Foundations of Psychophysiology

Part 4: Psychophysiological experimentation

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Psychophysiology: Definition and scope

Psychophysiology

Psychophysiology is …

"… the scientific study of social, psychological, and behavioral phenomena as related to and revealed through physiological principles and events in functional organisms."

Cacioppo *et al.* (2007)

In psychophysiological research …

"… the dependent variable is a physiological measure and the independent variable a 'behavioral' one …"

Stern (1964)

Stern, J. A. (1964). Toward a definition of psychophysiology. *Psychophysiology, 1*(1), 90–91.
Cacioppo, J., Tassinary, L. G., & Berntson, G. G. (2007). *The handbook of psychophysiology* (Third ed., p. 4). New York, NY, USA: Cambridge University Press.

Psychophysiological experimentation

Basics of experimental design

Psychophysiology-specific design issues

Additional issues to consider

Psychophysiology: Experimentation

Basics of experimental design

https://hpmor.com/chapter/8

The scientific method

"Science" is a method that uses observation and experimentation to find and explain regularities in nature.

We need to

- formulate precise questions,
- employ appropriate measurement modalities,
- identify factors that could confuse the answer, and
- draw valid conclusions from the data.

Concepts and constructs

A *concept* is a generally accepted understanding of objects, situations, events, etc., in terms of associated characteristics or meanings.

A *construct* is a more abstract idea, usually combining multiple concepts into a whole that is more difficult to verify.

The concepts and constructs used in scientific research need to be defined carefully.

Operationalisation creates a definition in terms of specific, measurable or otherwise testable criteria.

Concepts and constructs: Example

Heart rate is a concept, generally understood in terms of associated characteristics concerning the number of contractions a heart performs in a minute.

EEG activity is a concept, generally understood in terms of voltage differences related to specific neuronal activity as measured by scalp electrodes.

Mental workload is a construct that may be understood in terms of a specific parameter in a “workload task”, or in terms of specific patterns of cardial and EEG activity, or in terms of …?

Physiological measurements usually clear—psychological phenomena in particular require careful operationalisation!

Variables

In experimental design, operationalised concepts and constructs are generally represented by variables.

"… a variable is a symbol of an event, act, characteristic, trait, or attribute that can be measured and to which we assign values."

The regularities in nature which science aims to find are expressed as relationships between variables.

Variables

A relationship has at least one independent variable (IV) and one dependent variable (DV); e.g. “IV influences DV”.

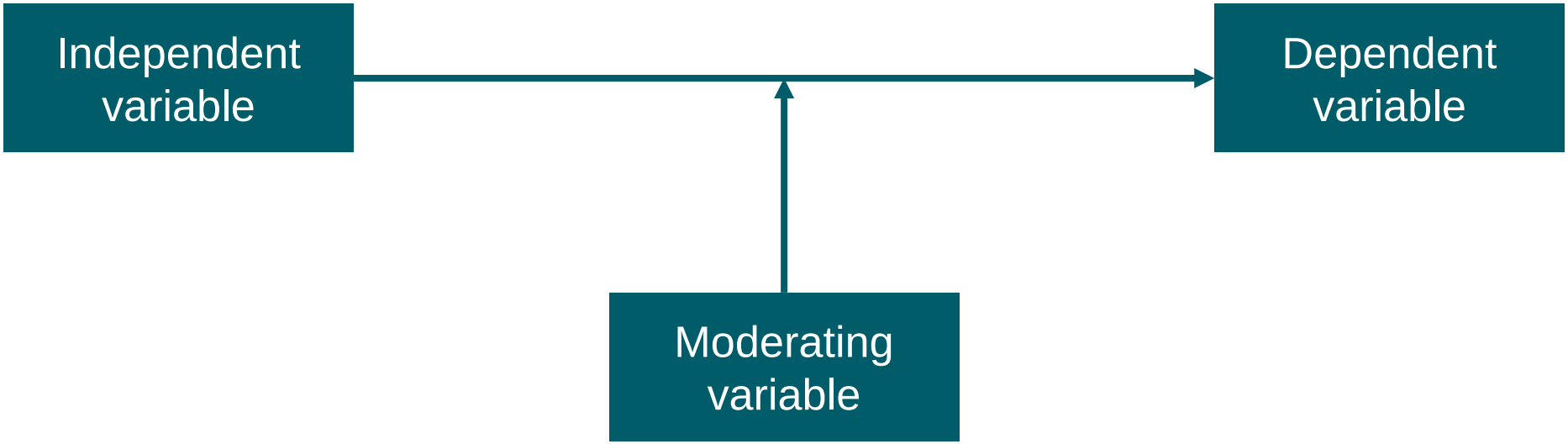
The IV is “manipulated” by the researcher in order to induce the assumed effect on the DV. The DV is then measured or otherwise observed to confirm.

Variables

Experimental manipulation can happen *within-subjects*, meaning different values of the IV are induced in the same test subjects, or *between-subjects*, meaning different test subjects are used for the different values of the IV.

Variables

Moderating variables (MoVs) influence the relationship, and are included to better describe the relationship.



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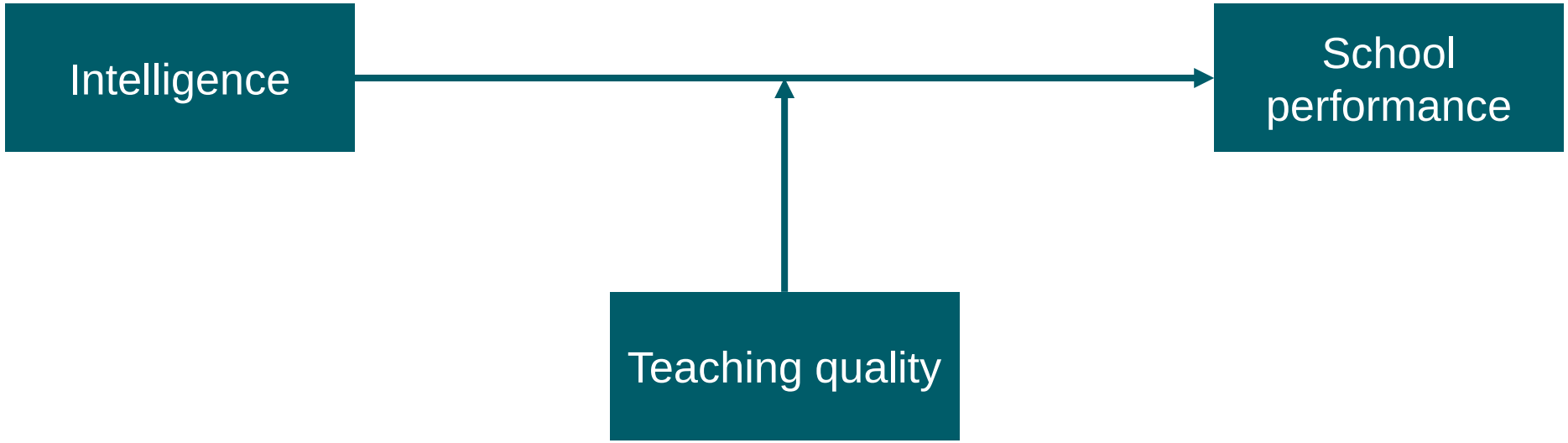

Variables

Mediating variables (MeVs) help explain the mechanisms of the IV-DV relationship, but are not manipulated directly.

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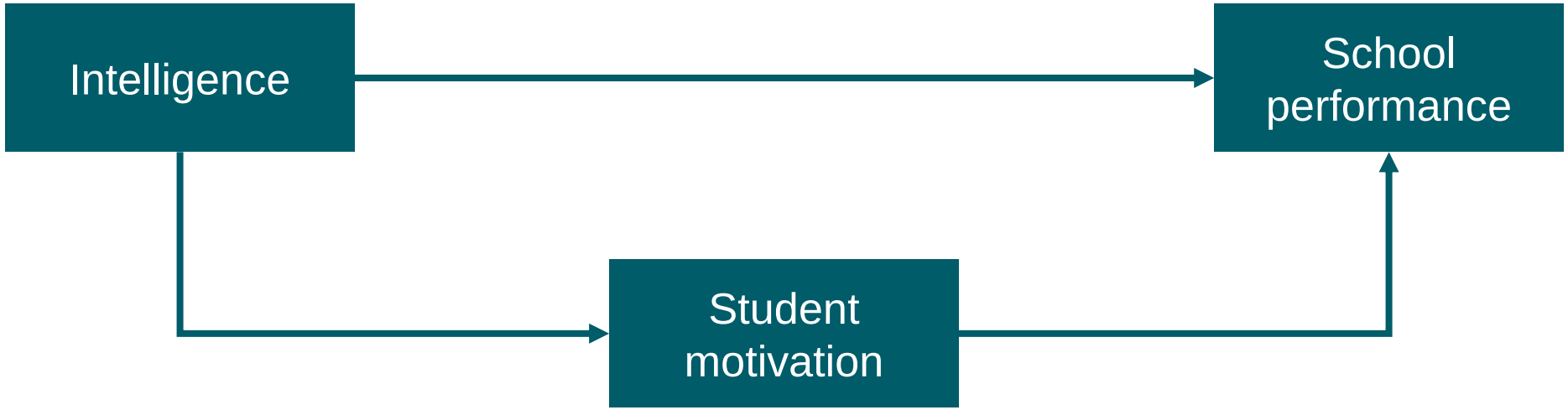
Variables

Mediating variables can be *fully* or *partially* mediating.



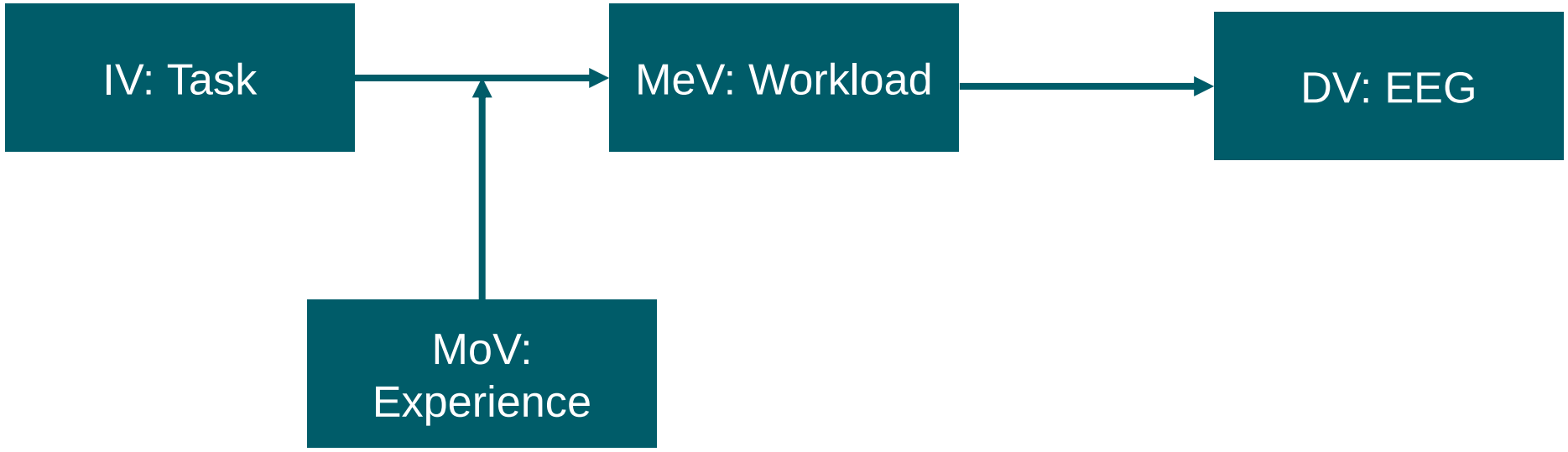
Variables

These are the variables that are part of the (hypothesised) theoretical model.

- Independent variable: manipulated to induce an effect.
- Dependent variable: measured to reveal the effect.
- Moderating variable: influences a relationship.
- Mediating variable: mediates a relationship.

Variables

What could a model for an EEG-based mental workload measurement look like?



Variables

There are additional variables that are **not** part of the theoretical model.

They do not help explain the relationship of interest, but do play a role in our experiment investigating that relationship.

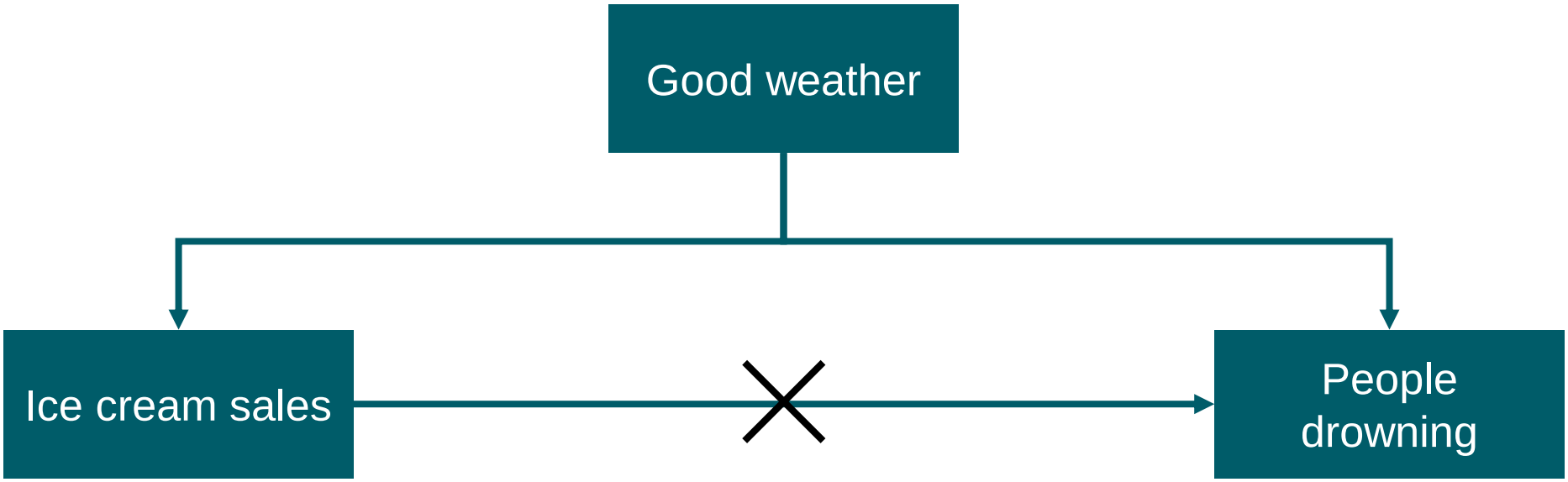
- Extraneous variable (EV): any factor that might conceivably influence the relationship or the results. Usually ignored.

- Control variable (CtV): EV that is included in the investigation in order to prevent biased results.

- Confounding variable (CfV): relevant EV that we cannot (or forgot to) control for.

Variables

The CfV is often defined as influencing both the IV and the DV, causing a spurious relationship.



More generally, CfVs can also act as MoVs or MeVs.

Variables

What are possible extraneous variables in the example “intelligence → school performance” model?

Teacher, age, socioeconomic status, weather, colour of the classroom wall, …

Basics of experimental design

Experimentation involves the design of a testable theoretical model of a relationship that is assumed to exist in nature.

Different kinds of variables are a part of that model.

Other influences need to be controlled.

Psychophysiology-specific design issues

Psychophysiological inference

We assume that some psychological state Ψ (psi) is expressed as some physiological state Φ (phi).

Psychophysiological inference

Multiple psychological, physiological, and environmental factors (EVs) may need to be included as IV or CtV to avoid confounded results.

Multiple DVs may be required to find a pattern that is sufficiently specific to the IV.

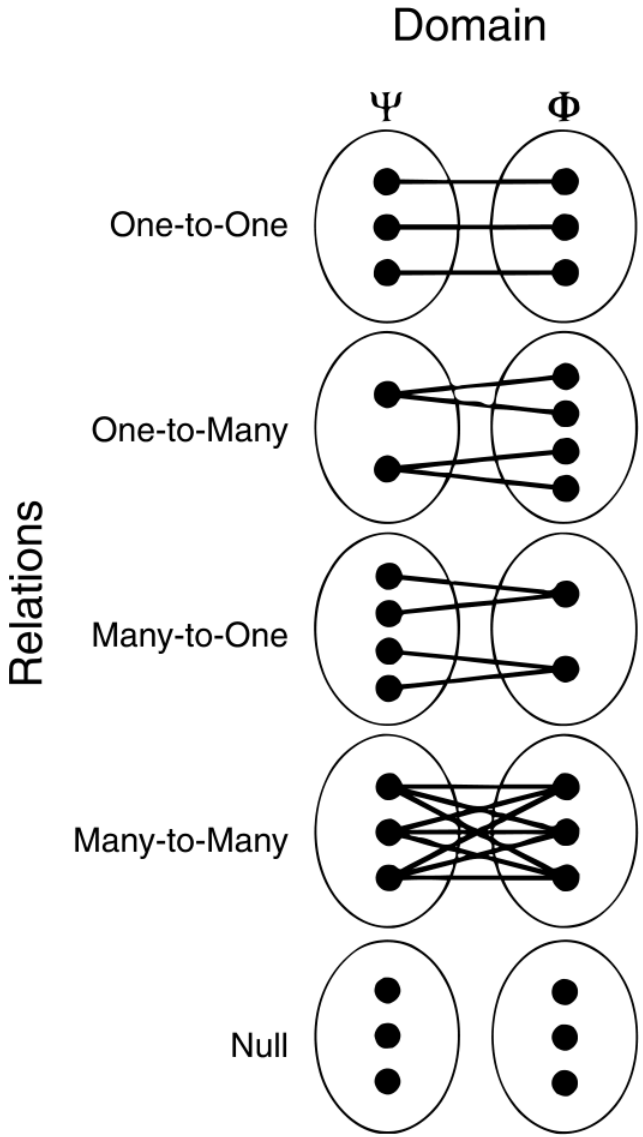


Figure: Cacioppo, J., Tassinary, L. G., & Berntson, G. G. (2000). *The handbook of psychophysiology* (Second ed., p. 12). New York, NY, USA: Cambridge University Press.

Information (data) sources

We commonly collect from three sources of information.

- Physiological
- Subjective:
  - Questionnaires, interviews, debriefings …
- Behavioural
  - Responses, response times, error rate …

Aside from IV, DV, and MeV, these can be used as CtV.

For example, a higher error rate (behaviour) may lead to frustration, biasing other parameters.

Within- versus between-subjects

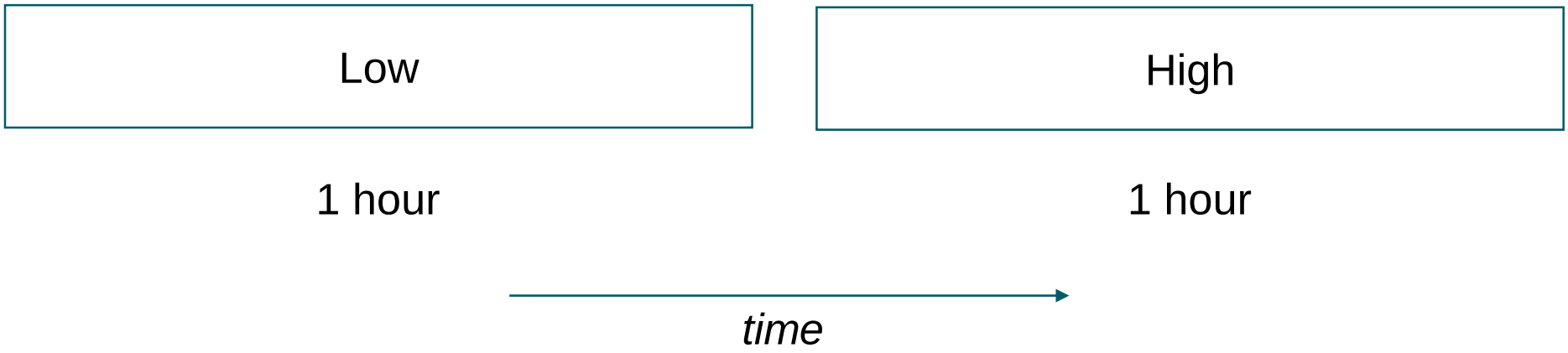
Because of individual differences, there is a large between-subjects variability of most psychophysiological measures.

Within-subjects variability tends to be lower.

Therefore, psychophysiology usually uses within-subjects designs.

Within-subjects blockwise design

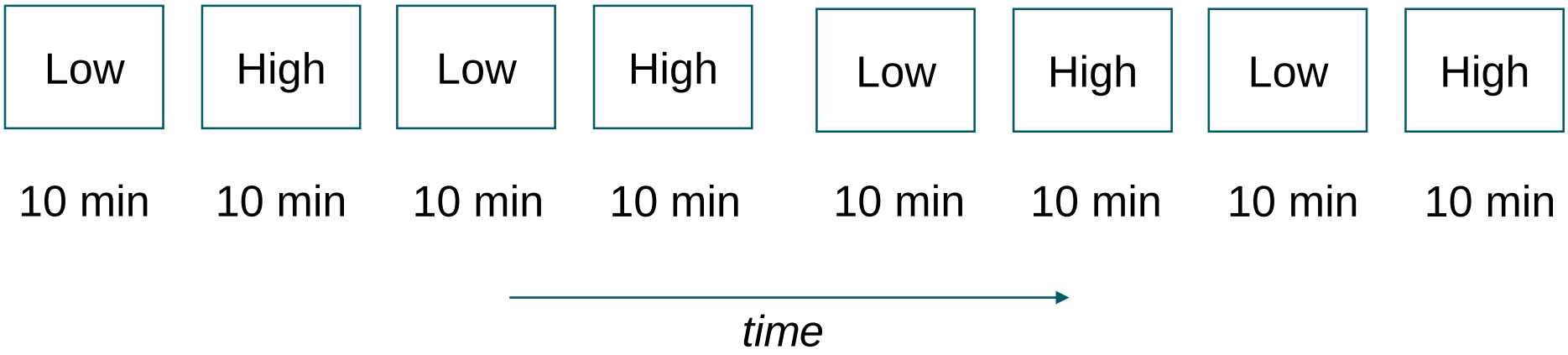
Experiment with two workload conditions: “low” and “high”.



Possible confound: fatigue

Within-subjects blockwise design

Experiment with two workload conditions: “low” and “high”.



Balanced or randomised conditions may control for temporal effects in within-subjects designs.

Serial dependency

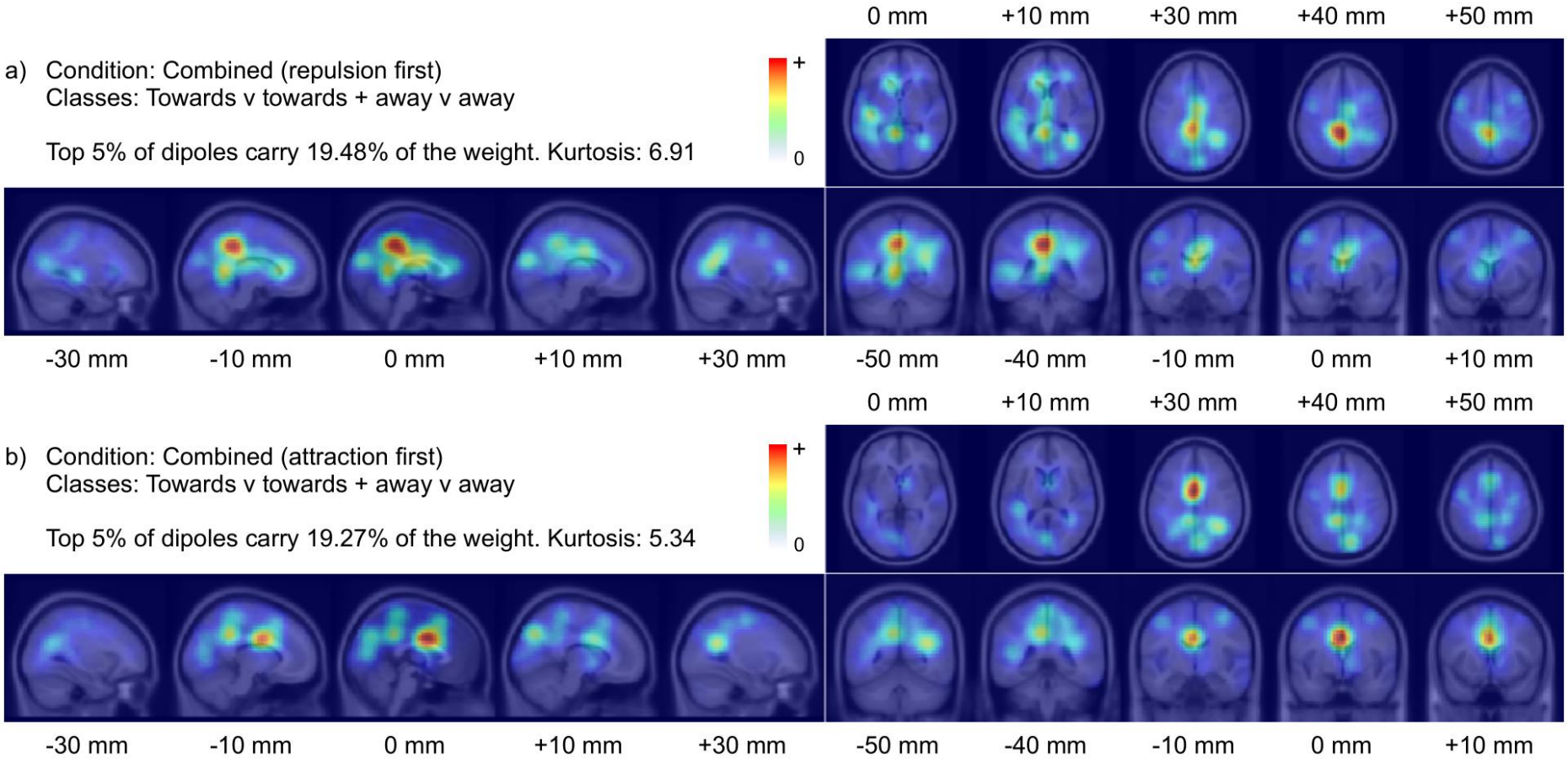
Serial dependency between conditions may exist: participants may behave differently depending on the condition they perceived first (or previously).

For example, in “noisy” and “quiet” conditions, adaptation first to noise or stillness may influence the way the other condition is perceived.

A between-subjects design, or between-subjects control condition may be necessary.

Serial dependency: Example

Example: serial dependency caused different brain areas to dominate depending on a task being done first or second.



Different analysis techniques

Generally speaking, two types of analysis techniques can be distinguished.

- Continuous techniques consider a *period* of time as a whole, extracting parameters as DV that describe this period. IV is usually (a property of) an experimental *condition*.

  e.g.: Power in a frequency band throughout a condition.

- Event-related techniques consider parameters following specific *instances* of time as DV. IV is usually (a property of) an experimental *event*.

  e.g.: Mean signal increase 200 ms after stimulus onset.

Continuous or event-related?

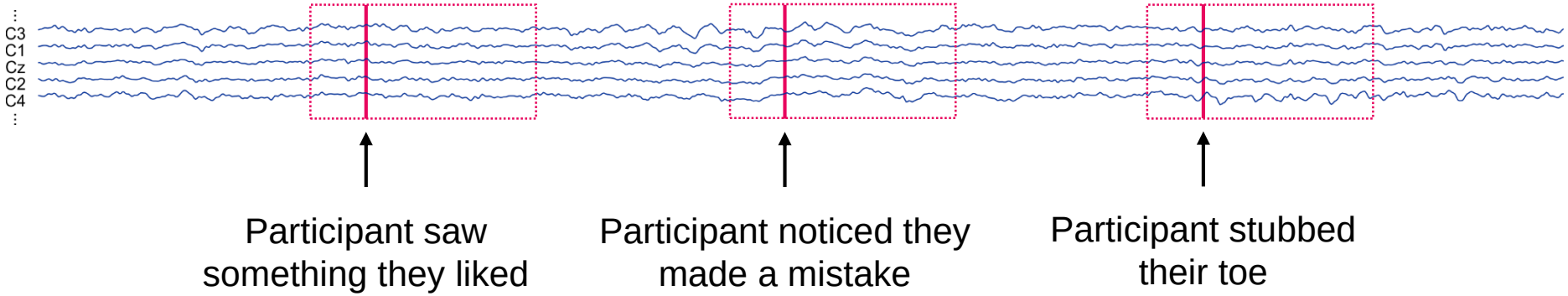
Continuous	Event-related
Measuring engagement in a video game depending on difficulty level	Measuring reactions to visually presented pictures
Measuring drowsiness during driving	Measuring the physiological processing of errors
Measuring the ability to focus on one voice in mixed speech	Measuring movement intentions

In many cases, (semi-)continuous measurements can also be performed using events, e.g. using a secondary task.

Event-related analysis

Event-related analysis thus focuses on changes in physiological activity relative to specific events, rather than activity generalized across conditions.

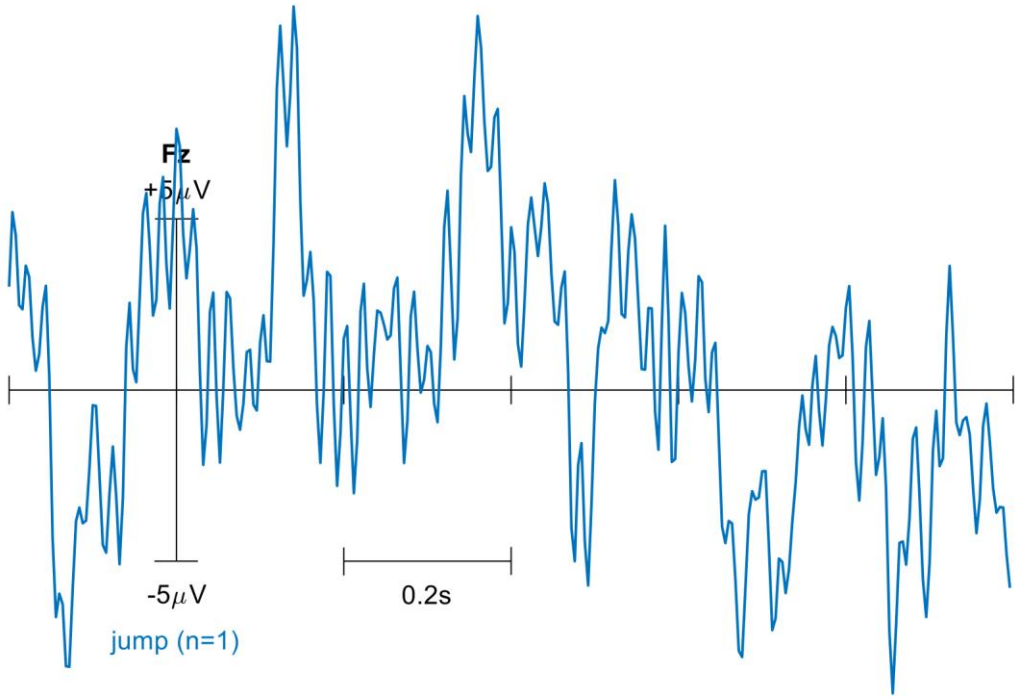
Note that the measurement itself is still continuous.



The event-related analysis considers small windows of time relative to the event of interest.

Epoching and ERP averaging

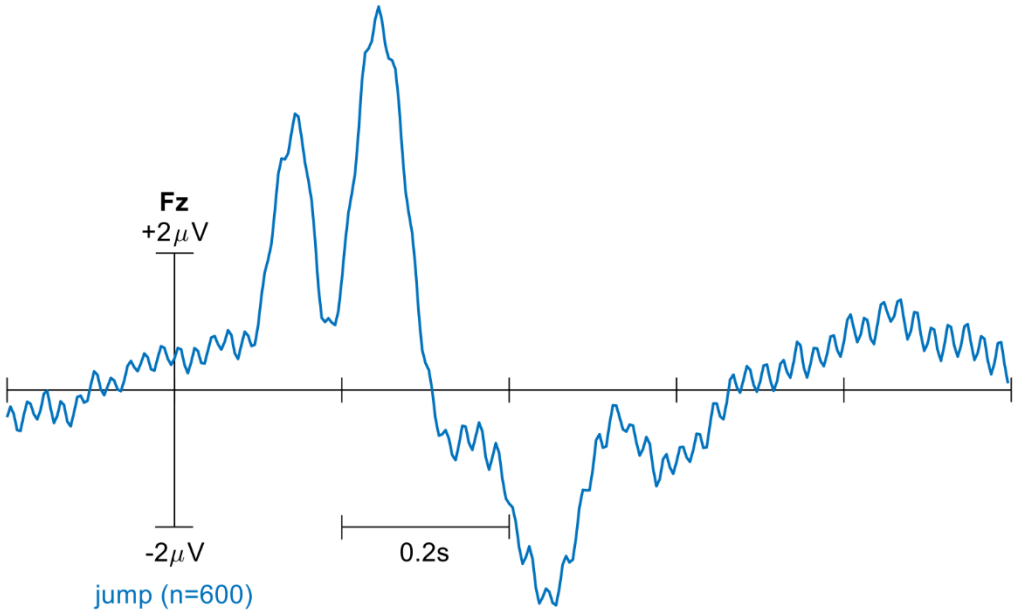
In EEG, the resulting time windows reflect *event-related potentials*, as they reflect measured potential differences.



A single such time window is usually too noisy to see any meaningful effects.

Epoching and ERP averaging

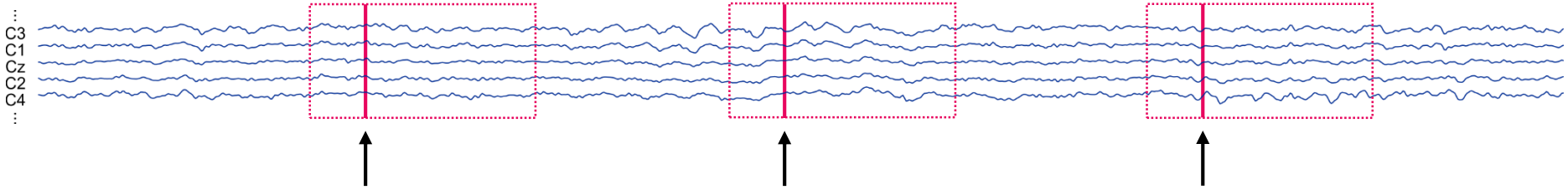
Epoching is the practice of extracting all time segments relative to specific events from a recording.



When you take the average ERP across multiple epochs, activity that does not systematically vary relative to the event and a specific baseline is averaged out.

Event markers

Given the high frequency of some physiological signals and the sub-millisecond precision of the recording equipment, accurate timing of relevant experimental events is important.



Additional equipment may be necessary to obtain so-called *event markers* or *triggers* that accurately reflect the timing of experimental stimuli or manual responses.

Event markers

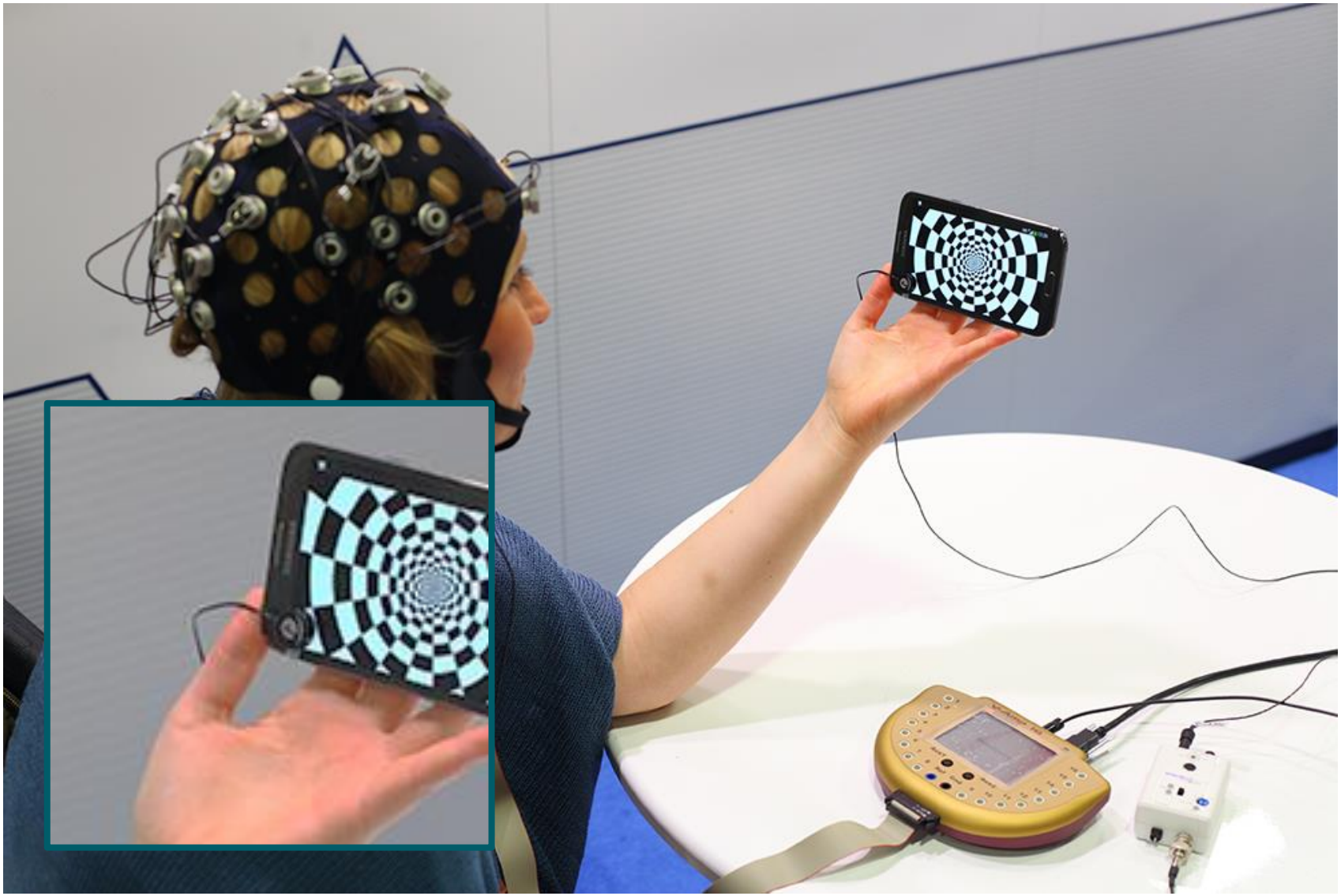
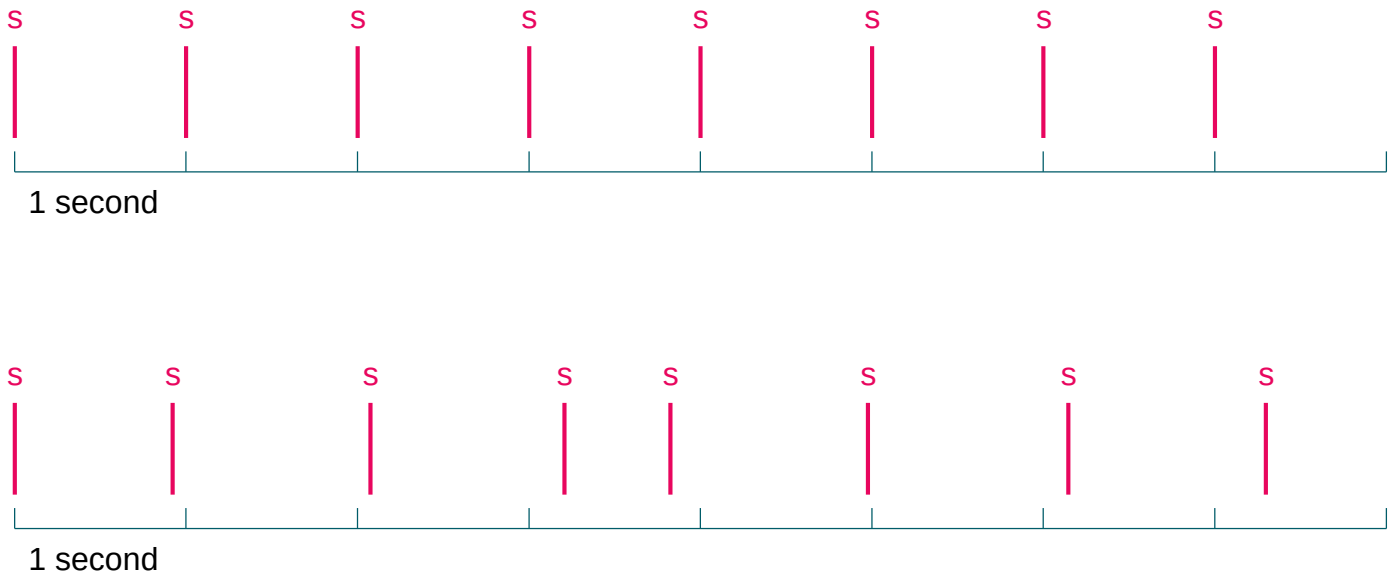


Photo: © Brain Products GmbH

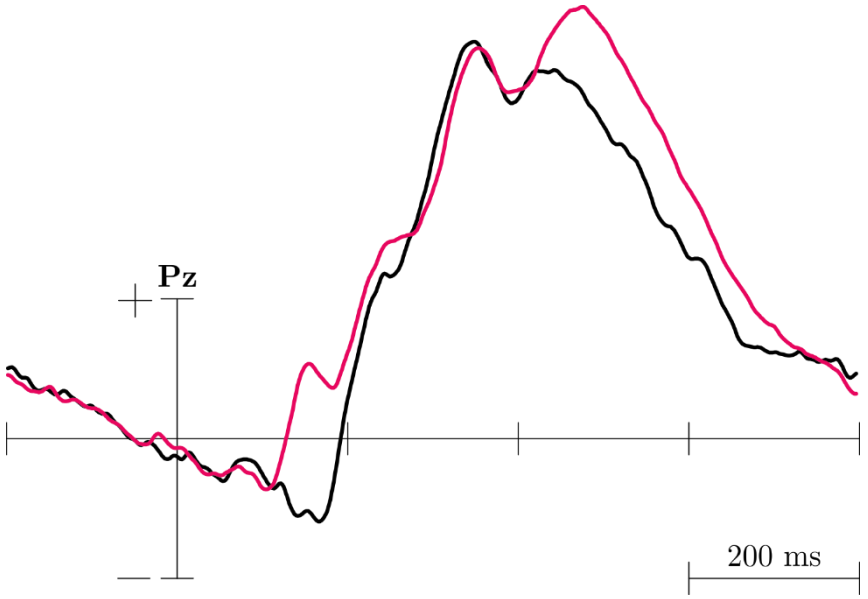
Variable stimulus onset asynchrony

Variability of the signal requires multiple repetitions. These repetitions are usually spaced somewhat irregularly in time.

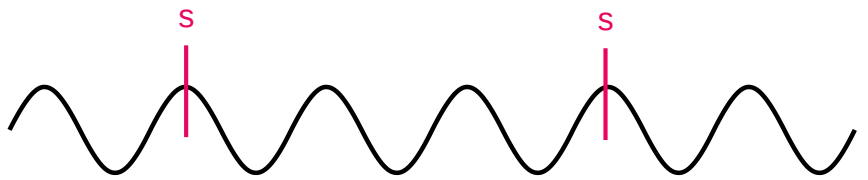


Variable stimulus onset asynchrony

Variable stimulus onset asynchrony avoids expectancy effects. Example: expectancy-related activity can be seen in EEG when participants anticipate upcoming events.



Precisely-timed events may also systematically coincide with a particular phase of biosignal oscillations, creating a confound.



Artefacts

Specific focus of psychophysiological experimentation is on controlling EVs known as artefacts.

“Artefacts” in the recording are those signals that do not represent the biosignal of interest.

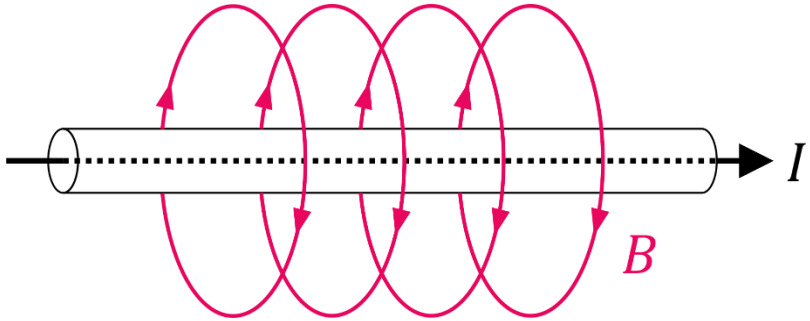
Artefacts can be of

- external (mechanical, environmental), or
- internal (biological)

origin.

External artefacts

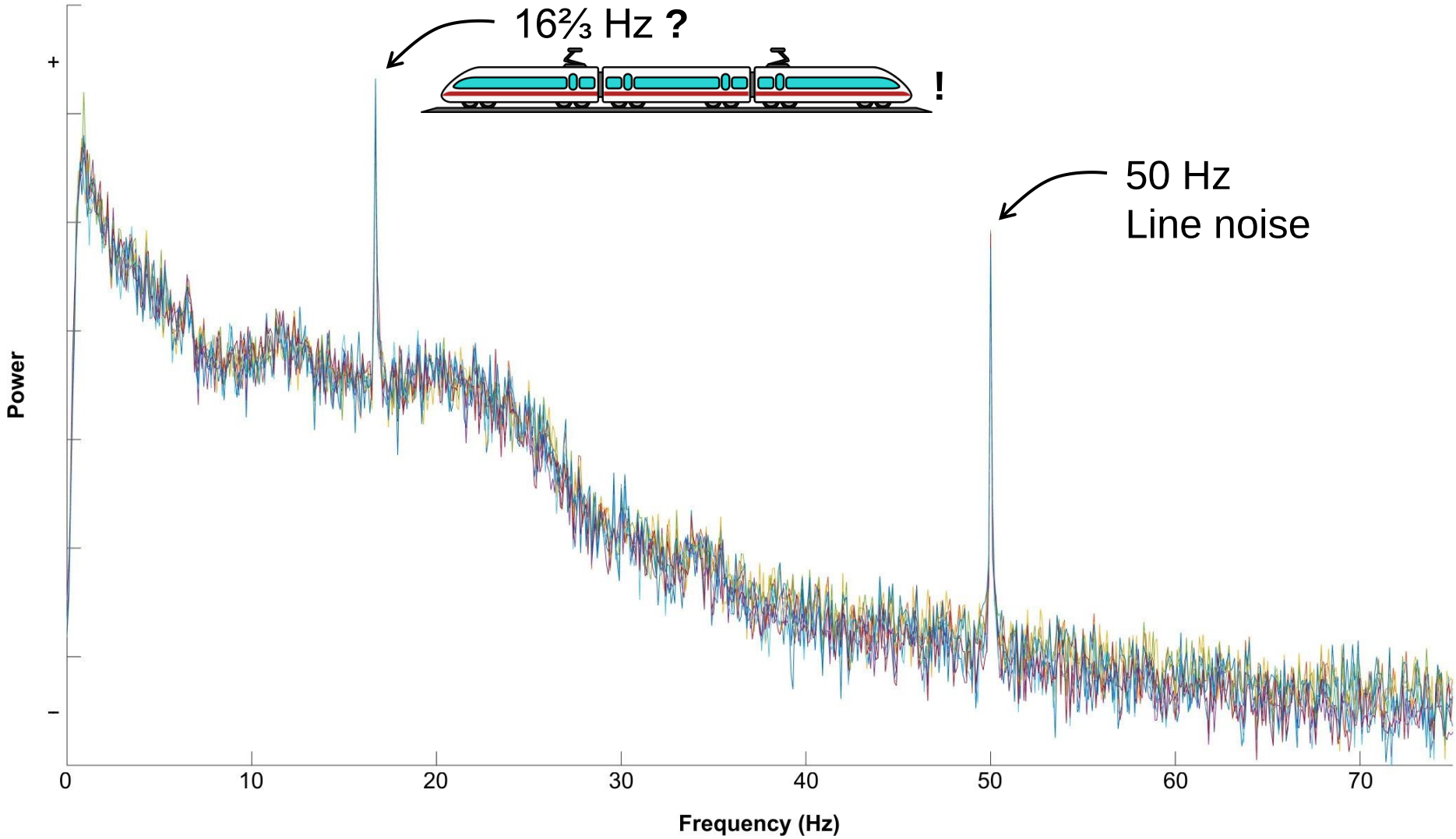
Electromagnetic activity in the environment is picked up by the electrodes.



Most commonly, this is utility-frequency (50 Hz) “line noise” coming from e.g. power cables, computers, light bulbs…

Any electrical device operating at any frequency can potentially contaminate the recorded signal.

External artefacts: Example



Mechanical artefacts

Mechanical artefacts are caused by movement of the equipment.

The movement of an electrode across the skin can lead to differences in resistance, and thus differences in the recorded signal.

The movement of electrode cables suspended in the air can lead to changes in their position in electromagnetic fields, thus causing differences in the recorded signal.

Controlling external artefacts

Ahead of time:

- Shield the room and the equipment.
- Use electrodes with pre-amplifiers.
- Have participants be stationary and comfortable.

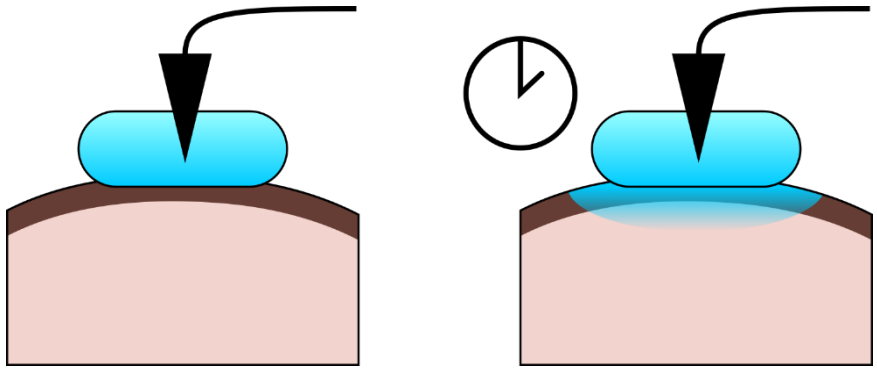
Post hoc:

- Preprocess data to remove known artefacts.
- Discard contaminated data.

Internal artefacts

A number of biological processes can either directly interfere with, or otherwise influence, the biosignal of interest.

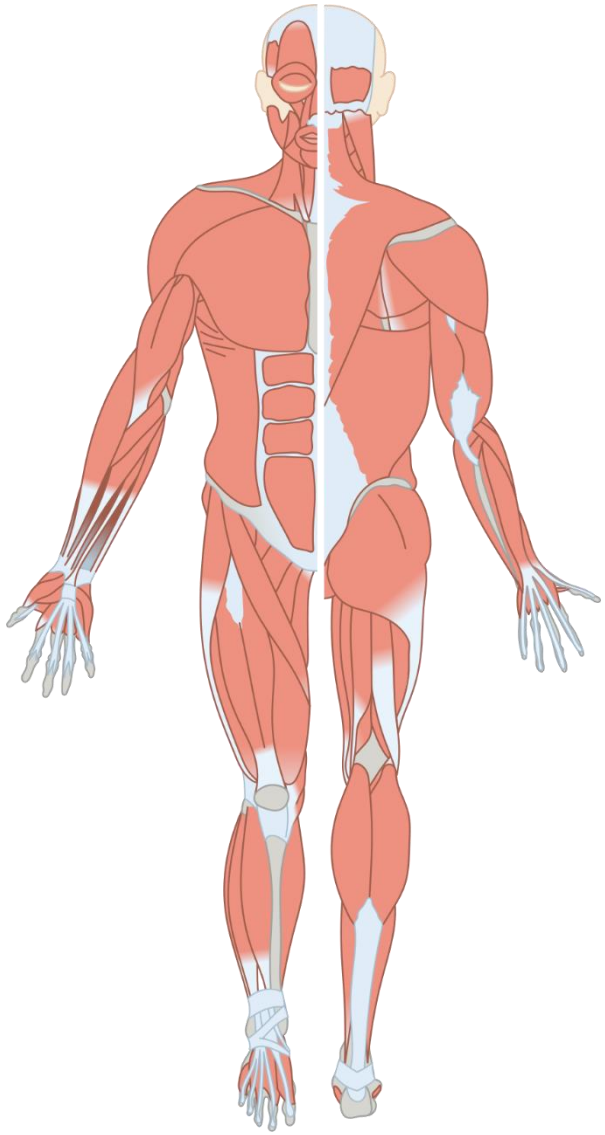
For example, when using electrodes on the skin, *skin potentials* are slow impedance differences caused by sweating, leading to slow changes in the recorded signal.



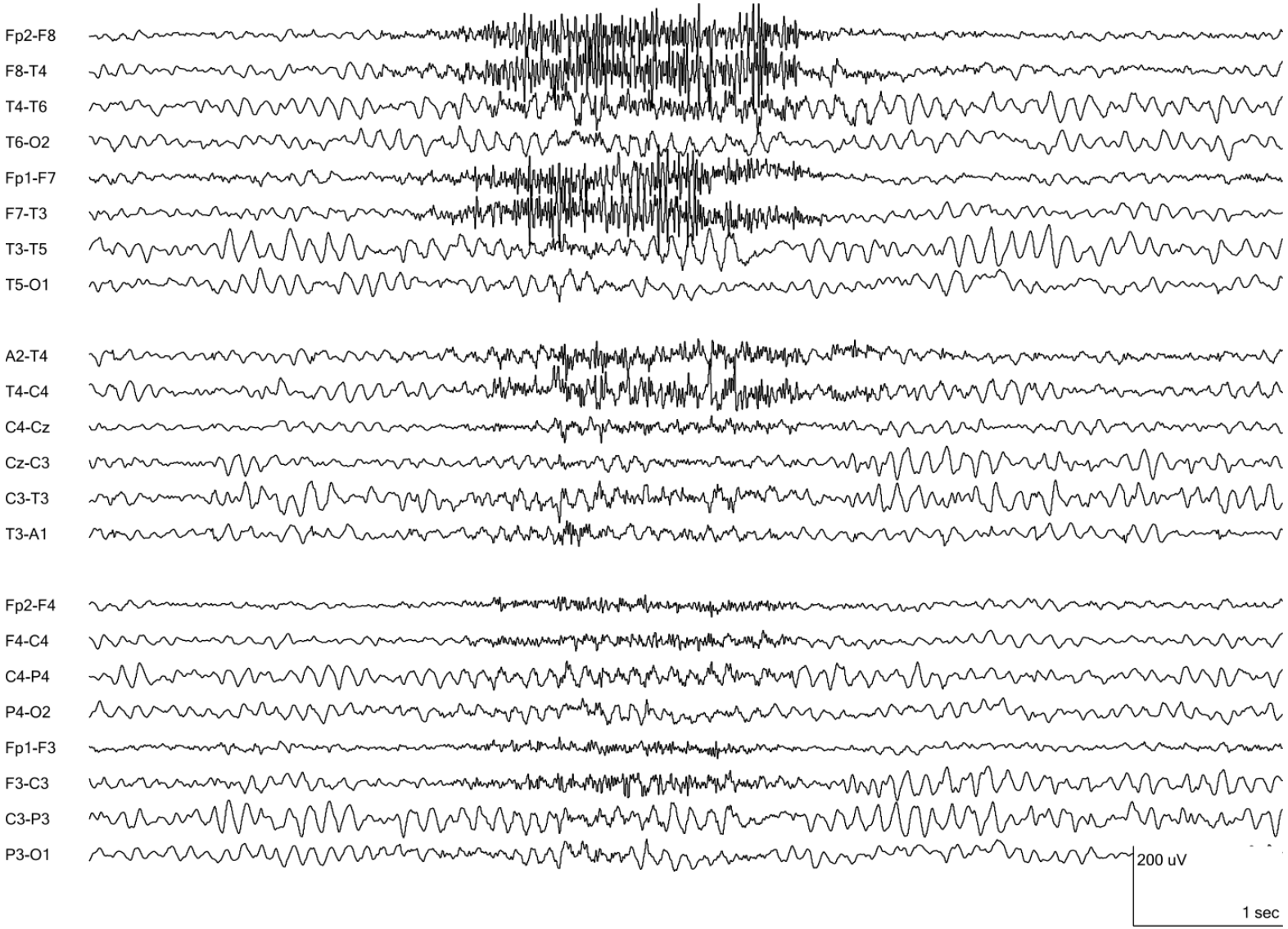
Muscle activity

Aside from causing mechanical artefacts, muscle activity by itself produces measurable electrical activity due to (near-)simultaneous muscle fiber action potentials.

Being high-amplitude and near the surface of the skin, these signals interfere with other signals recorded at the skin.



Muscle activity in EEG



Stern, J. (2013). Atlas of EEG Patterns (second ed.). Philadelphia, PA: Lippincott Williams & Wilkins.

Second-order internal artefacts

Rather than producing activity that interferes with the biosignal of interest, a number of natural biological processes influence the biosignal of interest itself.

For example, the respiratory cycle can be seen in ECG: breathing in increases the heart rate, and breathing out decreases it.

In psychophysiology, essentially any psychological state that is not the Ψ of interest can influence Φ and affect the recording.

Systematic versus random artefacts

When artefacts are sufficiently random across conditions, their effects may ideally average out.

Internal artefacts in particular can be systematically related to the experimental manipulation. This can lead to erroneous conclusions about the experimental effect.

- More sweating in one condition
- Frowning when something goes wrong
- Eye blinks after stimulus onset
- Personal thoughts specific to one condition

Controlling internal artefacts

Neutral, temperature-controlled environment

Low electrode impedance

Comfortable, stationary participants

Guided gaze fixation

Signal post-processing

Exclude contaminated data

Clever experimental design!

Photo by University of Southampton, via AAAS / EurekAlert!

Artefacts galore? Mobile Brain/Body Imaging

Psychophysiology-specific design issues

In psychophysiology, the independent variable is usually a psychological state, and the dependent variable a physiological measurement.

Physiological parameters can be event-related or continuous.

Special care must be taken that external and internal artefacts are controlled for.

Note that artefacts can be systematically related to the manipulation.

Additional issues to consider

Ethics of human experimentation

Psychophysiological experimentation relies on human participants. The experimenter is responsible for the well-being of their participants. Research comes second.

Declaration of Helsinki (1964; current revision 2013) agreed, among other things, on participant's right to

- make informed decisions (e.g. informed consent)
- self-determination (e.g. quit experiment at any time)
- not be subjected to unnecessary risks, etc.

Incidental findings

Even non-medical experimental recordings may reveal indications of medical significance, e.g. related to epilepsy (EEG), cysts (fMRI), or cardiac arrhythmia (ECG).

Send recorded data for medical review?

Inform participants of these findings?

Psychophysiological research does not generally use standardized tests for reliable clinical diagnosis. Likely to find many false positives.

Participants may or may not want to know.

Psychophysiology
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