# Mouse-tracking

1) MOUSE-TRACKING.

a. Mouse-tracking as a tool

b. What is mouse-tracking used for in perception and action.

c. (MAYBE) Issues with current mouse-tracking analysis, things improve.

## Mouse tracking as a tool

(possible beginnings: “Before mousetracking researchers tried to infer… ”, “Donders…”, “Evolution of decisions in everyday life…”, Maybe saying that is has become popular to investigate a lot of different stuff and come with examples, i.e. like Maldonado does it)

In 1869 Franciscus Cornelis Donders was the first ever to measure reaction time of a person with the goal of trying to assess something about the underlying cognitive process of the behaviour (Donders, 1868) (read about his study and the task). Using the reaction times and Donders’ subtraction method, he was making inferences about the time course of two hypothetical distinct cognitive processes, a method still used today when researchers try to infer the presence of a cognitive process.

However, a lot has happened since 1869 and researchers are no longer limited to only measuring simple behavioural responses. The method of electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) makes us able to measure neural activity with either a very high temporal resolution or a good spatial resolution depending on the method used and the goal of the experiment. This way we can map a quite good neural representation of a certain process happening. The method of eye-tracking has made us able to get a better understanding of the underlying cognitive processes by measuring behavioural data in a very high temporal quality (continuous cognition?). But insights into the actual development of the behavioural response can be hard given these methods.

A possible solution to this problem can be using mouse-tracking. By tracking the mouse movements of a participant, it is possible to map the real-time evolution of a certain behaviour possibly answering question about the nature of the processes underlying the behaviour (Freeman, 2018).

Other important mouse-tracking points?

What about mentioning decision research? Use the term “decision conflict” and how mouse-tracking has changed the assessment of this

Alternative introduction (a work in progress):

In the last 20 years mouse-tracking has become an increasingly popular method of studying movements as a continuous measure of an underlying cognitive process. It has seen use and popularity in many fields like spoken word-recognition (Spivey et al., 2005), emotion perception (Brooks & Freeman, 2018), social cognition (Freeman et al., 2010), numerical representation (Fischer & Hartmann, 2014) and self-control (Sullivan et al., 2014; Stillman et al., 2017).

## What is mouse-tracking?

Mouse-tracking is a method used to assess real-time cognitive processing in psychological tasks. The movement of a computer mouse is logged by saving x- and y-coordinates of a computer mouse on a screen along with timestamps for these. A very high temporal resolution is achieved by logging the position of the mouse and time hundreds of times each second. This is the basis of mouse-tracking, but other measures can be added depending on the task, such as what response was given in the specific trial (Ambady & Freeman, 2010).

A classic experimental setup of a mouse-tracking experiment involves a repeated binary choice selection task, where participants must click on one of two options located in the top left and top right corner of the screen. To create a common starting point for all trials, either the mouse will reset its location between trails to a point somewhere in the bottom centre of the screen or participants should click a start button also placed somewhere in the bottom centre of the screen (Stilman et al., 2018).

## Actions as continuous cognition

Research have shown that perception, action, and cognition are all closely linked to each other, meaning that action can often be seen as the result of complex cognitive processing unfolding real-time in the world. Single-cell recordings of monkeys have shown that “[…] ongoing updates of a decision process are made immediately available to the premotor cortex, which continuously guides response-directed hand movement as a decision unfolds” (Freeman, 2018). Similar research has established the same process in humans (Cisek & Kalaska, 2010) showing that our actions are continuously updated from decision processes. The cognitive process of making a decision is not necessarily finished when transferred to motor areas of the brain, but instead a constant flow of information from the processes in relation to decision to sub-areas involving motor activation creates a continuous update (McKinstry et al., 2008). In relation to mouse-tracking this results in mouse-trajectories in a decision task being a real-time product of continuous updated actions based on decision processes. The trajectories will change depending on the state of the decision. How these trajectories will change/look like is related to an area or research, which was the focus of a lot of mouse-tracking research back when the method was developed. This is the theoretical controversy of dual-system frameworks vs. dynamic system frameworks.

There are several varieties of dual-system frameworks but they have some central characteristics in common. Kahnemann’s dual-system theory serves as a good prototype. According to this theory, every action/decision is created by the interaction between two systems: an unconscious automatic process (system I) and a conscious rational controlled process (system II) (Kahneman, 2011). System I will create a quick initial automatic response/decision which will be re-evaluated by system II that either affirms this initial response or corrects it. In relation to mouse-tracking a system II correction of the decision will be seen as an extreme mid-flight correction in direction creating a sharp angle in the mouse trajectory, while an affirmation will result in an approximately straight mouse-trajectory. A cognitive decision process following a dual-system framework will end up with a bimodal distribution of the mouse trajectories with either straight trajectories towards an option or angled trajectories corrected mid-flight (Stillman, 2018).

As opposed to dual-system frameworks, dynamical frameworks were proposed. Here decisions are not the result of just two systems but many conscious and unconscious processes competing continuously changing the resulting actions in connection with the decision gradually. Neurophysiological research has even shown that as a decision process develops a gradual change in strength of neural activity for the chosen option increases, while the activation for the other option is inhibited (Freeman, 2018 (might want to rephrase it)). A dynamic system model would predict the mouse-trajectories of a decision task to be unimodally distributed, since the trajectories will change gradually as opposed to rapidly because of many underlying processes affecting the decision to be either option A or B (Freeman, 2018).

Mouse-tracking have been used to assess if the dual-system or dynamic system approach describe decision making the best, with the evidence most often supporting dynamic systems (McKinstry et al., 2008;Freeman, 2018).

Continuous cognition? Eye-tracking?

## Methodology used in mouse-tracking

Researchers use of mouse-tracking have shown high ingenuity in the application of the method across many different fields of research. The high flexibility of the method has proven fruitful in many different contexts. However, the lack of a common standard in methodology have caused a high heterogeneity within the method when it comes to features of the experimental design, measures used for analysis, methods of analysis and quality of reporting. All of this is important for building new knowledge upon existing studies as well as the reproducibility of science (Schoemann et al., 2021; Fischer & Hartmann, 2014; Kieslich et al., 2018; Kieslich, 2018).

Design features such as the start procedure, response procedure and location of relevant stimuli can be very important for the resulting type of trajectories and size of effect (Grage et al., 2019). For example, the effect of tastiness found by Sullivan et al. (2015) strongly decrease or completely disappear when a static start procedure is used instead of a dynamic start procedure (Schoemann et al., 2019; Scherbaum & Kieslich, 2018). This example shows that researchers need to understand the impact of their design choices when doing a mouse-tracking study. If not, unreliable results might be the consequence of this (Schoemann et al., 2021).

In research today data from mouse-tracking experiments are being used for calculating a high amount of different related measures to perform one or more statistical analyses from a large number of possible analyses, i.e. ranging from simple approaches focusing on temporal development of trajectories to more advanced ones like generalized processing tree models (Heck et al., 2018; Kieslich et al., 2018; Hehman et al., 2015).

Concerns have been raised about the lack of a “best practice” in mouse-tracking, with high variability in features of experimental design and quality of reporting threatening reproducibility of research, and high variability of measures used for analysis and methods of analyses threatening the validity of research and opening possibilities of p-hacking (Schoemann et al., 2021).

Sections:

Common method of analysis (motivating Maldonado stuff)