Biosignals for assessment of cybersickness

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This lecture is based on the results prepared for the ICIST 2019 conference, ICT for Automotive Session, Kopaonik, March 10-13, 2019, Serbia.

Topics

- Motion sickness
- Cybersickness phenomenon
- Biosignals for assessment of motion sickness
- Case study: Cybersickness assessment by electrogastrography (EGG)
- Pathways and pitfalls for EGG for sickness assessment

- This lecture is based on the results prepared for the ICIST 2019 conference, ICT for Automotive Session, Kopaonik, March 10-13, 2019, Serbia.
- The results presented here are summating collaborative efforts of Faculty of Electrical Engineering, University of Ljubljana and University of Belgrade – School of Electrical Engineering to develop EGG-based appropriate sickness assessment procedure (hardware & software & protocols).

MOTION SICKNESS

By NASA's Marshall Space Flight Center and Science@NASA (U.S. Federal Government) - http://science.nasa.gov/headlines/y2001/ast07aug_1.htm, Public Domain, https://commons.wikimedia.org/w/index.php?curid=6883973

Sickness

- Motion sickness:
  - Seasickness
  - Airsickness
  - Carsickness
  - Trainsickness
- Cybersickness
- Spacesickness

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Sickness

- Motion sickness:
  - Seasickness
  - Airsickness
  - Carsickness
  - Trainsickness
  - Cybersickness
  - Spacesickness

Skiing, camel & elephant riding, wide-screen cinemas, …

Motion sickness symptoms

In general, motion sickness produces unpleasant feeling that can be accompanied by the following symptoms:

- dizziness
- nausea
- sweating
- salivation
- stomach discomfort
- vomiting
- fatigue
- vertigo
- headache
- pallor
- fullness of stomach
- disorientation
- ataxia
- depressed appetite
- dryness of mouth
- eye strainn
- warmth/flushing
- tremor
- …

In case you wondered …

Or you knew. Animals can experience motion sickness too.

Photo: 003 by nikoretro; Flickr https://www.flickr.com/photos/bellatrix6/43004999690/; CC BY-SA 2.0 Generic.

Causes

- Not discovered, yet.
- Three theories:
  - Sensory conflict theory (widely used)
  - Evolutionary poison theory (the most interesting)
  - Postural instability theory (I'd say similar to sensory conflict theory, posture system "resists" conflicting information together with stomach)
- Reference: Jr. J. J. LaViola, "A discussion of cybersickness in virtual environments," *ACM SIGCHI Bulletin*, vol. 32, pp. 47-56, 2000, DOI: 10.1145/333329.333344.

VIRTUAL REALITY & SICKNESS
CYBERSICKNESS

Photo: Exploring alternate realities by Johan Larsson; Flickr https://www.flickr.com/photos/johanl/46632246802/; CC-BY 2.0 Generic.

But, …

Health and Safety

* These health & safety warnings are periodically updated for accuracy and completeness. Check *www.oculus.com/warnings* for the latest version.

⚠ WARNING Discomfort

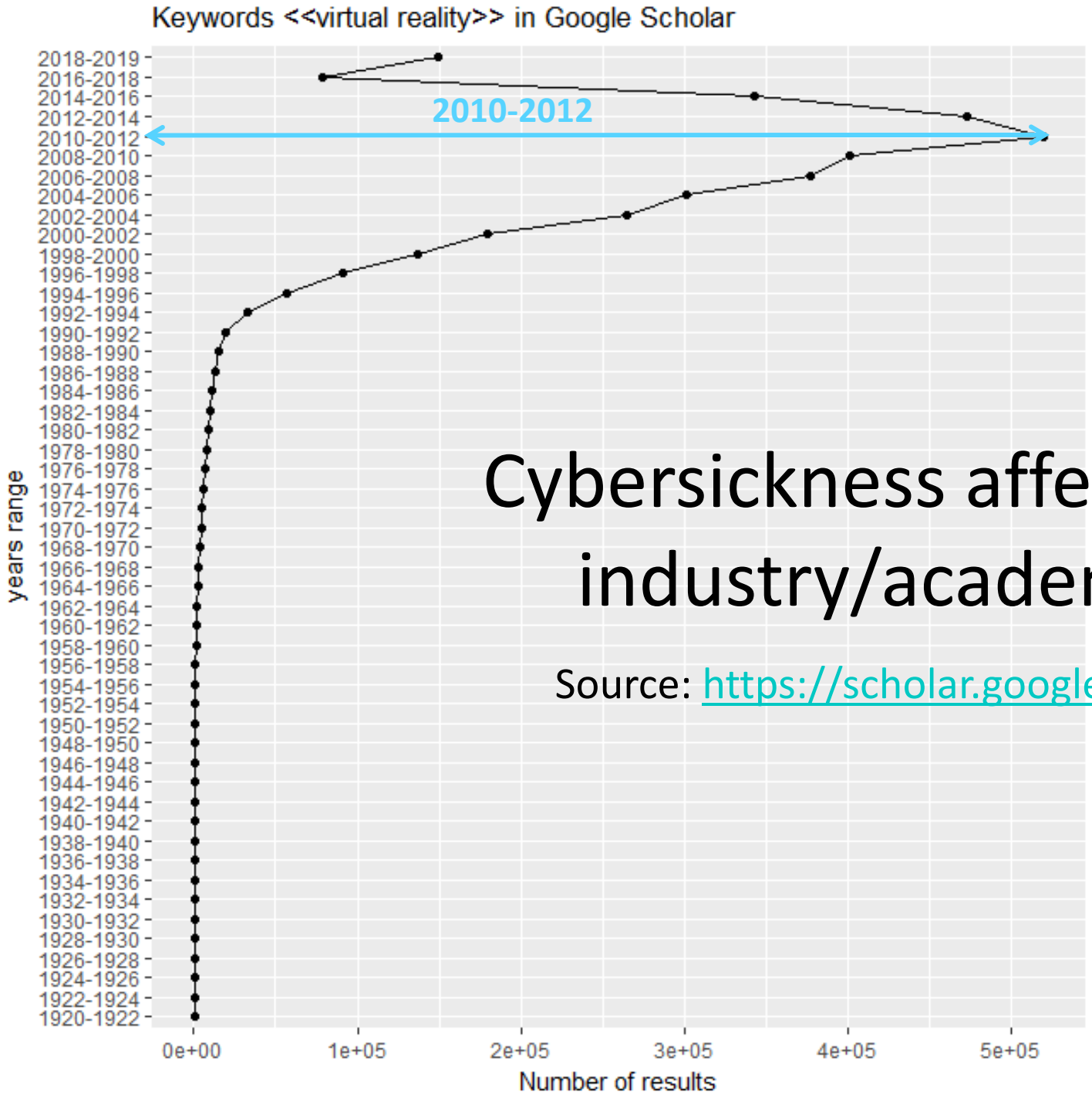
- **Immediately discontinue using the headset if any of the following symptoms are experienced: seizures; loss of awareness; eye strain; eye or muscle twitching; involuntary movements; altered, blurred, or double vision or other visual abnormalities; dizziness; disorientation; impaired balance; impaired hand-eye coordination; panic or anxiety attack; excessive sweating; increased salivation; nausea; lightheadedness; discomfort or pain in the head or eyes; drowsiness; fatigue; or any symptoms similar to motion sickness.**

Cybersikness symptoms

Health and safety warnings are available online for Oculus Rift and Touch, Oculus Go, and Samsung Gear VR: https://www.oculus.com/legal/health-and-safety-warnings/ (Assessed February 27, 2019). 25% to 40% of VR consumers experience sickness: http://fortune.com/2018/02/06/virtual-reality-motion-sickness/ (Assessed February 27, 2019)

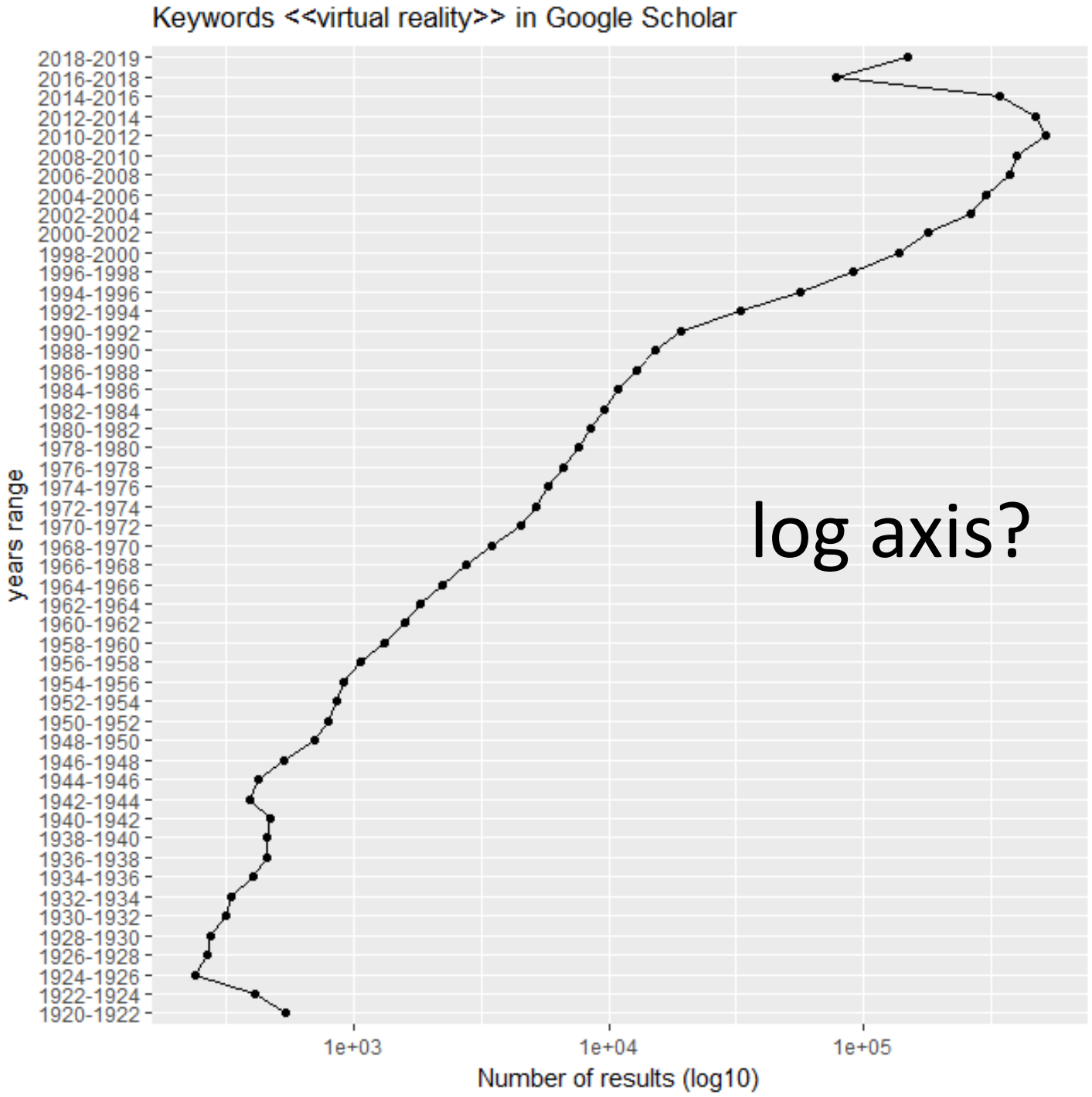
Consequences

https://arstechnica.com/gaming/2014/08/developer-cites-motion-sickness-in-delaying-oculus-rift-support/



Cybersickness affects VR industry/academia

Source: https://scholar.google.com/.


Keywords <<virtual reality>> in Google Scholar
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2014-2016
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1928-1930
1926-1928
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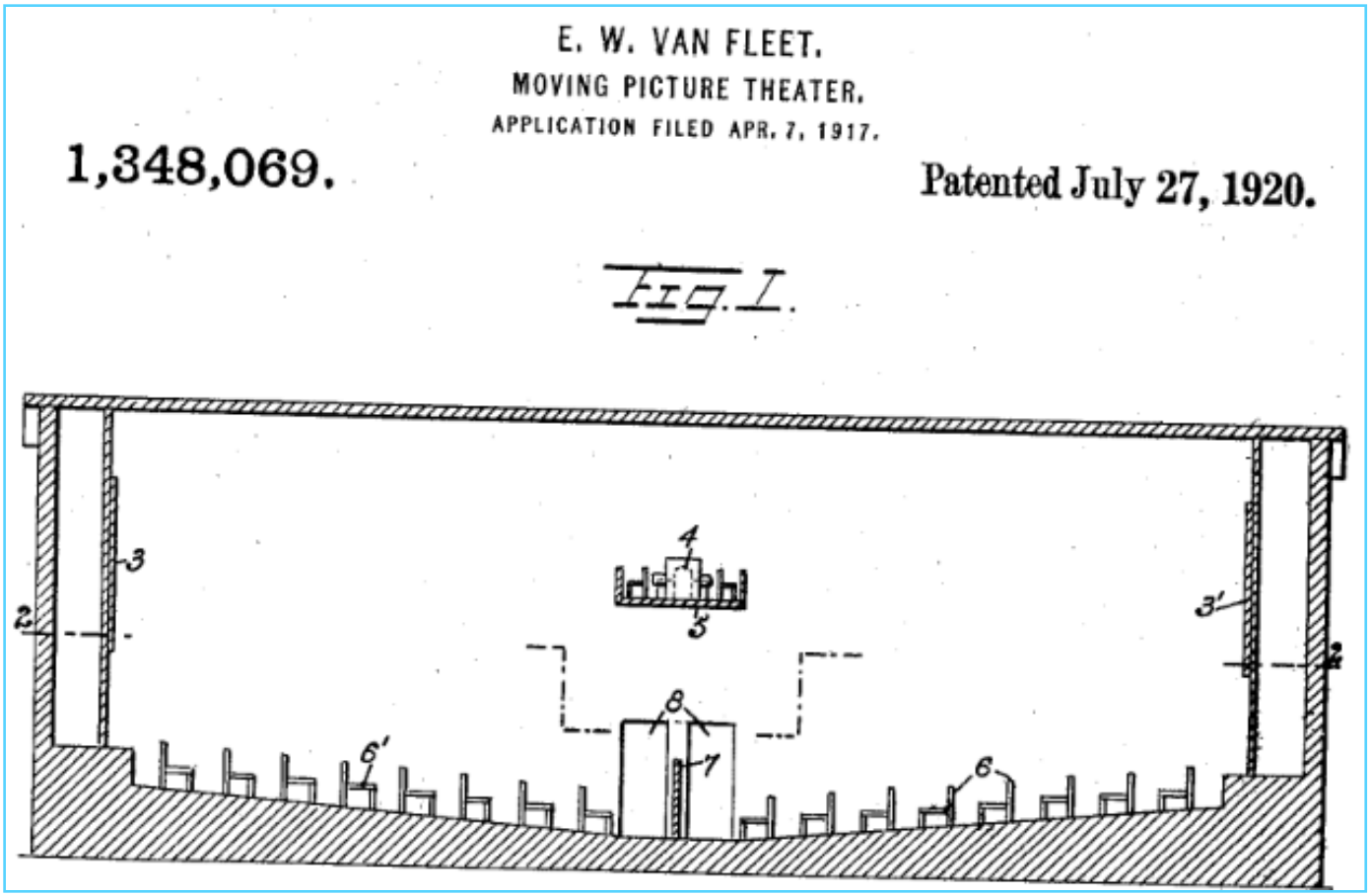
1e+03
1e+04
1e+05
Number of results (log10)
log axis?

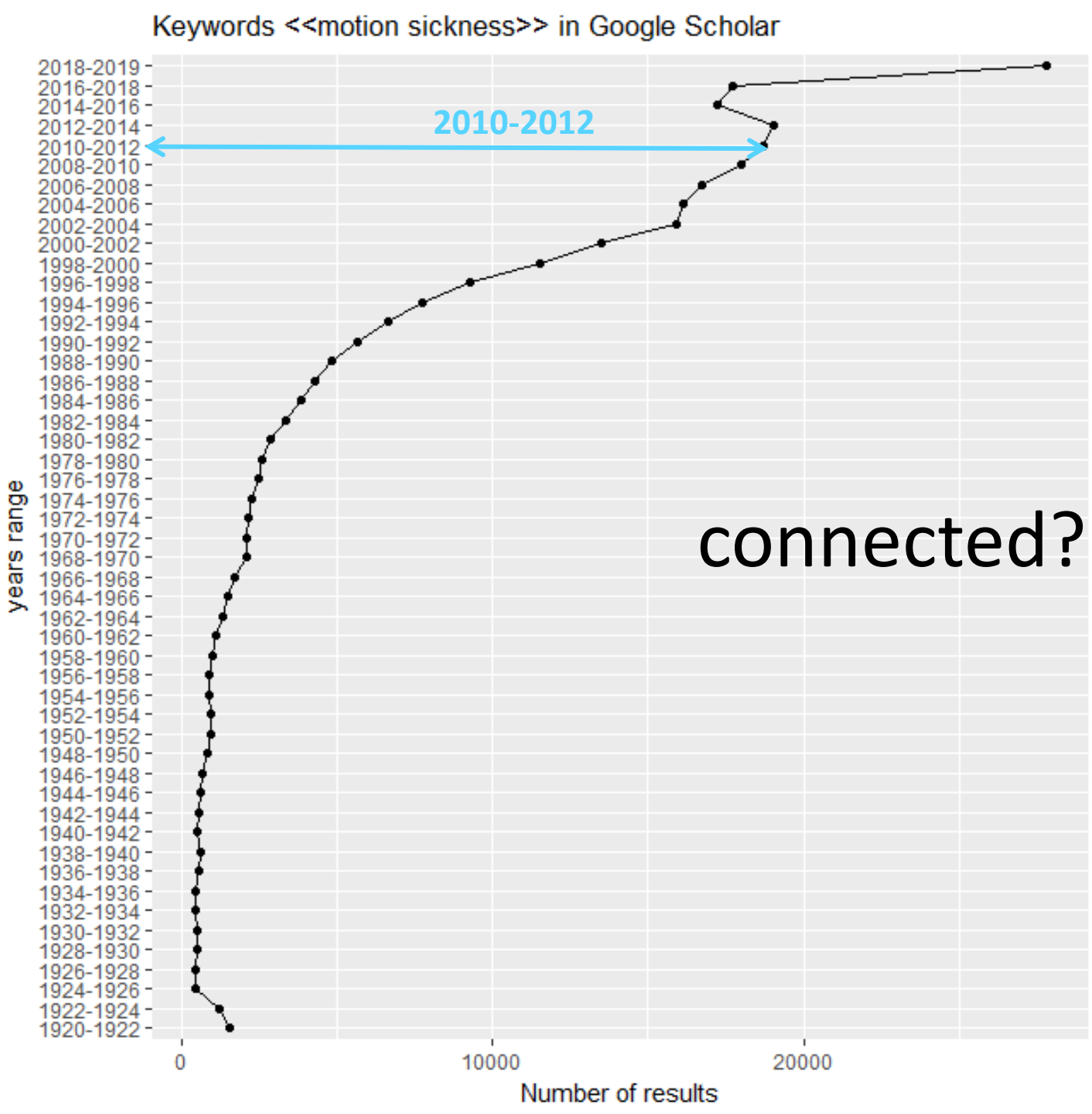
Moving picture theater


E. W. VAN FLEET.
MOVING PICTURE THEATER.
APPLICATION FILED APR. 7, 1917.

1,348,069. Patented July 27, 1920.

Fig. 1.

Van Fleet EW, inventor; Donato Cozzolino, assignee. Moving-picture theater. United States patent US 1,348,069. 1920 Jul 27, https://patentimages.storage.googleapis.com/49/51/20/069b866726d929/US1348069.pdf.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1934-1936
1932-1934
1930-1932
1928-1930
1926-1928
1924-1926
1922-1924
1920-1922
years range
2010-2012
connected?
0
10000
20000
Number of results

INDIVIDUAL DIFFERENCES

If you are

- female (wider field of view than males)
- young or old
- having fatigue, stress, flu, ear infection, hangover …
- standing during VR
- using VR with another person(s)
- using VR for longer periods of time
- not in a control
- not Chinese, but Caucasian
- not seeing a horizon during ride
- reading during ride
- using more realistic simulations/VR
- using VR with enhanced flicker
- …
- applying more than one above-mentioned features

Chances you'll experience motion sickness are high!

How to suppress the symptoms?

- deep breathing
- eating before experiencing VR (!?)
- relief band (check https://www.reliefband.com)
- chewing ginger
- biofeedback
- …

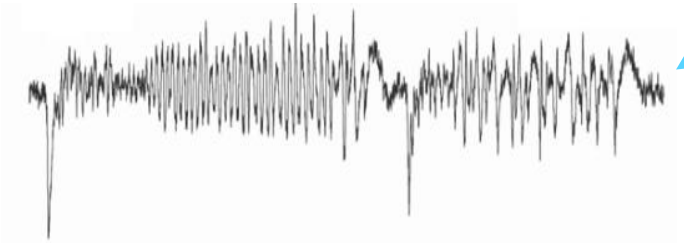
(CYBER)SICKNESS ASSESSMENT

Motion sickness manifestations

See Paul Green “Motion Sickness and Concerns for Self-Driving Vehicles: A Literature Review”, Technical Report UMTRI-2016, The University of Michigan, http://umich.edu/~driving/publications/Motion-Sickness--Report-061616pg-sent.pdf (assessed on April 1, 2019).

Biosignals

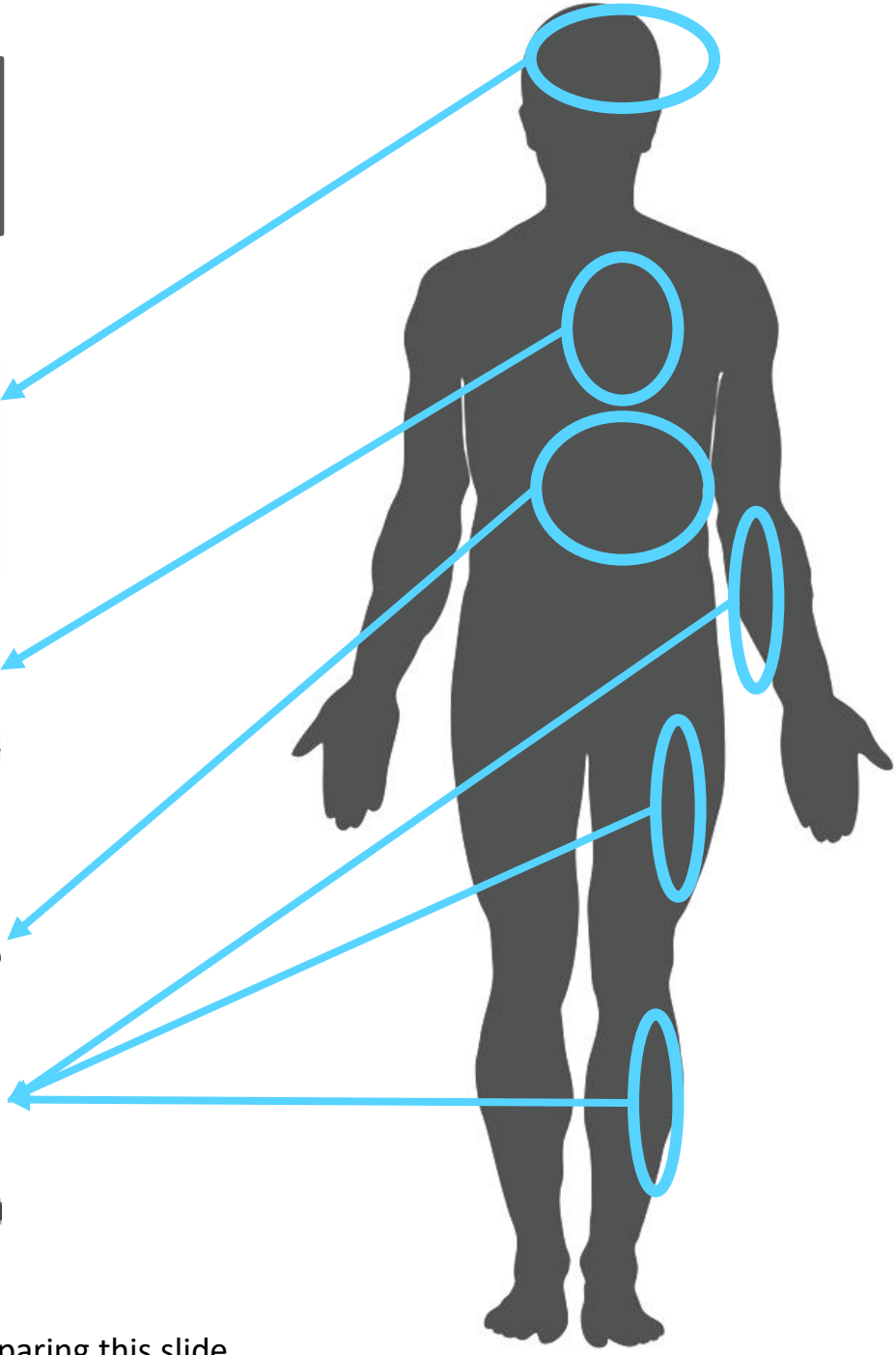
EEG



ECG

EGG

EMG

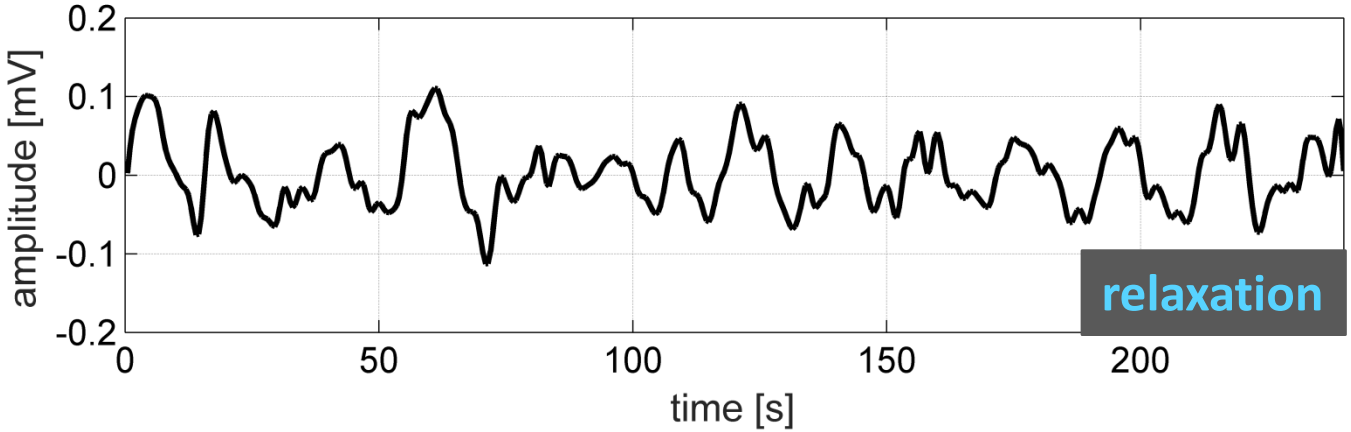


Special thanks to my PhD student Nenad B. Popović for preparing this slide.

Previously used biosignals

- sweating measured by GSR/EDA (galvanic skin response, electro-dermal activity)
- gastric myoelectric activity measured by EGG (electrogastrography)
- eye blink rate measured by EOG (electrooculography)
- respiration
- cardiac vagal tone measured by ECG (electrocardiography)
- delta power of EEG (electroencephalography)
- skin temperature
- …

We propose … EGG



- EGG is a method that records electrical activity of stomach smooth muscles by placement of surface Ag/AgCl electrodes over stomach.
- EGG during relaxation is presented in figure.
- Very slow activity.
- Three typical rhythmical ranges:
  - Normal – normogastria: 2-4 cpm (cycles per minute)
  - Fast – tachygastria: 4-10 cpm
  - Slow – bradygastria: 1-2 cpm

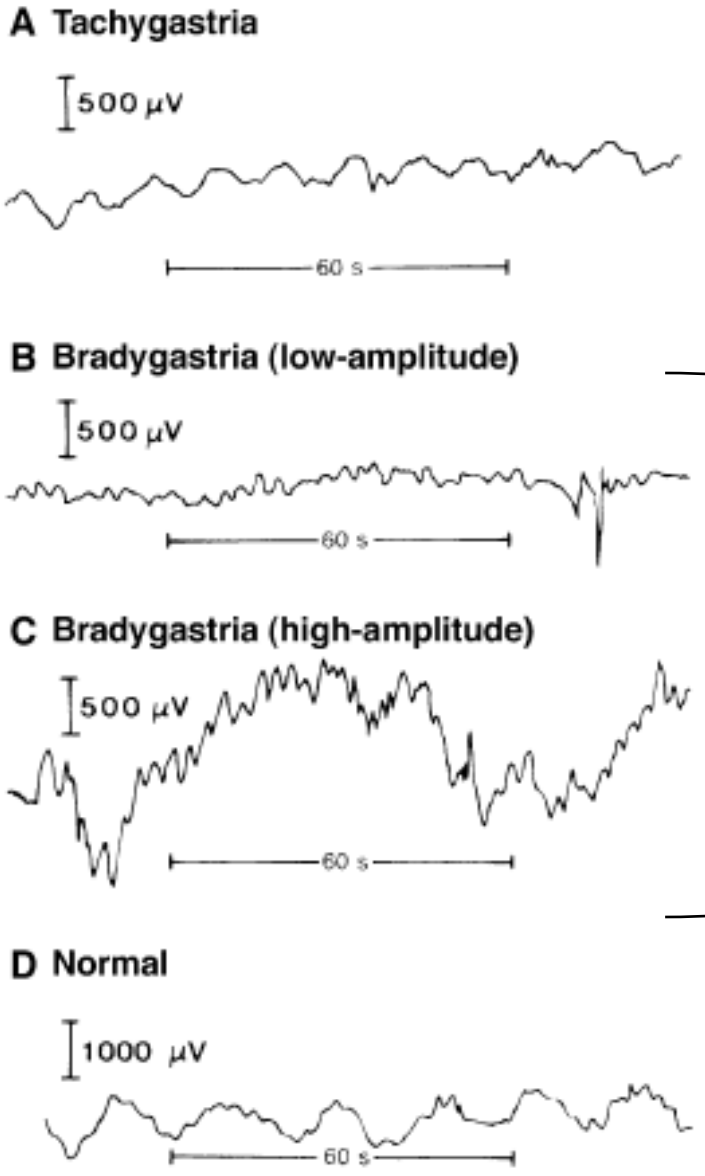


Fig. 3 Spectrum of gastric dysrhythmias recorded from women with morning sickness during the first trimester of pregnancy. Dysrhythmias range from tachygastria to bradygastria. Women who had normal 3 cpm myoelectrical activity (*Panel D*) had little or no nausea on the morning of the recordings. See text for details

Morning sickness in pregnancy

The most vulnerable range to artifacts

Invasive & endoscopic (minimally invasive) EGG

- We are not using it… but they should be mentioned.
- Cutaneous EGG lacks resolution and is prone to artifacts
- Reference: Farajidavar A. Bioelectronics for mapping gut activity. Brain research. 2018;1693:169-73, DOI: 10.1016/j.brainres.2018.03.004.

EGG & motion sickness

- Used previously and its potential has been recognized.
- Has been shown that:
  - dysrhythmias in EGG signal that can be either faster (tachygastria) or slower (bradygastria) than normal EGG rhythm (2-4 cpm, cycles per minute)
  - during motion sickness, total power of EGG increases
- However, there have been reports on limitation of this procedure… [see Gavgani, A. M., Walker, F. R., Hodgson, D. M., & Nalivaiko, E. (2018). A comparative study of cybersickness during exposure to virtual reality and" classic" motion sickness: are they different?. *Journal of Applied Physiology*]

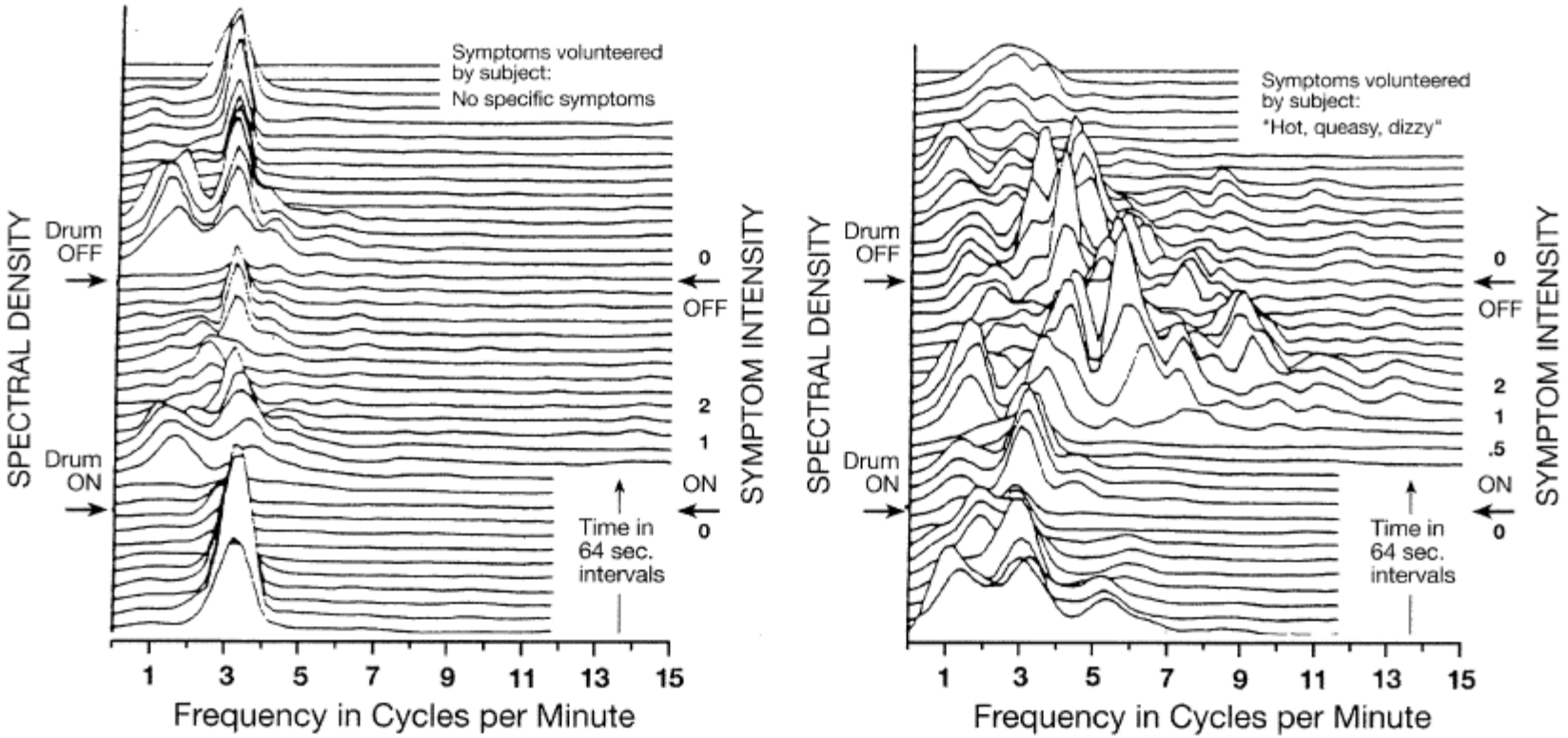


Fig. 2 Gastric electrical activity recorded during exposure to illusory self-motion produced by an optokinetic drum in healthy subjects. The *left panel* shows consistent 3 cpm EGG activity during drum rotation in a healthy subject who reported no symptoms of nausea. The *right panel* shows the acute development of tachygastrias from 4 to 9 cpm after approximately 5 min of drum rotation and the concomitant development of nausea related to motion sickness. See text for details

EGG-BASED ASSESSMENT PROCEDURE
CASE STUDY

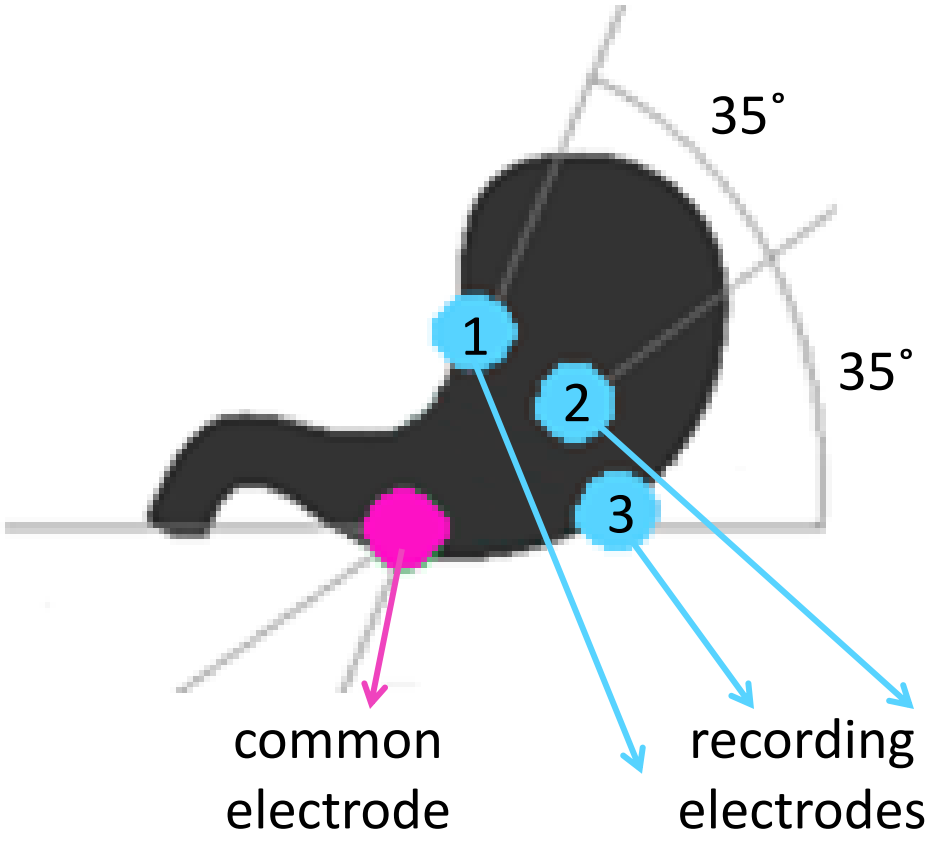
Research questions

- The key research questions presented in this paper are:
  - Can EGG effectively measure cybersickness?
  - What is the appropriate EEG-based parameter (PSD shape and/or PSD power)?
  - Are there any EGG related individual characteristics in two similar VR environments?

Hardware & software

- Three EGG channels.
- Hardware:
  - Ag/AgCl electrodes
  - EGG device: amplification and filtering
  - NI USB 6210 A/D (National Instruments Inc., Austin, USA) digitization
- Software:
  - custom-made LabVIEW software (National Instruments Inc., Austin, USA).
- Parameters: 16 bits of resolution, gain of 1000 and sampling frequency of 2 Hz.

Electrode placement



According to: N. B. Popović, N. Miljković, M. B. Popović, “Simple gastric motility assessment method with a single-channel electrogastrogram,” *Biomedical Engineering/Biomedizinische Technik*, in print, 2018, DOI: 10.1515/bmt-2017-0218.

Reference electrode is placed on *iliac crest*.

Measurement procedure

Rock Falls, Epic Roller Coaster VR by Grey The Gamer
https://youtu.be/kse7JqNVDxs

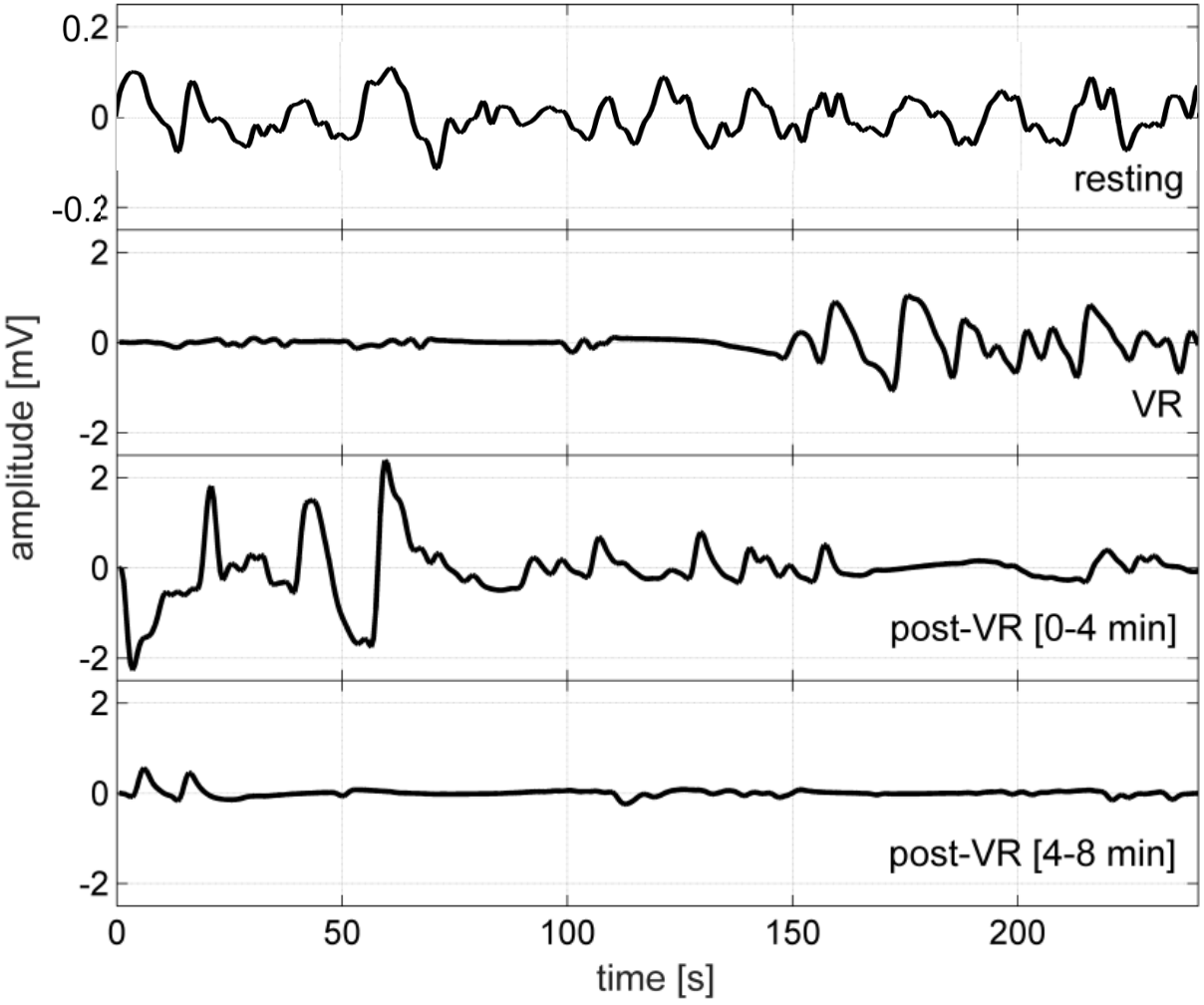
T-Rex Kingdom, Epic Roller Coaster VR by Grey The Gamer
https://youtu.be/MzVGlTUuCGA

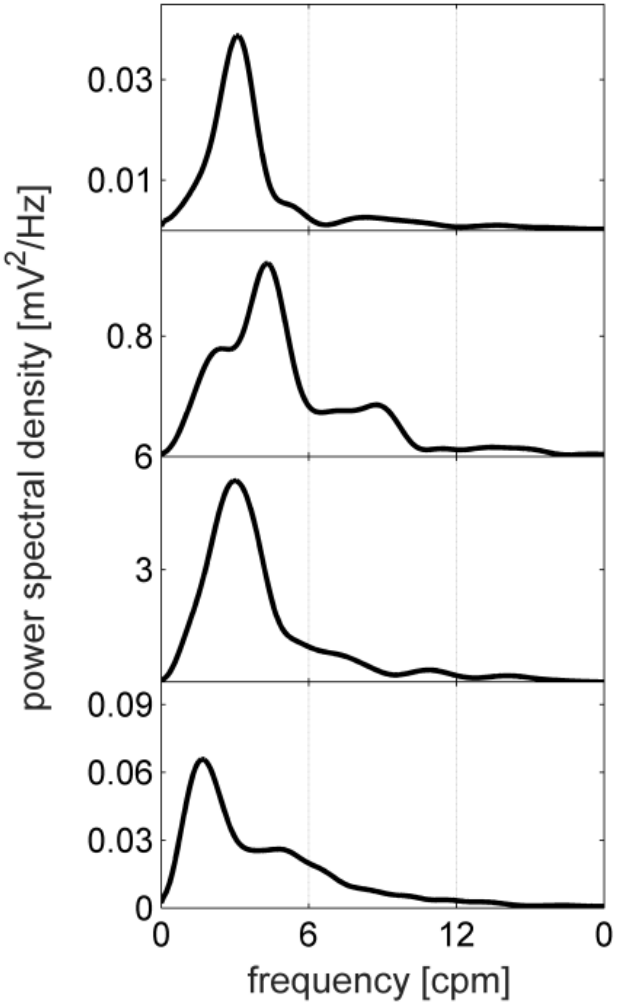
- Three subjects
- Procedure:
  - 5 min relaxation before both sessions
  - 1st session: Rock Falls VR (RF VR) roller coaster (4 min), and 2nd session: T-Rex Kingdom VR (TRK VR) roller coaster (6 min 20 s)
  - post-VR (8 min)
- Instructions:
  - To avoid excessive movements
  - To raise right hand if they feel sick
  - To inform investigator if they cannot continue

EGG pre-processing

- In order to reduce noise:
  - 5^{th} order Butterworth band-pass filter (from 0.0167 Hz to 0.3333 Hz i.e. from 1 cpm to 10 cpm)
- In order to assess parameters in spectral domain:
  - Welch power spectral density (PSD) with Hamming window (overlap of 50%) for periodogram

Recorded & filtered signals





Quantitative outcome measures

- Calculated EGG parameters in frequency domain:
  - Shape (crest factor and median frequency)
  - Spectral power (total and for three ranges)

- We chose channel ch1, since no excessive noise (by visual inspection) was found in channel ch1 in all recordings.

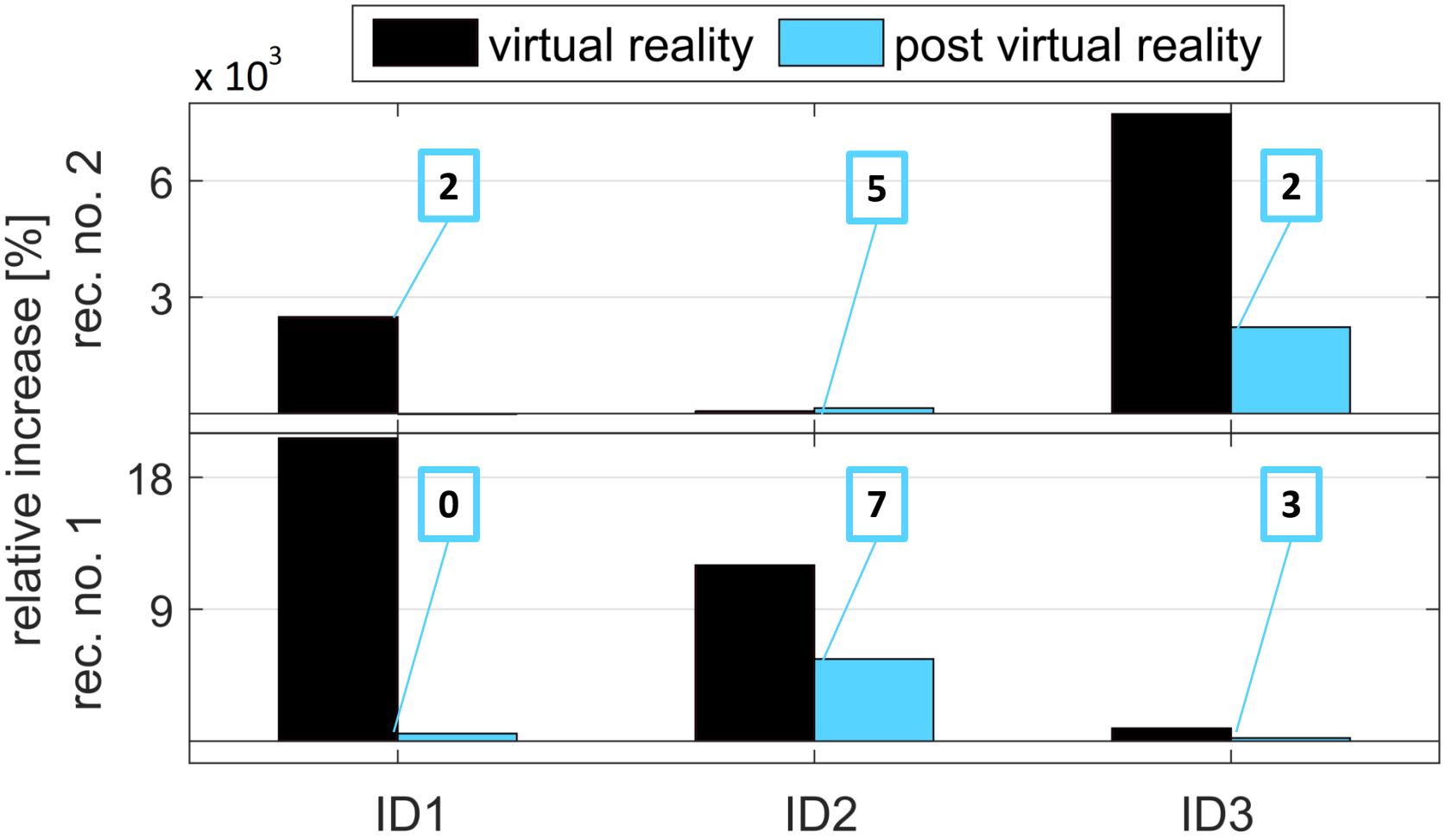
- All parameters were calculated for three intervals:
  - resting period of 5 min duration,
  - VR sequence
  - post-VR (8 min duration).

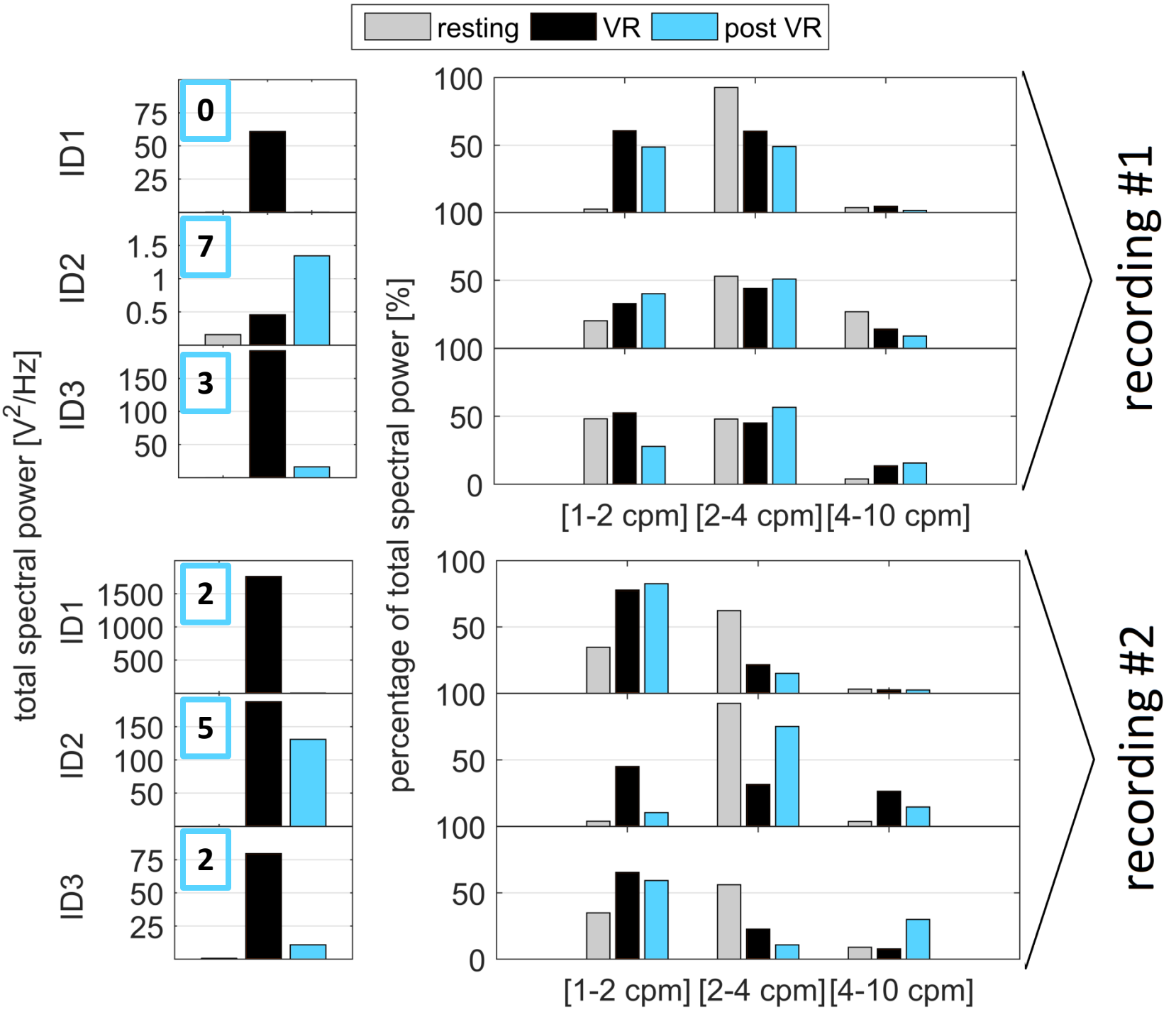
Qualitative outcome measures

- Subjective scale:
  - 0: no nausea
  - 1: …
  - 10: almost vomiting

- Number of self-reported cybersickness episodes were noted.

Power increase compared to relaxation



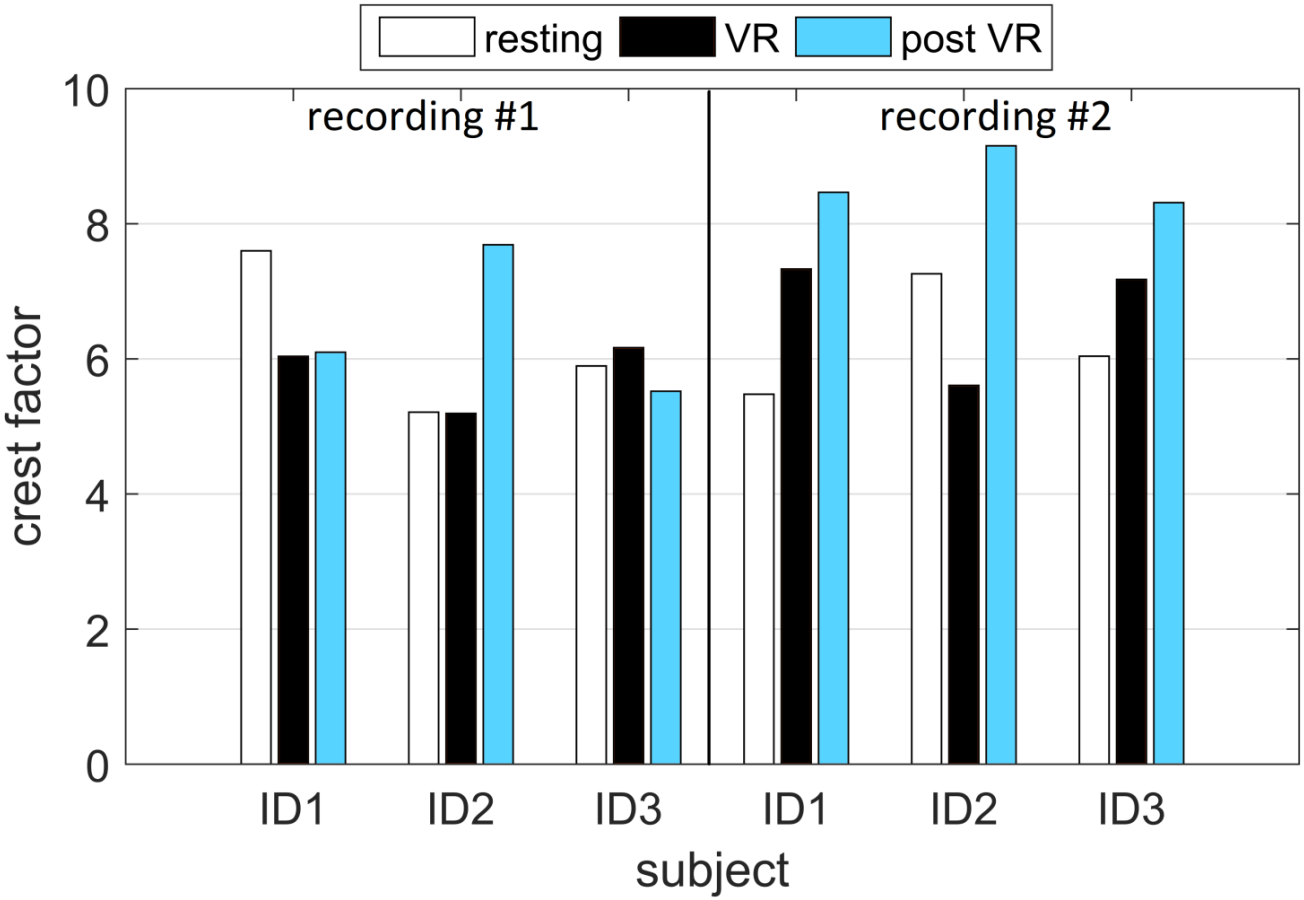

resting
VR
post VR
total spectral power [V²/Hz]
ID1
ID2
ID3
0
7
3
2
5
2
75
50
25
1.5
1
0.5
150
100
50
1500
1000
500
percentage of total spectral power [%]
100
50
0
[1-2 cpm]
[2-4 cpm]
[4-10 cpm]
recording #1
recording #2

Median frequency

subjects	RF VR / TRK VR		
	Relaxation	VR sequence	post-VR sequence
ID1	0.06 / 0.05	0.05 / 0.04	0.06 / 0.04
ID2	0.06 / 0.06	0.06 / 0.06	0.05 / 0.06
ID3	0.05 / 0.05	0.05 / 0.05	0.06 / 0.05

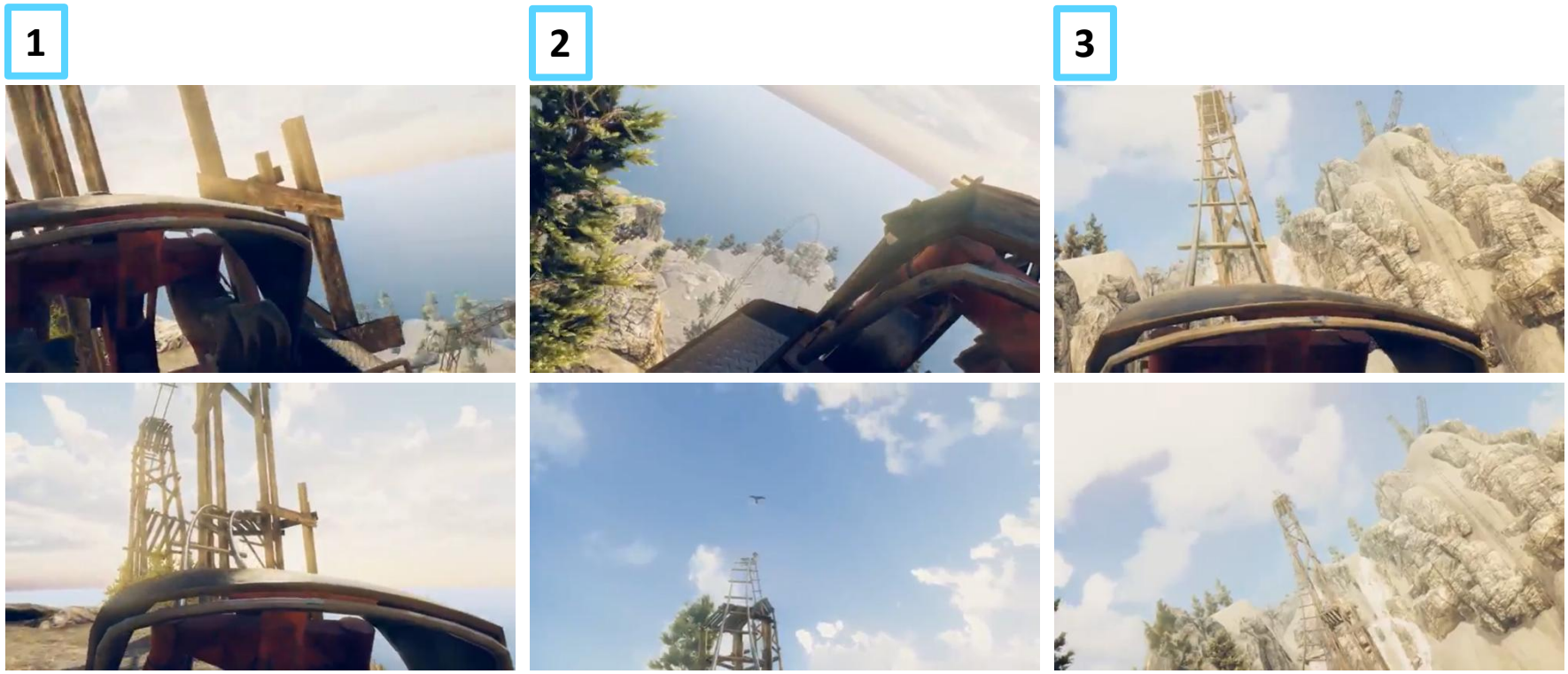
- Median frequencies are presented in Hz
- RF VR is Rock Falls Roller Coaster VR
- TRK VR is T-Rex Kingdom Roller Coaster VR

Crest factor



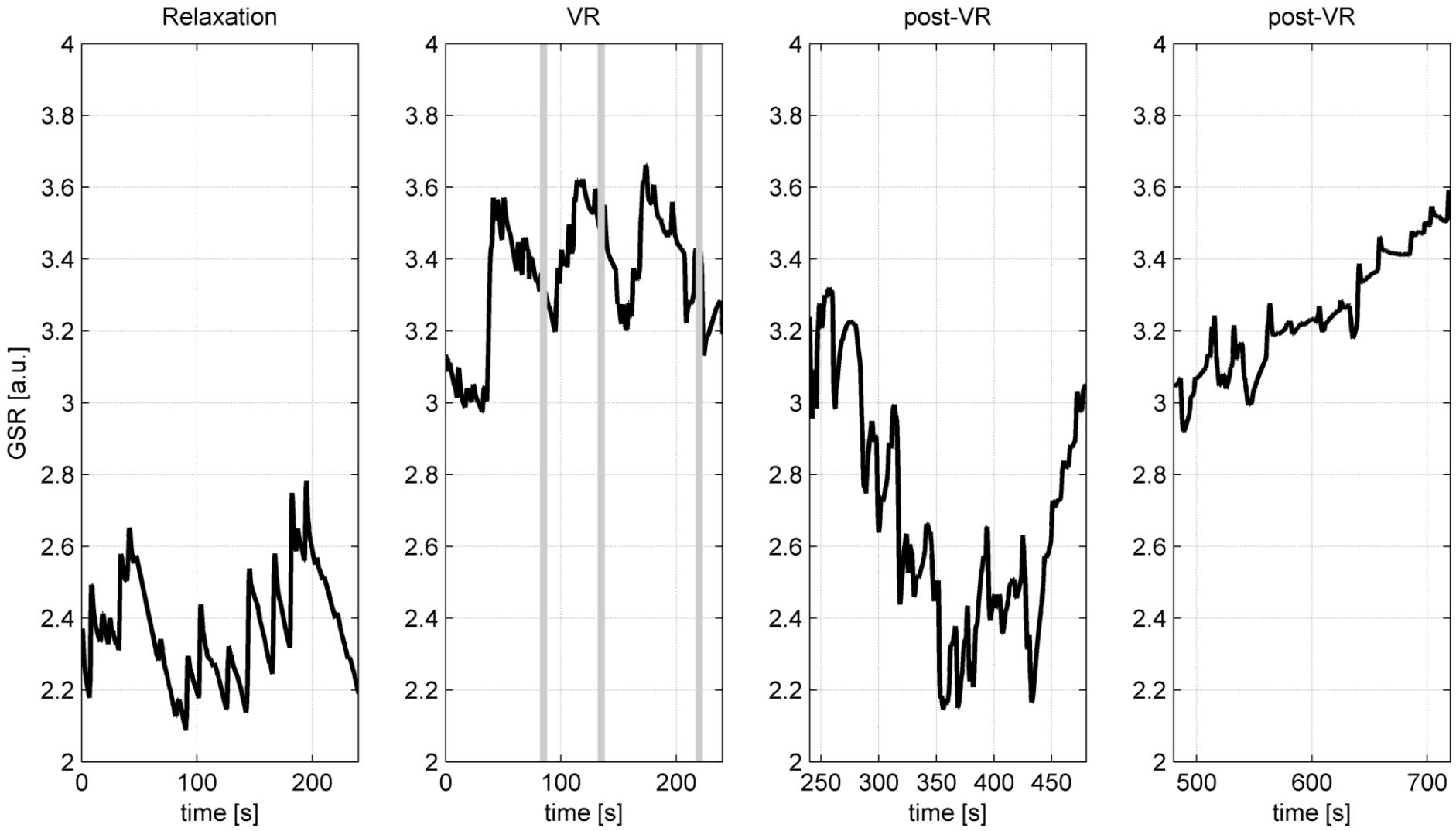
- crest factors ~1 indicate no peaks, higher the crests -> higher the peaks prominence
- recording #1 is Rock Falls Roller Coaster VR
- recording #2 is T-Rex Kingdom Roller Coaster VR

Anxiety

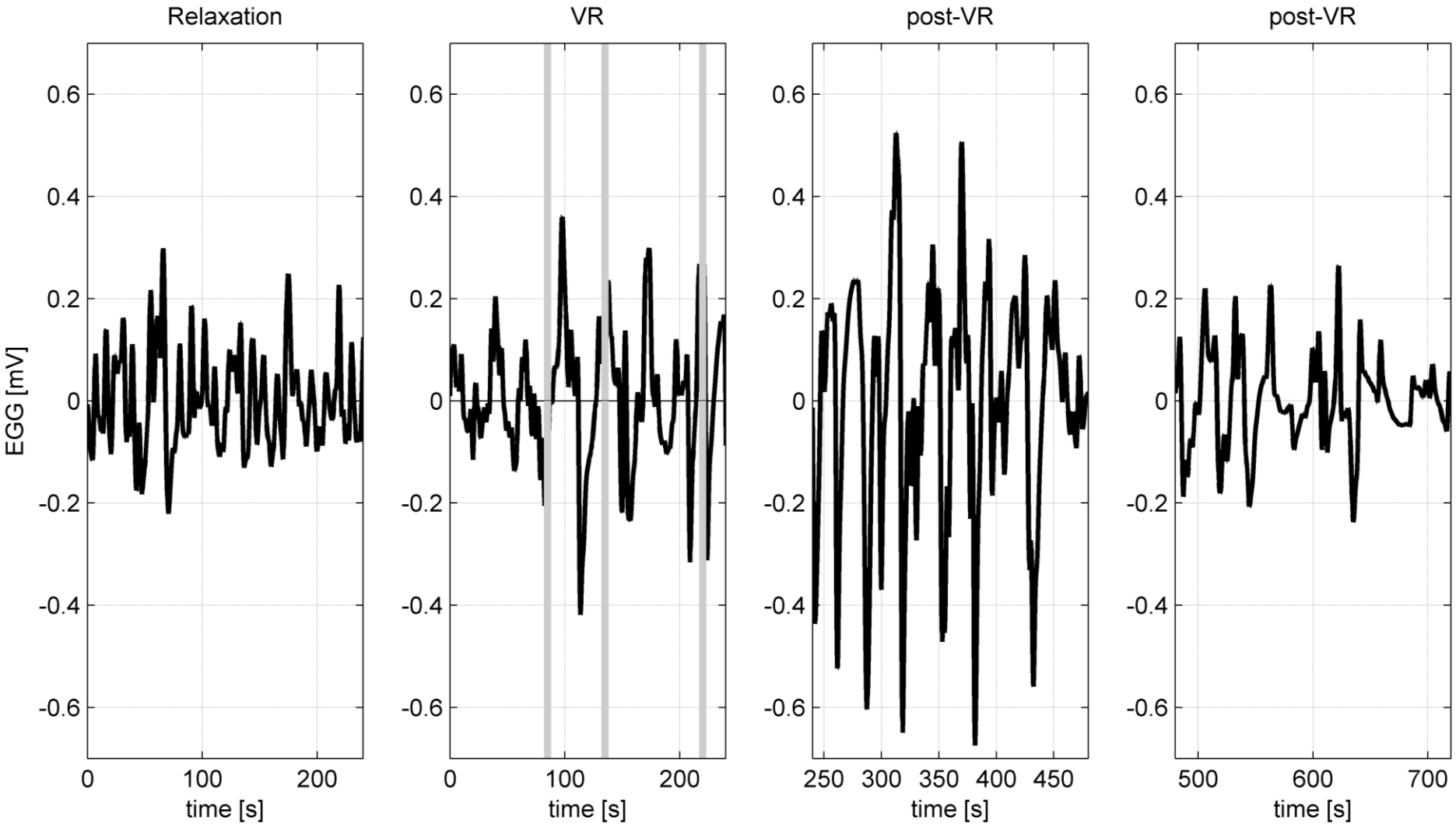


- Anxiety (acrophobia *i.e.* fear of heights) might be increasing cybersickness.
- On a scale from 0 to 10, subject reported 7 (critical moments 1-3 presented above) compared to 5 for VR without heights.
- Screenshots Rock Falls, Epic Roller Coaster VR by Grey The Gamer, 2018, https://www.youtube.com/watch?v=kse7JqNVDxs at the moments when subject reported cybersickness (Assessed on March 2, 2019).

Sickness episodes are marked during VR



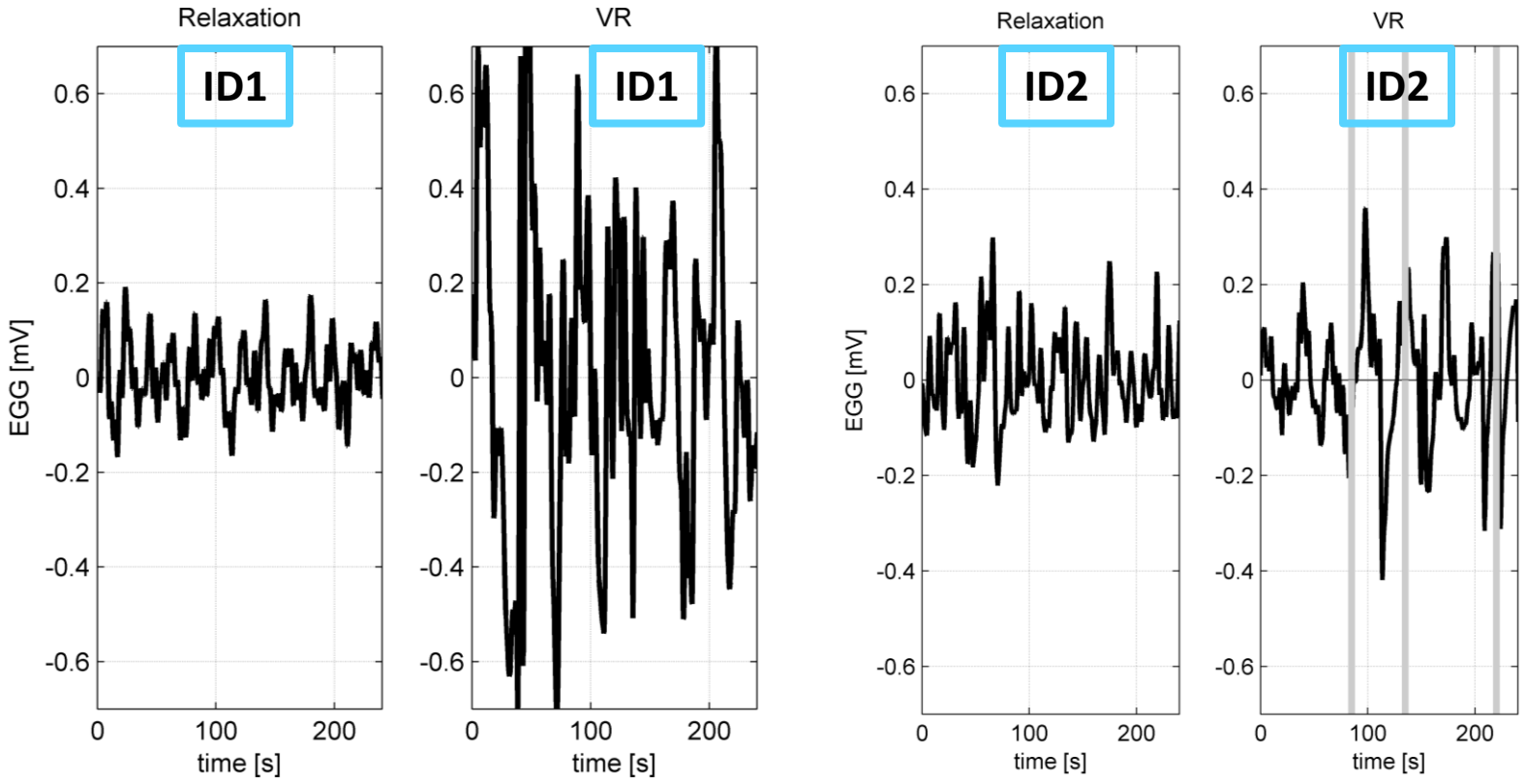
Sickness episodes are marked during VR



So, notes should be noted!

- ID1: “Sudden cessation of movement was unpleasant.”
- ID2: “Sudden changes of acceleration and direction of movement (especially rotation) were unpleasant.”
- ID3: “Negative prediction due to previous experiences caused unpleasant sensation.”

What about excitement?



- ID4: additional one-session measurement
- subject was naïve for Oculus Rift and VR
- RF VR scenario experience revealed immediate increase in EGG TP of PSD after application of VR headset
- In figures, naïve subject ID1 and experienced ID2 are presented on left and right panels, respectively.

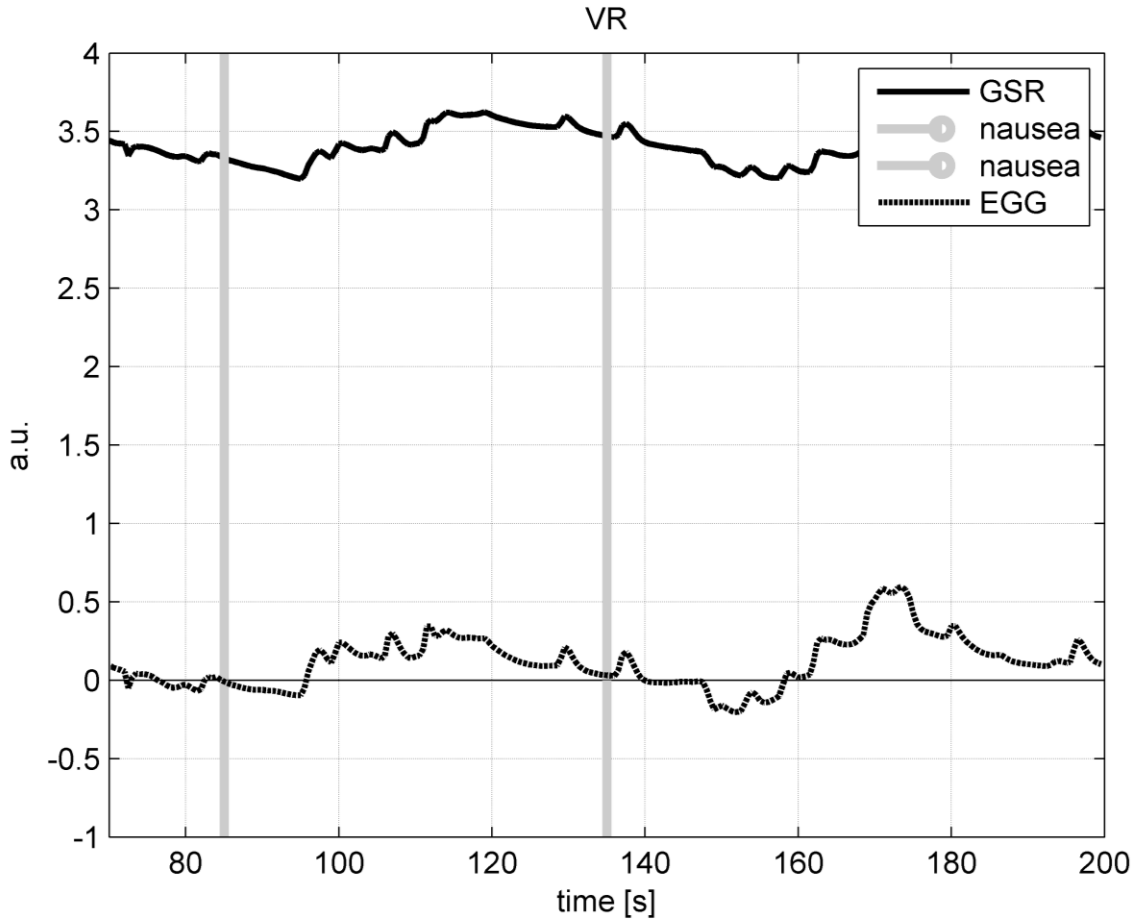
Overall on pathways

- total power change and power shares proved usable
- dysrhythmias can be assessed
- easily applicable (surface Ag/AgCl electrodes)
- prosperous combination for analysis of EGG and other signals
- duration of power changes after VR
- emotions might be influencing the results and this combination is a promising field to examine

and pitfalls

- skin-electrode impedance can be tricky to accomplish
- vulnerability to body movements, fat tissue, and surrounding signals (ECG, breathing)
- median frequency is not indicative at all
- crest factor may be indicative, but also may be not
- individual and VR dependent differences exist, but might be to complex to study
- power increase may not correlate with qualitative assessment
- no consensus about normalization procedure (in Dennison M. S. et al., Use of physiological signals to predict cybersickness. Displays. 2016;44:42-52. “**dividing data from all epochs by the baseline data**” was proposed)

Channel saturation



corr = 0.74

- cross-talk indicates noisy EGG (with other EGG channels and other signals)
- for details, see reference: O'Grady G. Gastrointestinal extracellular electrical recordings: fact or artifact?. Neurogastroenterology & Motility. 2012;24(1):1-6, DOI: 10.1111/j.1365-2982.2011.01815.x.

FUTURE RESEARCH

Future work

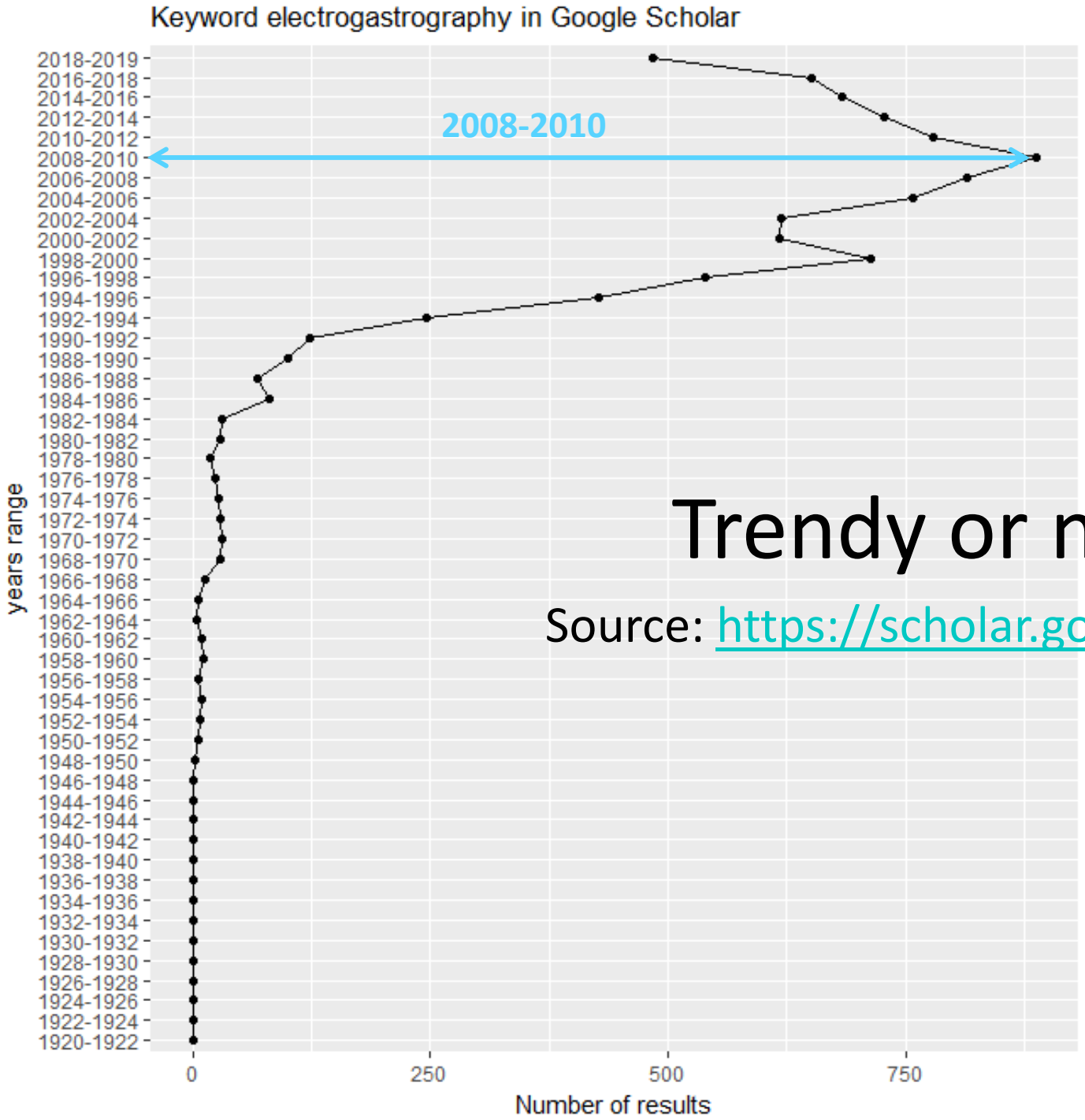
- larger and balanced study
- more strict protocol (instructions on VR navigation, eating habits, etc.)
- evaluation of cybersickness in driving simulator
- relation between emotions/anxiety and sickness

ICIST 2019 – 9th International Conference on Information Society and Technology, Kopaonik, Serbia Mar 10-13, 2019, image adopted from ICT for Automotive Special Track, http://www.eventiotic.com/eventiotic/conference/icist2019, Assessed on Feb 28, 2019.

Flying & driving simulators

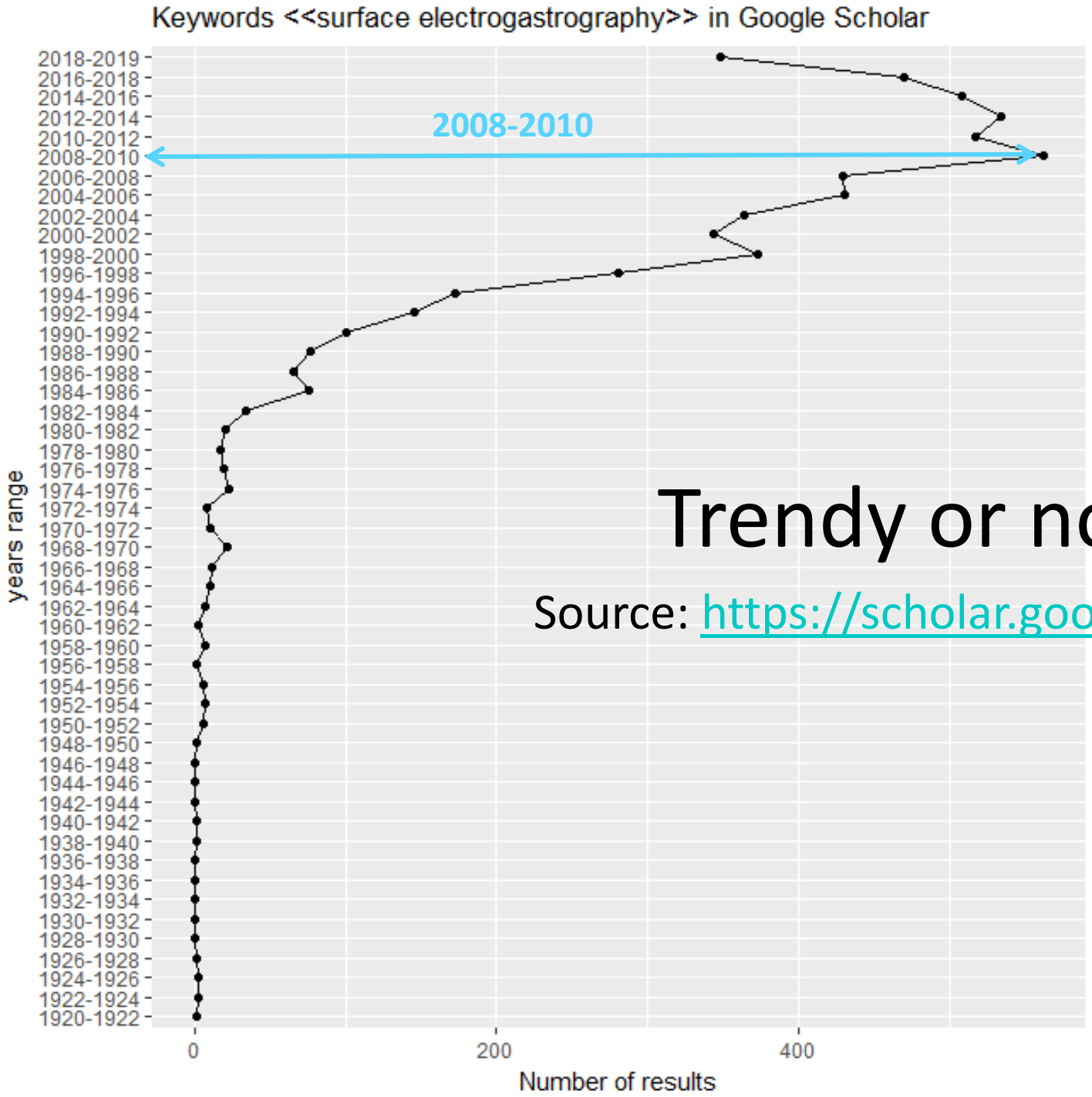
Modified Photo: Flying on the ground: VMR-1 Marines train on simulator by CherryPoint; Flickr https://www.flickr.com/photos/mcas_cherry_point/6731300823/; CC BY 2.0 Generic.

- Appropriate assessment procedures can contribute to better understanding of consequences, nature, and origins of cybersickness.
- Why?
  - boosting VR user experience
  - designing VR and flying & driving simulators
  - proposing strategies/medications to suppress sickness
  - autonomous flying & driving



Trendy or not?

Source: https://scholar.google.com/.



Trendy or not?

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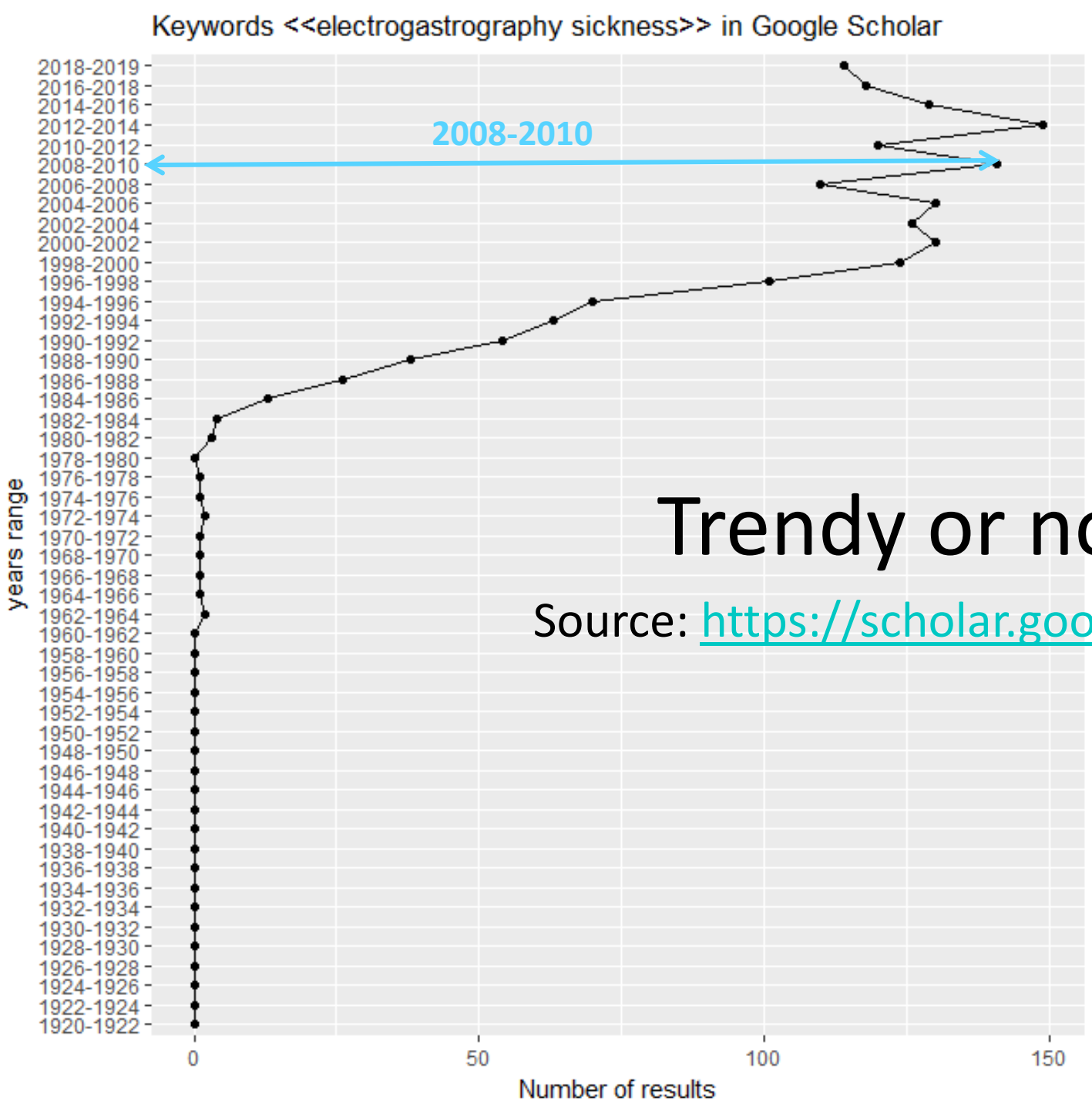

Trendy or not?

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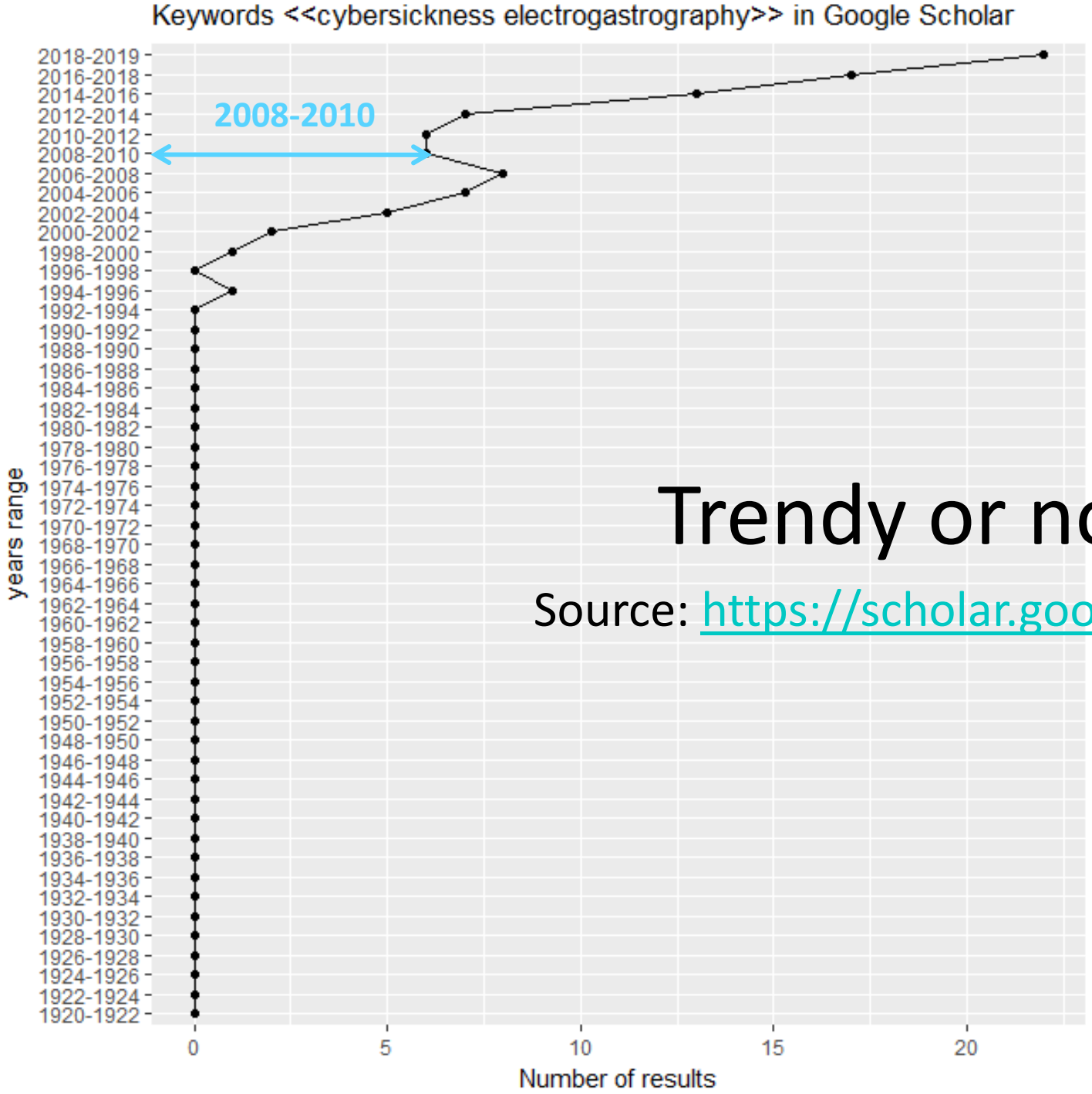

Trendy or not?

Source: https://scholar.google.com/.

AT THE END

Acknowledgement

- I am very grateful to
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Hands-on EGG measurements during driving simulation in room DrivingSimulator-A04 will be held by Nenad Popović, PhD student at the University of Belgrade – School of Electrical Engineering .

In sickness and in health…

fr. *Mal de mer*, Modified Photo: Stormy Weather (Ferry from La Palma to Tenerife) by Jörg Bergmann; Flickr https://www.flickr.com/photos/gomera/38656195015/; CC-BY –NC – ND 2.0 Generic.

Biosignals for assessment of cybersickness

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