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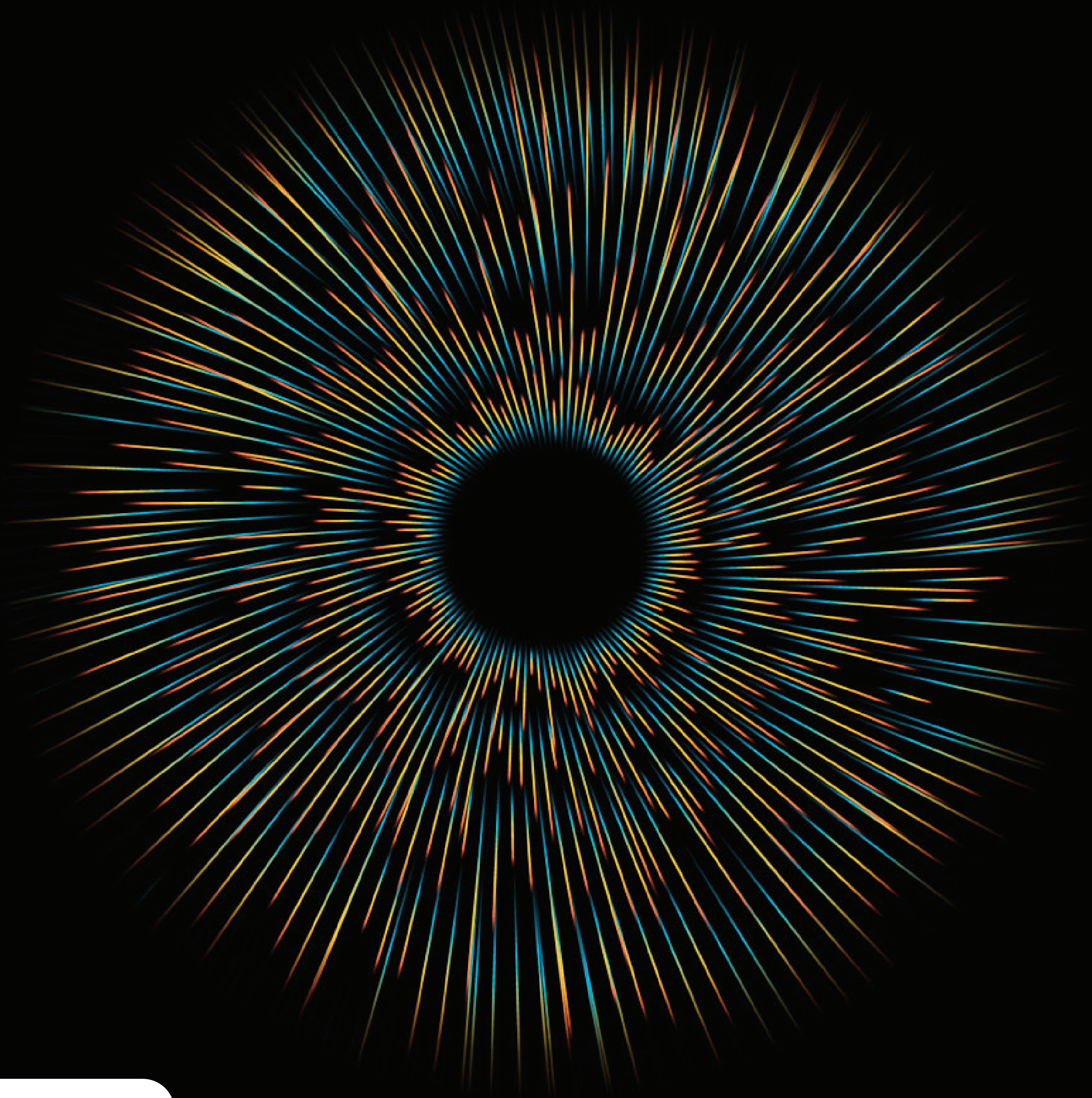

WHITEPAPER

# Conscious Perception

Revolutionizing Cognitive Insights through Advanced Eye Tracking Analysis of Human Perception

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# What is Conscious Perception...

Unlocking the Full Potential of Human Consciousness through Advanced Eye Tracking

## Summary

Eye tracking is more than a tool for observing where we look; it is a window into the very core of our conscious experience. The Conscious Perception Index represents a bold new frontier, harnessing advanced eye tracking metrics to quantify the nuances of human attention, awareness, and perception.

Through this advanced understanding of conscious perception, we will open new pathways for research, innovation, and applications that empower individuals to interact with their environments more naturally, improve health outcomes, and push the boundaries of what it means to be consciously aware.

### Definition

Consciousness of perception refers to the state in which visual **information is not only registered by the sensory system but also reaches conscious awareness**, allowing for **deliberate processing, interpretation, and interaction.**

In the context of visual perception, this means that a person is not just looking at something (which could involve a blank stare or automatic eye movements), but that the visual input is being **consciously recognized, understood, and integrated into cognitive processes.** This form of perception is tied to the ability to act consciously on the perceived information, including the capacity to verbalize what is seen and interact meaningfully with the environment.

The Conscious Perception Index (CPI) aims to provide a quantitative measure which enables to distinguish between mere visual attention (which can involve automatic, subconscious eye movements) and conscious perception. CPI provides a continuous measure which can be interpreted as a probability that the currently focused content is actually being consciously perceived.

# ...and what to do with it?

## 01 Our Vision

Our vision is to transform eye tracking from a simple gaze measurement device into a powerful tool, enabling multidimensional biomarkers, capable of revealing the intricate patterns of conscious thought and behavior.

## 02 Our Mission

By decoding the subtleties of our visual and cognitive engagement, we aim to redefine how we understand human cognition, optimize user experiences, and revolutionize clinical care. From enhancing our grasp of cognitive processes in real-time to personalizing interventions in mental health and neurological care, the future of eye tracking holds immense potential.

### Key Benefits of Conscious Perception by SOMAREALITY

**Modeling Awareness**

With CPI, it becomes possible to determine what information is actively processed and understood, not just passively viewed.

**Deeper Insights in Cognitive States**

Objective measures of CPI can provide a richer analysis of underlying cognitive state (e.g., engagement, surprise, confusion).

**Enhance Evaluation of Task Performance**

CPI can indicate not only where attention is directed but also the quality of that attention, such as focus and intention.

**Improved Diagnostic Capabilities**

CPI allows for more precise interventions, as it can highlight breakdowns between looking and consciously processing information.

# What's inside Conscious Perception

The goal of the proposed Conscious Perception Index (CPI) is to provide a quantifiable measure of not only WHERE someone is looking but also whether they are consciously aware of the target - or if the person is actually occupied with inner thought processes. To approach this abstract modeling of conscious perception, the CPI leverages established eye-tracking features such as pupil dilation dynamics, saccadic latency, and fixation patterns to infer the level of conscious awareness.

Most related research activities result in identifying some correlation or even soft causal relationship between gaze metrics and consciousness of perception, but fail to provide specific algorithmic implementations of quantifiable measures. The proposed CPI identifies and builds upon such associations established in cognitive psychology and integrates these parameters into a computational quantifiable metric that offers a more nuanced perspective on how visual information is processed, filtered and attended to by the brain.

## Depth of Insights:

Conscious perception involves awareness and deliberate processing of stimuli, while established gaze behavior interpretations only focus on where and how long a person looks at something. Differentiating the two allows researchers and developers to gain deeper insights into cognitive processes such as attention, awareness, and decision-making, thus opening the door for high level, abstract interpretations of underlying visual perception:

CPI enables

- Better understanding of complex interactions
- Improving the accuracy of cognitive assessments with objective measurements
- Enhancing user experience with tailored interventions and personalized services
- Refining educational techniques with effective learning strategies and feedback mechanisms
- Improving safety and performance in critical tasks
- By recognizing the differences between what is merely seen and what is consciously perceived, researchers and practitioners can develop more effective, personalized, and accurate tools and interventions across various domains

CPI provides

1. A continuous, live estimation of the probability of Conscious Perception of the current focus of attention as well as
2. Object- or area of interest-based analytics of Conscious Perception aggregating perception information over time with respect to pre-defined objects, summarizing the consciousness probability scores per digital object or area of interest as a summary of the overall recording session
3. Spatial visualization of Conscious Perception as heatmap visualizations, similar to established gaze behavior depictions.

## Building the CPI

The algorithmic realization of the CPI is organized along the following categories which have been identified to contribute to conscious perception in academic research:

- fixation and saccade metrics
- spatial gaze distribution
- vergence
- cognitive load

The CPI accumulates these insights from academic research into quantifiable algorithms via a heuristic model that allows

- live, embedded analytics to trigger actions in adaptive, interactive systems
- live analytics for human monitoring
- detailed offline analytics of recording sessions with continuous or accumulated data.

### Fixations & Saccades

Conscious perception is only possible during fixation activities and not during saccades. Fixations, the moments when our eyes are relatively still and focus on a target, play a significant role in how visual information is processed and integrated into our conscious experience. However, also saccadic gaze behavior holds relevant information, as targeted saccades and conscious perception are closely linked through attentional mechanisms.

### Spatial Distribution of Gaze Behavior

Focal gaze behavior is beneficial for conscious perception in contrast to highly distributed gaze behavior.
Focal processing is associated with intellectual assessment and conscious perception, while ambient processing (peripheral vision) is linked to pre-conscious spatial awareness and atmospheric experience.

### Vergence

Gaze Vergence describes the angle between the two eyes which is required to focus on an object and enable stereoscopic vision. While vergence is essential for depth perception, it also allows the identification of focused interaction in comparison to a blank stare which is often associated with inner cognitive processes in comparison to conscious processing of visual information.

### Cognitive Load

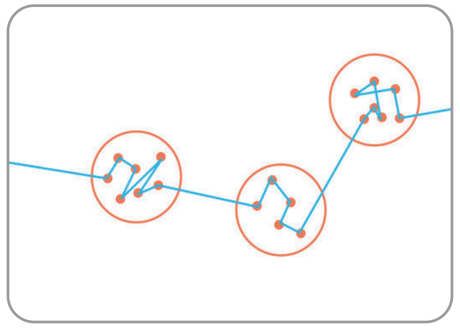
Conscious perception of stimuli requires a certain amount of cognitive load. Without cognitive load, there cannot be conscious perception. However, too high a cognitive load attributed to secondary tasks also limits consciousness of visual perception. As a summary, conscious perception works best in neither under- nor overload conditions regarding workload.

# How it works

## 01

### Detect and Analyze Fixations and Saccades

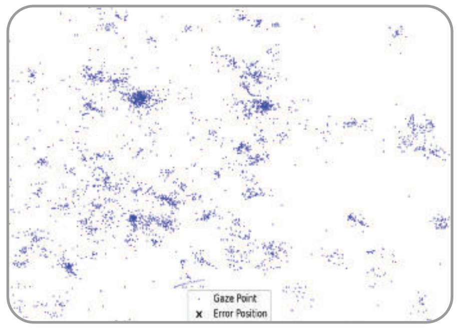
As a first step, fixations and saccades, and derived statistical values are computed based on raw eye tracking data. For this purpose, we use a velocity-based fixation detection algorithm to separate fixation and saccade phases. Subsequently, the data is analyzed to compute fixation center, radius, duration as well as saccade metrics, such as saccade velocity, distance, and directness.



## 02

### Analyze Spatial Gaze Distribution

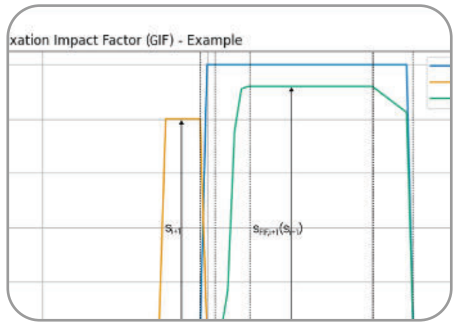
We use the established K-coefficient as a descriptive feature to parametrize focal vs. ambient gaze behavior. The K-coefficient investigates the spatial distribution and length of fixations and saccades to compute a value in the range [-1;1], whereas positive values indicate focal and negative values indicate ambient (distributed) gaze behavior.




## 03

### Compute Heuristic Model

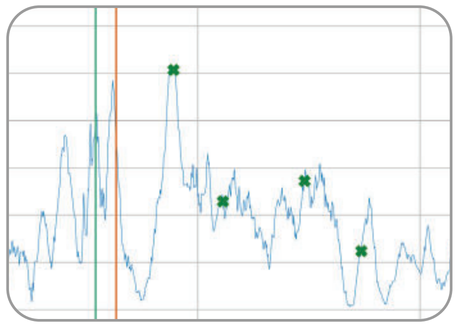
Taking into account relevant findings from Cognitive Psychology, we developed heuristic algorithms to combine the identified temporal and level characteristics of saccades, fixations, and gaze distribution into a rule-based model to estimate the gaze behavior aspects of conscious perception.




## 04

### Combine Heuristic Model with Cognitive Load

To add cognitive activity to gaze behavior, the computed heuristic model is used as a window and weight function to combine gaze behavior with associated cognitive load levels.





# Visual Attention vs. CPI

The Conscious Perception Index (CPI) goes beyond basic tracking, as it measures not only where a person's gaze lands but also the cognitive depth with which visual content is processed.

This metric considers the brain's active engagement with visual stimuli, evaluating how much of the viewed information is genuinely registered and understood, rather than simply observed. By doing so, the CPI offers a more comprehensive view of visual attention, bridging the gap between superficial glances and meaningful interactions.

This added dimension makes CPI especially valuable in fields like marketing, user experience design, and cognitive research, where understanding not just attention but true engagement can lead to more effective communication and content strategies.

Visual Attention

Conscious Perception Index

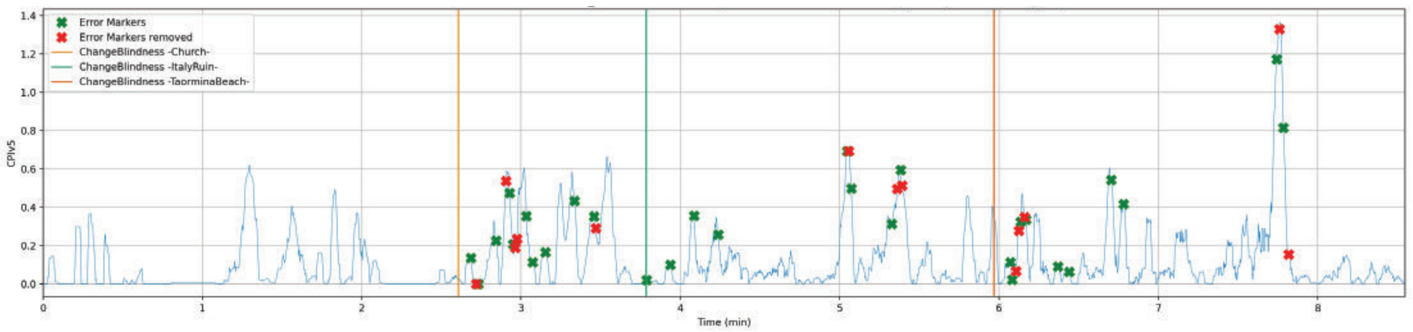

## Impact

1. Depth of Cognitive Processing: Standard visual attention metrics only tell us where attention is directed even without conscious awareness. For example, a person may look at an advertisement or an object without truly perceiving it.
   CPI, however, is focusing on whether the visual information reaches conscious awareness, capturing whether the individual recognizes, interprets, and processes the visual input.
2. Intentional Interaction: Visual attention metrics often conflate passive and active attention. If someone's gaze lingers on an element on a screen, it's unclear whether they are consciously interacting with it, a phenomenon described as the 'Midas Touch Problem'.
   As a consequence, the CPI aims to quantify intentionality—whether the subject is actively engaging with what they see.
3. Behavioral Implications: Standard attention metrics may indicate high levels of gaze fixation or scanning across a visual scene, suggesting that a user is "paying attention." However, these metrics don't account for whether that attention leads to understanding or action.
   CPI connects visual perception to conscious behavior, offering a better prediction of what information will likely be remembered and acted upon.
4. Implications for System Design: Designing eye-tracking-based interactive systems, the distinction between visual attention and conscious perception is critical. Traditional attention metrics can result in false-positive inputs (e.g., triggering actions based on passive gazes). By integrating the CPI, systems can better determine when users are consciously engaging with interface elements, improving accuracy in capturing intentional inputs.

# Change Blindness

To evaluate the conscious perception metric, a change blindness test was used, involving three sets of paired images presented to the participants. Each pair contained 6-7 differences, which participants were tasked with identifying. They located each difference by directing their gaze to the specific position in the right image (focusing on the discrepancy) and confirmed their selection by pressing a button on a handheld controller. Participants had 120 seconds per image pair to detect and confirm each difference in the error image.

The aim of this experimental design was to create a challenging search task that demands high engagement while incorporating a component of explicit, conscious interaction. This setup allows for assessing whether and how engagement levels correlate with various visual interaction metrics and evaluating the effectiveness of these metrics as indicators of conscious interaction.

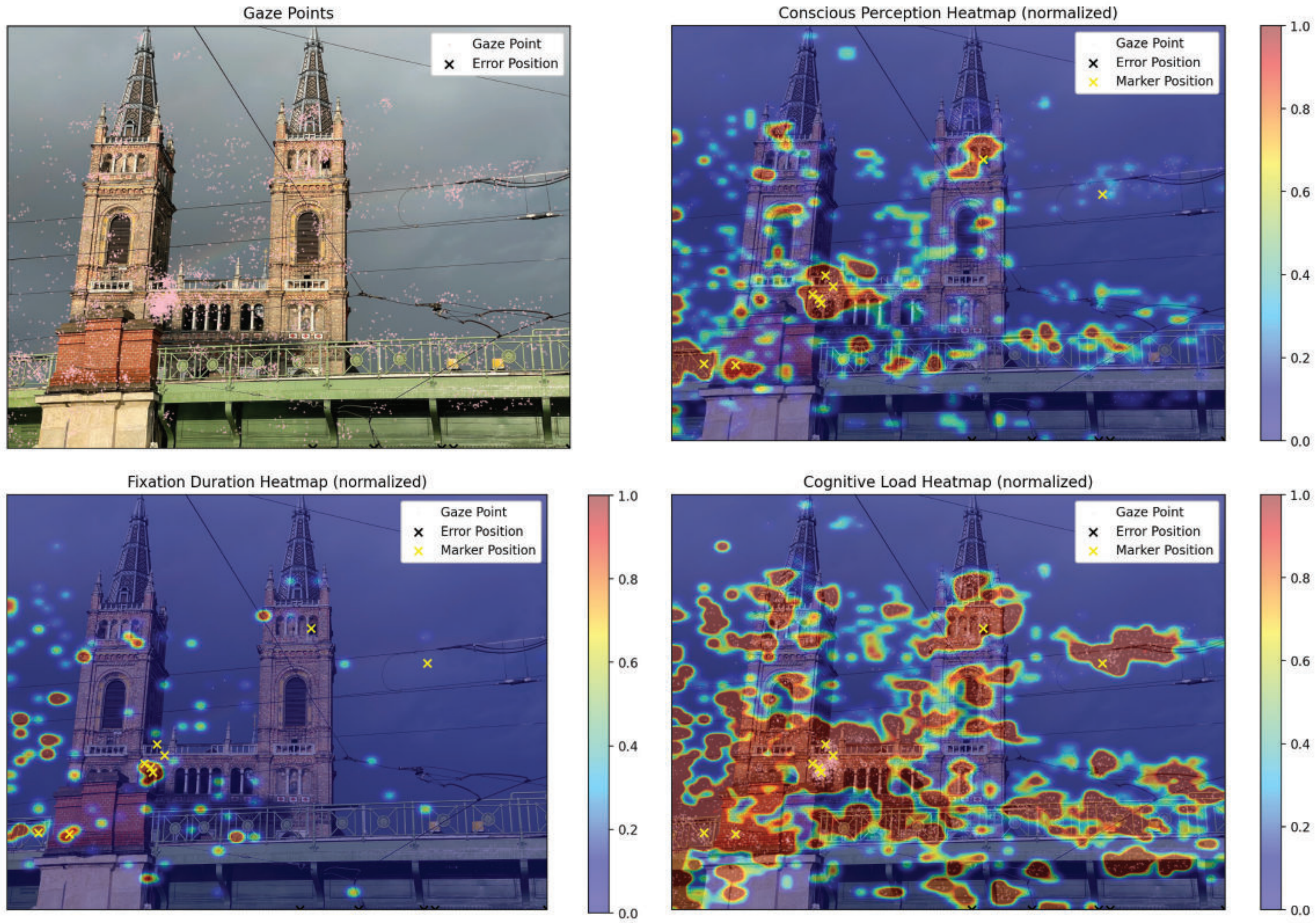



The temporal data shows a significant relationship between moments of conscious interaction and increased activity in the CPI measure. Specifically, we observe that most interaction events (67.7%) occur close to either local or global maxima within the dataset. This alignment between interaction events and peak values in the CPI strongly suggests that the CPI measure is effectively capturing meaningful patterns, adding both value and validity to its use. Interestingly, examining the relationship between the CPI and CL (Cognitive Load) signals, results show no significant Pearson correlation (-0.034). This lack of correlation suggests that CPI is not merely a scaled reflection of cognitive load levels, but provides its own unique insights



# Validation & Applications

In order to assess overall scene perception, various metrics have been compared and visualized through accumulated heatmaps. The comparison reveals that, unlike visual attention data, CPI data is more sparsely distributed and tends to cluster tightly around specific detected interaction points. This suggests that CPI is particularly focused, capturing data primarily around areas where conscious interactions occur. In contrast, the cognitive load metric is less effective at clearly distinguishing between interaction zones.




We applied a Mann-Whitney U test to confirm CPI's separation between interaction and non-interaction zones with $p<0.001$. While the extremely low nature of the p-value may be associated to the size of the dataset, the significant difference in p-values still highlights the ability of CPI to differentiate between areas of explicit interaction and those of passive observation.

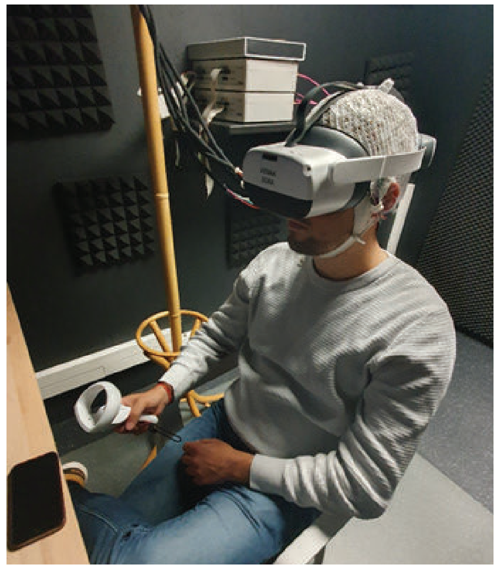
While statistical tests reveal whether there is a significant difference in the data sets, they do not directly indicate if an individual data point can reliably be classified accordingly.
To address this need for classification, we trained a Logistic Regression model to assess the model's accuracy in distinguishing interaction and non-interaction zones and achieved an overall accuracy of 76.4%.

# Correspondencies between CPI and EEG

To further explore and validate the conscious perception metric, we conducted an **eye tracking study in a VR setting in combination with EEG** to compare our biomarkers with established biomarkers for Cognitive Load and Conscious Perception derived from EEG data. The experiment aims to model the participants' ability to notice changes in a virtual environment while engaged in a mentally demanding primary task via the digital biomarkers of Cognitive Load, and especially Conscious Perception.

In this study we were able to show:

- **Cognitive Load increases** on both eye tracking and EEG analytics **with growing task difficulty**
- **Cognitive Load is higher** when **looking at target vs non-target cars**
- **CPI indicates detection of background changes**
- **EEG CL features correlate with the SOMA CL biomarker**
- **EEG features of conscious perception correlate with SOMA CPI biomarker**



### Experiment Setup

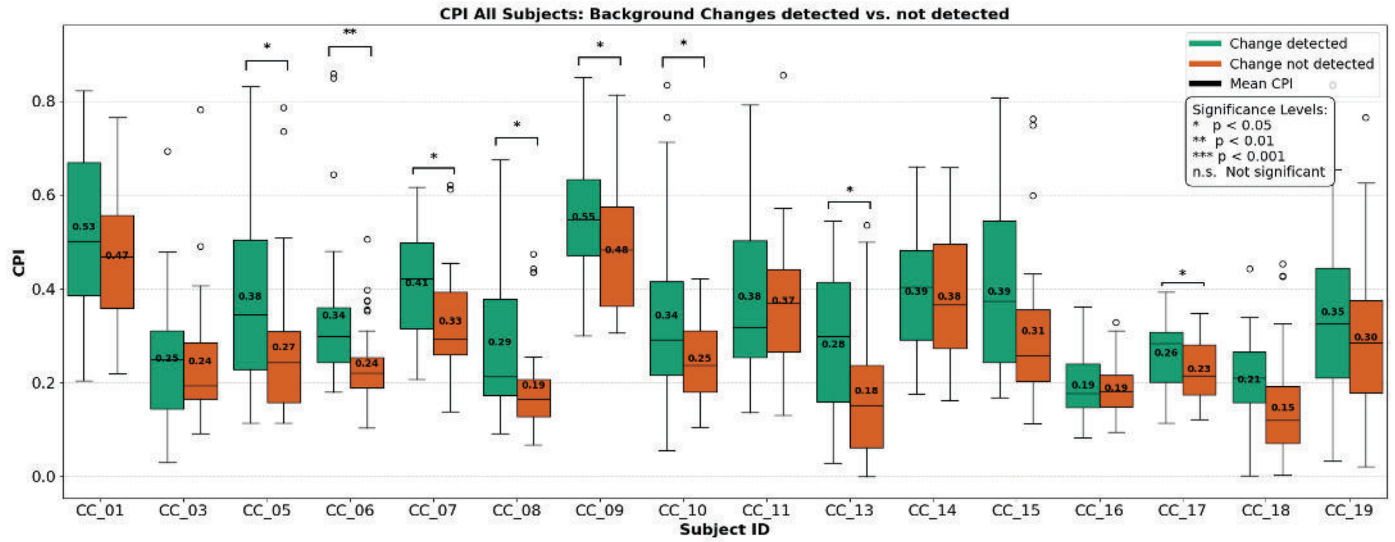
The experiment contains a **primary task** of varying difficulty in which numbers on by-passing cars need to be counted, added or manipulated using further arithmetic methods, increasing task difficulty with increasing complexity.
Meanwhile, the **secondary task** requires the participants to notice changes in the background like changes in facade colors, decorations, etc., and actively report the changes via explicit interaction.

### Recording Devices

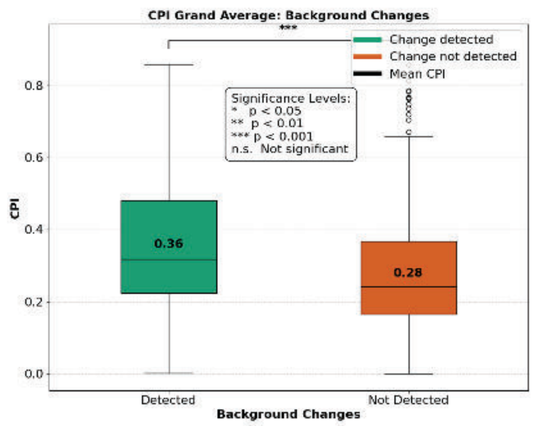
- Bittium NeurOne Tesla EEG System with 2 amplifiers:
  - » 64 passive electrodes (10-20 system)
  - » Sampling rate: 1 kHz
- Pico Neo 3 Pro Eye (stand-alone HMD)
  - » Frame rate: 72 fps
  - » Tobii Ocumen (research license) for advanced eye-tracking metrics

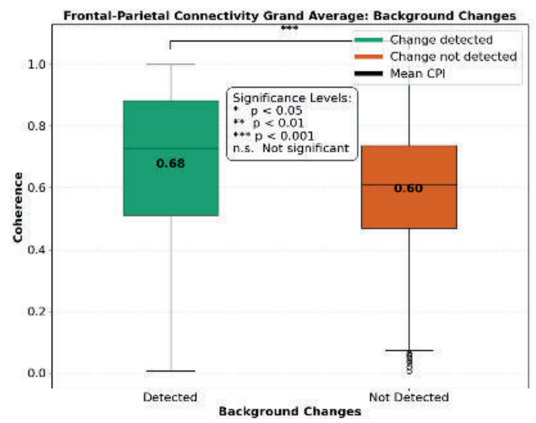


# Validation & Applications




The figure compares the CPI in cases where participants detected background changes with those where they did not. **Across all participants, successful detection of changes coincided with higher CPI levels.** This suggests that conscious perception of changes can be predicted using the SOMA CPI biomarker.




In **EEG analysis**, conscious perception is indicated by increased coherence between prefrontal and parietal regions. Higher coherence reflects stronger connectivity and, thus, greater conscious awareness.
In the study, we investigated coherence during detected vs. undetected background changes, finding that the detection of changes is associated with significantly higher coherence across all participants.

**Both, eye tracking biomarker and EEG coherence metrics** show a **highly significant increase (p < 0.001) during successful detection of background changes.**

# What you need...

## Eye Tracker

Provides pupil dilation levels in real-time with no restrictions to movement and minimal intrusiveness.

**AR/VR Headsets with integrated Eye Tracking**

**Wearable Eye Tracker**

**Remote Eye Tracker**

## Requirements towards Eye Tracker and API

open access to relevant data streams

- pupil dilation
- pupil dilation confidence
- world camera image (or screen image capture)

Wired or wireless connection (WIFI) for live data streaming

# ...what we provide

## Soma Aware SDK for Data Processing & Analytics

Enables the analysis of raw eye tracking data and provides insights on Cognitive Load levels in real-time


## Soma Aware SDK provides

**Free Hardware Choice**
Compatibility with most available Eye Trackers

**Brightness Compensation**
From the lab into real-world applications via compensation of environmental brightness

**Real-time Insights**
Obtaining expressive, continuous Cognitive Load measures in real-time

**In-Task Analytics**
Integration in processing and analytics processes

**Green Field Capability**
Complete freedom of motion for your Cognitive Load Studies

**Contextualization**
Combination with further SOMA biomarkers (Visual Attention, Cognitive Load)

# Team

At SOMAREALITY, we believe in a world where everyone can unlock their full cognitive potential. Therefore, we develop scientifically validated digital biomarkers to enable technologies in industry, health care, society, and beyond.

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