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Beyond Clicks: What Can Brain Signals Tell Us About User Experience?

Dr. R. Stefan Greulich

Introduction R. Stefan Greulich

Who am I?

Postdoc & PhD candidate at TUD Dresden University of Technology

PhD in Neuroscience

What do I do?

NeuroIS → Perception of anthropomorphism in conversational agents

Digital Health → Digital assistant for Parkinson patients with AI based symptom tracking

Why am I here?

Looking for further research collaborations

Agenda

1. A short introduction into NeuroIS
2. A case for NeuroIS: Reaction to Conversational Agents
3. NeuroIS in X-AI Research
4. Q&A

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A short introduction into NeuroIS

A short history of NeuroIS

- **emerged in 2007**
- **200 publications in the first decade (2008-2018; Riedl et al., 2010)**
  - 31 contributions to basket of eight
- **2009 first NeuroIS retreat in Viena**
  - developed to main conference of the field
- **community estimated to 300-400 researchers worldwide**

Riedl, R., Fischer, T., Léger, P. M., and Davis, F. D. 2020. "A Decade of NeuroIS Research," *Data Base for Advances in Information Systems* (51:3), ACM PUB27 New York, NY, USA, pp. 13–54. (https://doi.org/10.1145/3410977.3410980).

What is NeuroIS?

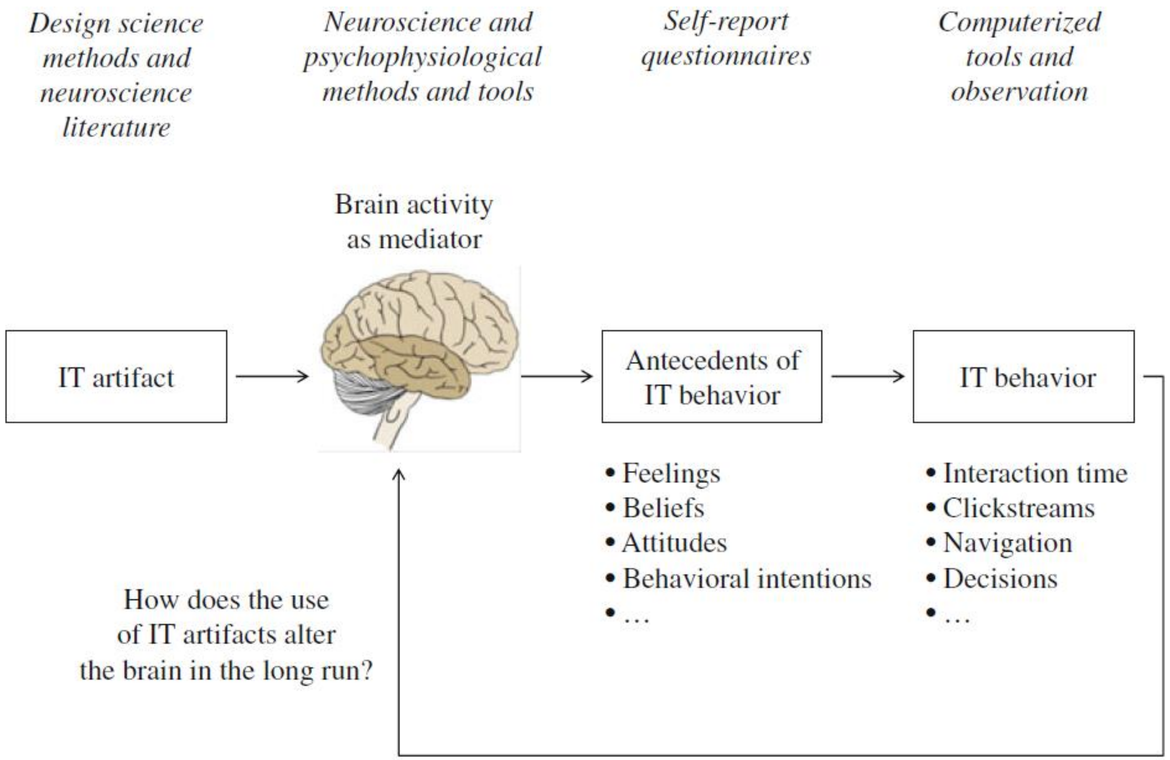
*„**NeuroIS** is an **interdisciplinary field** of research that relies on knowledge from disciplines related to **neurobiology** and behavior, as well as knowledge from engineering disciplines. NeuroIS pursues **two complementary goals**. First, it contributes to an **advanced theoretical understanding** of the design, development, use, and impact of information and communication technologies (IT). Second, it **contributes to the design and development of IT systems** that positively affect practically relevant outcome variables such as health, well being, satisfaction, adoption, and productivity."*

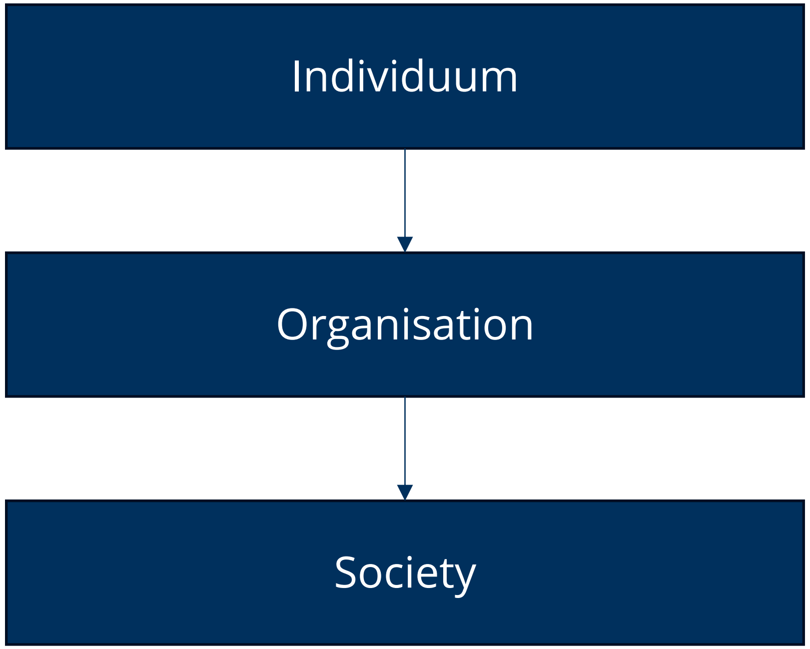
-Riedl et al. (2010)

Riedl, R. 2016. "Fundamentals of NeuroIS Information Systems and the Brain," *Springer* (Vol. 1).

Focus of NeuroIS

- **influence of technical system on the brain and vise versa**
- **NeuroIS targets the individual level**
- **indirect inferences onto society and organization**

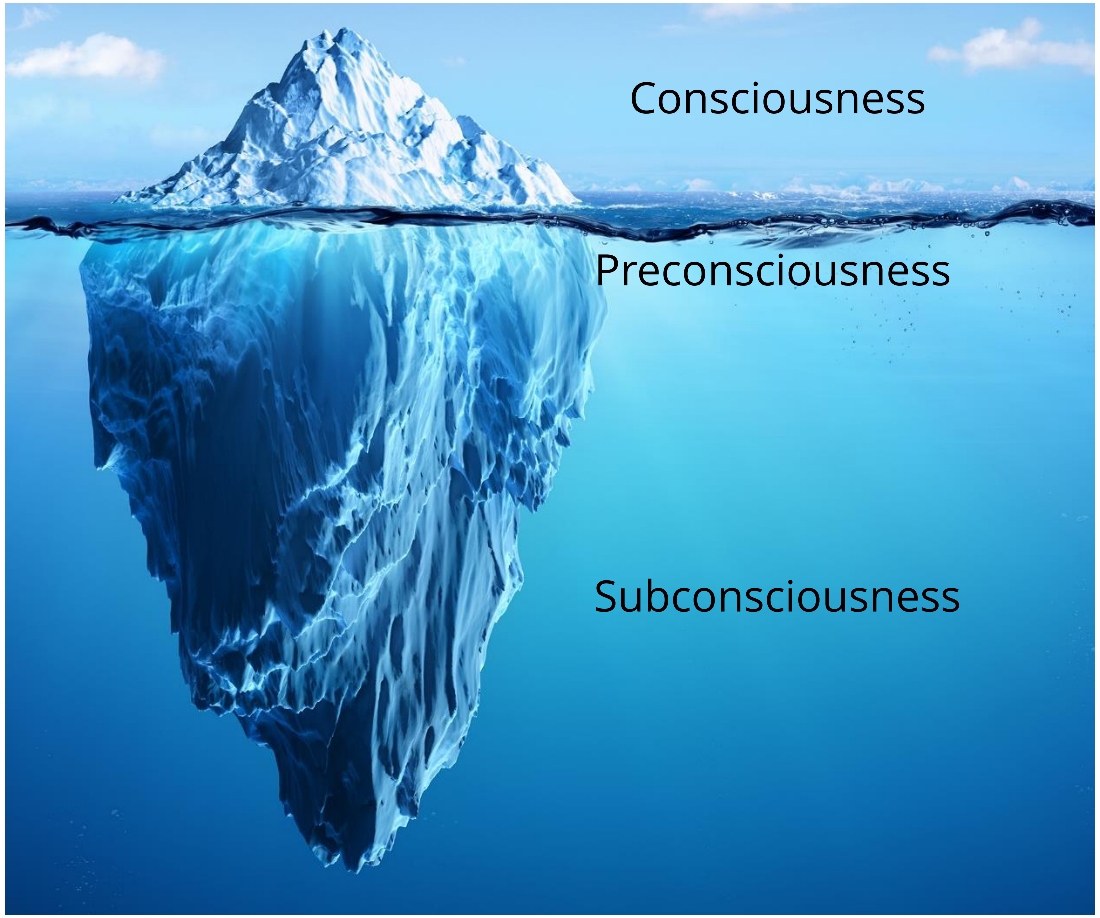




Riedl, R. 2016. "Fundamentals of NeuroIS Information Systems and the Brain," *Springer* (Vol. 1).

A glimpse into the subconscious

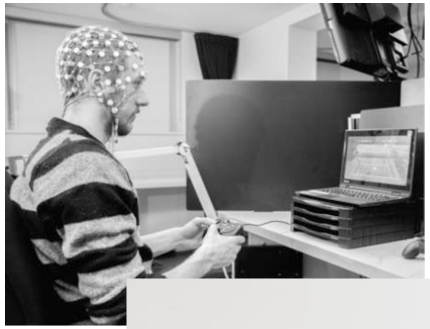
- **human behavior strongly influenced by emotional and subconscious** **(Lieberman, 2007)**
- **questionnaires do not give full picture**
  - response biases
  - conscious reflection
- **NeuroIS allows recording of underlying neural activity**

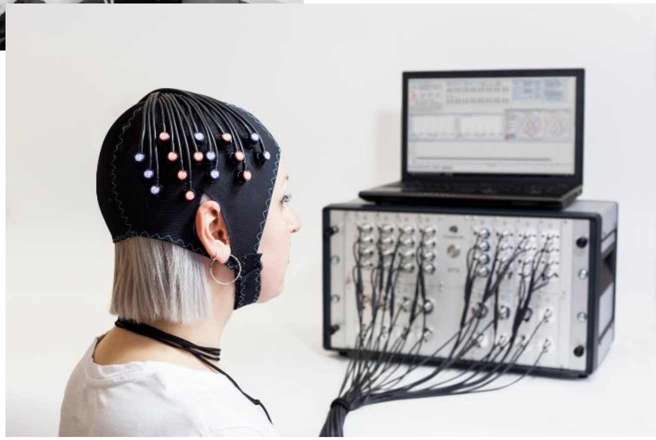


Lieberman, M. D. 2007. "Social Cognitive Neuroscience: A Review of Core Processes," *Annual Review of Psychology* (58), Annu Rev Psychol, pp. 259–289. (https://doi.org/10.1146/ANNUREV.PSYCH.58.110405.085654).

A selection of NeuroIS methods

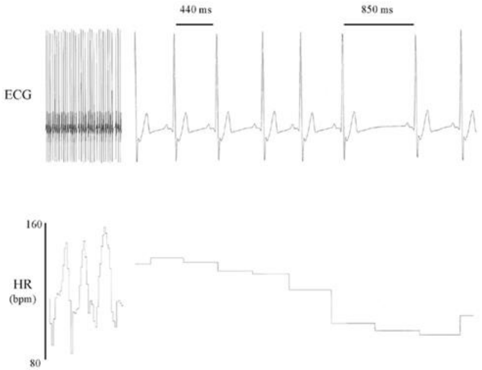
EEG



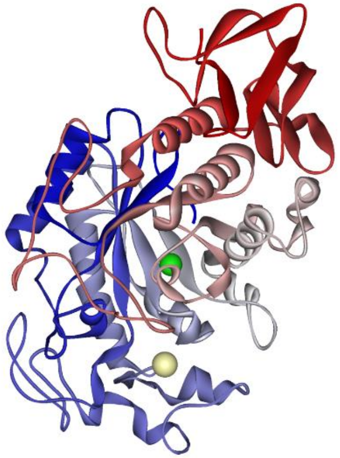


fNRIS

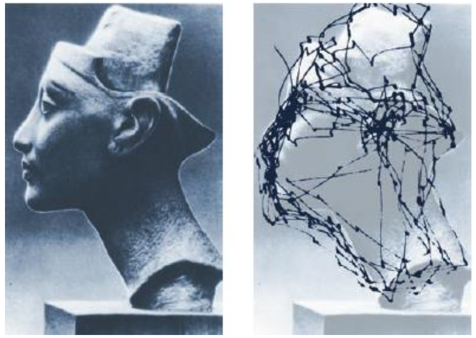
EKG/HRV



fMRI



hormonal measurements

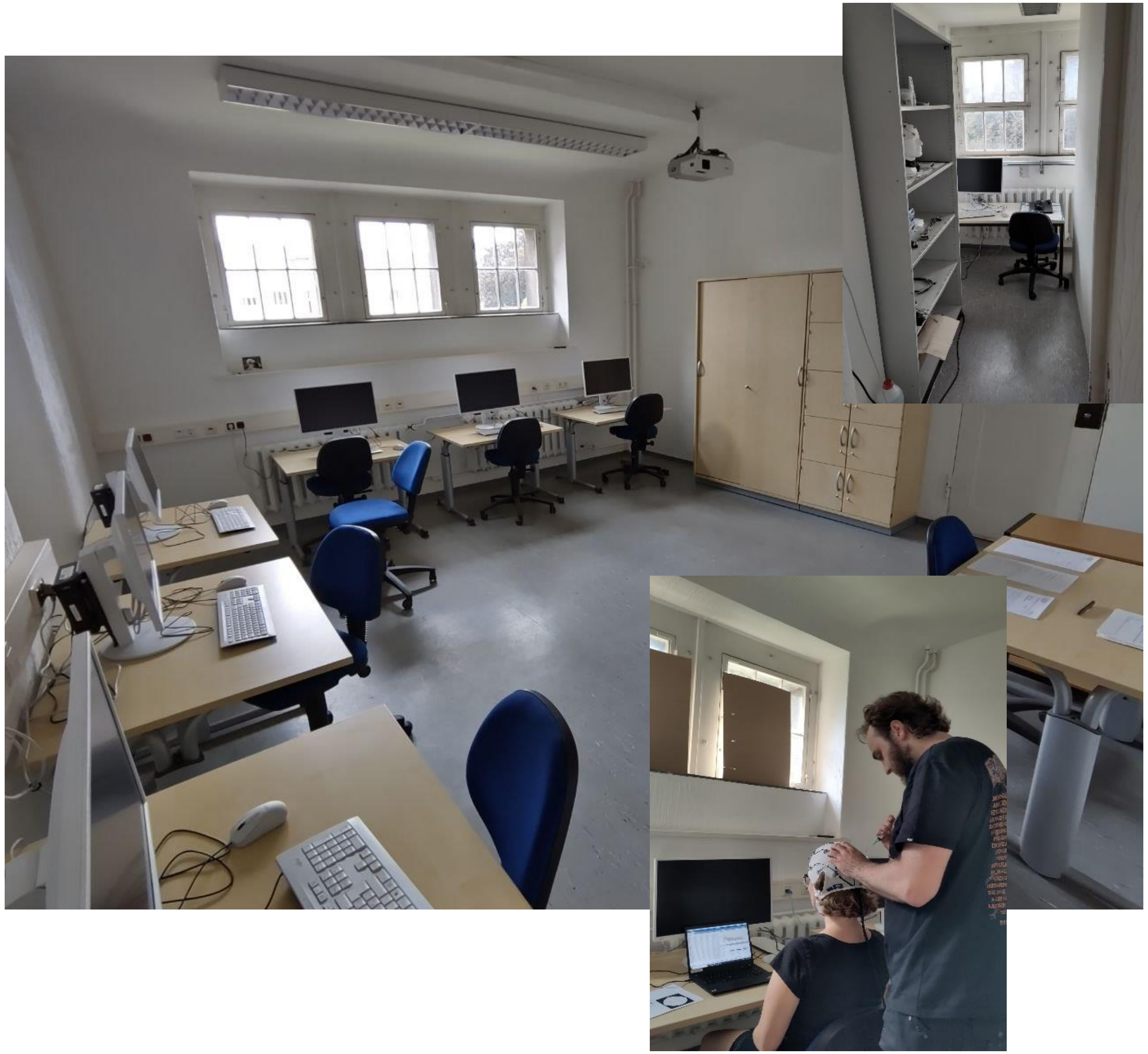


Eye-Tracking/Oculometry

NeuroIS-Lab@TUD

- **investigating different elements of CAs**
  - typing errors
  - avatars
  - hallucinations
- **within different contexts**
  - service setting
  - workplace

- **NeuroIS lab established**
- **currently utilizing EEG, HRV, & eye tracking**



A Case for NeuroIS

Reaction to Conversational Agents

Conversational Agents

Conversational agents (CAs) are

"software-based systems designed to interact with humans using natural language" **(Feine et al., 2019)**

- **e.g. Alexa, Siri, chatbots, talking robots, and more**
- **rise of the CA was driven by NLP developments**
- **increased area of research since 2016 (Diederich et al., 2022)**
- **widespread application especially in customer service and social networks (Diederich et al., 2022)**
- **renewed interest since publication of ChatGTP**

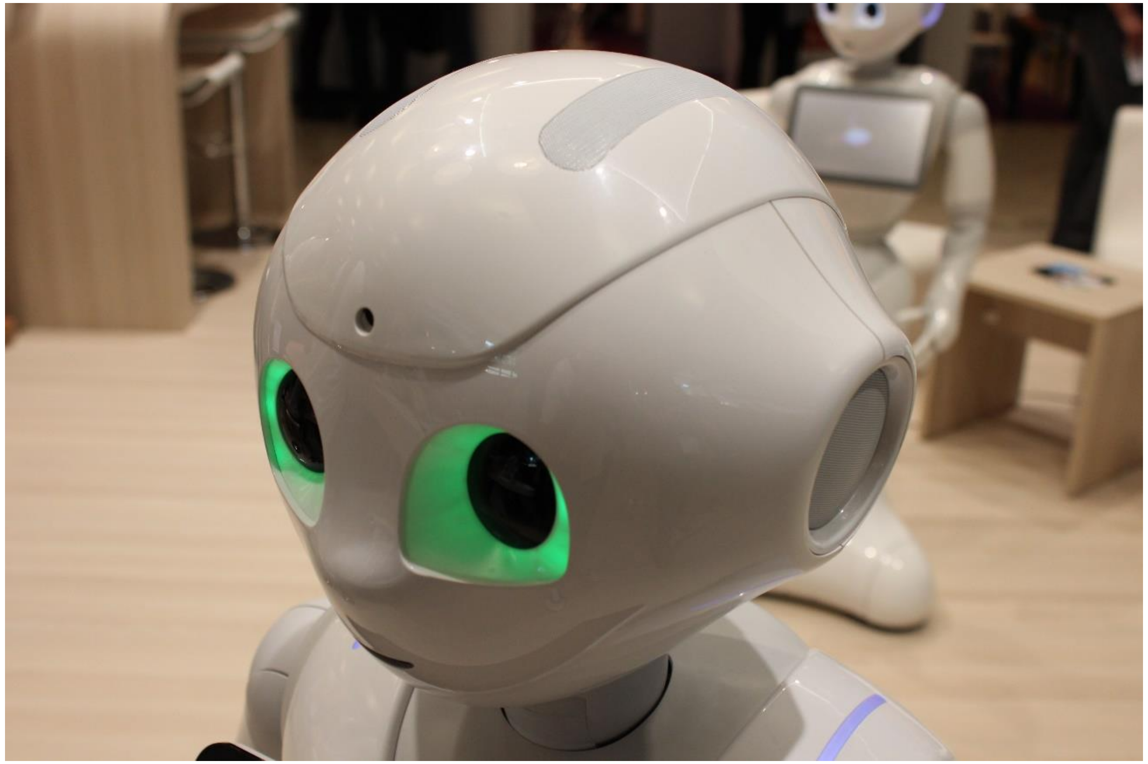
Feine, J., Gnewuch, U., Morana, S., and Maedche, A. 2019. "A Taxonomy of Social Cues for Conversational Agents," *International Journal of Human-Computer Studies* (132:June), Academic Press, pp. 138–161. (https://doi.org/10.1016/J.IJHCS.2019.07.009).

Diederich, S., Brendel, A. B., Morana, S., and Kolbe, L. 2022. "On the Design of and Interaction with Conversational Agents: An Organizing and Assessing Review of Human-Computer Interaction Research," *Journal of the Association for Information Systems* (23:1), Springer Gabler, pp. 96–138. (https://doi.org/10.17705/1jais.00724).

Anthropomorphism & Conversational Agents

"Anthropomorphism describes the tendency to imbue the real or imagined behavior of nonhuman agents with humanlike characteristics, motivations, intentions, or emotions." ***(Epley et al., 2007)***

- **strong influence in perception of technical system**
  - increased service satisfaction (Gnewuch et al., 2018)
  - increased trust (Seeger et al., 2017)
  - and more
- **human-CA interaction resembles social human-human interaction (Lang et al., 2013; Nass et al., 1994; Nass & Moon, 2000)**



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Epley, N., Waytz, A., and Cacioppo, J. T. 2007. "On Seeing Human: A Three-Factor Theory of Anthropomorphism," *Psychological Review* (114:4), pp. 864–886. (https://doi.org/10.1037/0033-295X.114.4.864).

Gnewuch, U., Morana, S., Adam, M. T. P., and Maedche, A. 2018. "Faster Is Not Always Better: Understanding the Effect of Dynamic Response Delays in Human-Chatbot Interaction," in *26th European Conference on Information Systems: Beyond Digitization - Facets of Socio-Technical Change, ECIS 2018*, , November 28, p. 143975.

Seeger, A.-M., Pfeiffer, J., and Heinzl, A. 2017. "When Do We Need a Human? Anthropomorphic Design and Trustworthiness of Conversational Agents," *SIGHCI 2017 Proceedings*.

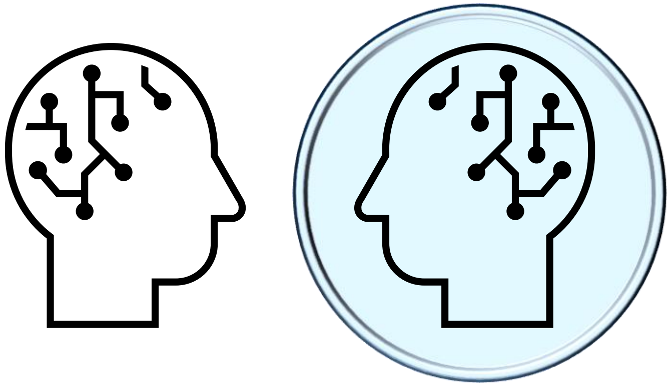
The Need for NeuroIS in CA research

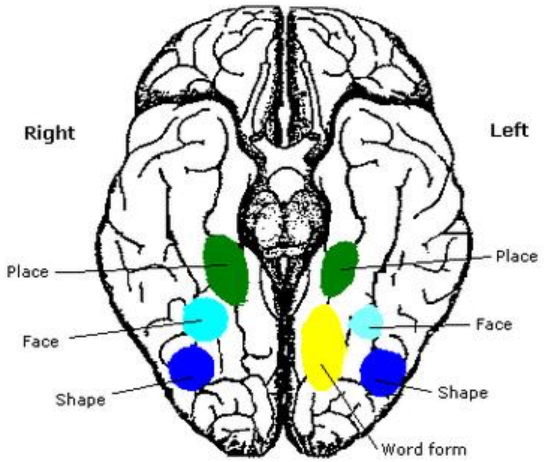
- **human behavior strongly influenced by automatic & subconscious processes (Lieberman, 2007)**
- **questionnaires suffer from a range of biases (Moon, 2003; Fisher & Katz, 2000; Krumpal, 2013; Santhanam et al., 2020; Thomas & Diener, 1990) & only probe conscious mind**
- **NeuroIS allows insight into subconsious processing**

To understand how to trigger anthropomorphism, we must understand how anthropomorphism is processed in the brain!

Lieberman, M. D. 2007. “Social Cognitive Neuroscience: A Review of Core Processes,” *Annual Review of Psychology* (58), Annu Rev Psychol, pp. 259–289. (https://doi.org/10.1146/ANNUREV.PSYCH.58.110405.085654).
Moon, Y. 2003. “Don’t Blame the Computer: When Self-Disclosure Moderates the Self-Serving Bias,” *Journal of Consumer Psychology* (13:1–2), No longer published by Elsevier, pp. 125–137. (https://doi.org/10.1207/s15327663jcp13-1&2_11).
Fisher, R. J., and Katz, J. E. 2000. “Social-Desirability Bias and the Validity of Self-Reported Values,” *Psychology & Marketing* (17:2), John Wiley & Sons, Inc, pp. 105–120. (https://doi.org/10.1002/(SICI)1520-6793(200002)17:2).
Krumpal, I. 2013. “Determinants of Social Desirability Bias in Sensitive Surveys: A Literature Review,” *Quality and Quantity*, Springer, pp. 2025–2047. (https://doi.org/10.1007/s11135-011-9640-9).
Santhanam, S., Karduni, A., and Shaikh, S. 2020. “Studying the Effects of Cognitive Biases in Evaluation of Conversational Agents,” in *Conference on Human Factors in Computing Systems - Proceedings*, Association for Computing Machinery, April 21. (https://doi.org/10.1145/3313831.3376318).
Thomas, D. L., and Diener, E. 1990. “Memory Accuracy in the Recall of Emotions,” *Journal of Personality and Social Psychology* (59:2), pp. 291–297. (https://doi.org/10.1037/0022-3514.59.2.291).

Two possible explanations of anthropomorphic perception





Mirror neurons & Theory of mind network :

- specialized neurons fire during the observation of an action and during the execution of said action
- also activate during observation of robot actions (Gazzola e.a. 2007)
- originally proposed as neural basis by Epley e.a. (2007)
- brain is simulating mental state of third party

Face recognition:

- specialized pattern recognition to detect faces & human shapes
- fusiform face area
- activates during perception of faces in objects (Kühn et al., 2014)

Gazzola, V., Rizzolatti, G., Wicker, B., and Keysers, C. 2007. "The Anthropomorphic Brain: The Mirror Neuron System Responds to Human and Robotic Actions," *NeuroImage* (35:4), Academic Press, pp. 1674–1684. (https://doi.org/10.1016/J.NEUROIMAGE.2007.02.003).

Epley, N., Waytz, A., and Cacioppo, J. T. 2007. "On Seeing Human: A Three-Factor Theory of Anthropomorphism," *Psychological Review* (114:4), pp. 864–886. (https://doi.org/10.1037/0033-295X.114.4.864).

Kühn, S., Brick, T. R., Müller, B. C. N., and Gallinat, J. 2014. "Is This Car Looking at You? How Anthropomorphism Predicts Fusiform Face Area Activation When Seeing Cars," *PLOS ONE* (9:12), Public Library of Science, p. e113885. (https://doi.org/10.1371/JOURNAL.PONE.0113885).

Example: Interaction Behavior & Design

Context:

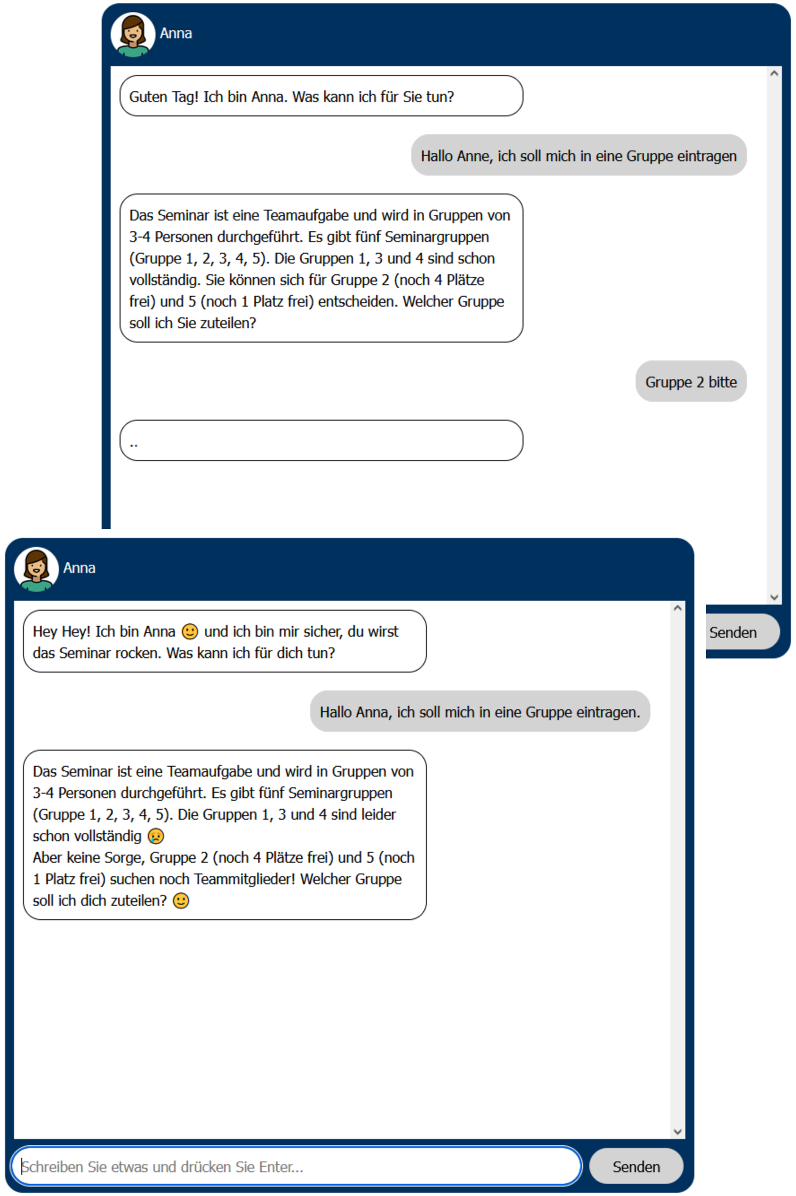
- Assistant to organize study group

Human-Like design elements:

- Name
- Avatar
- Typing delay

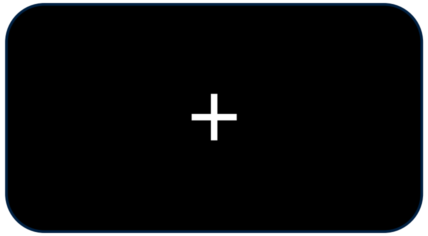
Language design elements:

- Type of address (“siezen” vs. “duzen”)
- Precise language vs. “Chitchat”
- Emojis



Experimental Design

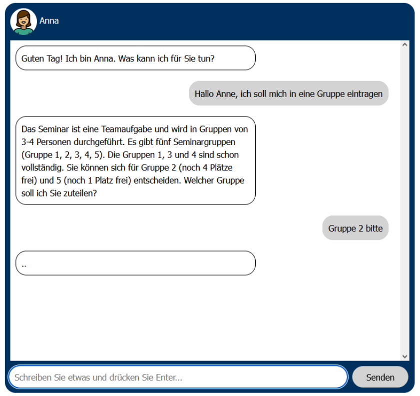
1. **5 min fixation**



2. **5 min humanness baseline (abbot and Wikimedia dataset)**

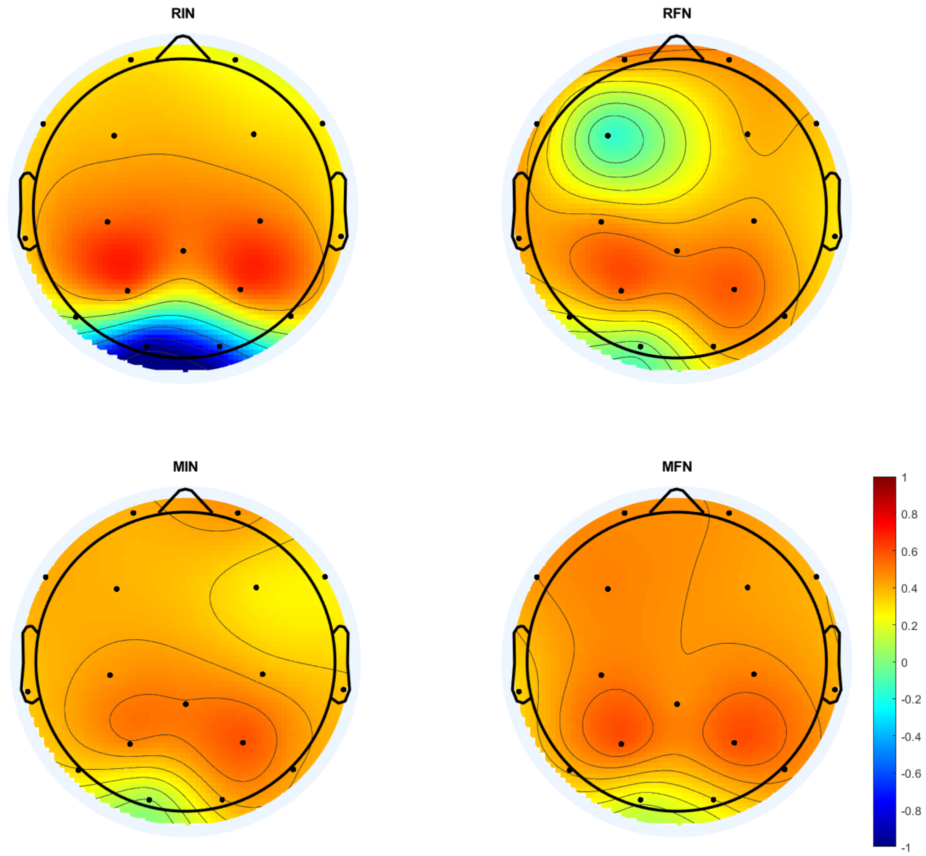
3. **20 min emotion baseline (LIRIS-ACCEDE dataset)**

4. **Chatbot interaction**



Frontal Alpha Asymmetry (Coan & Allen, 2004)

- **emotional control is located to the middle rim of the interhemispheric fissure**
- **engagement of emotional control leads to difference in alpha power (8-12 Hz) between left and right frontal electrodes**
- **measures emotional valence**



Coan, J.A. and Allen, J.J.B. (2004) ‘Frontal EEG asymmetry as a moderator and mediator of emotion’, *Biological Psychology*. Elsevier, pp. 7–50. doi:10.1016/j.biopsycho.2004.03.002.

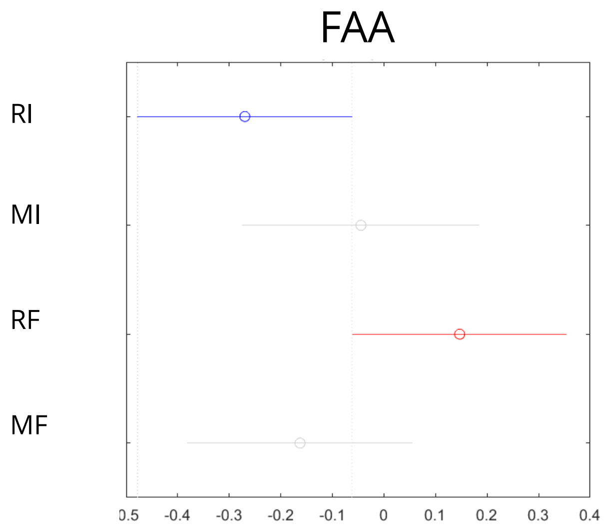
Preliminary Results FAA

- **significant interaction effect**
- **reject robot like chatbot using informal speech**
- **like robot like with formal speech**

Analysis of Variance

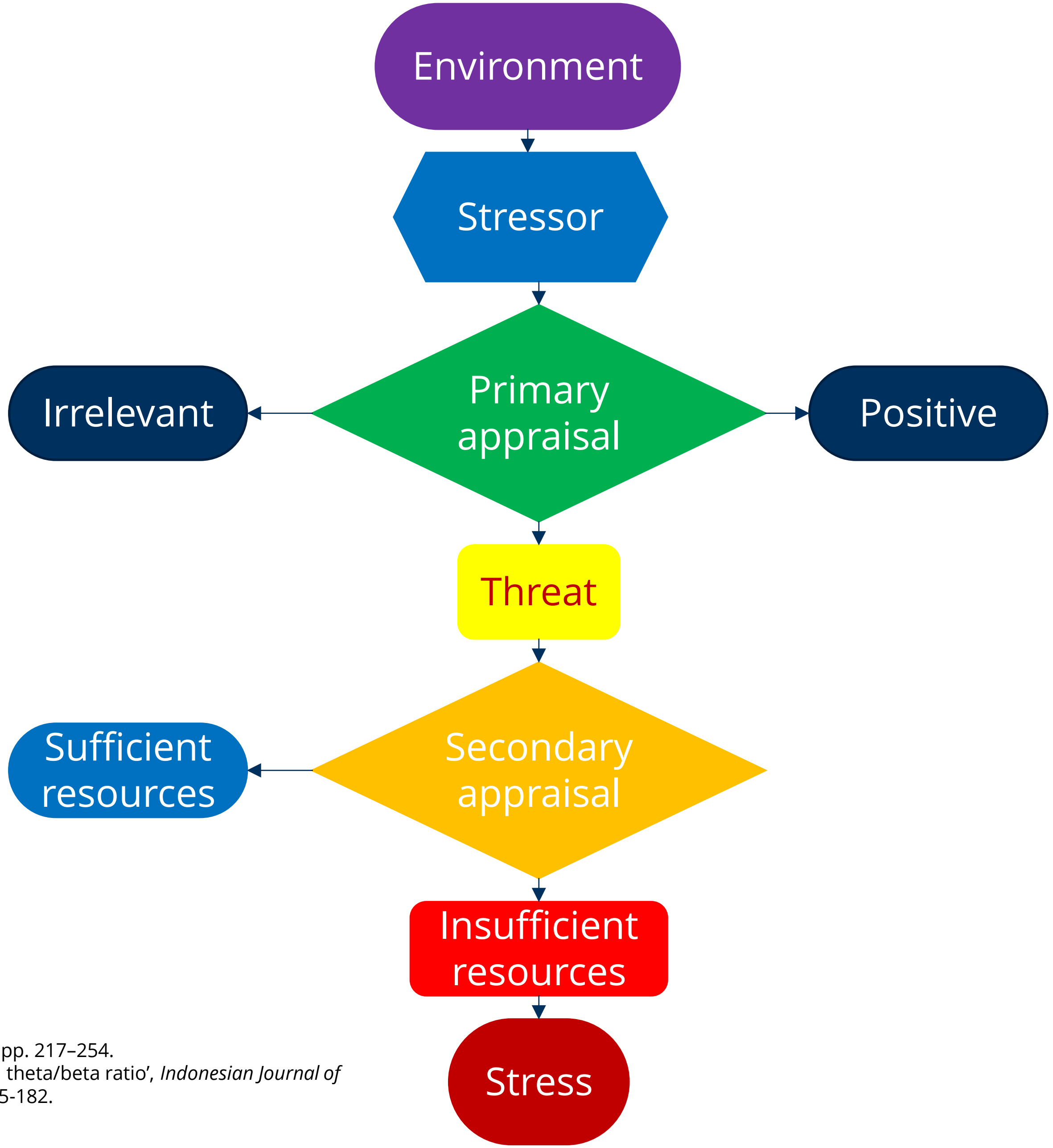
Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
Humanness	0.0181	1	0.0181	0.14	0.7128
Speech	0.22649	1	0.22649	1.72	0.1975
Humanness*Speech	0.72754	1	0.72754	5.53	0.0241
Error	4.86664	37	0.13153		
Total	5.90776	40			

Constrained (Type III) sums of squares.



Stress in EEG

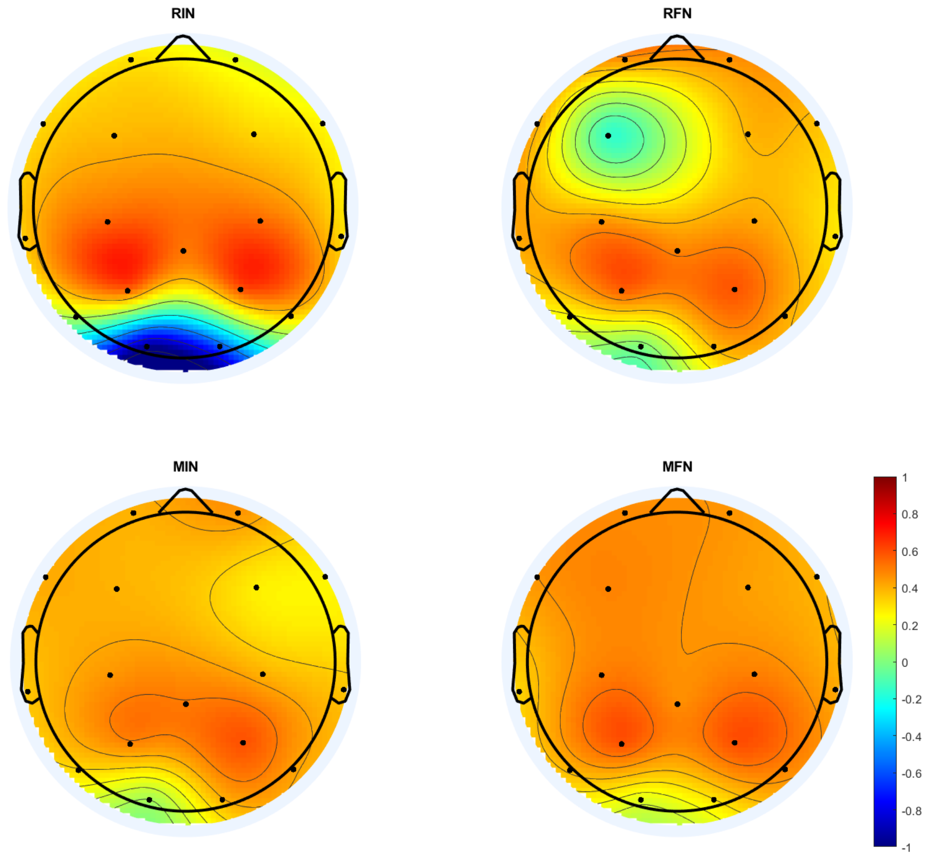
- **stress is bodies reaction to situations requiring additional resources** **(Lazarus & Folkman, 1984)**
- **stress hormones increase heart rate, metabolic consumption, and more**
- **Measurable in EEG via Beta (12-30 Hz) vs Alpha ration over whole cortex** **(Wen & Aris, 2020)**



Lazarus, R.S. and Folkman, S. (1984) 'Stress, Appraisal, and Coping', in *Health Psychology: A Handbook*, pp. 217–254.
Wen, T.Y. and Aris, S.A.M. (2020) 'Electroencephalogram (EEG) stress analysis on alpha/beta ratio and theta/beta ratio', *Indonesian Journal of Electrical Engineering and Computer Science*, 17(1), pp. 175–182. doi:10.11591/ijeecs.v17.i1.pp175-182.

Preliminary Results

- 61 subjects, 41 usable datasets
- common average reference and reference electrode reconstruction (CPz)
- ICA based artefact removal
- mean Alpha & Beta ERS/ERD between CA and baseline



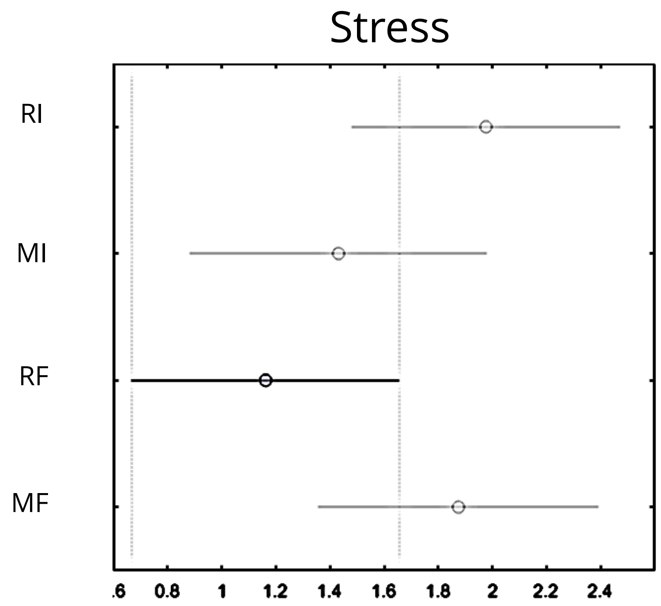
Preliminary Results Stress

- **significant interaction effect**
- **robot informal and human formal show enhanced stress**

Analysis of Variance

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
Humanness	0.0714	1	0.07139	0.1	0.7586
Speech	0.3505	1	0.35054	0.47	0.4969
Humanness*Speech	4.0245	1	4.02453	5.4	0.0257
Error	27.5542	37	0.74471		
Total	32.2246	40			

Constrained (Type III) sums of squares.



Preliminary Results Summary

Social identity theory:

- robotlike CA is considered outgroup member

→ power difference is perceived and formal speech preferred

→ no effect on human like CA

Social stress theory

- humanlike CA with formal language leaves user unsure about social power dynamic

→ increased stress during interaction

	RI	RF	MI	HF
FAA	↘	↗	—	—
Stress	↗	—	—	↗

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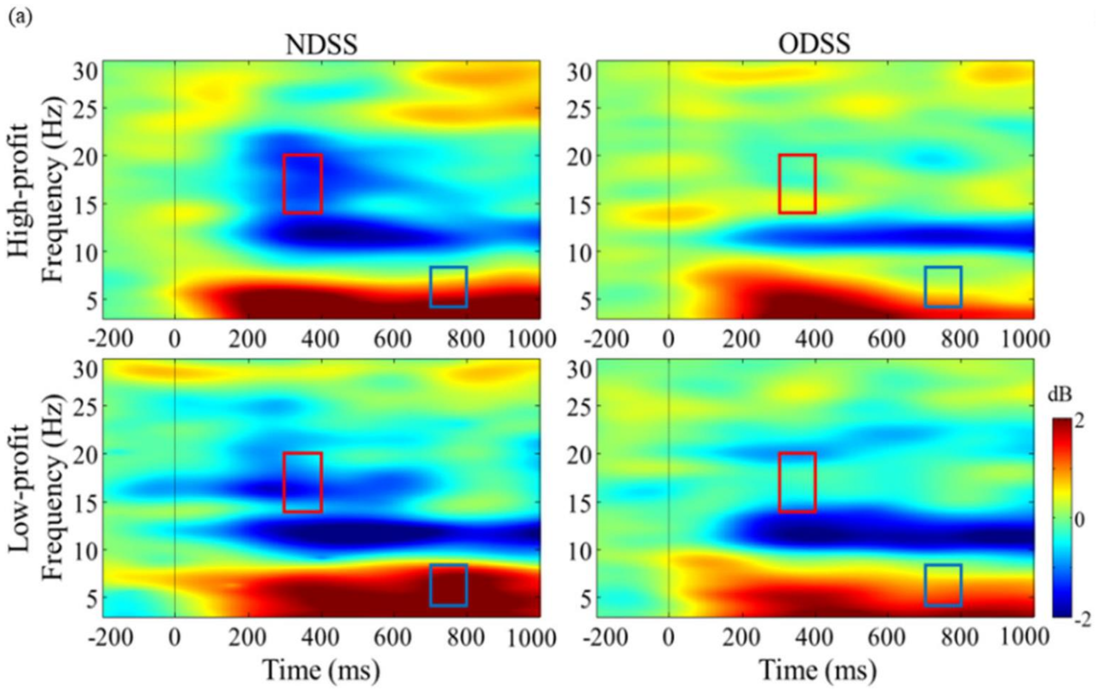
NeuroIS in X-AI Research

A Practical Example & Research Ideas

A Short Example: Wang, Y., Xu, M. & Zhao, L. Exploring the Cognitive Mechanisms Behind the Adoption of Algorithmic Advice. *Bus Inf Syst Eng* (2025). https://doi.org/10.1007/s12599-025-00925-7

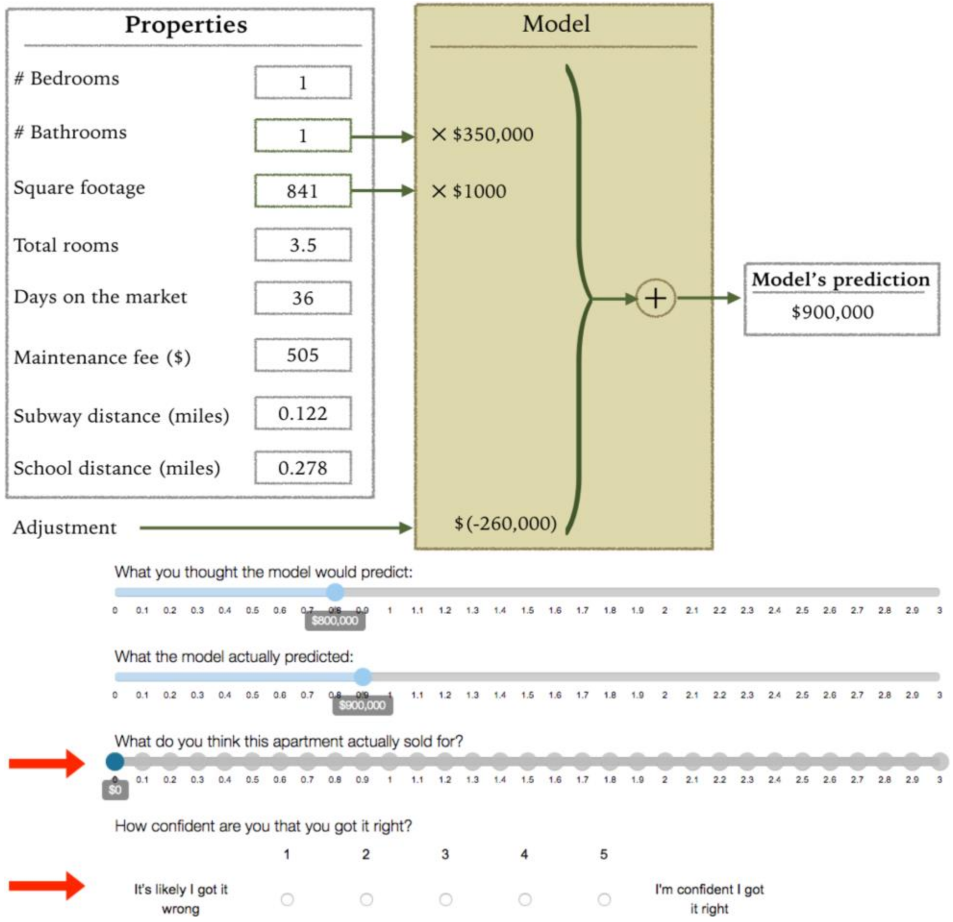
- **newsvendor task (price & demand given, must select order size)**
- **decision without DSS (NDSS) vs. with optimal DSS (ODSS)**
- **EEG experiment**
- **DSS reduces information conflict processing (red square)**
- **DSS influences decision making (blue square)**
- **DSS reduces reward prediction error (not shown)**



How do users process information?

Information processing steps:

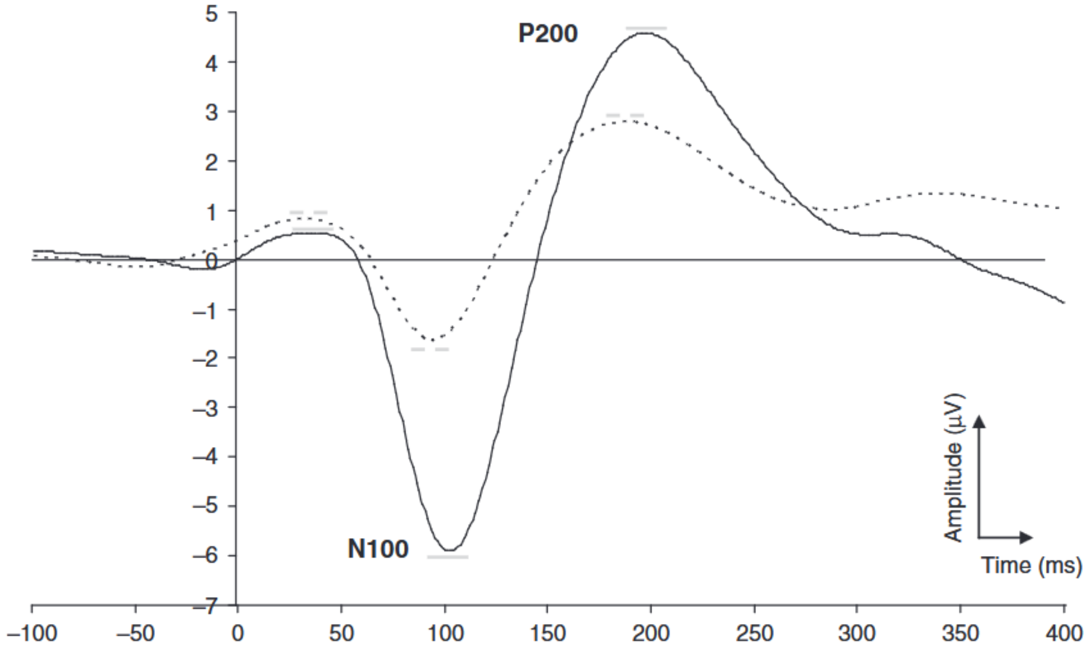
1. **Visual search**
   - Eye tracking
   - Visual attention
   - What information is collected
2. **Cognitive processing**
   - EEG & fMRI
   - Cognitive load
   - Information processing
3. **Decision making**
   - EEG
   - Cognitive conflict
   - Reward prediction
4. **Behavior**
   - Click Stream
   - Reaction time
   - Choice selection



Wang, Y., Xu, M. & Zhao, L. Exploring the Cognitive Mechanisms Behind the Adoption of Algorithmic Advice. *Bus Inf Syst Eng* (2025). https://doi.org/10.1007/s12599-025-00925-7

Do X-AIs help to detect errors?

- **Error detection & conflict monitoring well researched in neuroscience**
- **Characteristic EEG signals (e.g. P200, N400, theta-band)**
- **Combination eye-tracking & EEG might be needed (visual evoked potential)**



Lijffijt, M., Lane, S. D., Meier, S. L., Boutros, N. N., Burroughs, S., Steinberg, J. L., ... & Swann, A. C. (2009). P50, N100, and P200 sensory gating: relationships with behavioral inhibition, attention, and working memory. *Psychophysiology*, *46*(5), 1059-1068.

Do users trust X-AI systems?

- **Trust & emotion processed in deep brain structures**
- **fMRI examination of activity in caudate nucleaus**
- **Emotional valence as moderator with EEG axessible**

Source: Wikipedia

Let‘s go!

Discussion

Questions?

Ideas for collaborations?

Further examples of NeuroIS research

Commen Questions in X-AI Research

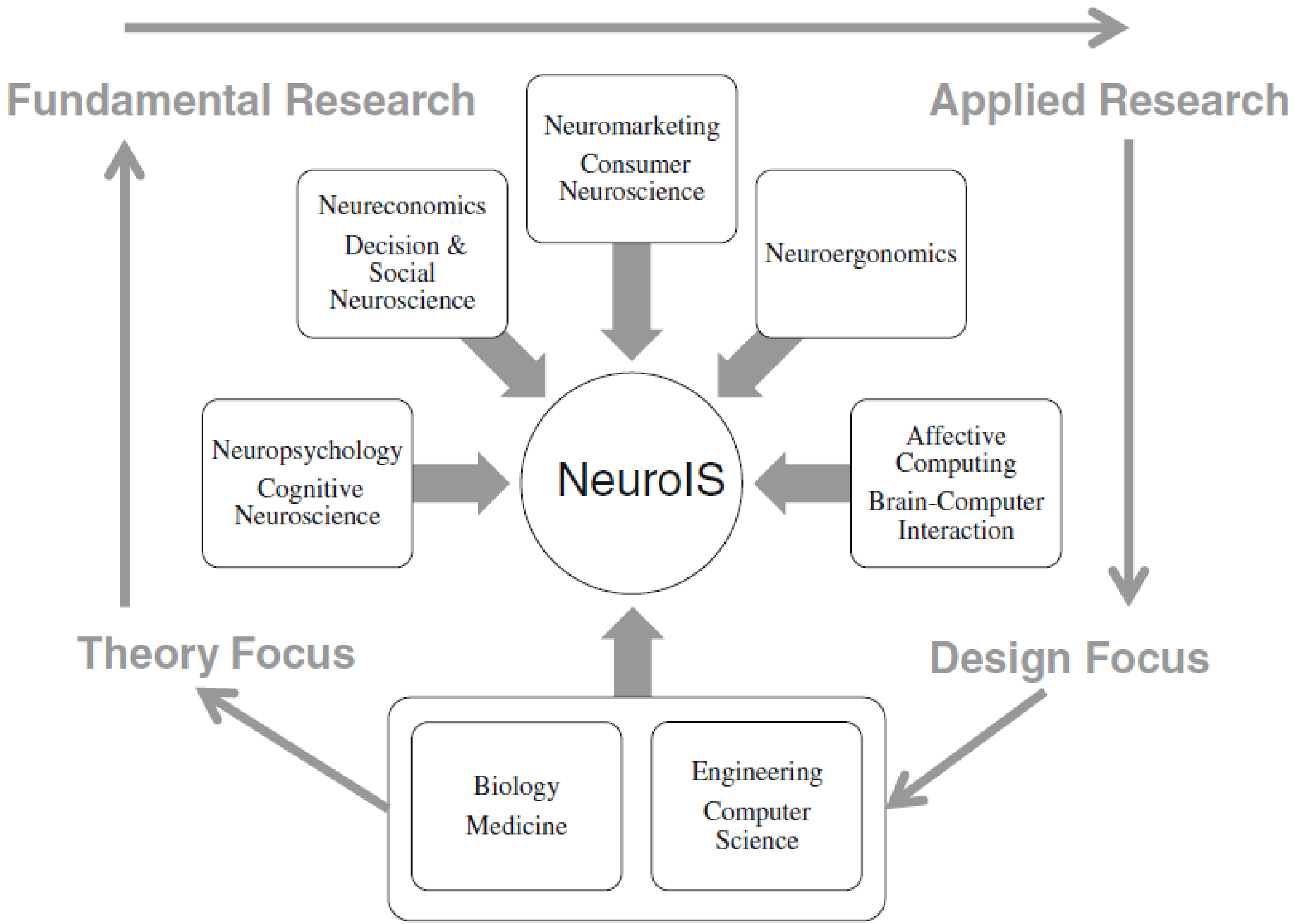
Do X-AI models do their jobs?

Do people detect errors in X-AI?

Do people trust X-AI models more?

Information overload?

Reference disciplines of NeuroIS



Riedl, R. 2016. “Fundamentals of NeuroIS Information Systems and the Brain,” *Springer* (Vol. 1).

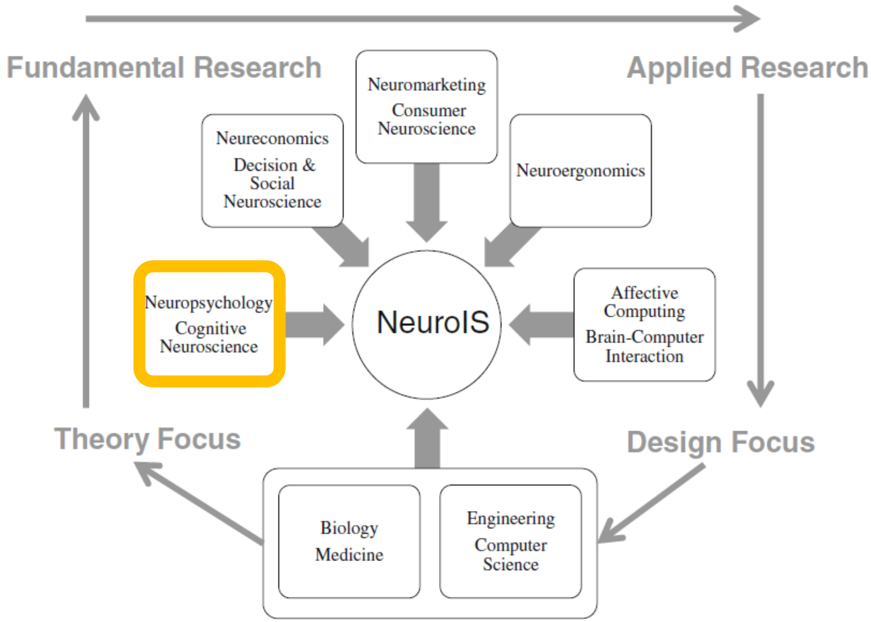
Cognitive Neuroscience

Understand the emergence of complex behavior

- utilization of IT systems
- human-human interactions in IT contexts

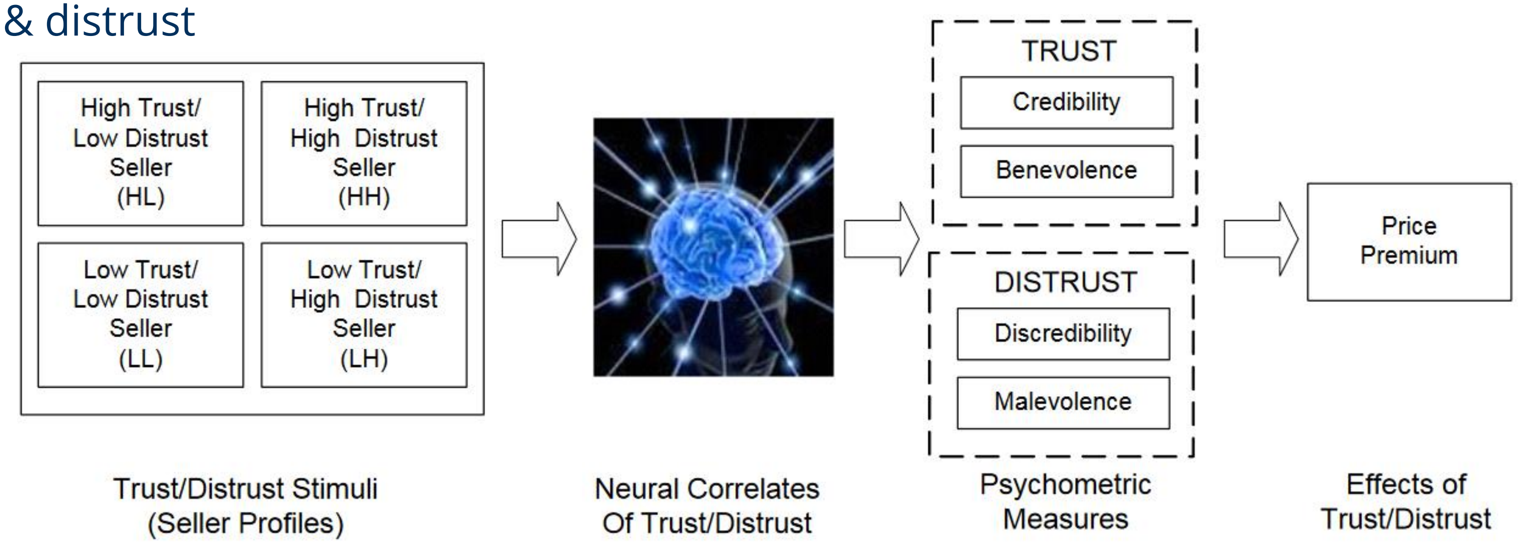
Examining drivers and inhibitors of human behavior

- motivation
- trust
- emotions
- cognitive load
- stress
- and more



Example: Dimoka, A. (2010) What Does the Brain Tell Us About Trust and Distrust? Evidence from a Functional Neuroimaging Study. *MIS Quarterly, 34(2), 373–396.*

- **investigation trust and distrust**
- **context online marketplace**
- **presented seller profile with manipulated user ratings**
- **uses functional neuroimaging (fMRI) to investigate neural corelates of trust and distrust**
  - understand dimensionality of trust & distrust
  - drivers of trust & distrust
  - predict economic outcome



Example: Dimoka, A. (2010) What Does the Brain Tell Us About Trust and Distrust? Evidence from a Functional Neuroimaging Study. *MIS Quarterly, 34(2), 373–396.*

Trust

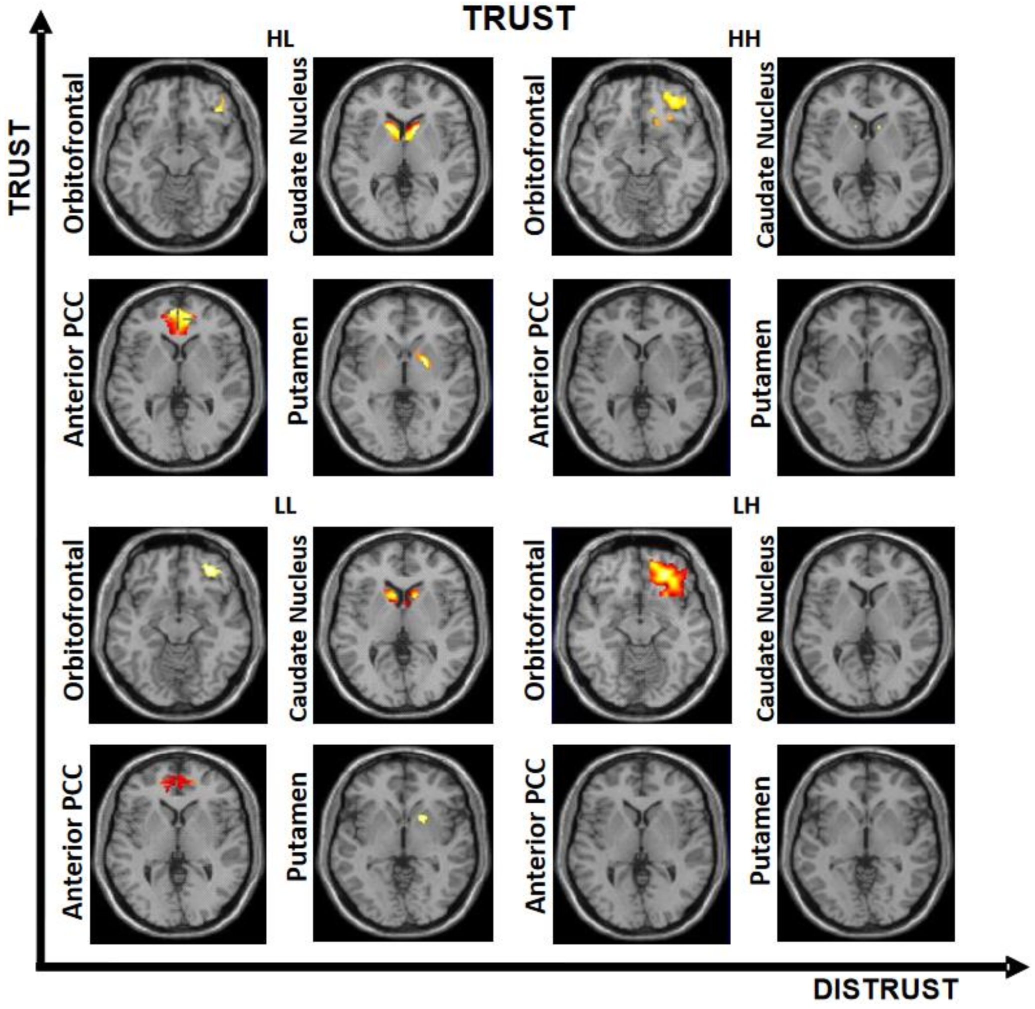
- reward processing areas (putamen + caudate nucleus)
- social interactions (anterior paracingulate cortex)
- prediction & uncertainty (orbitofrontal cortex)

Distrust

- emotion regulation (amygdala)
- fear of loss (insular cortex)

Other results

- activity in trust (20% var.) and distrust (29% var.) predict price premium
- credibility–discredibility is cognitive process (prefrontal cortex)
- benevolence-malevolence is emotional process (limbic system)



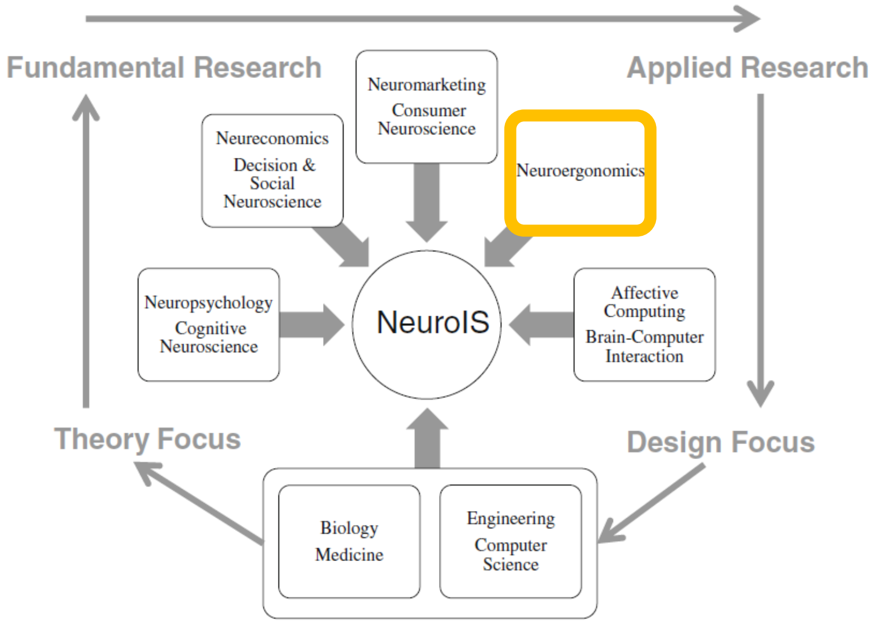
Neuroergonomics

Investigate long term effect of IT construct on user

- stress
- cognitive load
- attention
- and more

Improve design based on neurotheoretical understanding

- dual processing theory
- visual attention
- and more



Example: Vance, A., Jenkins, J. L., Anderson, B. B., Bjornn, D. K., & Kirwan, C. B. (2018). Tuning out security warnings: A longitudinal examination of habituation through fMRI, eye tracking, and field experiments. *MIS Quarterly*, 42(2), 355–380.

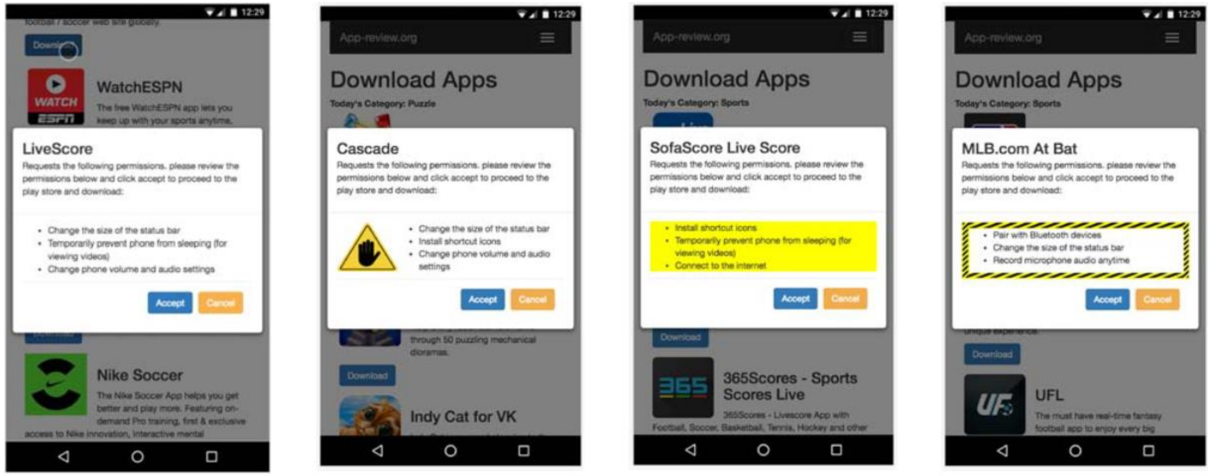
users habituate to warnings

ignored warnings lead to security problems

two experiments:

- longitudinal fMRI + eye tracking study over 5 days
- behavioral study over 3 weeks

4 different warning designs (standard & polymorphic)



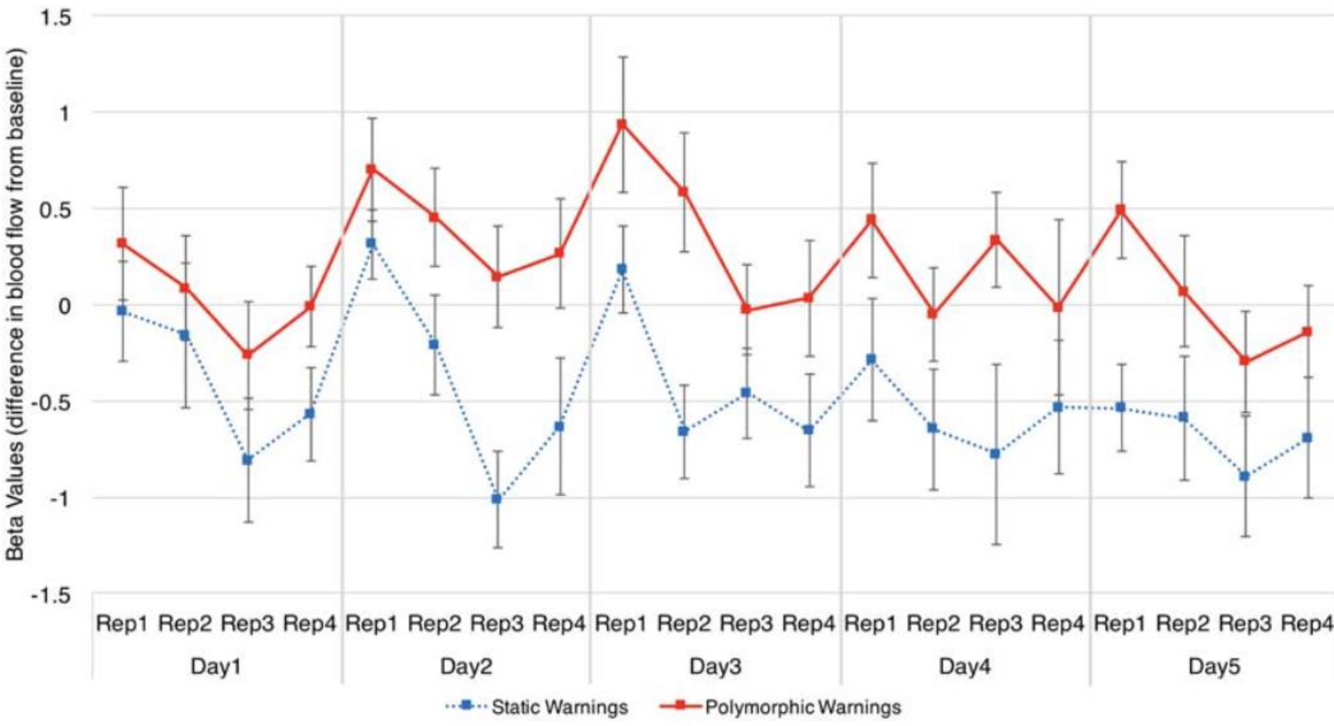
The leftmost warning shows the appearance of the warning in the static condition. The other three warnings are a sample of the 15 variations used in the polymorphic condition.

Example: Vance, A., Jenkins, J. L., Anderson, B. B., Bjornn, D. K., & Kirwan, C. B. (2018). Tuning out security warnings: A longitudinal examination of habituation through fMRI, eye tracking, and field experiments. *MIS Quarterly*, 42(2), 355–380.

Results experiment 1:

- habituation measurable with eye tracking and fMRI
- habituation to both warning types

Fewer habituation towards polymorphic warnings!



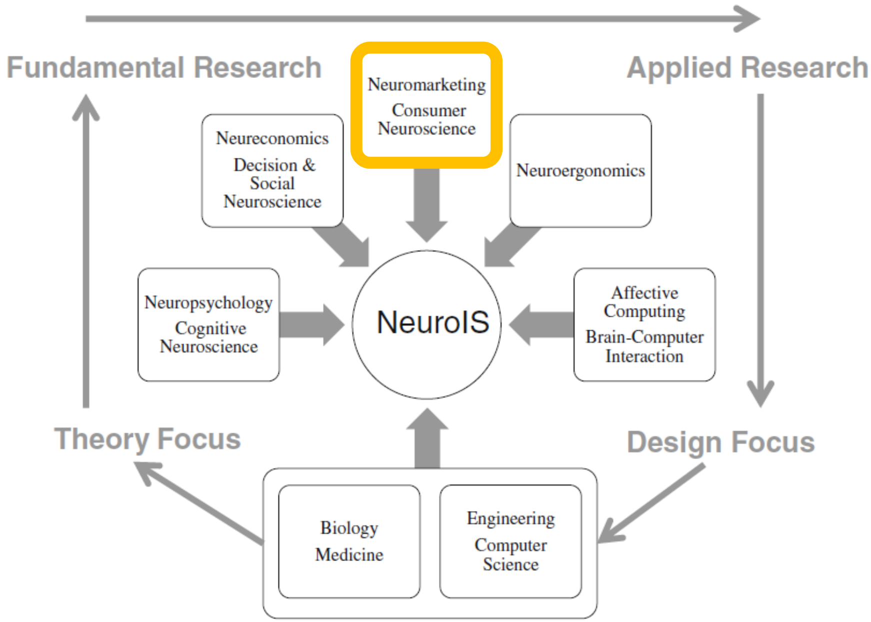
Neuromarketing

Evaluation of product preference, advertisement, and marketing exchange

- attention
- product preference
- emotions

Strong ethical and legal implications

Rebranding attempt to “consumer science”



Example: Tusche, A., Bode, S., and Haynes, JD. (2010) Neural Responses to Unattended Products Predict Later Consumer Choices. *Journal of Neuroscience*, 30 (23) 8024-8031;

fMRI experiment with images of cars as stimulus

Group 1:

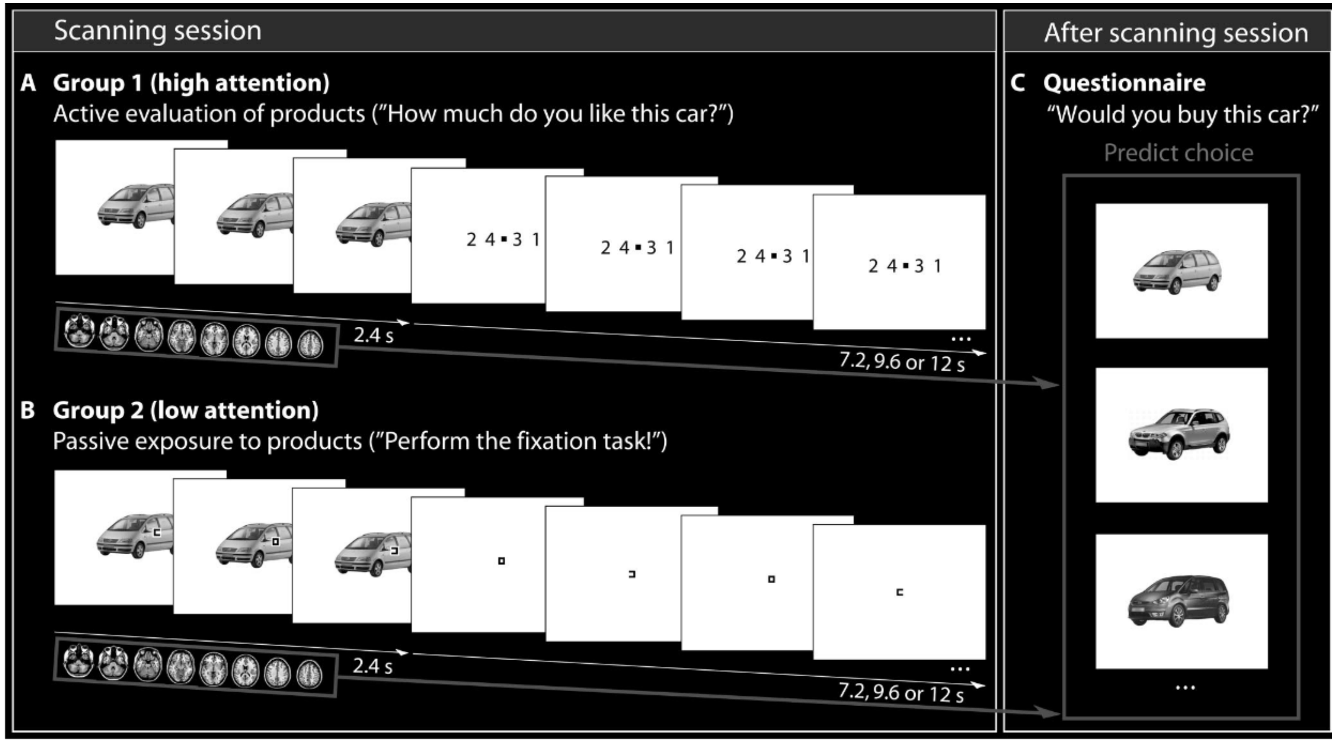
- user instructed to pay attention to images of cars
- rate preference

Group 2:

- user distracted via unrelated task

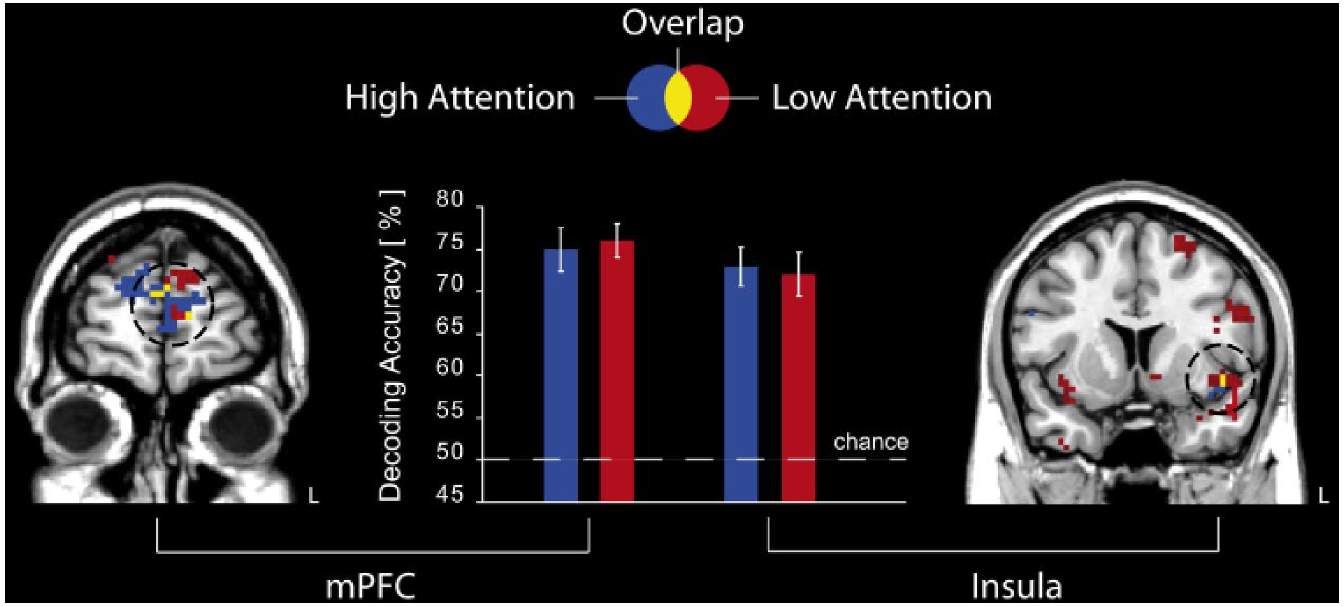
Both groups:

- intention to purchase collected after scanning



Example: Tusche, A., Bode, S., and Haynes, JD. (2010) Neural Responses to Unattended Products Predict Later Consumer Choices. *Journal of Neuroscience*, 30 (23) 8024-8031;

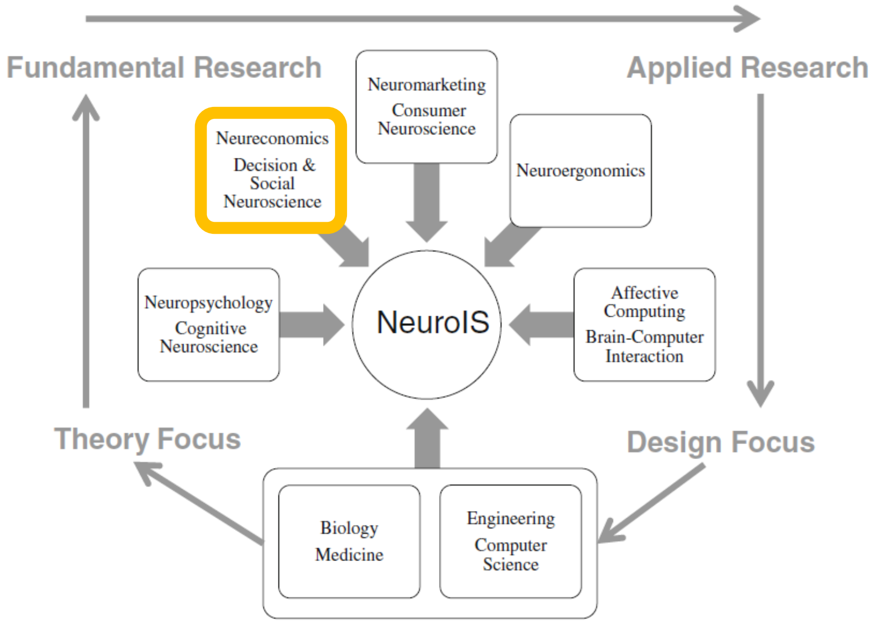
- **analysis via multivariate pattern classification**
- **consumer preference could be decoded even from low attention group**
- **product preference is formed in the brain and can be extracted without conscious evaluation of the user**
- **consumer choice information located to Insula and medial prefrontal cortex**



Neuroeconomics

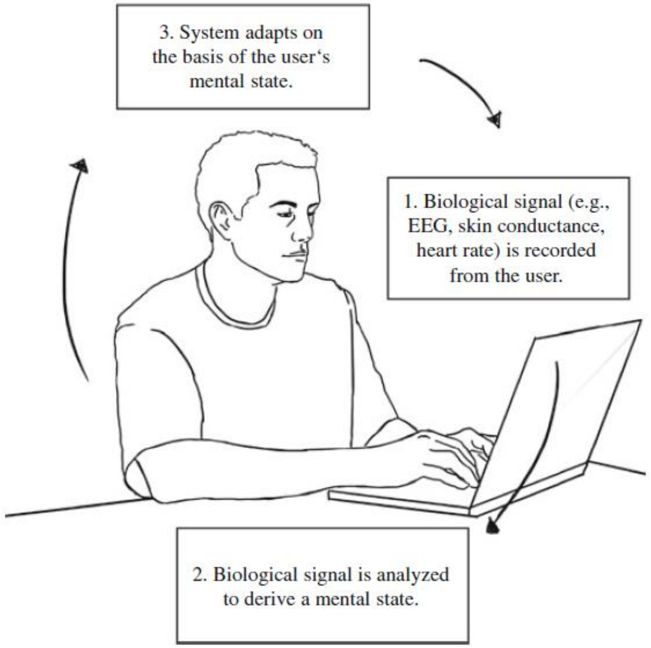
- **investigate decision making in market context**

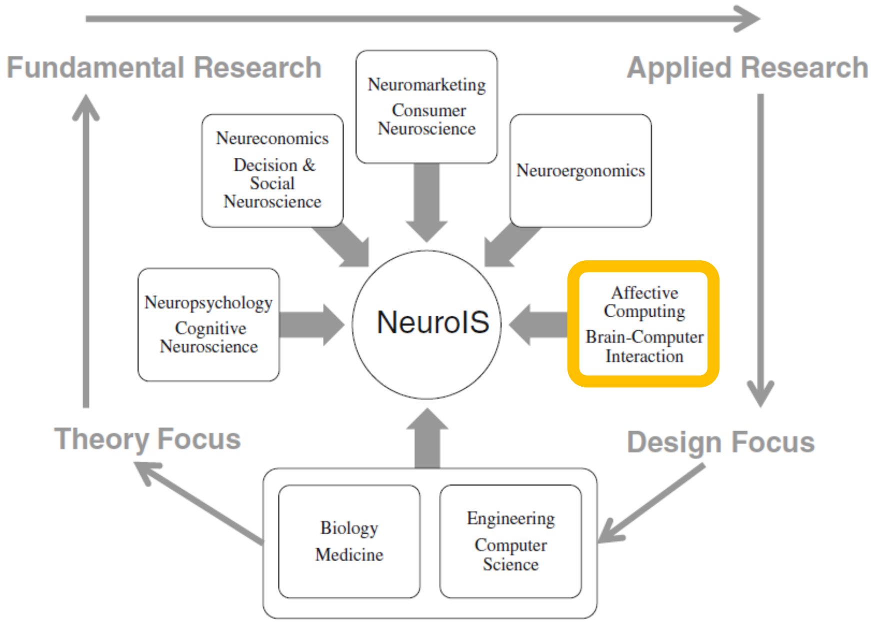
- **price & value formation**
  - emotional value
  - cognitive evaluation
  - biases



Affective Computing

- collect physiological data
- build mental model of user
- response of system changes according to user state





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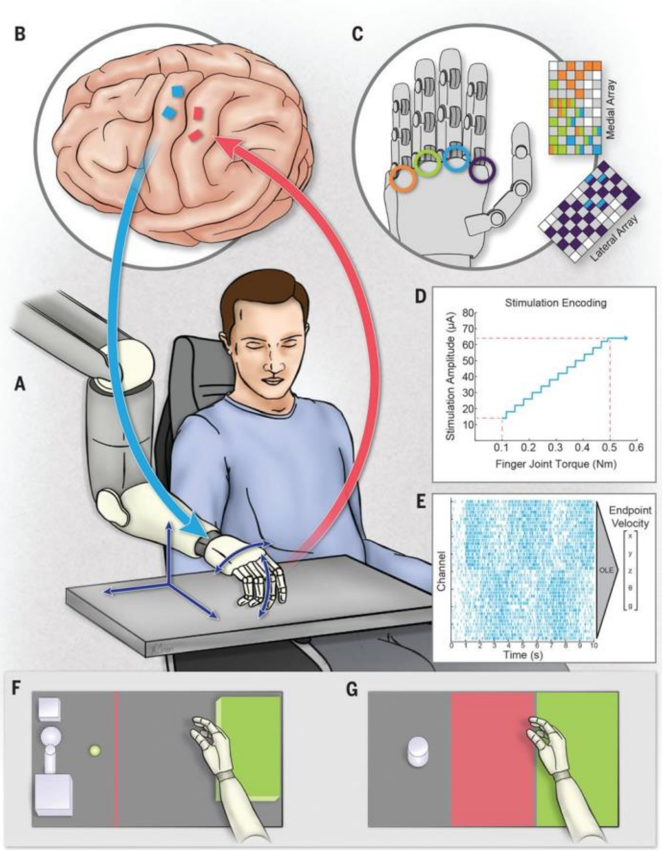
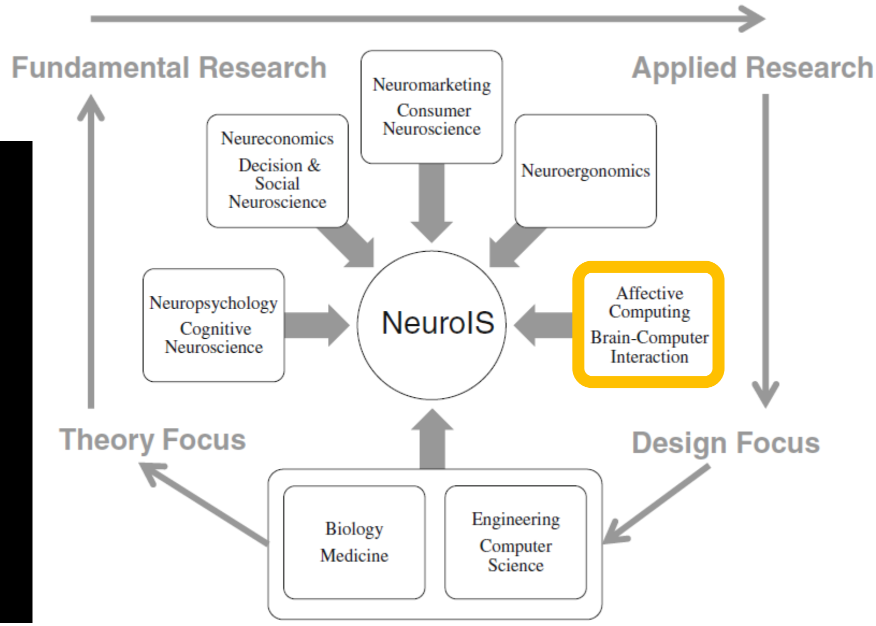
Brain Computer Interfaces

- **replace input device with neural input**
- **current advancements in implanted electrode technology**





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Thank you for your attention!

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Q&A