.411)

Does level of vibration affect performance under vibration with decimal input devices? (10.424)

How do ten-button keyset, rotary controls, and thumbwheels compare, with and without turbulence, and what would be a desirable key activation pressure for the keyset keys? (12.412)

How, in terms of speed, accuracy, and operator preference, do ten-button keyset, matrix keyboard, vertical levers, and rotary selectors compare for data entry? (12.415)

Under vertical axis vibration at 0.17 Hz with a magnitude of 0.24 m/sec<sup>2</sup>, is performance in keyboard digit punching affected by the vibration? (10.425)

### Toggle Switches

When toggle switches are used, how does error rate vary with the spacing between switches, the switch orientation, and the direction of throw? (12.404)

What system factors influence toggle switch activation time, and how does activation time vary with them? (12.405)

### Dials and Rotary Selectors

When rotary switch selectors are to be used, what are the design requirements for scale/pointer, positioning, and shape? (12.413)

When rotary control knobs are used, how does performance vary with the separation between control knob edges and with knob diameter? (12.418)

When dials are read at leisure, how does reading accuracy vary with dial size? (11.213)

Under quick check conditions, what dial size is optimal? (11.213)

For all dial sizes, how does error vary as scale intervals are made smaller? (11.213)

When concentric (ganged) continuous rotary controls are used, how does operator performance vary with knob thickness and diameter? (12.420)

### Cursor Controls/Joysticks

For fine continuous positioning control of a cursor, what are some available design options? (11.321)

How do commonly available cursor control devices compare in cursor positioning speed and accuracy, and will device selection involve a speed/accuracy tradeoff? (12.422)

What type of joystick is best for position control of a cursor on a display? (9.201)

### Comparisons Among Controls

In selecting a control type for data entry, how do rotary selectors, thumbwheels, and digital pushbuttons compare in operator speed and errors? (12.414)

How do ten-button keysets, rotary controls, and thumbwheels compare, with and without turbulence? What would be a desirable key activation pressure for the keyset keys? (12.412)

How, in terms of speed, accuracy, and operator preference, do ten-button keyset, matrix keyboard, vertical levers, and rotary selectors compare for data entry? (12.415)

During vibration, do subjects prefer the pushbutton matrix or the thumbwheel array, and how do these compare in speed and accuracy? (10.424)

What are the advantages and disadvantages of touch screens as data input devices across different design approaches? (12.423)

Why, during whole-body z-axis vibration, is pursuit tracking with a rotary control no better than with a joystick? (10.423)

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## **Warnings and Alarms**

### **Visual Alarms**

What happens to detection probability as the number of possible signals increases from one to four? (1.627)

By how much should a visual warning precede a visual signal to reduce reaction time? (5.1014)

What is the probability of correctly responding to annunciators and discrete status lights? What are some of the factors affecting response time? (7.107)

What are some factors affecting the failure to respond to annunciator lights? How do failure probabilities vary with increasing number of annunciators? (7.115)

What must be avoided to make a warning signal salient enough to attract attention? (11.402)

### Coding

For selection of information coding techniques, what are the recommended applications, limitations, and design guidelines for the following code types: (1) color, (2) shape, (3) blinking, (4) brightness, and (5) alphanumeric? (11.329)

What are the recommended colors for signals that are high-priority alerting? cautionary? advisory? (11.401)

How do reaction times vary to colored signal lights? (11.406)

For warning signals, where warning is given by turn on (onset) or turn off (offset) of lights, which gives the most rapid response for foveal presentations? (11.405)

## **Brightness**

What is the minimum brightness recommended for visual alerting signals relative to other visual displays? (11.401)

Does the surround brightness level at day or at night influence detection time or speed for warning lights? (11.408)

## **Size Specifications**

What is the recommended height-to-width ratio and stroke width for warning signal legends? (11.401)

What is the minimum recommended legend height for warning indicators? (11.401)

For some messages, at what height in degrees does reaction time to a warning-message character no longer decrease? (11.409)

Under normal operating conditions, how important is caution warning-light size? (11.409)

Under worst-case conditions, what happens to reaction time as warning-light size increases? (11.409)

## **Position in the Field of View**

How close to the operator's line of sight should warning signals be? (11.401)

If a master caution light is used, does location of a light nearer the center of the field of view result in quicker detection? (11.408)

What additional equipment is recommended when visual signals are located in the peripheral visual field? (11.401)

## **Auditory Alarms**

### **Tone**

Does separating sound sources aid attention to one of them? (7.209)

For an auditory choice reaction time task, will preceding the auditory signal by an auditory warning improve performance? (5.1014)

Is selective attention possible for integral stimulus dimensions, such as loudness, pitch, and timbre? (7.206)

Does a more intense warning signal decrease reaction time? (9.108)

For what auditory frequency is detection better in the dark than in the light? (5.1004)

For auditory alerts, what is the recommended frequency range of multiple frequencies? (11.401)

How far above the amplitude of the masked threshold should the amplitude of an auditory signal be? (11.401)

If an auditory warning signal is not directional, should it be presented to both ears? to the dominant ear? (11.401)

Does use of a two-tone, warbling, master auditory warning signal yield reaction times shorter than a one-tone master or visual master alone? (11.413)

## **Voice**

In general, how does response speed to most voice warnings compare with that to tone warnings? (11.416)

What should precede voice messages? (11.401)

What is recommended about the language and phraseology of voice signals? (11.401)

How do response times compare for semantic (contracted sentence) and a shorter keyword version of a voice warning message? (11.417)

What is the effect on speed of reaction of a warning tone preceding either a semantic or a keyword voice warning when time is measured from start of event? (11.417)

## **Tactile Alarms**

Why are tactile alerts not recommended? (11.401)

For a vibrotactile warning system, does sensitivity of the wrist compare favorably with that of different locations other than the head? (3.106)

## **Combined Warning Displays**

### **Multiple-Modality vs. Single-Modality Displays**

How does detection during vigilance with both visual and auditory (simultaneous) signals compare to that with either alone? (7.410)

How does reaction time for combined auditory and visual signals compare with that for visual signals only? (5.1013; 11.415)

Does pairing a visual stimulus with an auditory stimulus decrease reaction time? (5.1012)

Does it aid reception of simultaneous auditory displays to give visual cues to message source location? (7.210)

### **Auditory vs. Visual Precedence**

For how long should warning signals be presented? (11.401)

In designing guidelines for alerting signals, what is the basis for assigning priority to signals? (11.401)

What does an auditory signal preceding a visual signal do to reaction time, and what should be the interval between them? (5.1014)

What should be the time order of onset of master visual and master aural alerts? (11.421)

### **Interaction Effects in Audio-Visual Displays**

What effect does moderate auditory stimulation have on white light sensitivity? (5.1003)

Can an auditory stimulus influence sensitivity to a visual stimulus, even though no response to the auditory stimulus is required? (5.1003)

With either visual or auditory warning, what happens to reaction time when warning signal strength is increased? (5.1015)

What does a visual signal following an auditory signal do to reaction time? (5.1014)

### Comparison of Auditory and Visual Warnings

How does intense light stimuli in the photopic vision range compare with sound with regard to speed of response? (11.404)

How do reaction times to visual and auditory stimuli compare? (5.1012)

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## Memory

What position in a visually presented list yields the poorest recall? (4.102)

How does the time taken to switch from element to element in a visual display compare with switching time in memory? (7.218)

In about how many seconds after an observation does an observer's memory of it become seriously deficient? (7.316)

If the items in a heard list are acoustically similar, does this help or harm recall? (4.101)

What position in a heard list yields poorest recall? (4.102)

How does auditory presentation of an additional item before presentation of a list (a prefix) affect item recall? (4.102)

How does auditory presentation of an additional item after presentation of a list (a suffix) affect item recall? (4.102)

How does the time to search a remembered list of items for a specified item increase as the number of items in the list increases? (4.103)

What three variables must be considered when observers must keep a running mental tally for several categories of information? (7.412)

How does reaction time (RT) vary with memory set size? (7.520)

What is the effect of earlier items presented in noise on the recall of later items presented without noise? (8.311)

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## Learning

What does the power law of learning say about the effect of practice on the instantaneous rate of learning? (4.201)

How does giving participants knowledge of results (feedback) affect performance in motor tasks? (9.404)

Do experimental results indicate that it is easy or difficult to ignore learned automatic responses? (7.520)

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## Attention and Allocation of Resources

### Selective Attention

How does selective attention performance compare with divided attention performance? (7.216)

Is selective attention possible for integral stimulus dimensions, such as loudness, pitch, and timbre? (7.206; 7.213)

Does separating sound sources aid attention to one of them? (7.209)

When the type of textual material of target and distractor differ, is performance improved? (7.209; 7.213)

Does presenting targets and distractors in different sound frequency bands aid attention to targets? (7.209)

If speaker gender for distractor and target differs, is attention to the target aided? (7.209)

How does ability to listen selectively vary with age? (7.209)

For a given channel, how does detectability vary as the number of signals increases in a competing channel? (7.214)

### Divided Attention

Does dividing attention between two channels, rather than attending to only one, decrease probability of detecting a target? (7.214; 7.216)

Is attention shift between different locations in a visual display, when the eyes do not move, continuous or discontinuous? (7.218)

As task compatibility in concurrent search tasks increases, does interference between them increase? (7.221)

In general, about how many independent displays can be effectively monitored by one observer, and what two things impose this limit? (7.110; 7.314)

What happens to detection probability as the number of possible signals increases from one to four? (1.627)

### Visual Search

In scanning an alphanumeric matrix for a specific target, upon what does rate of search depend? (7.502)

Are eye fixations more frequent on display areas containing higher information density? (7.505)

In searching an alphanumeric matrix, does searching for the absence of a target take as long as searching for target presence? (7.502)

How do the number and density of background characters affect visual search time on a display? (7.514; 7.517)

In designing a system for finding and attacking ground targets from the air, what factors must be considered when estimating the probability that targets will be detected? (7.501)

Does the frequency of eye movement increase or decrease when a target is recognized? (7.505)

Is redundant coding (more than one coding method) valuable for reducing search time and errors when visual search is involved? What happens with redundant coding at high levels of display density? (7.511; 11.202; 11.203)

How does the time required to determine how many objects are in the field of view vary with the number of objects? (7.512; 7.523)

Is a larger number of gray levels more important for recognition or for search? (7.604)

In general, how many shades of gray are adequate for simple search and how many are required for recognition tasks? (7.604)

## **Monitoring and Supervisory Control**

In a supervisory control system, what does the human interactive system do? (6.309; 7.301)

What are some of the disadvantages of supervisory control? (7.301)

Once a process has been correctly adjusted so that there is no residual drift due to control-setting error, what determines the operator's background sampling rate? (7.302)

During sampling behavior, does an operator attempt to estimate higher derivatives? (7.302)

What is evoked in place of habitual behavior when unforeseen events occur which have a high cost of errors? (7.303)

Under conditions of manual control, especially under high work loads, what system conditions are likely to go unnoticed? (7.304)

What are three reasons why allowing the operator to have actual manual control of a system or process results in better monitoring and response to failures? (7.304)

If a display is driven by a zero-mean Gaussian band-limited signal, how large a deviation (in standard deviations) will always be detected? (7.305)

Upon what do intermediate-loop processes depend? (7.305)

With a constantly monitored display, is an increase or a decrease in parameter value detected sooner? (7.305)

What probability of correctly operating a continuous control while monitoring dynamic displays is realistic for simple and multiple displays at various levels of required accuracy, visibility, and available viewing time? (7.113)

How does sampling rate vary with the bandwidth of the monitored process? (7.314)

What happens to sampling frequency as a system approaches the tolerable limit of system operation? (7.314)

In designing a computer-assisted system, how should incentives, task duration, task complexity, mental load, and pacing be arranged to optimize operator efficiency? (7.801; 7.803)

What are five general, high-level cognitive and computational functions involved in allocation of decision functions between human and computer? (7.721)

## **Vigilance**

For a higher event rate, how does response time vary with false alarms, correct rejections, correct detections, and misses? (7.404)

In a vigilance task, how does reaction time to signals vary with variability in intersignal interval? (7.406; 7.412)

What effect do longer signal durations have on signal detectability and on vigilance decrement? (7.406)

What is the relationship between signal strength during vigilance and detection probability? (7.406; 7.415)

In a vigilance task, at what signal frequency is detection probability maximum? (7.406)

During vigilance, do multiple signal sources aid performance? (7.410)

In vigilance for sequential events, how many categories yield best accuracy? (7.413)

During vigilance sessions, how do hit rates and false alarm rates compare for single- and multiple-response conditions? (7.414)

During vigilance, how do visual, auditory, and cutaneous modes compare? (7.410; 7.412)

In a vigilance task, how does vigilance decrement compare for the auditory signals alone, visual signals alone, and combined (visual-auditory) signals? (7.409)

In a vigilance task, does adding an auditory signal to a visual one improve detection probability? (7.409; 7.410)

## **Measures of Vigilance**

What method is used to measure accuracy of detection? (7.402)

Do values of physiological measures, such as skin conductance, heart rate, respiration rate, and muscle tension, correlate with vigilance performance? (7.413)

## **Vigilance Decrement**

What is vigilance decrement and how long a period is required before it occurs? (7.401)

In a vigilance task, what does a higher probability of a signal do to detection probability and to vigilance decrement? (7.406)

With knowledge that vigilance will be of long duration, how quickly does decrement occur and is it increased over no-knowledge conditions? (7.410)

Does irrelevant information harm vigilance? (7.412)

Does adrenaline level during vigilance correlate with vigilance decrement? (7.413)

In vigilance tasks, when is performance impairment likely with noise? (10.302)

### Techniques for Improving Vigilance

Do short breaks help during vigilance tasks? (7.410)

Is performance during vigilance aided by isolation? (7.410)

Can target detectability in a vigilance task be kept high by adaptive techniques based on performance, and is there still some loss over time? (7.410)

How can the number of categories displayed simultaneously be increased to at least three without performance loss? (7.412)

In general, does vigilance practice aid performance? (7.414; 7.416)

Does signal cueing aid vigilance? (7.416)

In systems where sustained attention is required, what are the upper time and temperature limits for unimpaired performance? (10.601)

## **Workload**

### Channel Sensitivity and Capacity

What are the best operating ranges of vision (wavelength, color, illumination), audition (frequency, dB range), taste (concentration), and the vestibular sense (head-to-foot acceleration)? (5.1001)

How many channels does the human operator have? (7.301)

What is the transmission rate for visual nerve fibers, and how does it compare with how much information/sec a person can absorb and interpret? (4.301)

What is the ear's transmission rate for random sound? for loud sounds? for spoken English? (4.301)

How many bits of information is the limit of channel capacity according to studies on vision, audition, and taste? (4.302)

In terms of ability to distinguish two successive stimuli as successive, what is the minimum time between stimuli for vision, audition, touch, taste, and smell? (5.1001)

### Workload Theory

What does "workload" mean? (7.704)

What are some of the operator behaviors resulting from display of too much information at one time? (11.332)

Is there a demonstrated relationship between workload and system operability? (7.711)

Under conditions of manual control, especially under heavy workloads, what system conditions are likely to go unnoticed? (7.304)

In workload assessment, what does the multiple resources model assume? (7.202)

In workload assessment, what three dimensions defining separate resources have been proposed? (7.202)

### Workload Measurement

What are the three broad categories of techniques used to assess workload? (7.704)

What information do global measures of workload provide? (7.703)

What determines the level of diagnosticity required in a situation? (7.703)

In workload assessment, how are sensitivity criteria validated? (7.701)

In workload assessment, what is indicated by a significant interaction between difficulty and priority? (7.203)

What is the relationship between perceived effort and spare mental capacity? (7.709)

What impact does skill level have on workload measurement? (7.702)

In workload assessment, which of the two, a difficult motor task or a difficult cognitive task, competes for resources with tracking? (7.203)

What two things are simply defined by the performance operating characteristic (POC) curve, and how are they measured or shown on the plot? (7.205)

### *Primary and secondary tasks*

At what workload levels are primary-task measures insensitive to workload? (7.701)

In workload assessment, what are secondary tasks? (7.709; 7.719)

How is performance on a secondary task related to the difficulty of a primary task? (7.709)

What is a common criticism of secondary tasks by operators? (7.719)

To ensure sensitivity to workload associated with a particular primary task, what characteristics must a secondary task possess? (7.202; 7.701; 7.720; 7.721)

How much practice should be given on a secondary task? (7.721)

How can the peripheral interference associated with response competition be avoided while ensuring the use of appropriate processing resources? (7.721)

In workload assessment, why should several levels of secondary-task difficulty be employed? (7.721)

Can mental arithmetic and tracking, encoding and tracking, and vocal response and tracking be carried out without interfering with one another? (7.204)

What three variables should be considered when observers must keep a running mental tally for several categories of information? (7.412)

### *Subjective workload measures*

How is mental workload measured? (7.402)

How diagnostic of workload are subjective techniques? (7.701)

What is the Subjective Workload Assessment Technique (SWAT) designed to do? (7.712)

At what workload level are SWAT ratings much better than primary task performance for indicating level of workload? (7.714)

### *Physiological measures*

What is the commonly used physiological response for measuring workload? (7.704)

How sensitive is eye pupil diameter relative to other indicators of workload? (7.728)

As a percentage range, how much does pupil diameter vary over a period of several seconds when stimulus conditions do not change? (7.728)

What happens to the diameter of the eye's pupil when a person engages in information processing? (7.728)

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## **Reaction Time**

What is reaction time, in milliseconds, to make a simple muscular movement to a visual stimulus? an auditory stimulus? a tactile stimulus (for a stimulated finger)? (5.1001; 5.1012; 5.1013)

What sense modality has the shortest reaction time? (5.1012; 9.108; 11.404)

How does visual target contrast affect reaction time? (9.108)

Under dim light with good brightness contrast, how do reaction times for different colors compare? (11.406)

What part of the visual field yields the shortest reaction time? (9.108)

In a choice reaction time task, how does reaction time vary with stimulus probability when stimulus and response are highly compatible? when stimulus and response are incompatible? (9.113; 9.116)

Are vocal responses faster than manual responses? (9.108; 9.120)

How do the number of words in a response and the number of syllables per word combine in a reaction-time task? (8.208)

How do reaction times compare for one-handed and two-handed tasks of equal difficulty? (9.202)

As target distance increases, do hand and eye response time both increase? (9.206)

Does pairing a visual stimulus with an auditory stimulus decrease reaction time? (5.1012)

### *Speed-Accuracy Tradeoffs*

As a general rule, what is the relationship between the speed of a response and its accuracy? (9.105)

When observers are instructed to be more accurate, what happens to their reaction time? (9.105)

In designing a system where very rapid operator responses are essential, how does speed of response vary with the number of bits of information that must be used to make decisions? (9.106)

### *Effects of Number of Alternatives*

How does reaction time for manual responses vary with the number of stimulus alternatives and with stimulus probability? (9.119; 9.120)

What does the presence of redundant stimulus information do to reaction time in a choice reaction time task? (11.420)

### *Effects of Warning Signals*

For an auditory choice reaction time task, will an auditory warning prior to the auditory signal improve performance? (5.1014)

What is the relationship between reaction time and the length of interval between a warning signal and a subsequent stimulus? (9.108)

In reaction-time tasks, when reaction time decreases due to a warning signal, what generally happens to error frequency? (5.1014)

With either visual or auditory warning, what happens to reaction time when warning signal strength is increased? (5.1015)

(See also Warning and alarms)

### *Effects of Feedback, Motivation, and Training*

Does seeing the hand moving to a target position aid response time and accuracy? (9.206)

When movements are guided by visual feedback of hand position, what is the formula for movement time as a function of movement amplitude and target width? (9.207)

If subjects are rewarded for quick rather than accurate responses, what happens to their reaction time? (9.105)

Can subjects be trained to meet specified reaction times? (9.105)

## **Tracking Control Performance**

Is tracking with most cutaneous displays as good as with visual displays? (9.538)

With practice, is tracking with three cutaneous vibrators in a row similar in error to tracking with three lamps in a row? (9.538)

When the feedback signal in a stationary compensatory tracking task consists of only the error signal, how does tracking accuracy compare for visual and tactile displays? (9.501)

When a tone in each ear indicates error direction, with higher pitch for greater error, is control of two independent axes better with one visual and one auditory than with both visual? (9.538)

How does auditory intensity tracking error compare with visual tracking error? (9.538)

How does auditory tracking compare with visual, when error direction is indicated by a tone to the right or left ear, and error size by interruption rate of the tone? (9.538)

With tracking of auditory pitch, which is better, compensatory or pursuit tracking? (9.538)

How does tracking error compare for a tracked target to right and to left of the fixation point? (9.534)

How does tracking error compare for targets above the fixation point and below it? (9.534)

### **Tracking Performance with Time Delay**

How short a pure transmission delay (transport delay) can affect tracking? (9.516)

Does the human operator have to detect a transport delay for it to hurt tracking? (9.516)

With increasing transport delay in a zero-order tracking system, what happens to human control? (9.516)

Is it difficult for human operators to predict vehicle location when the system has lag sources other than that of the operator? (9.510)

Does training with up to 200 msec delays still benefit later actual flying performance? (9.517)

How does performance with motion cues compare to performance without cues for delays up to 300 msec? (9.517)

### **Tracking Performance with Time-Sampled Visual Displays**

If continuous target exposure produces accurate tracking, what happens with intermittent (stroboscopic) exposure? (1.959)

With intermittent viewing, how does increased viewing frequency make up for shorter glimpses? (9.530)

For an intermittently viewed display, how does tracking error vary with frequency of intermittence, for a given on-time? When does it level off? (9.530)

For an intermittently viewed display, for a given off-time, how does tracking error vary with increase in viewing time? (9.530)

### **Manual Control with Vibration**

Is there a model for predicting the effects of vibration on manual control that can predict performance within  $\pm 1$  standard deviation for a range of electrical control stick gains, forcing functions, display gains, and vibration axes? (10.421)

When a continuous manual control task is performed for an extended duration, how does the proportion of the tracking error related to the movement of the target vary with duration? (10.434)

For what range of whole-body vibration is manual pursuit tracking most sensitive? (10.422)

With sinusoidal vibration, does collimating a display to place it at optical infinity improve tracking performance? (10.417)

With no vibration, are reading errors fewer with greater pixel definition? (10.415)

What is the approximate frequency of major body resonance at which tracking is most affected by z-axis vibration? (10.422)

How do zero-order and first-order control groups compare in tracking during whole-body z-axis vibration? (10.422)

In zero-order (simple gain) pursuit tracking during whole-body z-axis vibration, how much of tracking error is due to direct transmission of vibration through the body into the control system? (10.422)

In pursuit tracking during z-axis vibration, is direct transmission of vibration of the body into the control system (breakthrough) as large with rotary controls as with joysticks? (10.423)

During pursuit tracking with z-axis whole-body vibration, how does high-frequency phase lag for an isotonic joystick compare with that for either isometric or isotonic control knobs? (10.423)

In zero-order (simple gain) pursuit tracking during whole-body z-axis vibration, how much of tracking error is due to direct transmission of vibration through the body into the control system? (10.422)

With vibration, how does tracking error attributable to breakthrough in pursuit tracking with simple gain (zero-order dynamics) compare to that with pure integration (first-order dynamics)? (10.422)

With vertical axis vibration under ship-motion conditions, what vibration magnitudes affect tracking and navigational plotting? (10.425)

In what range of vibration frequencies for vertical (z-axis) vibration is manual control performance affected, particularly with an unsupported control arm? (10.425)

(See also Visual displays: Transmission of vibration; Vestibular displays: Vibration)

### Control Order and Noise in Tracking

Does tracking error increase with control order? (9.536)

What general statement can be made about tracking performance as tracking system order increases? (9.524)

Do tracking tests discriminate between pilots and non-pilots? (7.612)

Why are higher-order tracking systems extremely difficult to control? (9.526)

Does integrated tracking error differ appreciably for position control (zero-order) and rate control (first-order) systems for pursuit and for compensatory tracking? (9.521)

Which system, position or rate control, is worse for lower frequencies and for higher frequencies? (9.521)

How do operators using zero-order and first-order control compare in tracking during whole-body z-axis vibration? (10.422)

Can use of separate controls for position and velocity for one display cursor aid tracking? (9.532)

What happens to tracking performance in going from a first-order system to one of higher order? (9.520)

As compared to continuous control, how well do discrete-state controllers perform with third-order or noisy systems? (9.526)

With what order of system is bang-bang control inappropriate? (9.524)

In dual-axis control, does a second order (rate) system yield longer or higher error than a first order (position) system? (9.536)

How does target acquisition (response to a step input) vary with increasing system order? (9.520)

Does an integrated display and control yield lower error than a separated control and display? (9.536)

For what order of system is a redundant display useful? (9.532)

What effect does 120-dB intermittent and random noise have on continuous-tracking performance? (10.302)

In a tracking situation, what is the upper limit on number of decisions/sec when there is some spatial uncertainty? (9.510)

### System Gain and Tracking Performance

How may gain be expressed in a way that permits comparison among different systems? (9.513)

Is there an optimum gain in compensatory tracking? (9.528)

What is meant by "optimum" control gain? (9.515)

In pursuit tracking with whole-body z-axis vibration, how does optimal control gain for minimum total tracking error compare with optimal gain with no vibration? (10.423)

In pursuit tracking during z-axis vibration, is tracking improved by lowering control gain? (10.423)

Why does tracking performance decrease only slightly as system gain increases beyond optimum gain? (9.515)

In a tracking system, can time delay and gain be varied independently? (9.509)

What is the effect upon the operator of low control gain? (9.515)

When system gain is low, why is tracking hurt by increasing lags and why, when gain is high, may tracking benefit from longer lags? (9.518)

What problems may occur with a high-gain system? (9.515)

In tracking with a joystick, as system gain increases, what happens to the average force applied to the stick? (9.515)

Why can a pilot not distinguish between the closed-loop gain of the aircraft control system and the closed-loop gain of the display? (9.513)

### Techniques for Aiding Tracking Performance

For better tracking, how can system dynamics be changed to a lower order to obtain a rate-aided system? (9.526)

In terms of system order, how does quickening affect apparent system order? (9.525)

How does quickening a display aid a tracking operator? (9.525)

Is information about higher-order derivatives, such as velocity and acceleration, useful in tracking? (9.532)

Is it useful to display derivative information as position? (9.532)

Does it help tracking to display velocity on a cursor? (9.532)

Does a peripheral display of velocity, such as a barber pole, aid tracking? (9.532)

In a manually controlled system, how easily can the operator perceive higher-order derivatives? (9.510)

Can operators involved in manual tracking predict acceleration directly when not receiving vestibular cues? (9.510; 9.539)

What is pseudo-quickening, and what effect has it on system control and tracking error? (9.525)

In a quickened display, what effect do time constraints, bandwidth, and time span of prediction have on tracking accuracy? (9.525)

What problems may occur in operating a system with a quickened display that requires a second display? (9.525)

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## Cyclical Variations in Human Performance

### Characteristics of Cyclical Variations

What is the period of a circadian rhythm? (10.701)

In humans, what is the average length of the period of the ultradian rhythm? (10.703)

In long-duration missions or in tasks extending over time zones, what are the expected effects of schedule changes? (10.710; 10.712; 10.713)

About how much difference is there between maximum and minimum skin temperature in the daytime? (10.702)

How does heat conductance during early night (1800-2400 hr) compare with that in the morning (0600-1200)? (10.702)

Does core body temperature appreciably increase during work relative to rest? (10.702)

Do subjects preferring morning work differ in phase of body temperature rhythm or in performance rhythms from those preferring evening work? (10.711)

### Effects of Fatigue on Performance

What three types of anomalous eye movement result from visual fatigue? (1.908)

In a multi-person system, where operations are around the clock every day and rotating shifts are used, what are the expected effects of occasional sleep loss and fatigue? (10.801; 10.802; 10.803; 10.804; 10.806; 10.808; 10.810; 10.811)

How do fatigue, noise, sleep loss, heat, and time of day affect reaction time, gaps, and errors in multiple-choice serial reaction time? (10.704; 10.705; 10.706)

How does loss of the first half of a night's sleep compare with loss of the second half for recall of presented material? (10.809)

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## Human Reliability and Error Prediction

In system design, how does one apply the technique for human error rate prediction (THERP) to analyze human reliability? (7.103)

What human performance data and sources are available for human reliability analyses? (7.104)

What is realistic for the probability of correctly setting continuous controls to given values while monitoring a dynamic display, or of doing so while tracking with continuous controls? (7.114)

What are some of the factors affecting the probability of error in reading and recording information from various types of display devices? What are the nominal probabilities for error and their ranges? (7.116)

What is the probability of correctly activating a discrete control while reading a meter or other dynamic display, and what is the effect on performance of control display configuration, modular organization, visibility, required accuracy, and viewing time? (7.112)

What is the probability of correctly responding to annunciators and discrete status lights, and what are some of the factors affecting response? (7.107)

What is the probability of correctly reading meters for various conditions (different numbers of meters, meter visibility, viewing time, etc.)? (7.108)

How much time is required, and what accuracy can be expected, in reading counters? (11.217)

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