ME 327: Design and Control of Haptic Systems
Autumn 2020

Lecture 4: Psychophysics and User Studies

Allison M. Okamura
Stanford University

psychophysics

the scientific study of the relation between stimulus and sensation

- fundamental to psychology
- has become fundamental to understanding haptic devices and virtual environments

More information & sources of figures in this section: Gescheider, "Psychophysics: Method, Theory and Application," 1984

two principal functions

- **Descriptive:** Involves the specification of sensory capacities

- **Analytical:** Testing of hypothesis about the underlying biological mechanisms that determine human sensory capacity

history

- 1879 Wundt (British empiricist) articulated the idea of **senses** as key to human understanding
- Simultaneous advances in sensory physiology
  - Facilitated transition of psychology from a philosophical to scientific discipline
  - 1860: Fechner published "Elements of Psychophysics": techniques for measuring mental events

measurement thresholds

- "sensory threshold" is a central idea
- **absolute threshold**
  - –sensitivity
  - –smallest amount of stimulus energy required to produce a sensation
- **difference threshold**
  - –resolving power
  - –amount of change in the stimulus required to produce a ***just noticeable difference (JND)*** in the sensation

Just Noticeable Difference (JND)

the amount of change in a stimulus that creates a perceptible increment in sensation

example:

- stimulus intensity = 10 units
- goes up to 12 units before observer notices a change
- therefore, JND = 2 units at that stimulus level

sensory dimensions

- **intensity or magnitude**
  e.g., amplitude, frequency
- **quality or sensory modality**
  e.g., visual or auditory stimulus
  haptic: vibration, force, movement
- **extension**
  e.g., size, location, separation
  haptic: bump width, space between bumps
- **duration**

psychophysical "laws"

- Empirically derived
- Hold true across all senses in many situations

- Many such "laws" exist

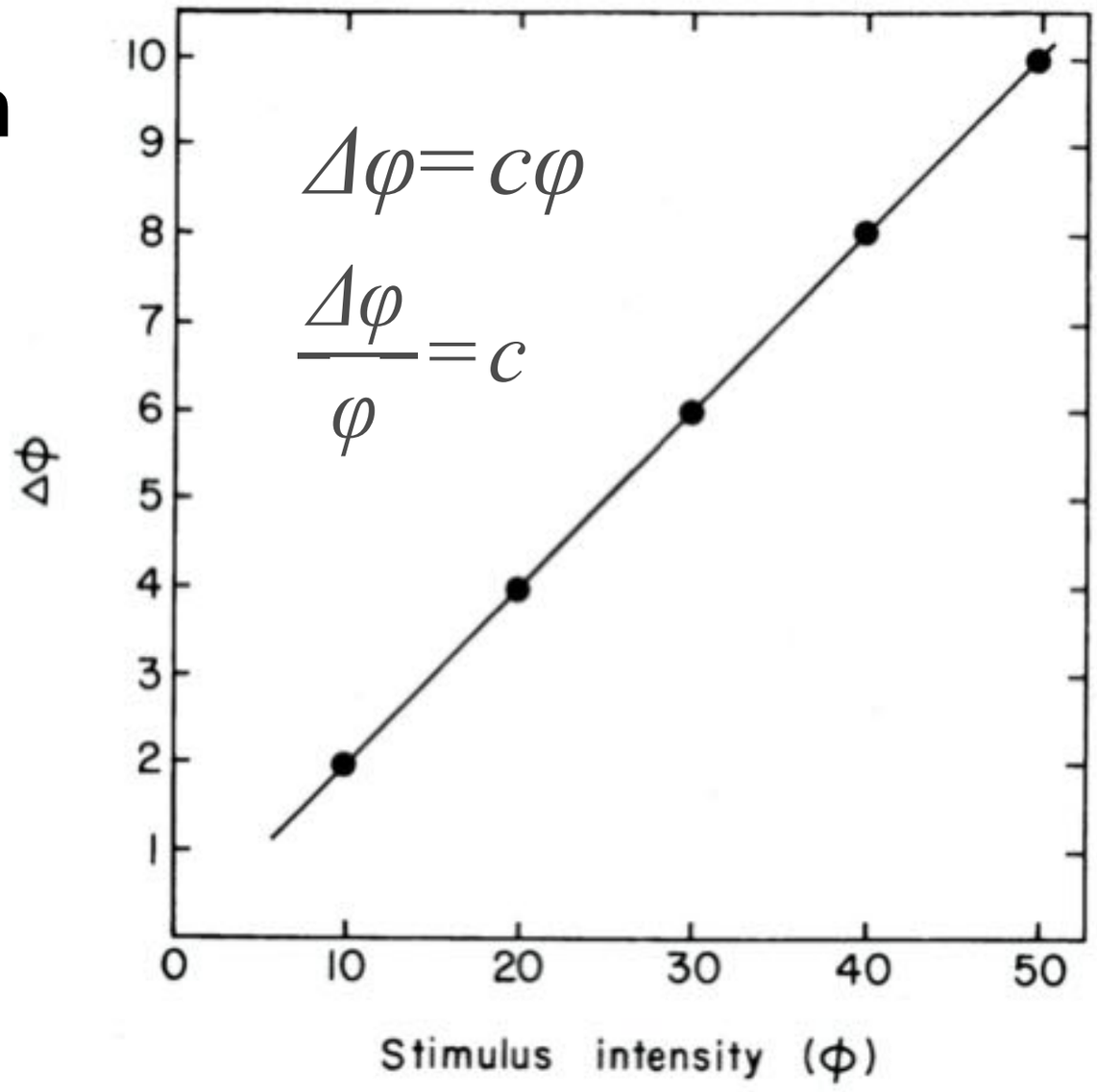
  Oldest example still has experimental relevance (after almost 200 years!)

Weber's Fraction, 1834

German Physiologist E. H. Weber

Linear relationship between differential threshold and stimulus intensity

For example: to feel different, 2 heavy weights must differ more than two light weights



Gescheider, 1984

Weber Fraction

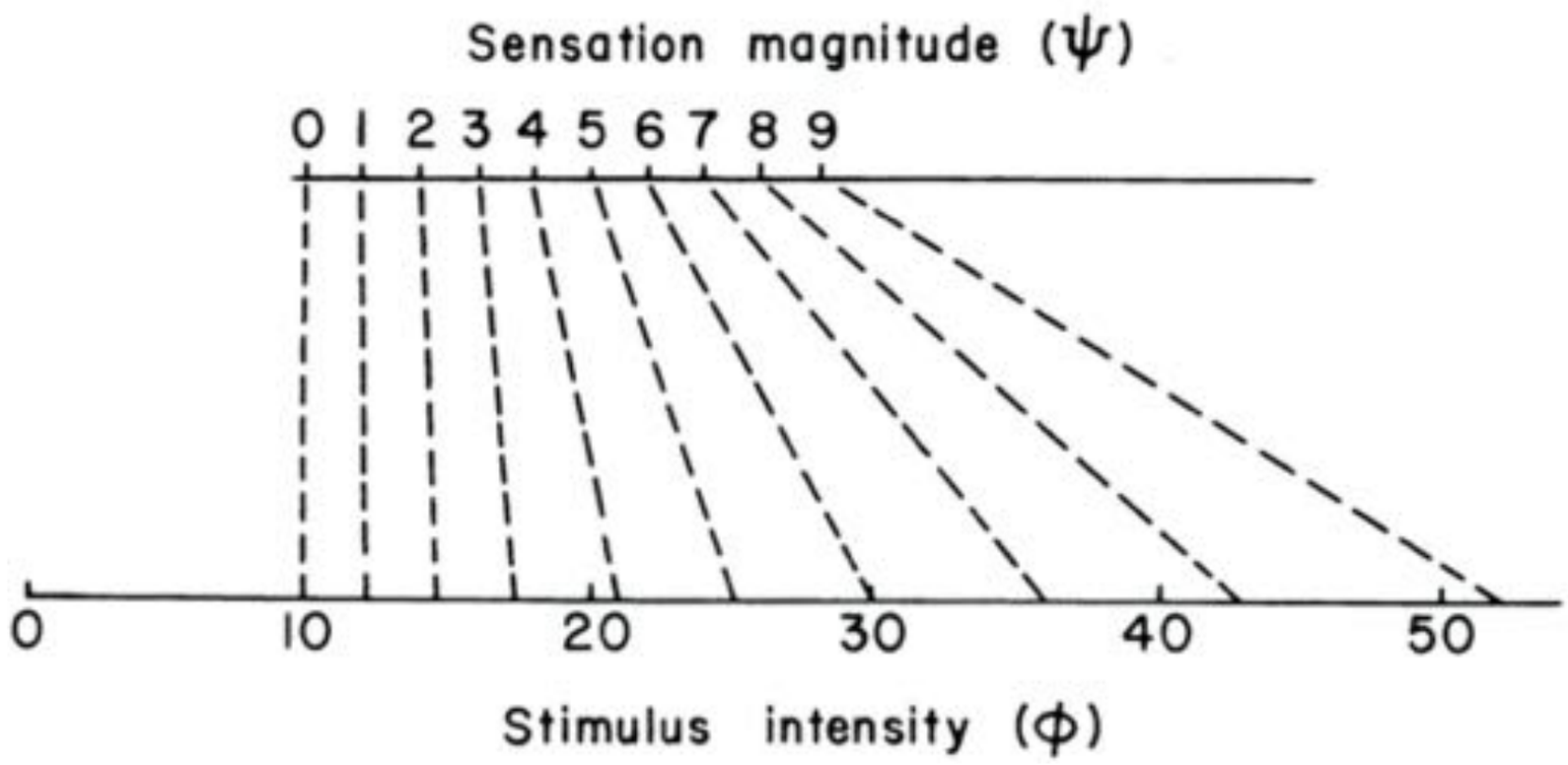
- for weights placed on the skin, the Weber fraction is approximately 1/30

- this provides a useful index of sensory discrimination that can be compared **across different conditions and modalities**

- however, the WF "law" is not always perfect, especially near the absolute threshold (φ=0)

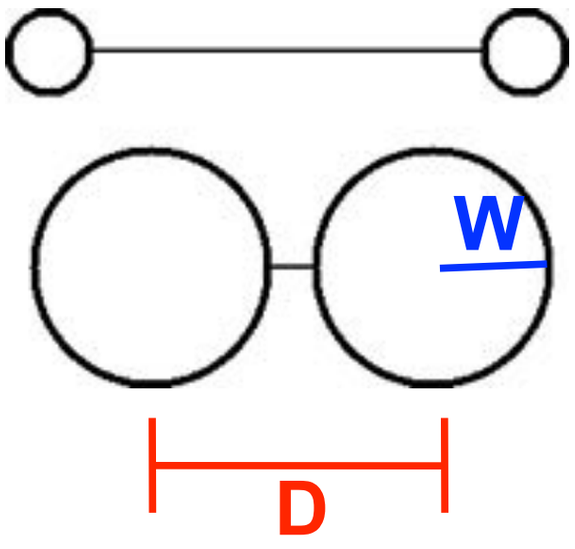
Fechner's Law, 1860

Assumption: All JND's are equal psychological increments in sensation magnitude, regardless of the size of $\Delta\phi$



Fitts' Law

Fitt's Law states that the **time to acquire a target (T)** is a function of the **distance to (D) and size (W) of the target**



$$T = a + b \underbrace{\log_2 \left(\frac{D}{W} + 1 \right)}_{\text{index of difficulty}}$$

For a haptic virtual environment or teleoperation system, you often want to show that you can minimize difficulty via haptic feedback

Demonstration of Fitts' Law

psychophysical methods

methods for determining sensory thresholds:

- method of limits (and staircase method)
- method of constant stimuli
- method of adjustment

method of limits

measures absolute and difference threshold location

Present subjects with ascending and descending stimulus series, and ask: is a comparison >, =, or < a reference?

TABLE 2.2
Determination of the Absolute Threshold for Hearing by the Method of Limits[a]

Stimulus intensity (dB)	*A*	*D*	*A*	*D*	*A*	*D*	*A*	*D*	*A*	*D*
10						Y				
9		Y				Y				Y
8		Y				Y				Y
7		Y		Y		Y				Y
6		Y		Y	Y	Y		Y		Y
5	Y	Y		Y	N	Y	Y	Y		Y
4	N	Y	Y	N	N	N	N	Y	Y	N
3	N	N	N		N		N	Y	N	
2	N		N		N		N	N	N	
1	N		N		N		N		N	
0	N		N				N		N	
−1	N		N				N			
−2	N						N			
−3	N						N			
−4	N									
−5	N									
−6	N									
−7	N									
−8	N									
−9	N									
−10	N									
Transition points =	4.5	3.5	3.5	4.5	5.5	4.5	4.5	2.5	3.5	4.5

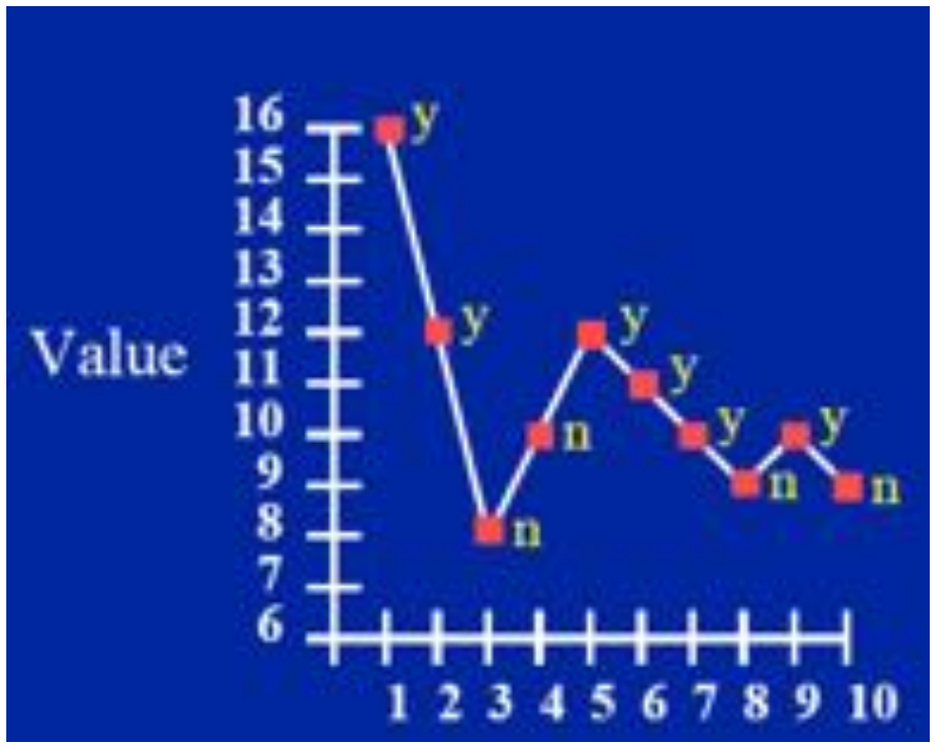
[a] Mean threshold value = 4.1

absolute difference: average transition
JND: size of "equal" band

staircase method

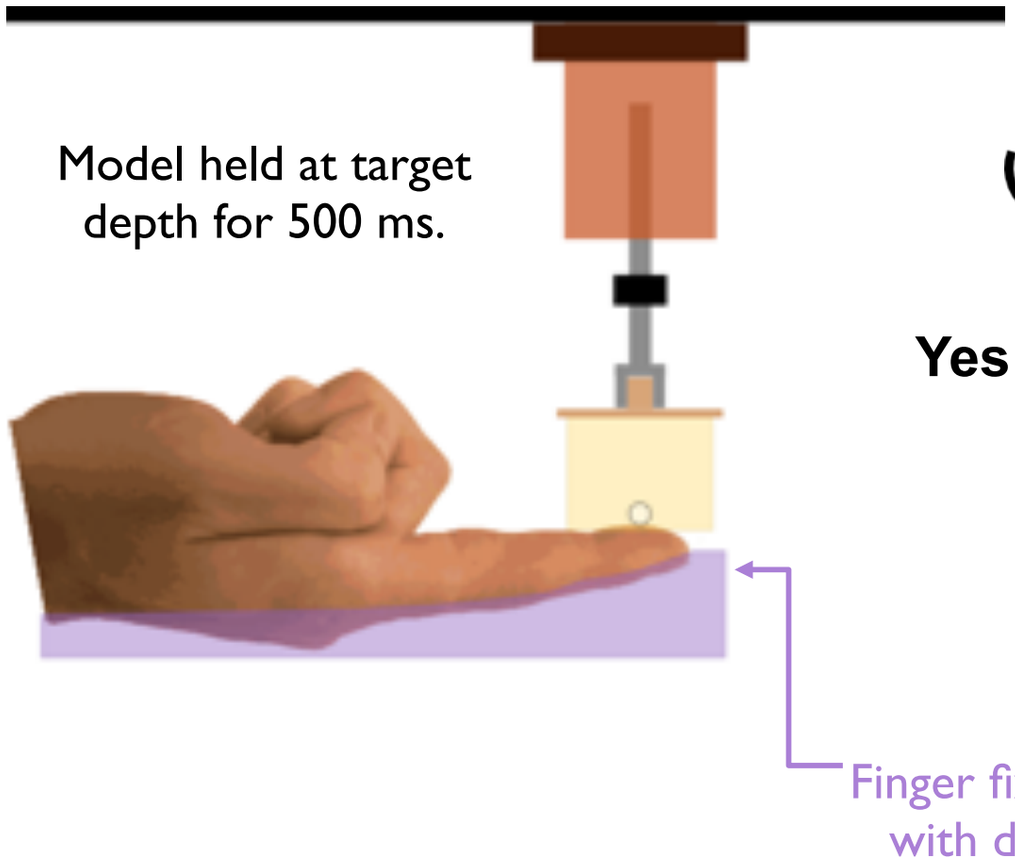
(Modified Method of Limits)

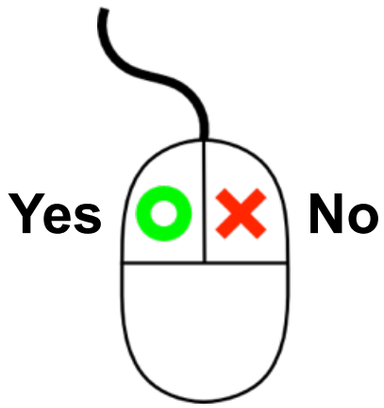
- Begin with high-intensity stimulus
- Intensity is reduced until observer makes error
- Stimulus intensity reverses until subject detects stimulus
- Reversal values averaged
- Multiple staircase methods:
  - step size
  - up/down increments

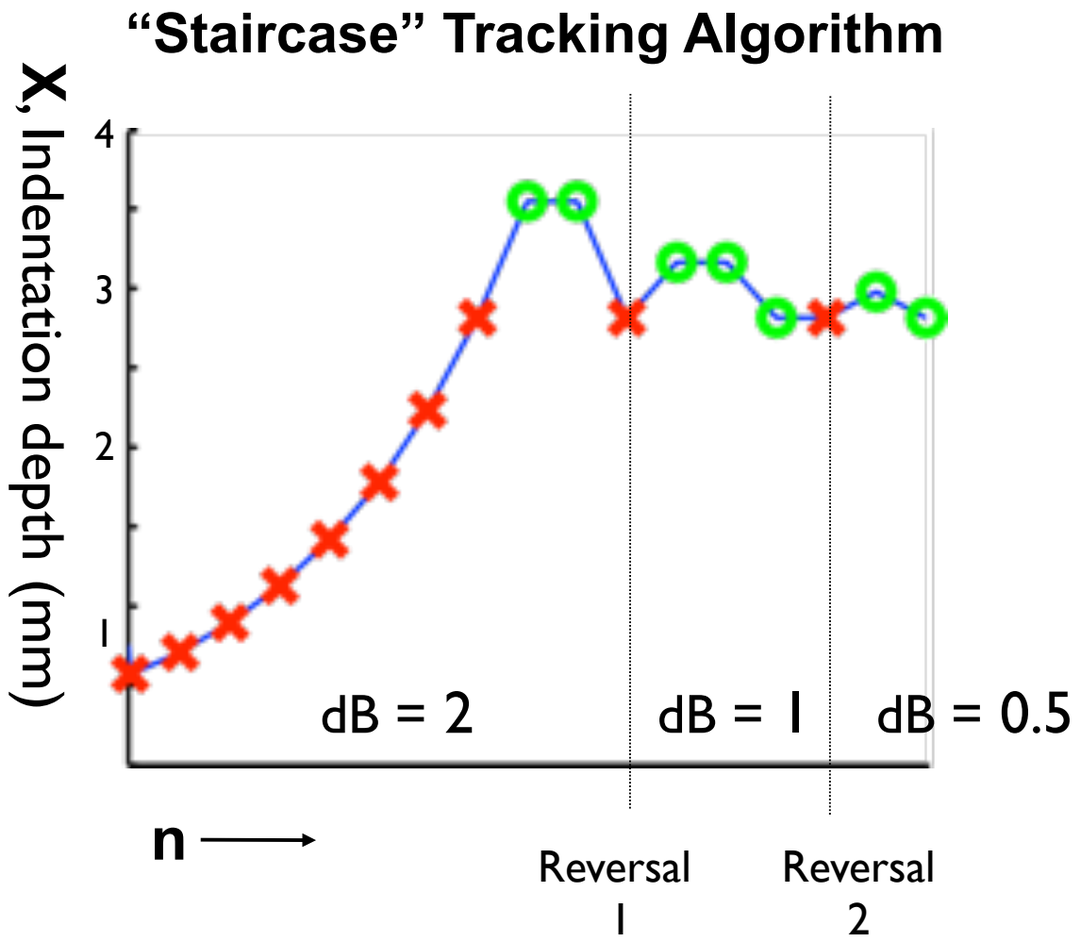


H. Levitt, "Transformed Up-Down Methods in Psychoacoustics," The Journal of the Acoustical Society of America, vol. 49, 1971, pp. 467-477.

example study







- subjects trained with 5 models
- initial indentation is random, below threshold
- trial ends when last 10 indentations are within 2 dB
- indentation depth required for detection is mean of last five indentation values

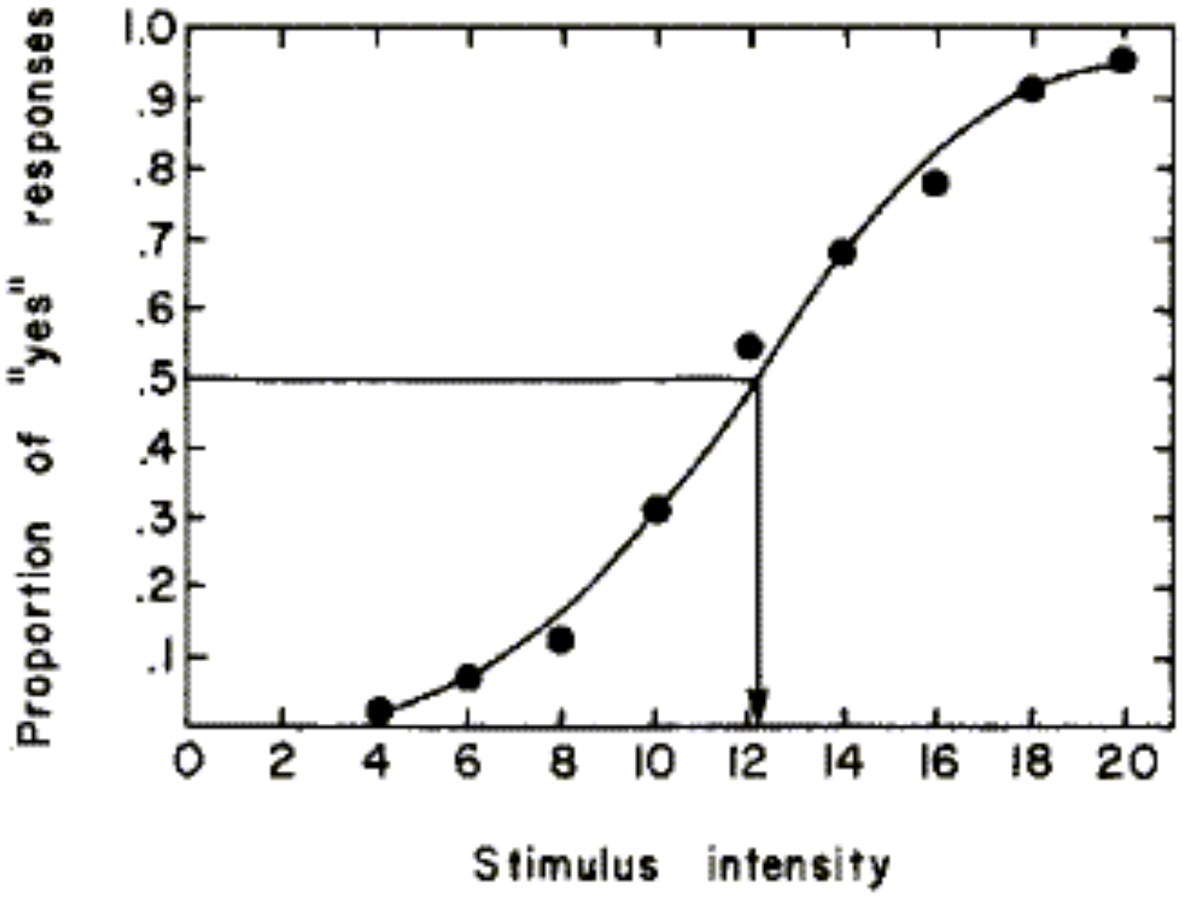
indentation depth defined by:

$$X_n = (X_{n-1})\, 10^{\frac{dB}{20}}$$

method of constant stimuli

Absolute threshold location at 50%

JND between 25% and 75%



- repeat same 5-9 stimuli
- randomly present each ~100x
- detect stimulus? (Y/N)
- percent of positive responses calculated for each stimulus intensity
- fit curve to get psychometric function (usually s-shaped)
- advantage: subject can not predict level of next stimulus intensity (removes errors of habituation and expectation)

method of adjustment

gives absolute and difference threshold locations

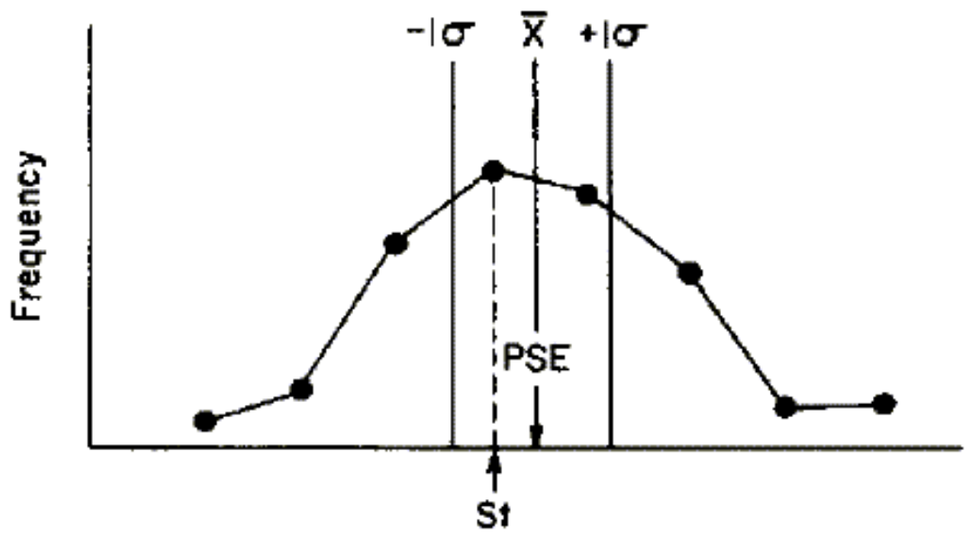


FIG. 2.8. Frequency distribution of setting of the comparison stimulus when the method of adjustment is used to measure the difference threshold. The mean of the distribution is the point of subjective equality, and the standard deviation is used as the difference threshold.

- set stimulus intensity far above or below threshold
- subject "tunes" stimulus intensity to:
  - be perceptible (absolute threshold)
  - match a reference stimulus (difference threshold)
- mean = subjective equality
- difference threshold = standard deviation

perceptual and performance experiments

not all haptic experiments are psychophysical experiments...

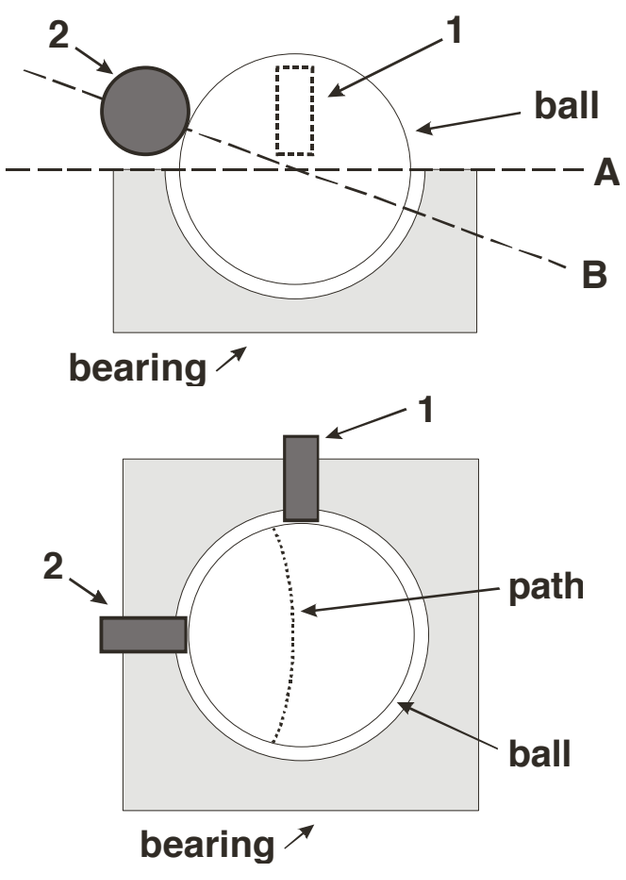
some are perceptual (i.e., they ask different questions about perception)

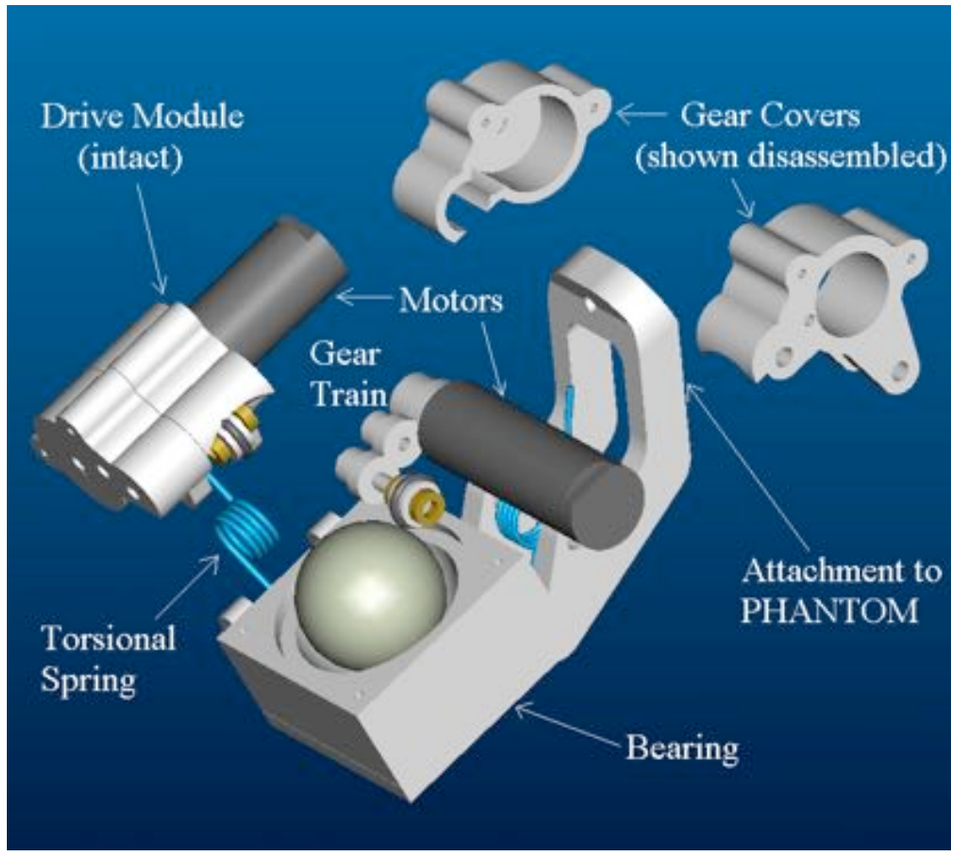
some are related to user performance

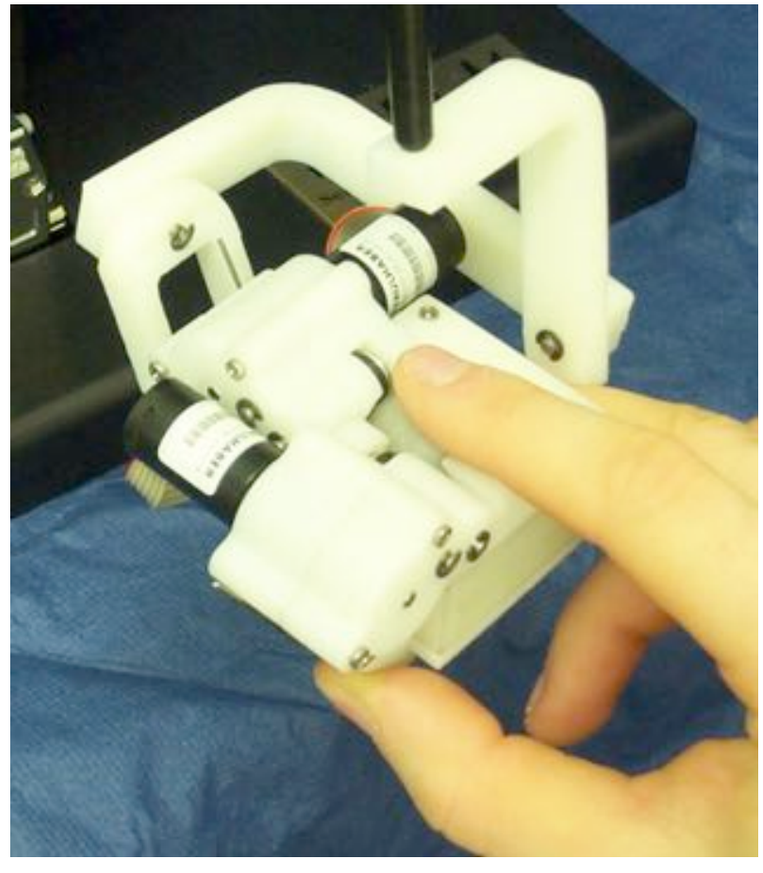
example study, part 1

Design and Performance of a Two-Dimensional Tactile Slip Display
Todd E. Murphy, Robert J. Webster III, and Allison M. Okamura
Proceedings of EuroHaptics 2004, Munich Germany, June 5-7, 2004.

Part 1: Design



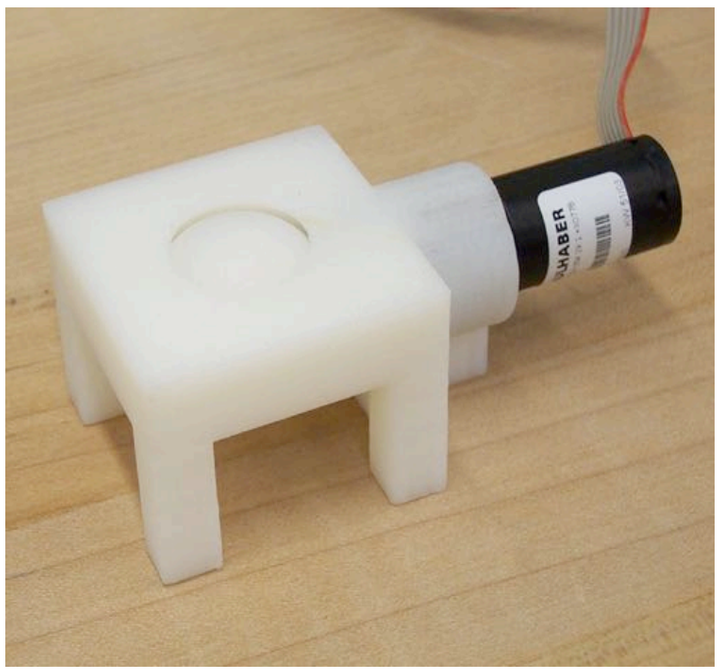


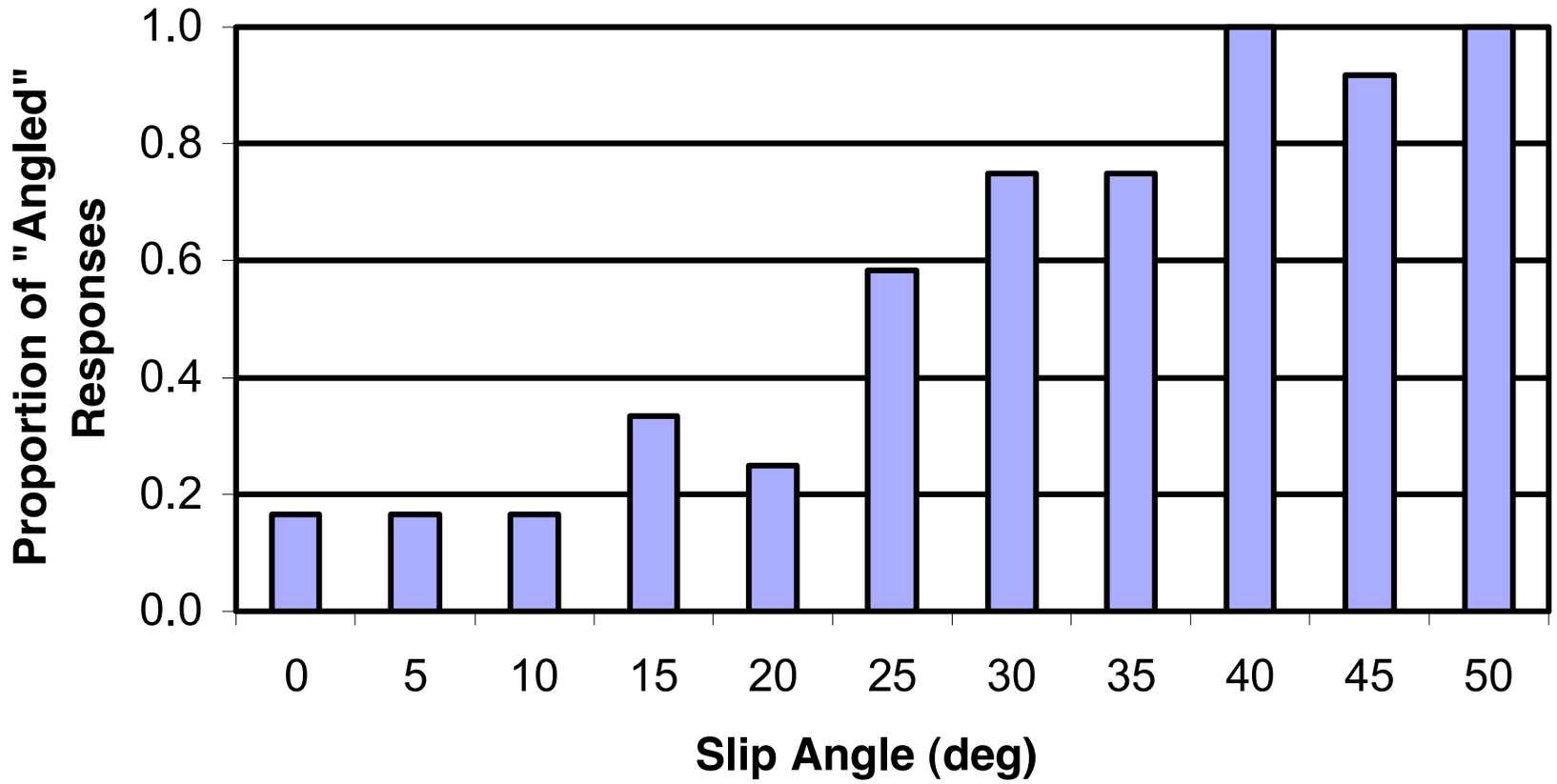


example study, part 2

Design and Performance of a Two-Dimensional Tactile Slip Display
Todd E. Murphy, Robert J. Webster III, and Allison M. Okamura
Proceedings of EuroHaptics 2004, Munich Germany, June 5-7, 2004.

Part 2: User Study

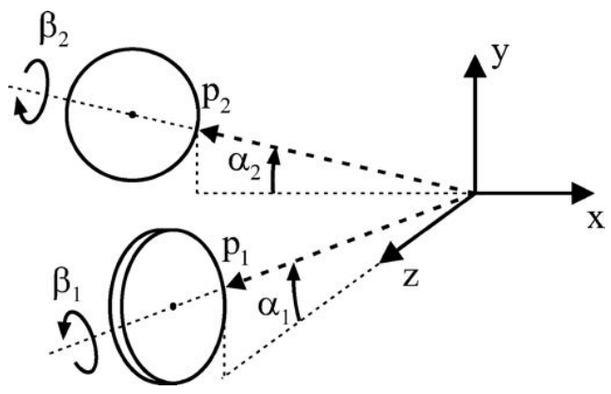




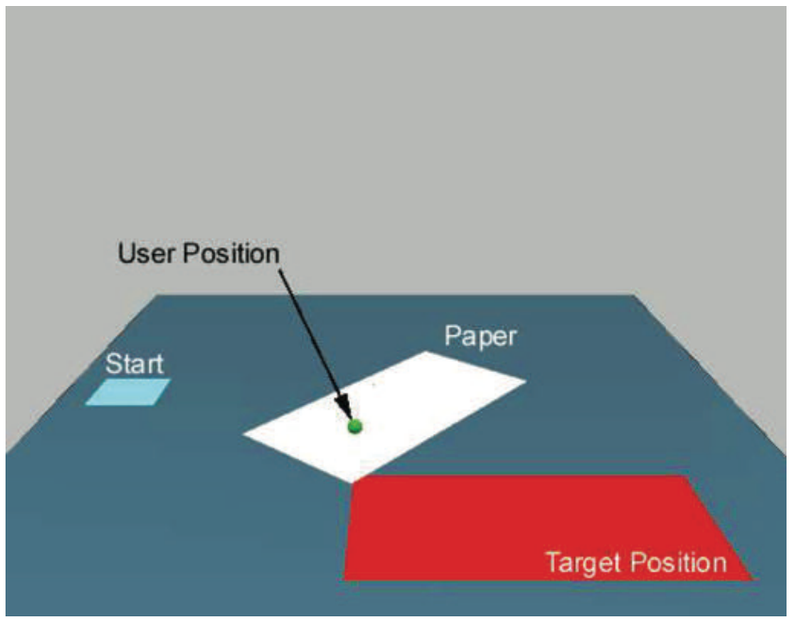
example study, part 3

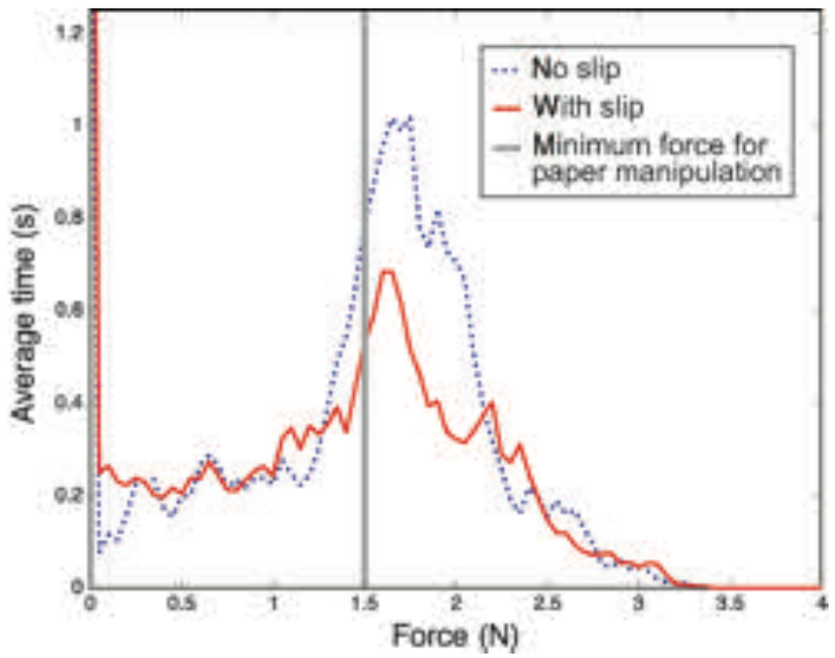
A Novel Two-Dimensional Tactile Slip Display: Design, Kinematics and Perceptual Experiments. Robert J. Webster III, Todd E. Murphy, Lawton Verner, and Allison M. Okamura. ACM Transactions on Applied Perception, 2005.

Follow-on Study



$$\begin{bmatrix} v_x \\ v_z \end{bmatrix} = \eta \begin{bmatrix} \sin\alpha \sin\beta & \cos\beta \\ \cos\beta & \sin\alpha \sin\beta \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$





Types of user studies

types of haptics human subjects experiments

- **system performance**: measures human-machine system performance, typically during execution of a specific task

- **psychophysics**: measures fundamental human capabilities

- **ergonomics**: measures comfort or effect of system on human health

system performance

- design and implement system
- form hypotheses
- determine experiment conditions
- select performance metrics
- implement experiment conditions
- preliminary testing (pilot study)
- final experiment (sometimes w/supplementary studies)

- *Think carefully about experiment design*
- *"Storyboard"*

psychophysics

- the scientific study of the relation between stimulus and sensation

- psychophysical methods were covered earlier

ergonomics

- we don't usually study this in haptics research, but this (and human factors) could certainly be relevant

process of implementing a user study

experiment design considerations

- length of experiment/user fatigue
- location
- subject recruiting (payment?)
- statistical significance (number of users, groups)
- reliability of data; confounding factors
- what constitutes data you can "throw out"?

experiment procedure

- develop a strict experimental procedure (called a protocol)
- develop a very clear set of instructions for your subjects (written, oral, video)
- develop a questionnaire of relevant information about your subjects
- submit an IRB application; receive approval
- perform experiment and analyze data; document thoroughly (save records)

IRB procedure

- any project involving human subjects must be cleared by an IRB before research begins (sometimes this is an exemption)

- this presentation covers ***non-medical*** human subject experiments for ***expedited*** review

- experiments that qualify for expedited review are those with minimum risk to subjects.

http://humansubjects.stanford.edu

IRB

The primary concerns of the IRB in all deliberations is to determine that:

1. the rights and welfare of the subjects are protected adequately,
2. the risks to subjects are outweighed by the potential benefits of the research,
3. the selection of subjects is equitable, and
4. informed consent will be obtained and, when appropriate, documented.

deciding whether or how to apply

- if a project involves human subjects and research, you must complete an application for one of these forms of clearance:
  - an exemption issued by the IRB
  - **IRB approval based on an expedited review**
  - IRB approval based on a full-board review
- study is qualified for an expedited review if it presents no more than minimum risk to subjects and falls under one of the categories listed by DHHS and FDA
- exemption and expedited review typically take one month

expedited review

To complete an application, you must submit

1. **IRB Application:** A general application form stating the purpose, design, and procedure of the human subject experiment you want to run. Include any forms/surveys you will have the subjects fill out.
2. **Consent Form:** A form for subjects to sign that makes sure they understand the risks, benefits and procedure of the experiment and agree to be a subject.
3. **Recruitment Methods:** A copy of what you will send out to your target audience in order to get them to participate.

expedited review, cont'd

4. **List of Team Members and Certification of Training:** After taking the human subject training test, a copy of certification is needed for each experimenter
5. **Copy of Grant Proposal:** You must include this if the research is funded or proposed to be funded

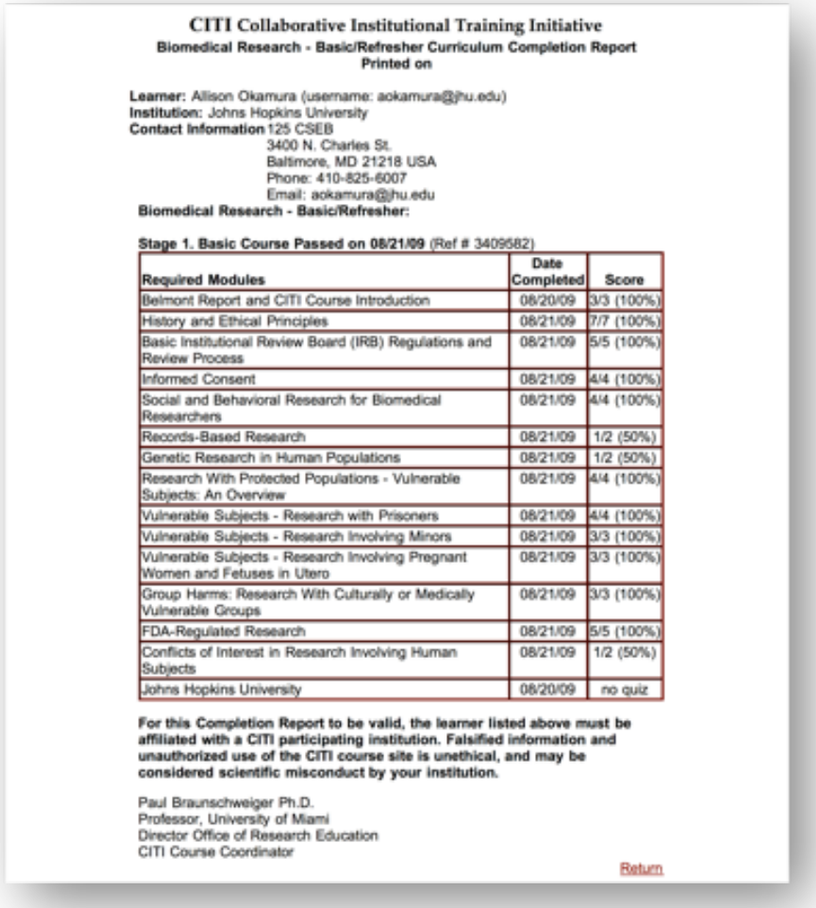
things to consider when writing your application

- **know your audience**
  The people reading this are not engineers, but typically psychologists or sociologists. Give a brief but clear background of what you are trying to do. Make sure acronyms are spelled out.

- **recruiting**
  Your recruiting has to reach a large population in order to get a representative sampling of volunteers. Check for representation in terms of race, gender, experience. Better if recruiting is not done by a supervisor (who might make volunteers feel pressured into participating).

things to consider when writing your application

- **safety**
  Emphasize the safety of your experiments. It is wise to schedule in a rest time if a session is long or strenuous.
- **certification**
  The person submitting the application *and* anyone running the experiments must be certified. The Training and Certification Test is available at https://www.citiprogram.org/



CITI Collaborative Institutional Training Initiative

Biomedical Research - Basic/Refresher Curriculum Completion Report
Printed on

Learner: Allison Okamura (username: aokamura@jhu.edu)
Institution: Johns Hopkins University
Contact Information 125 CSEB
3400 N. Charles St.
Baltimore, MD 21218 USA
Phone: 410-825-6007
Email: aokamura@jhu.edu

Biomedical Research - Basic/Refresher:

Stage 1. Basic Course Passed on 08/21/09 (Ref # 3409582)

Required Modules	Date Completed	Score
Belmont Report and CITI Course Introduction	08/20/09	3/3 (100%)
History and Ethical Principles	08/21/09	7/7 (100%)
Basic Institutional Review Board (IRB) Regulations and Review Process	08/21/09	5/5 (100%)
Informed Consent	08/21/09	4/4 (100%)
Social and Behavioral Research for Biomedical Researchers	08/21/09	4/4 (100%)
Records-Based Research	08/21/09	1/2 (50%)
Genetic Research in Human Populations	08/21/09	1/2 (50%)
Research With Protected Populations - Vulnerable Subjects: An Overview	08/21/09	4/4 (100%)
Vulnerable Subjects - Research with Prisoners	08/21/09	4/4 (100%)
Vulnerable Subjects - Research Involving Minors	08/21/09	3/3 (100%)
Vulnerable Subjects - Research Involving Pregnant Women and Fetuses in Utero	08/21/09	3/3 (100%)
Group Harms: Research With Culturally or Medically Vulnerable Groups	08/21/09	3/3 (100%)
FDA-Regulated Research	08/21/09	5/5 (100%)
Conflicts of Interest in Research Involving Human Subjects	08/21/09	1/2 (50%)
Johns Hopkins University	08/20/09	no quiz

For this Completion Report to be valid, the learner listed above must be affiliated with a CITI participating institution. Falsified information and unauthorized use of the CITI course site is unethical, and may be considered scientific misconduct by your institution.

Paul Braunschweiger Ph.D.
Professor, University of Miami
Director Office of Research Education
CITI Course Coordinator

Return

approval typically lasts for one year, then it has to be renewed

no protocol changes, consent form changes, amendments, or addenda may be made without re-review and approval

STANFORD UNIVERSITY

Stanford, CA 94305 [Mail Code 5579]

Penelope D Eckert, Ph.D. (650) 723-2480
CHAIR, PANEL ON NON-MEDICAL HUMAN SUBJECTS (650) 725-8013

Certification of Human Subjects Approvals

Date: August 9, 2012
To: Allison Mariko Okamura, Mechanical Engineering - Design
Anneliese Rogers, Michele Frances Rotella MSME, Ann Majewicz PhD ME, Jaehyun Bae MSME, Ilana Nisky, Margaret Irene Schatz Koehler Junior, Samuel Benjamin Schorr MSME, Zhan Fan Quek MSME

From: Penelope D Eckert, Ph.D., Administrative Panel on Human Subjects in Medical Research

Protocol Haptics in Virtual Environment and Teleoperation Systems
Protocol ID: 22514 **IRB Number:** 349 (Panel: 2)

The IRB approved human subjects involvement in your research project on 08/09/2012. **'Prior to subject recruitment and enrollment, if this is: a Cancer-related study, you must obtain Cancer Center Scientific Review Committee (SRC) approval;** a GCRC study, you must obtain GCRC approval; a VA study, you must obtain VA R and D Committee approval; and if a contract is involved, it must be signed.'

The expiration date of this approval is 09/30/2012 at Midnight. If this project is to continue beyond that date, you must submit an updated protocol in advance for the IRB's re-approval. If this protocol is used in conjunction with any other human use it must be re-approved. Proposed changes to approved research must be reviewed and approved prospectively by the IRB. No changes may be initiated without prior approval by the IRB, except where necessary to eliminate apparent immediate hazards to subjects. (Any such exceptions must be reported to the IRB within 10 working days.) Unanticipated problems involving risks to participants or others and other events or information, as defined and listed in the Report Form, must be submitted promptly to the IRB. (See Events and Information that Require Prompt Reporting to the IRB at http://humansubjects.stanford.edu.)

All continuing projects and activities must be reviewed and re-approved on or before Midnight of the expiration date. The approval period will be less than one year if so determined by the IRB. It is your responsibility to resubmit the project to the IRB for continuing review and to report the completion of the protocol to the IRB within 30 days.

Please remember that all data, including all signed consent form documents, must be retained for a minimum of three years past the completion of this research. Additional requirements may be imposed by your funding agency, your department, or other entities. (See Policy on Retention of and Access to Research Data at http://stanford.edu/dept/DoR/rph/2-10.html.)

This institution is in compliance with requirements for protection of human subjects, including 45 CFR 46, 21 CFR 50 and 56, and 38 CFR 16.

Penelope D Eckert, Ph.D., Chair

Approval Period: 08/09/2012 THROUGH 09/30/2012
Review Type: EXPEDITED - MODIFICATION
Funding: National Science Foundation - Grant: Pending: NSF Proposal #1227406 , SPO: 106431
Expedited Under Category: 4, 6, 7
Assurance Number: FWA00000935 (SU)

general experiment planning

- 6 weeks or more before experiment:
  - do human subjects training
  - write IRB application and edit
- 5 weeks (or more):
  - submit IRB application
- 2 weeks (or more):
  - have complete system working
  - go through procedure with "expert" subject
  - revise experiment (get pilot data and modify system parameters as needed)
- 1 week (or more):
  - send out recruitment notices and schedule subjects

