DCGI
DEPARTMENT OF COMPUTER GRAPHICS AND INTERACTION
CZECH TECHNICAL UNIVERSITY IN PRAGUE

EMPIRICAL STUDIES POWER ANALYSIS

SAN 2021/22

HUMAN FACTORS

HUMAN FACTORS | VARIABILITY

- Humans are complicated – Computers are simple
- Age, female, male, experts, novices, left- handed, right-handed, English-speaking, Chinese-speaking, from the north, from the south, tall, short, strong, weak, fast, slow, able-bodied, disabled, sighted, blind, motivated, lazy, creative, bland, tired, alert, …
- Humans are never precise

HUMAN FACTORS | TIME SCALE

- Workplace habits, groupware usage patterns, social networking, online dating, privacy, media spaces, design theory, …
- Web navigation, user search strategies, collaborative computing, ubiquitous computing, social navigation, …
- Selection techniques, force or auditory feedback, text entry, gestural input, …

HUMAN FACTORS | TIME SCALE

- Workplace habits, groupware usage patterns, social netw spaces, desi
- Web naviga collaborative social navig
- Selection te text entry, g

Scale (sec)	Time Units	System	World (theory)
10^7	Months		
10^6	Weeks		**SOCIAL BAND**
10^5	Days		
10^4	Hours	Task	
10^3	10 min	Task	**RATIONAL BAND**
10^2	Minutes	Task	
10^1	10 sec	Unit task	
10^0	1 sec	Operations	**COGNITIVE BAND**
10^{-1}	100 ms	Deliberate act	
10^{-2}	10 ms	Neural circuit	
10^{-3}	1 ms	Neuron	**BIOLOGICAL BAND**
10^{-4}	100 µs	Organelle	

Newell 1999

HUMAN FACTORS | TIME SCALE

- Workplace habits, groupware usage patterns, social networking, online dating, privacy, media spaces, design theory, …
- Web navigation, user search strategies, collaborative computing, ubiquitous computing, social navigation, …
- Selection techniques, force or auditory feedback, text entry, gestural input, …

Scale (sec)	Time Units	System	World (theory)
10^7	Months		SOCIAL BAND
10^6	Weeks		
10^5	Days		
10^4	Hours	Task	RATIONAL BAND
10^3	10 min	Task	
10^2	Minutes	Task	
10^1	10 sec	Unit task	COGNITIVE BAND
10^0	1 sec	Operations	
10^{-1}	100 ms	Deliberate act	
10^{-2}	10 ms	Neural circuit	BIOLOGICAL BAND
10^{-3}	1 ms	Neuron	
10^{-4}	100 µs	Organelle	

Newell 1999

HUMAN FACTORS | TIME SCALE

Qualitative

Quantitative

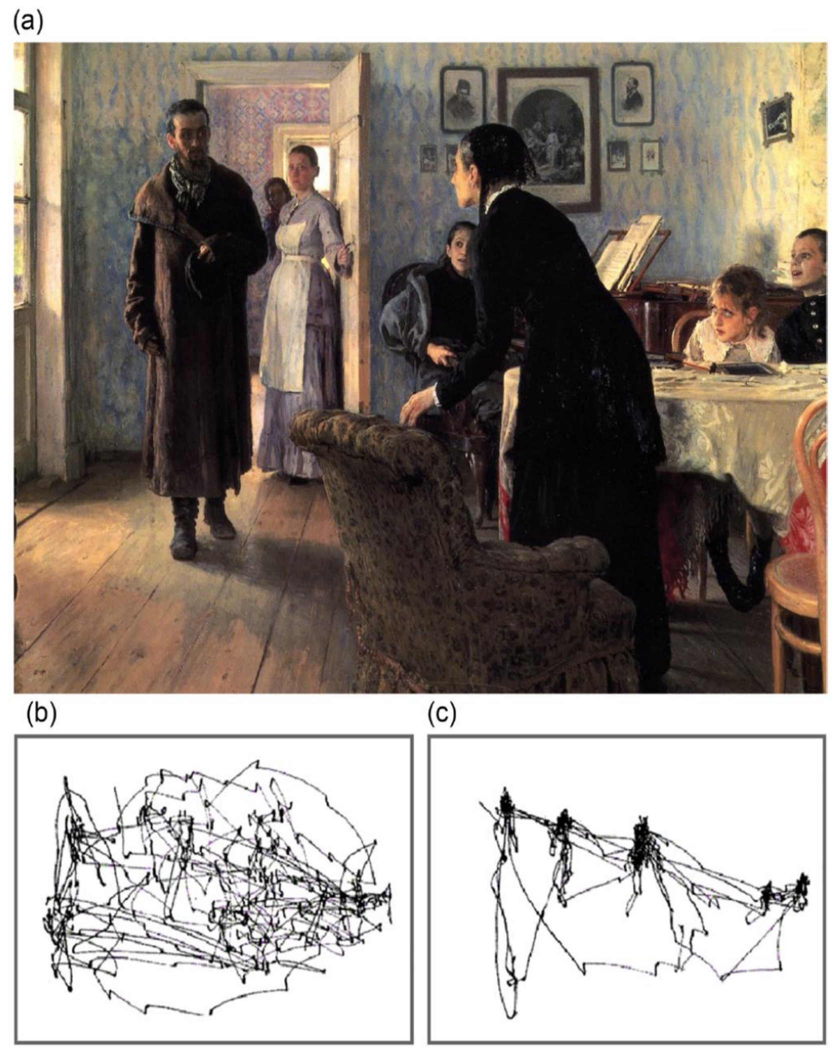
- Workplace habits, groupware usage patterns, social networking, online dating, privacy, media spaces, design theory, …
- Web navigation, user search strategies, collaborative computing, ubiquitous computing, social navigation, …
- Selection techniques, force or auditory feedback, text entry, gestural input, …

Scale (sec)	Time Units	System	World (theory)
10^7	Months		**SOCIAL BAND**
10^6	Weeks		
10^5	Days		
10^4	Hours	Task	**RATIONAL BAND**
10^3	10 min	Task	
10^2	Minutes	Task	
10^1	10 sec	Unit task	**COGNITIVE BAND**
10^0	1 sec	Operations	
10^{-1}	100 ms	Deliberate act	
10^{-2}	10 ms	Neural circuit	**BIOLOGICAL BAND**
10^{-3}	1 ms	Neuron	
10^{-4}	100 µs	Organelle	

Newell 1999

HUMAN FACTORS | SENSORS

- Vision
  - Intensity, Fixations, Saccades
- Hearing
  - Loudness, Pitch, Timbre
- Touch
  - Position, Texture, Temperature, Movement, Resistance

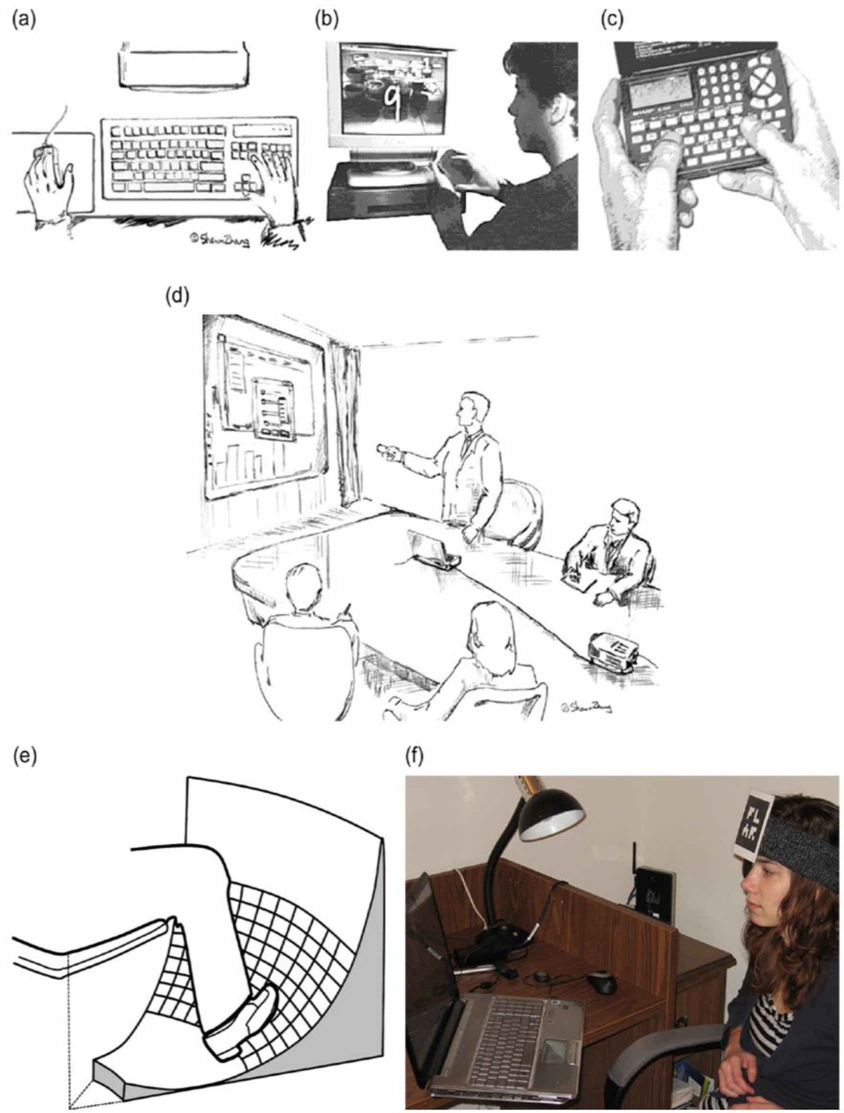


Tatler 2010

(a) Scene. (b) Task: Remember the position of the people and objects in the room. (c) Task: Estimate the ages of the people

HUMAN FACTORS | RESPONDERS

- Limbs
- Voice
- Eyes
- Taste and smell

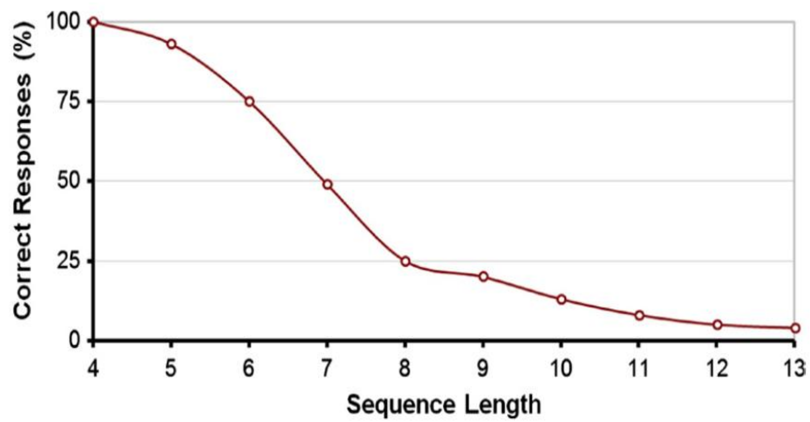


Use of the limbs in HCI: (a) Hands. (b) Fingers. (c) Thumbs. (d) Arms. (e) Feet. (f) Head.

a and d courtesy of Shawn Zhang; e, adapted from Pearson and Weiser, 1986, MacKenzie 2013

HUMAN FACTORS | BRAIN

- Cognition
  - Thinking, reasoning, and deciding
- Memory
  - Long-term vs short-term (working)
- Language
  - Corpus, redundancy, entropy




```
THE ROOM WAS NOT VERY LIGHT A SMALL OBLONG
----ROO------NOT-V-----I------SM----OB----

READING LAMP ON THE DESK SHED GLOW ON
REA----------O------D----SHED-GLO--0-

POLISHED WOOD BUT LESS ON THE SHABBY RED CARPET
P-L-S-----O---BU--L-S--O-------SH----RE--C-----
```

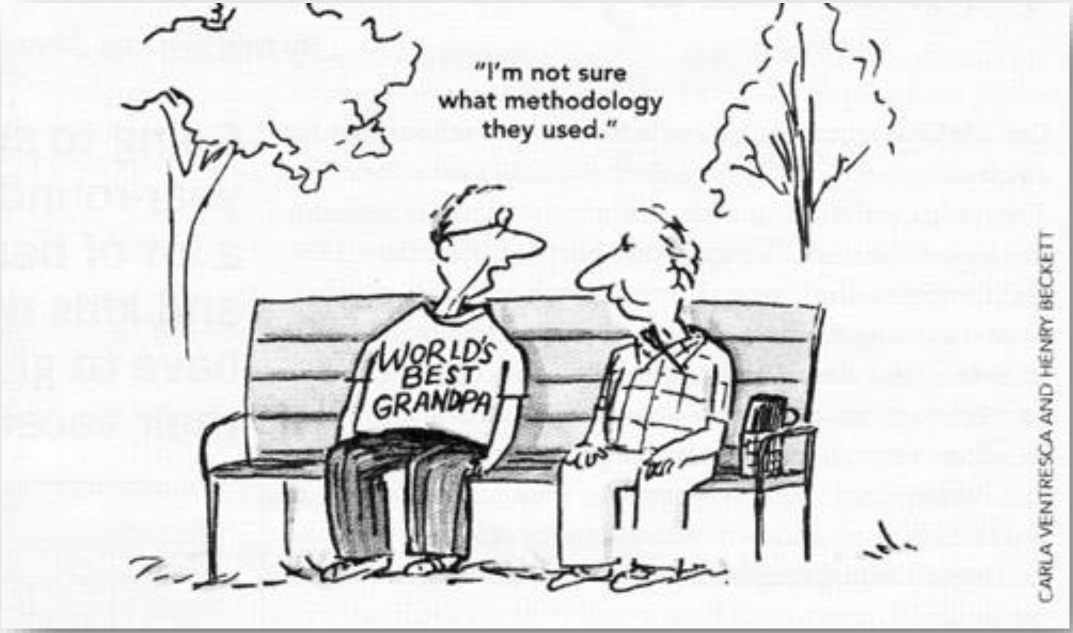
HUMAN FACTORS | PERFORMANCE

- Reaction time
  - stimuli->response delay
- Time to make decision
  - logarithmic if there is a system
- Visual search
  - linear relation to number of items
- Skilled behavior
  - performance improves through training
- Attention
  - no cognitive action without attention
- Error
  - error is a discrete event in a task, or trial, where the outcome is incorrect

RESEARCH METHODS

RESEARCH METHODS

- Observation
- Experiment
- Correlation

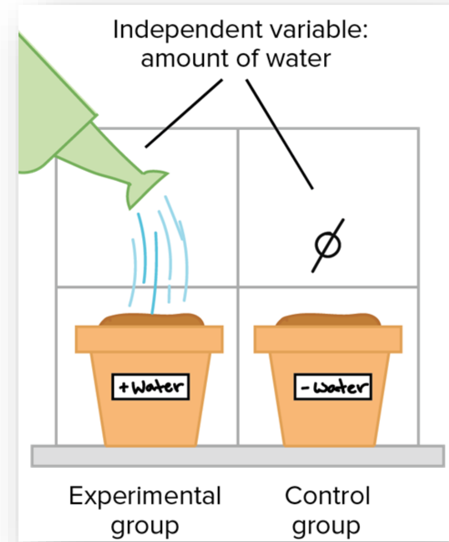


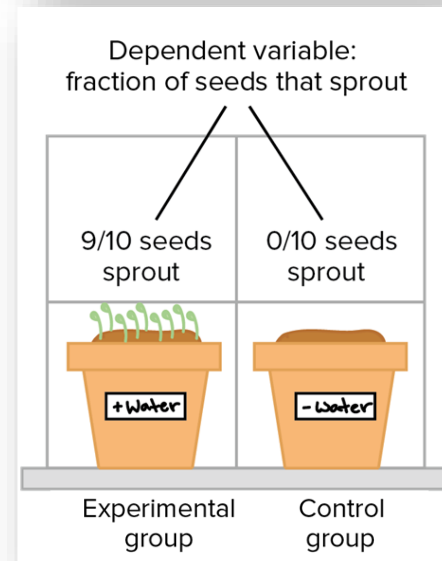
RESEARCH | OBSERVATION

- Interviews, field investigations, contextual inquiries, case studies, focus groups, …
- Focus on thought, feeling, attitude, emotion, reaction, expression, sentiment, opinion, mood, manner, strategy, …
- Qualitative rather than quantitative
- Achieves relevance while sacrificing precision

RESEARCH | EXPERIMENT

- Controlled experiments in laboratory settings
- Checking causality
  - manipulated (independent) variable => response (dependent) variable
  - systematically exposing participants to different configurations of the interface or interaction technique
- Measurement of responses
  - task completion time, number of errors, …
- Allows conclusion to be drawn
  - hypothesis test





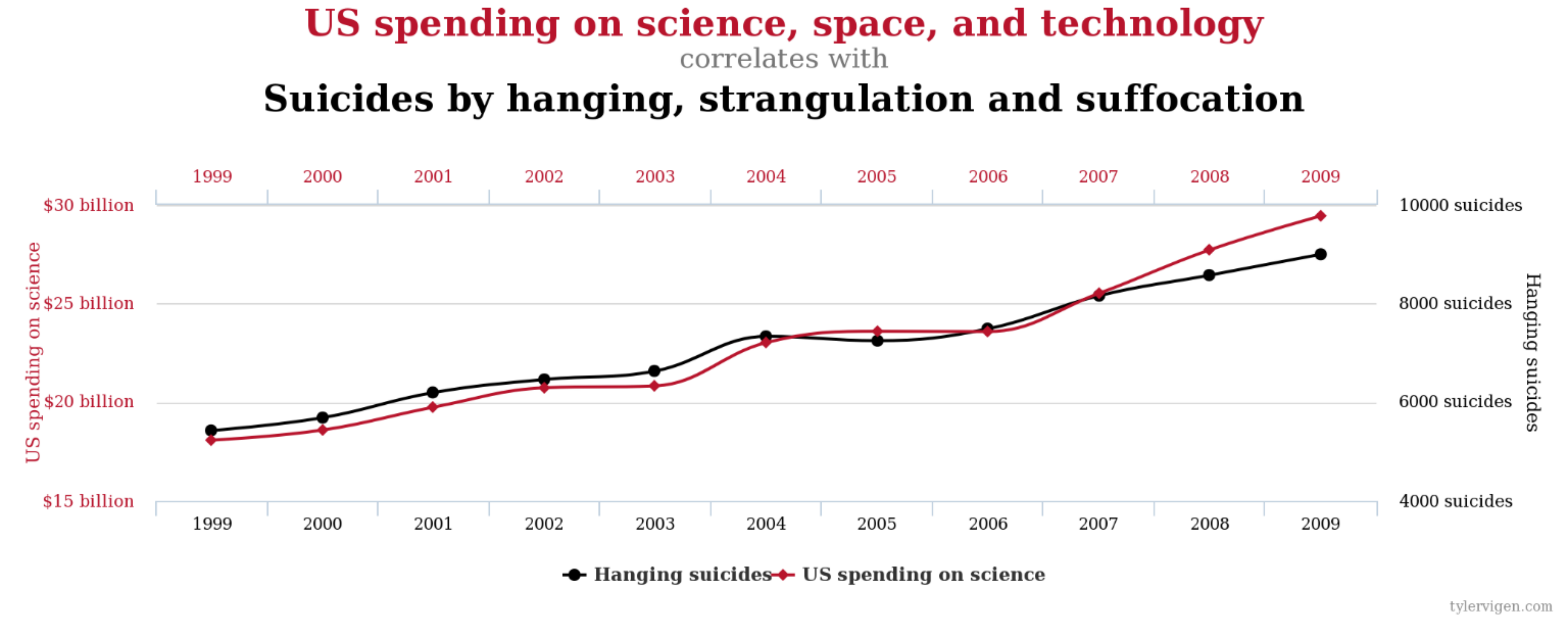
Khan Academy

RESEARCH | CORRELATION

- Looking for relations between variables
- Quantification of variables is necessary
  - age, income, number of privacy settings
  - nominal-scale variables are categorized (e.g., personality type, gender)
- Data collected through a various methods
  - observation, interviews, on-line surveys, questionnaires, or measurement
- Balance between relevance and precision

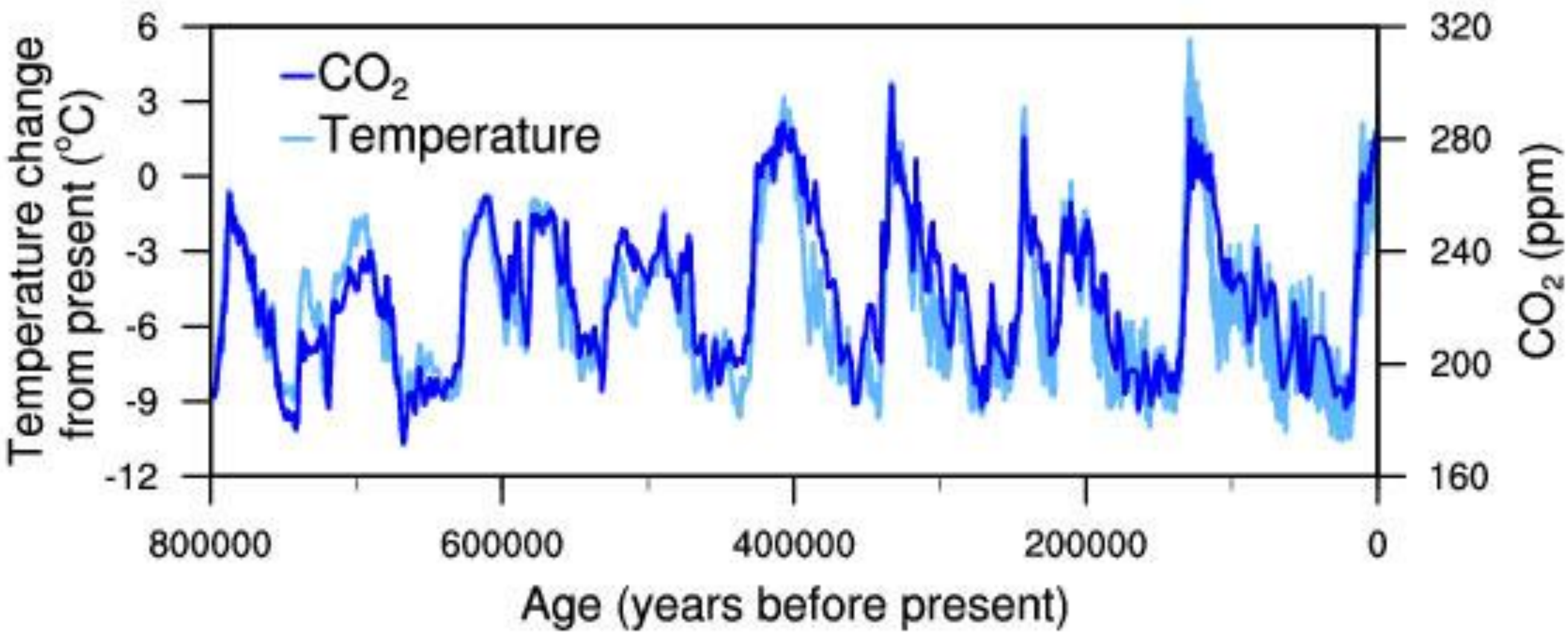
RESEARCH | CORRELATION

- Looking for relations between variables



RESEARCH | CORRELATION

- Looking for relations between variables



NOAA, Jouzel 2007

MEASUREMENT

MEASUREMENT | SCALES

- Nominal, ordinal, interval, ratio

- Different sort of information
- Different analysis possible

MEASUREMENT | NOMINAL

- Assigning a code to an attribute or a category
  - it does not need to be a number
- Often used with frequencies or counts

P02	F	BHAL	L	4
P06	F	AHBL	C	4
P07	F	ALBH	C	4
P08	F	BHAL	C	5
P09	F	BLAH	C	5
P10	F	AHBL	C	5
P11	M	ALBH	C	5
P13	M	ALBH		
P14	M	BLAH		
P15	F	BHAL		
P16	F	BLAH		
P18	M	BLAH		
P19	F	ALBH		
P20	M	AHBL		

Gender	Mobile Phone Usage		Total	%
	Not Using	Using		
Male	683	98	781	51.1%
Female	644	102	746	48.9%
Total	1327	200	1527	
%	86.9%	13.1%		

MEASUREMENT | ORDINAL

- Order or ranking
- Interval is not intrinsically equal between successive points on the scale
- Comparisons of greater than or less than are possible
- It is not valid to compute the mean

How many email messages do you receive each day?

1. None (I don't use email)
2. 1-5 per day
3. 6-25 per day
4. 26-100 per day
5. More than 100 per day

MacKenzie 2013

MEASUREMENT | INTERVAL

- Equal distances between adjacent values
- There is no absolute zero
- Mean can be computed
- Ratios of interval data are not meaningful
  - one cannot say that 20°C is twice as warm as 10°C

Please indicate your level of agreement with the following statements.

	Strongly disagree	Mildly disagree	Neutral	Mildly agree	Strongly agree
It is safe to talk on a mobile phone while driving.	1	2	3	4	5
It is safe to read a text message on a mobile phone while driving.	1	2	3	4	5
It is safe to compose a text message on a mobile phone while driving.	1	2	3	4	5

MacKenzie 2013

MEASUREMENT | RATIO

- Ratio data have an absolute zero
- Time
  - completion time
- Count
  - normalization is recommended
- Errors normalized as "error rates (%)"
  - number of errors/number of trials*100
  - number of incorrectly entered characters/total number of characters times 100

RESEARCH QUESTION IN HCI

RESEARCH QUESTION

- Research is conducted to answer (and raise) questions about new or existing user interfaces or interaction techniques
- Often the questions contains the relationship between two variables:
  - One variable is a circumstance or condition that is manipulated – interface property
  - The other is an observed and measured behavioral response – task performance

RESEARCH QUESTION

- ~~Is it viable?~~
- ~~Is it as good as or better than current practice?~~
- ~~What are its strengths and weaknesses?~~
- ~~Which of several alternatives is the best?~~

Relevant, but
not testable!

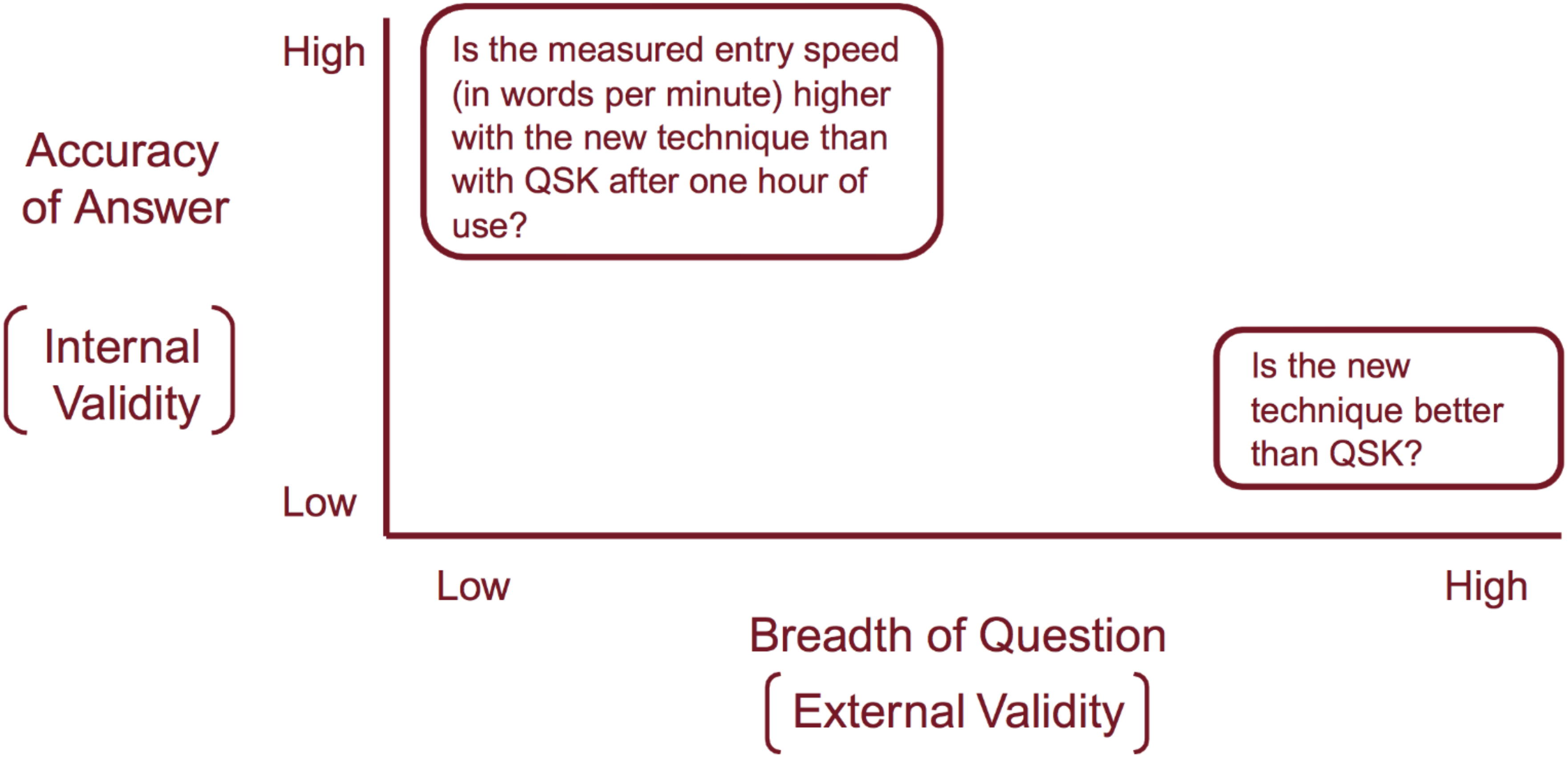
RESEARCH QUESTION

Example, questions about new input technique comparing to qwerty software keyboard (QSK).

- Is the new technique any good?
- Is the new technique better than QSK?
- Is the new technique faster than QSK?
- Is the new technique faster than QSK after a bit of practice?
- Is the measured entry speed (in words per minute) higher for the new technique than for a QSK after one hour of use?

More focused

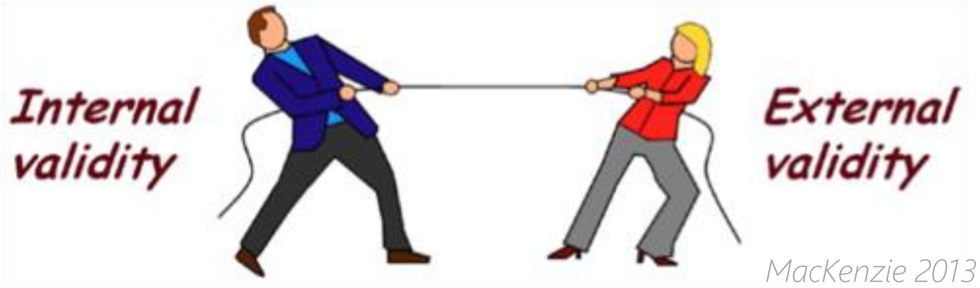
INTERNAL VS. EXTERNAL VALIDITY



MacKenzie 2013

INTERNAL VS. EXTERNAL VALIDITY

- Internal Validity
  - low in breadth (that's bad!) yet answerable with high accuracy (that's good!)
  - we can craft a methodology to answer it through observation and measurement
- External Validity
  - high in breadth (that's good!) yet answerable with low accuracy (that's bad)
  - we lack a methodology to observe and measure "better than"



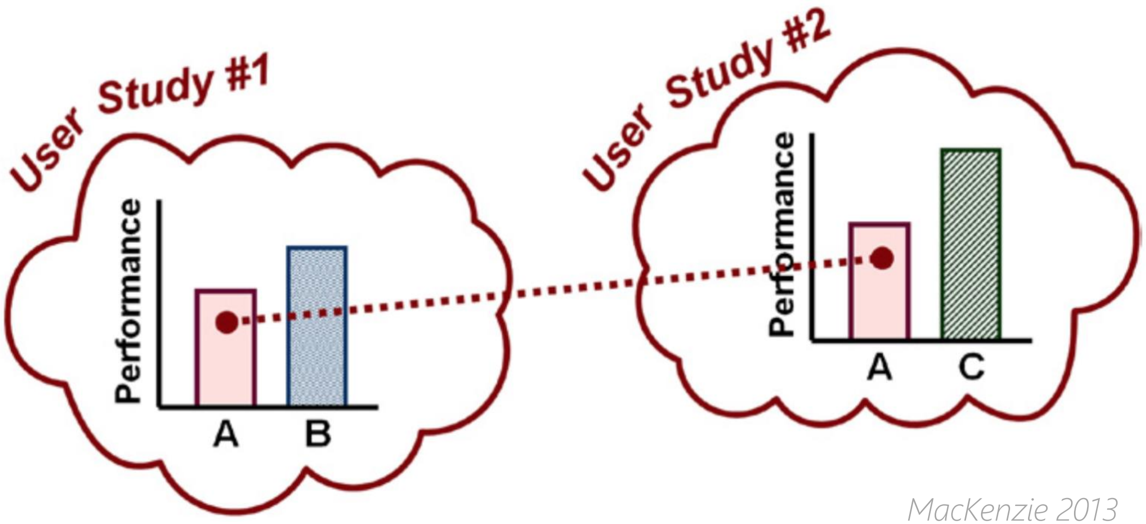
VARIABILITY AND CONFIDENCE

- People exhibit variability in their actions
- Variability person per person, but also person per task
- The result is always different!
- Variability strongly affects the confidence with which we can answer research questions

DESIGNING HCI EXPERIMENT

COMPARATIVE EVALUATION

- Evaluation on its own is questionable
- Baseline condition validates the methodology
- Testable research questions are crafted as comparisons



MacKenzie 2013

EXPERIMENT DESING

Process of bringing together all the pieces necessary to test hypotheses on a user interface or interaction technique:

- Variables
- Tasks and procedure
- Participants

VARIABLES | INDEPENDENT

An independent variable (factor) is a characteristic that is manipulated or systematically controlled to evoke a change in a human response.

- Manipulated across multiple levels (at least 2)
- Independent of participant behavior
- Typically a nominal-scale attribute, often related to a property of an interface
  - device, entry method, feedback modality, selection technique, menu depth, button layout
  - unchangeable human characteristic (age, handedness, gender, expertise, ...)
  - environment characteristics (room lightning, noise, ...)

VARIABLES | DEPENDENT

A dependent variable is a measured human behavior.

- Typically a ratio-scale human behavior
  - task completion time, error rate, accuracy, number of button clicks, scrolling events, gaze shifts, …
- Dependent on the human behavior
- Any observable, measurable aspect of human behavior is a potential dependent variable
  - all dependent variables must be clearly defined to ensure the research can be replicated

VARIABLES | OTHER

- Control variables
  - influence a dependent variable but are not under investigation => we try to make them constant
  - lighting, temperature, noise, display size, mouse shape, keyboard angle, chair height, participant characteristic
- Random variables
  - increase variability of measured behavior => results are less generalizable
  - typically characteristics of the participants: biometrics, social disposition (nervousness), genetics (gender, IQ)

Variable	Advantage	Disadvantage
Random	Improves external validity by using a variety of situations and people.	Compromises internal validity by introducing additional variability in the measured behaviours.
Control	Improves internal validity since variability due to a controlled circumstance is eliminated	Compromises external validity by limiting responses to specific situations and people.

MacKenzie 2013

VARIABLES | OTHER

- Confounding variables
  - any circumstance or condition that changes systematically with an independent variable is a confounding variable
  - very problematic in research – is the effect due to independent variable or confounding?
  - e.g. prior experience, experiment setup (difference in conditions), …

VARIABLES | EFFECTS

- Main effect vs. interaction effects on dependent variables
- Interaction effects that are three-way or higher are extremely difficult to interpret
- Optimal number of independent variables: one or two, three at most

TASK & PROCEDURE

- Procedure should contain all combinations of independent variable and their values
- Task is representative and discriminates

- Besides tasks the procedure contains instruction and training

PARTICIPANTS

- Select participants from the same population to whom to results apply
- Use sufficient number of participants
  - a priori power analysis
  - check similar research studies
- Increasing the number of participants increases the likelihood of achieving statistically significant results
  - Large number of participants: statistically significant results for a difference of no practical significance

PARTICIPANTS | WITHIN/BETWEEN S.

WITHIN-SUBJECT

- repeated measures
- less participants
- variance low
- interference between test cond.
  - learning effect
  - fatigue effect

BETWEEN-SUBJECT

- separate groups
- more participants
- balancing needed
- no interference between test cond.

PARTICIPANTS | CONTERBALANCING

- Simplest case 1 factor, 2 levels (A, B), within-subject experiment participants are divided into two groups, 12 participants:
  - 6 in one group order A, B
  - 6 in the other group order of conditions B, A
- This is the simplest case of **Latin square**
- n × n table filled with n different symbols positioned such that each symbol occurs exactly once in each row and each column

(a)

A	B
B	A

(b)

A	B	C
B	C	A
C	A	B

(c)

A	B	C	D
B	C	D	A
C	D	A	B
D	A	B	C

(d)

A	B	C	D	E
B	C	D	E	A
C	D	E	A	B
D	E	A	B	C
E	A	B	C	D

PARTICIPANTS | CONTERBALANCING

- **Balanced Latin squares** where each condition precedes and follows other conditions an **equal number of times**
- Number of levels of the factor must divide equally

A	B	C	D
B	C	D	A
C	D	A	B
D	A	B	C

4x4 unbalanced Latin square

(a)

A	B	D	C
B	C	A	D
C	D	B	A
D	A	C	B

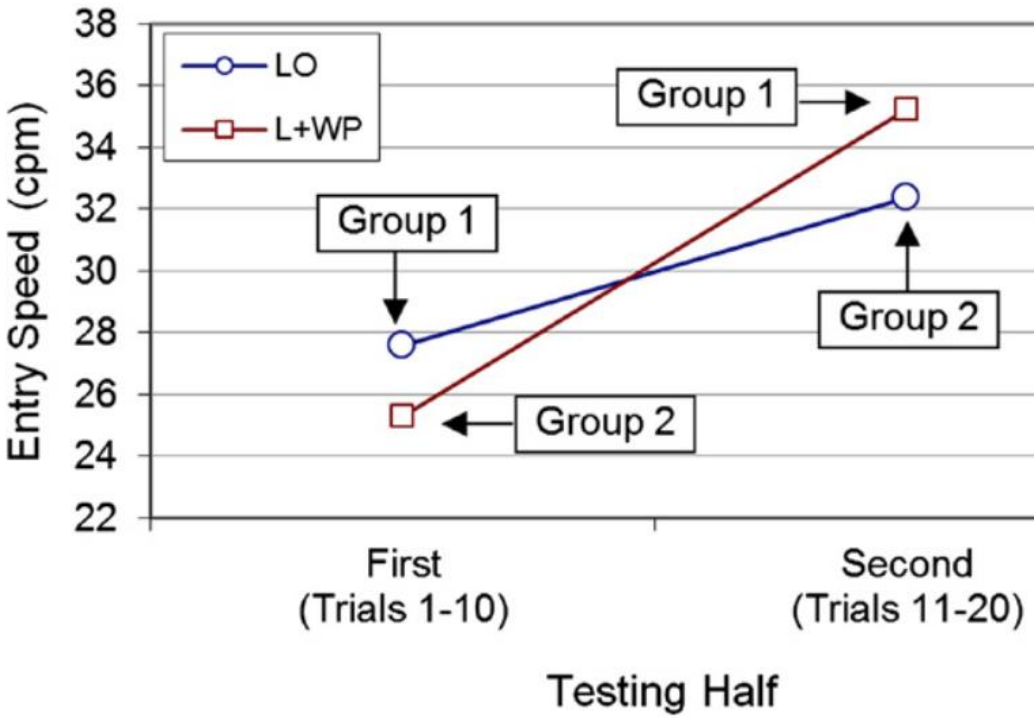
(b)

A	B	F	C	E	D
B	C	A	D	F	E
C	D	B	E	A	F
D	E	C	F	B	A
E	F	D	A	C	B
F	A	E	B	D	C

Balanced Latin squares (a) 4 × 4. (b) 6 × 6.

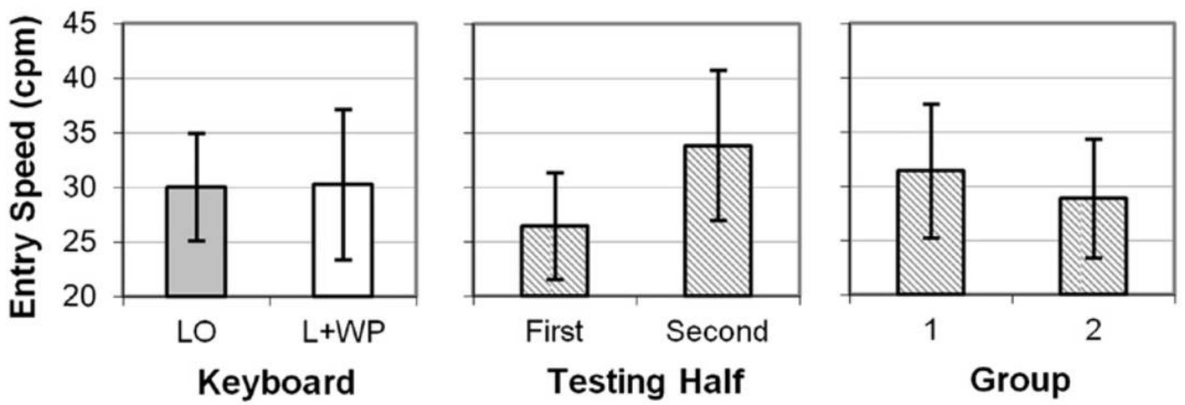
ASYMMETRIC SKILL TRANSFER

- There are occasions where different learning effects appear for one order (e.g., A→B) compared to another (e.g., B→A)
  - group effect =different amount of improvement depending on the order of testing



Asymmetric skill transfer

- Skills from first condition transfers to next condition e.g. unskilled/untrained participants
- This can be prevented either by between-subject design, or long enough training in within-subject design



POWER ANALYSIS

ERRORS IN EXPERIMENTS

- Type I error (False positive, α error)
  - H_0 is rejected, when in reality H_1 is not correct
- Type II error (False negative, β error)
  - H_0 is not rejected (H_1 is not accepted), when in reality H_1 is correct

	H0 not rejected	H1 accepted
H0 is truth	Correct	Type I error
H1 is truth	Type II error	Correct

SOURCES OF ERRORS

- 1. Usability properties identification
- 2. Prototype creation
- 3. Experiment design
- 4. Participants recruitment
- 5. Test execution and data collection
- 6. Data analysis
- 7. Conclusions and recommendations statement

SOURCES OF ERRORS | CONT.

- 3. Experiment design
  - poor choic
  - wrong cho
    - unaware
      design in
  - accidental
    insignificar
    - large spr
    - shift of m

- 6. Data analys
  - analysis of influence of test conditions on the data measured
  - evaluator bias => analysis performed by more evaluators

DATA ANALYSIS | OUTLIERS

- Outliers are always there
  - but more often for "long tail" distributions

- Outliers elimination
  - selection bias => "data fishing"
  - before looking at the data measured (step 6)
  - better: before test execution (step 5)

  - perform qualitative evaluation of outliers behavior

	method A					method B				
min	26	24	22	17	15	10	9	8	7	6
max	94	98	75	82	72	41	39	31	29	27

SAN 2018 experiment

POWER ANALYSIS

- Power of a test = (1 – β)
  - probability that the test correctly rejects H_0

$$\mathbf{power} = \mathbb{P}(\mathbf{reject}\,H_0 | H_1 \ \mathbf{is\ true})$$

- Depends on
  - significance level α (Type I error probability)
  - sample size *n*
  - effect size *d* (min. degree of violation of H_0)
    - specify on a priori grounds

t test: $$Cohen's\ d = \frac{\mu_1 - \mu_2}{\sigma}$$

POWER ANALYSIS | SIZE *d*

- t tests
  - Cohen's suggestion: 0.2, 0.5, 0.8

$$d = \frac{\mu_1 - \mu_2}{\sigma}$$

- ANOVA
  - Cohen's suggestion: 0.1, 0.25, 0.4

$$f = \sqrt{\frac{\sum_{i=1}^{k} p_i * (\mu_i - \mu)^2}{\sigma^2}}$$

$p_i = n_i / N$
$n_i =$ number of observations in group i
$\mu =$ grand mean

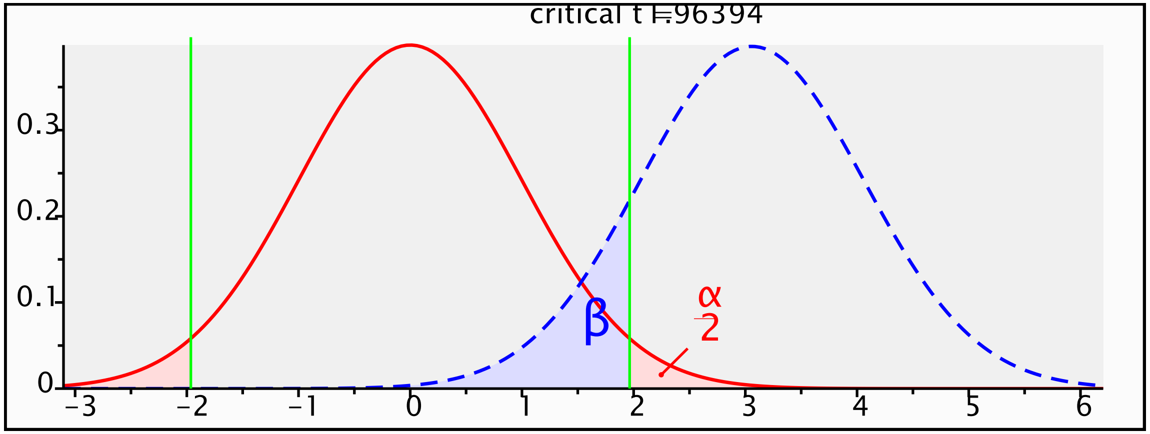
- Chi-square test
  - Cohen's suggestion: 0.1, 0.3, 0.5

$$w = \sqrt{\sum_{i=1}^{m} \frac{(p0_i - p1_i)^2}{p0_i}}$$

$p0_i =$ cell probability in i^{th} cell under H_0
$p1_i =$ cell probability in i^{th} cell under H_1

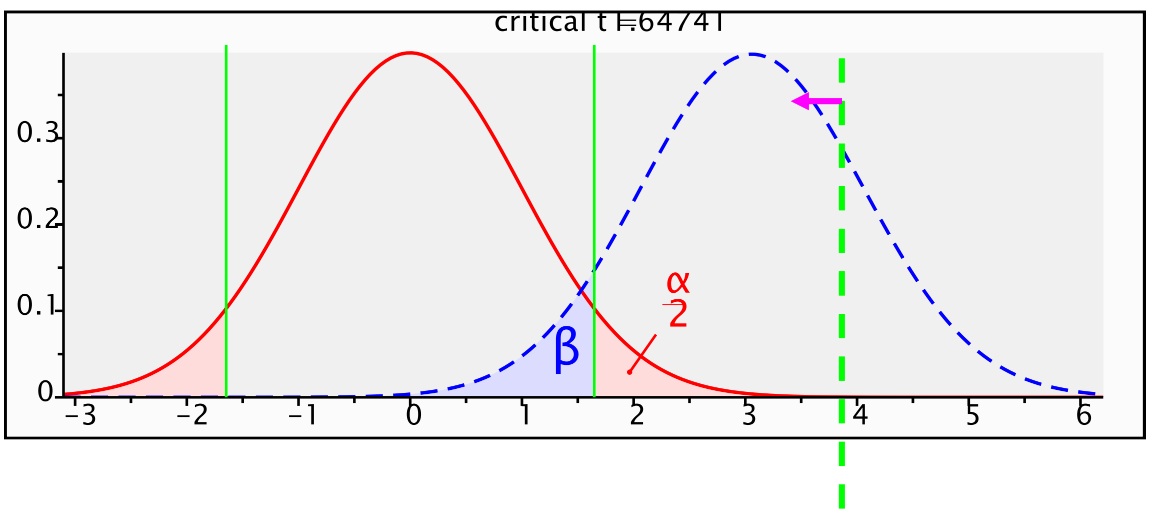
POWER ANALYSIS | DEPENDENCE

t test (difference between two independent means)



$\alpha = 0.05$

$\beta = 0.14$



$\alpha = 0.1$

$\beta = 0.08$

POWER ANALYSIS | TYPES

- A priori
  - controlling power level before conducting test
  - computing sample size *n*
  - function of required power level, specified α, *d*
- Post hoc
  - after a test was conducted
    - Does the test had fair chance to reject incorrect H_0?
  - computing the power level
- Compromise
  - fixed ratio between α and β
- Sensitivity
  - estimating/checking the size of an effect *d*

POWER ANALYSIS | DISCOVERY

- How many users do we need for discovering 95% of (**ALL**) problems?
- Golden rule of usability testing: Five users is enough to observe **all relevant** problems with **very high** probability.

- To detect X % of problems that affects Y % of users.
- To have a X % chance of detecting ...

$$n = \frac{\ln(1-X)}{\ln(1-Y)}$$

n = 5
very high = 95 %
all relevant = 50 %

POWER ANALYSIS | COMPARING

- Determining *n* for comparing two means
  - within-subject

$$n = \frac{\left(t_\alpha + t_\beta\right)^2 s^2}{d^2}$$

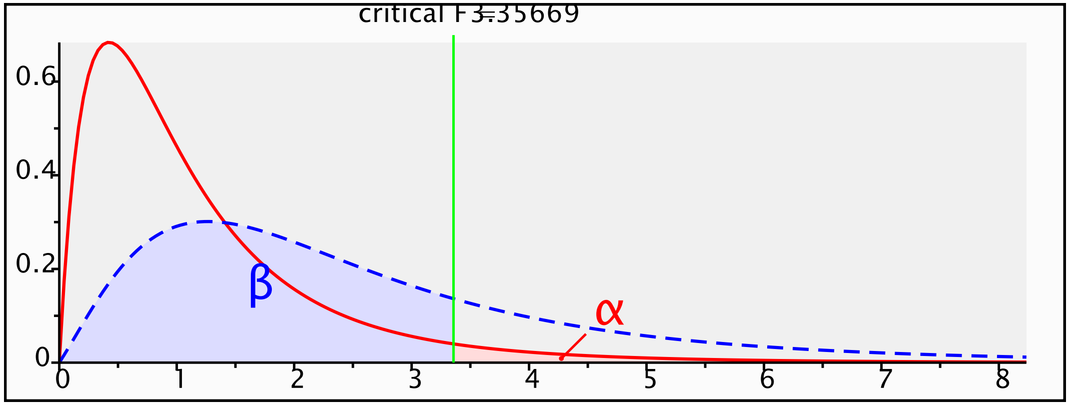
$$t_\alpha = critical\ value\ for\ Confidence\ level$$
$$t_\beta = critical\ value\ for\ Power$$
$$s^2 = the\ variance\ (estimate\ of\ SD^2)$$
$$d^2 = the\ square\ of\ critical\ diference$$

  - between subject

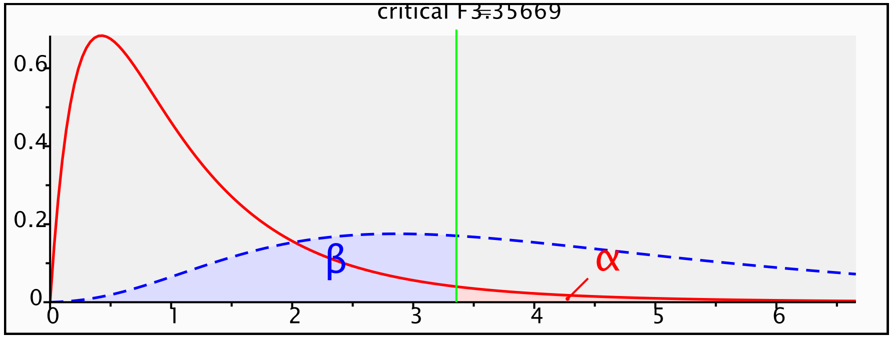
$$n = \frac{2\left(t_\alpha + t_\beta\right)^2 s^2}{d^2}$$

POWER ANALYSIS | COMPARING

F test (MANOVA: Repeated measures, within factors)



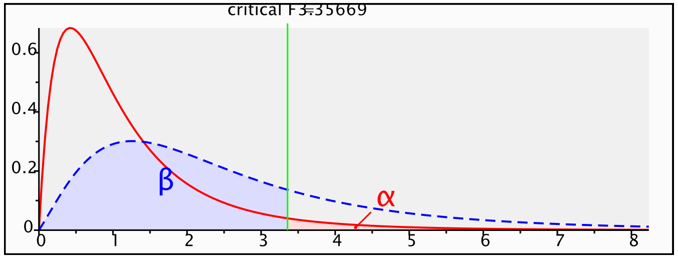
$\alpha = 0.05$
$\beta = 0.73$
$f = 0.25$ (medium)
$n = 16$



$\alpha = 0.05$
$\beta = 0.37$
$f = 0.4$ (large)
$n = 16$

POWER ANALYSIS | COMPARING

F test (MANOVA: Repeated measures, within factors)

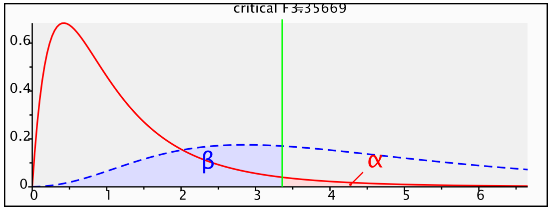


$\alpha = 0.05$

$\beta = 0.73$ for $\beta = 0.2, n = 44$

$f = 0.25$ (medium)

$n = 16$

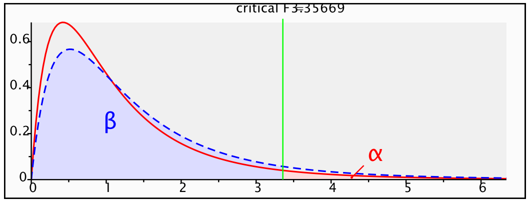


$\alpha = 0.05$

$\beta = 0.37$ for $\beta = 0.2, n = 22$

$f = 0.4$ (large)

$n = 16$



$\alpha = 0.05$

$\beta = 0.92$ for $\beta = 0.2, n = 244$

$f = 0.1$ (small)

$n = 16$

EXPERIMENT RESULTS

F test (MANOVA: Repeated measures, within factors)

```
Keyboard type means:
   A=41.86400
   B=14.40800
Group means:
   AB=29.92800
   BA=26.34400

============================================================================
Effect                    df        SS             MS            F          p
----------------------------------------------------------------------------
Group                      1     1605.632       1605.632       3.020    0.08865
Participant(Group)        48    25519.320        531.653
Keyboard type              1    94228.992      94228.992     341.435    0.00000
Keyboard type x Group      1     1083.392       1083.392       3.926    0.05330
Keyboard type_x_P(Grou    48    13247.016        275.979
Trails                     4     8265.372       2066.343     107.509    0.00000
Trails_x_Group             4       38.148          9.537       0.496    0.73855
Trails_x_P(Group)        192     3690.280         19.220
============================================================================
```

SAN 2018 experiment

THANK YOU FOR ATTENTION

DEPARTMENT OF COMPUTER GRAPHICS AND INTERACTION
CZECH TECHNICAL UNIVERSITY IN PRAGUE

Zdeněk Míkovec
xmikovec@fel.cvut.cz

REFERENCES

- MacKenzie, I. Scott. Human-computer interaction: An empirical research perspective. Newnes, 2012. (available online, google it)

Further reading

- “Personal Dynamic Media” by A. Kay and A. Goldberg (1977).
- “The Computer for the 21st Century” by M. Weiser (1991).

REFERENCES

- Power Analysis in R: http://www.statmethods.net/stats/power.html
- Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*, ISBN 978-0805802832, Routledge.
- Sauro, J., & Lewis, J. R. (2012). *Quantifying the user experience: Practical statistics for user research*. Elsevier.
- Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). *Statistical power analyses using G* Power 3.1. 9: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences*. Behavior Research Methods, 41(4), 1149-1160.
- Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). *Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses*. Behavior research methods, 41(4), 1149-1160.
- Kuniavsky, M. (2012). *Observing the user experience: a practitioner's guide to user research*. Morgan Kaufmann.
- MacKenzie, I. S. (2012). *Human-computer interaction: An empirical research perspective*. Newnes.