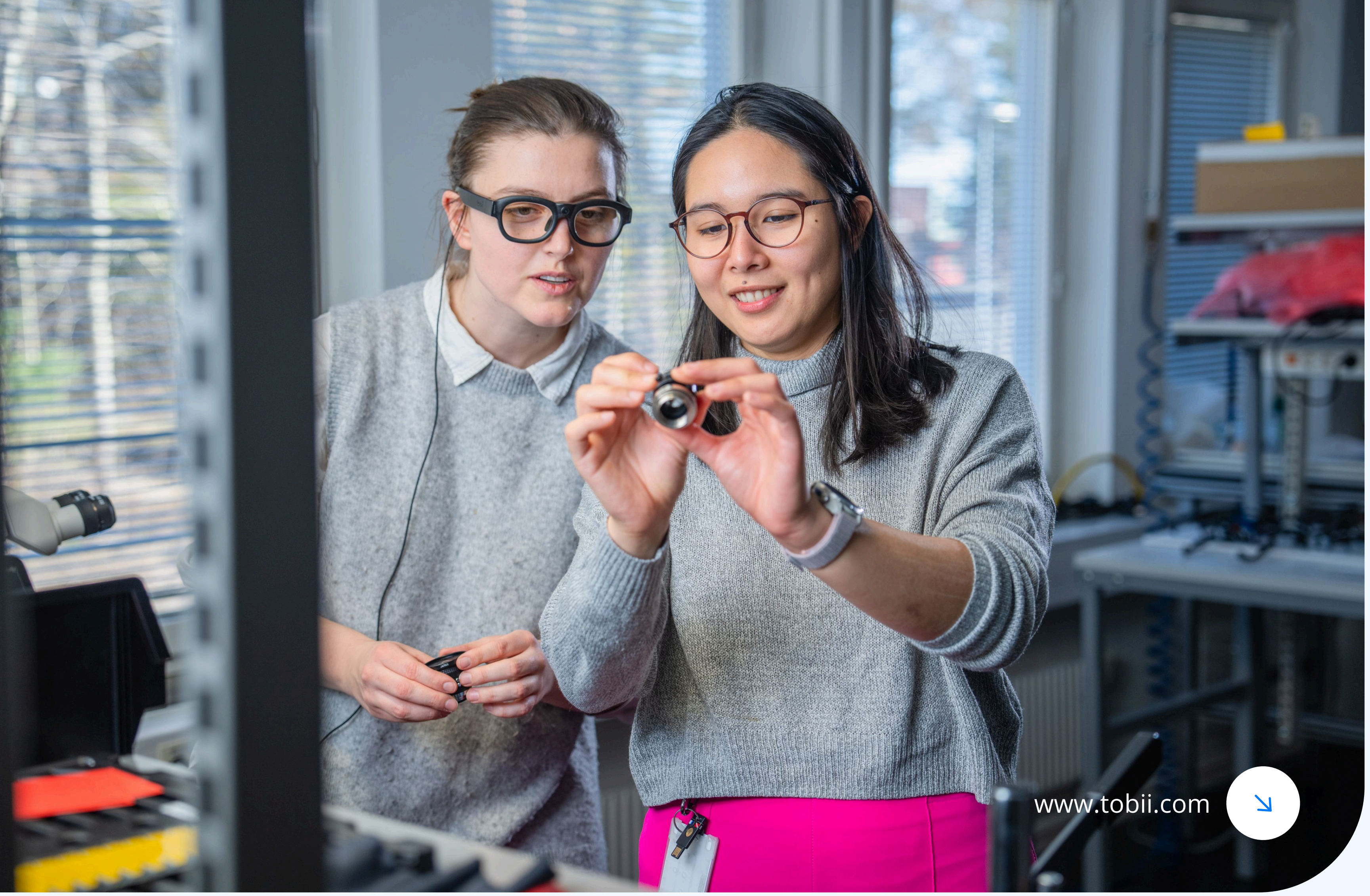
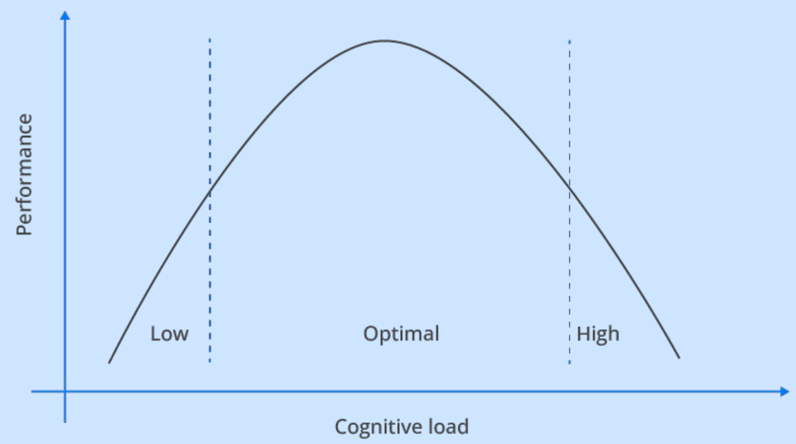




Inverted-U model of cognitive load and performance. The graph illustrates the relationship between cognitive load and task performance. On the left side, a section represents cognitive underload, characterized by passive fatigue and drowsiness. In the middle, an ideal cognitive load is linked to improved performance. Conversely, the right side shows overload, which induces active fatigue and stress and decreases task performance.

Understanding and measuring cognitive load through eye tracking

In an increasingly complex and information-rich world, understanding and optimizing how individuals process and manage heavy loads of information has become more important than ever. The mental effort required in occupational tasks and learning, is commonly referred to as **cognitive load**.

tobii

Despite decades of research, there is no universally accepted method for measuring cognitive load. Traditional approaches, like self-report questionnaires, task performance metrics, and physiological indicators, each offer unique insights, but also come with limitations. This has led to growing interest in eye tracking to observe visual attention and infer mental effort in real time, without interrupting the task at hand. By analyzing metrics such as pupil dilation, fixation duration, and saccadic behavior, eye tracking provides a window into the cognitive processes underlying perception, decision-making, and learning.

This guide introduces the concept of cognitive load, explores how it can be measured, and highlights the unique contributions of eye tracking in this context. Drawing on peer-reviewed research and practical applications, we compare eye tracking with other biometric and survey-based methods, present real-world use cases, and offer actionable tips for implementing cognitive load assessments in both experimental and applied settings.

Whether you're a researcher, designer, educator, or practitioner, this guide aims to equip you with a foundational understanding of cognitive load and how eye tracking, eye tracking can enhance your ability to measure and interpret mental effort with greater precision.

1

Introduction to cognitive load

Our working memory is a powerful system, but it is limited in capacity. When we read, solve problems, or interact with digital systems, we draw on this mental resource. If the demand exceeds our capacity, performance can suffer. Cognitive load refers to the mental effort required to process information in our working memory.

While cognitive load is often discussed alongside concepts like stress, fatigue, or emotional arousal, it is important to distinguish it from these related constructs. Cognitive load is not synonymous with stress, which involves emotional and physiological responses to perceived threats or challenges, nor is it the same as fatigue, which reflects a decline in performance due to prolonged effort or lack of rest.

Understanding this distinction is crucial because interventions aimed at reducing stress or fatigue may not necessarily reduce cognitive load—and vice versa. For example, a user may feel calm and well-rested but still experience high cognitive load when navigating a complex interface. Conversely, someone under stress might be performing a task imposing minimal cognitive demands.

Measuring cognitive loads allows you to:

- **Manage workload** and ensure that cognitive demands placed on individuals are matched to their capabilities.
- **Design interfaces** that are intuitive, efficient, and user-friendly. Knowing the cognitive load imposed by design allows to mitigate unnecessary extraneous load.
- **Improve training and skill acquisition** with learning materials optimized for efficiency and effectiveness and minimize cognitive fatigue and time loss.
- **Prevent errors, increase safety** by identifying situations where cognitive overload occurs, and develop interventions to mitigate those risks. Optimal cognitive load enhances performance and promotes safety.

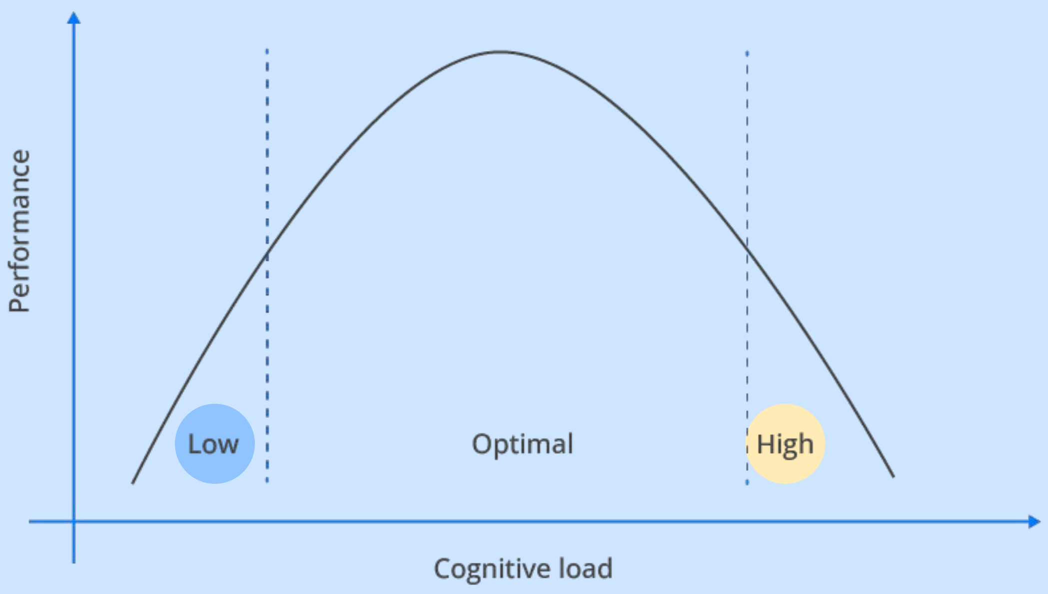
The concept of cognitive load was formalized in Cognitive Load Theory (CLT) by John Sweller in the late 1980s, has become a foundational framework in both academic research and applied fields like education, user experience (UX), and workplace training. CLT breaks cognitive load into three categories:

- **Intrinsic load** is tied to the complexity of the task itself, such as the number of elements that must be processed and how they interact.
- **Extraneous load** stems from how information is presented. Poorly designed interfaces or confusing instructions can increase this type of load unnecessarily.
- **Germane load** refers to the mental effort invested in learning and building understanding.

While these categories are useful for designing better learning and interaction experiences, measuring them accurately is still a challenge. There is no single, universally accepted method for estimating cognitive load, and different approaches often yield different insights (Skulmowski & Xu, 2022).

This has led to a growing interest in multimodal and context-sensitive methods of measurement. For example, recent research in digital learning and UX design has shown that immersive or interactive environments can both enhance and hinder learning, depending on how they affect cognitive load (Skulmowski & Xu, 2022). Similarly, in human factors and training, understanding when a user is overloaded can help prevent errors and improve performance (Beauchemin et al., 2024).

An infographic summarizing the types of eye movements that can indicate low and high cognitive loads

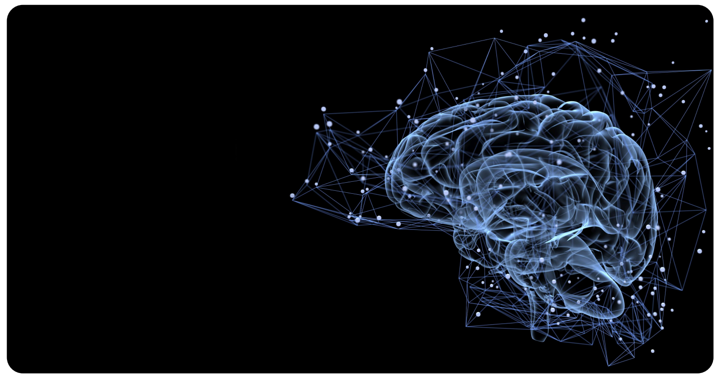


Underload

1. Longer fixation duration (Cazzoli et al., 2014)
2. Decrease in saccadic speed (Cazzoli et al., 2014)
3. Small pupil diameter (Halverson et al., 2012)
4. Low blink rate (Halverson et al., 2012)
5. High PERCLOS (Halverson et al., 2012)

Overload

1. Increased velocity of saccadic intrusion – horizontal micro-saccadic movements (Biswas and Prabhakar, 2018)
2. Low number of fixations (Walter and Bex, 2021)
3. Large pupil diameter (Halverson et al., 2012)
4. Decrease in the number and duration of saccades (Walter and Bex, 2021)
5. Higher gaze entropy (Di Stasi et al., 2016)
6. High Blink Rate (F. N. Biondi et al., 2023)



Discover how eye tracking helps researchers understand memory, decision-making, and problem-solving in real time.

Learn more: [What can eye tracking reveal about cognitive processes?]

See how a startup uses eye tracking and VR to assess cognitive load in education and healthcare.

Customer Story: [Measuring cognitive load in VR — the power of three]

2

Methods for measuring cognitive load

Measuring cognitive load is essential for understanding how people learn, make decisions, and perform under pressure. Yet, because cognitive load is not directly observable, researchers and practitioners rely on a variety of indirect methods, each with its own strengths, limitations, and suitability for different contexts.

Self-report measures

Self-report tools like the **NASA Task Load Index (NASA-TLX) and the Cognitive Load Questionnaire (CLQ)** are among the most widely used methods to measure cognitive load. They ask participants to reflect on their perceived mental effort, frustration, and task difficulty. These tools are easy to administer and cost-effective, making them popular in both academic and applied settings. However, they are inherently subjective and can be influenced by memory biases or social desirability (Krell et al., 2022).

Performance-based measures

Another approach is to infer cognitive load from task performance, such as reaction time, error rates, or accuracy. The assumption is that as cognitive load increases, performance tends to decline. While useful, these measures can be confounded by other factors like motivation, fatigue, or prior knowledge (Krell et al., 2022).

Physiological measures

Physiological indicators offer more objective insights into mental effort. Common methods include:

- **Heart rate variability (HRV):** Reflects autonomic nervous system activity and is sensitive to stress and cognitive demand.
- **Electroencephalography (EEG):** Measures brainwave activity and can distinguish between different types of cognitive processes.
- **Functional near-infrared spectroscopy (fNIRS):** Tracks blood flow in the brain and is less sensitive to movement than EEG.

These methods are powerful but often require controlled lab environments and specialized expertise (Krell et al., 2022).

Eye tracking

Eye tracking has emerged as a particularly promising method for estimating cognitive load in both lab and real-world settings. It captures how users allocate their visual attention and how their eyes respond to cognitive demands. Unlike many physiological methods, eye tracking is a nonintrusive, real-time, and portable option. This makes it suitable for applications ranging from classroom learning to cockpit simulations.

Key metrics include:

- **Blink rate and duration**
  A person's blink rate has been found to increase under high cognitive load (Biondi et al., 2023, Valtchanov & Ellard, 2015, Wascher et al., 2016). A reduced blink rate may signal increased concentration, while longer blinks can indicate fatigue or disengagement. These metrics are often used in combination with others to triangulate cognitive state. The opening and closing of the eye are also used to calculate the percentage of eye closure over time (PERCLOS), which is a measure to assess drowsiness or fatigue levels by monitoring the percentage of time a person's eyes are closed over a specific period. PERCLOS is commonly utilized in transportation safety, such as in aviation or driving, to detect when an individual may be at risk of falling asleep or experiencing impaired alertness due to fatigue. Moreover, PERCLOS can classify high and low workloads (Halverson et al., 2012).
- **Pupil dilation**
  Pupil size is a well-established physiological correlate of cognitive effort. As mental workload increases, so does pupil diameter—a phenomenon known as the task-evoked pupillary response (TEPR). This response is sensitive to both the intensity and duration of cognitive processing (Krejtz et al., 2018; Beatty, 1982). The relationship between the increase in cognitive load and pupil diameter has been shown in driving (Palinko et al., 2010), education (Borys et al., 2017), aviation (Babu et al., 2019), and clinical simulations (Wilbanks et al., 2021).
- **Fixation duration and frequency**
  Fixations—moments when the eye remains relatively still—are essential for information intake. Longer fixation durations can indicate increased processing demands, while higher fixation frequency may reflect scanning behavior or uncertainty. In learning and decision-making tasks, these metrics have been shown to correlate with task complexity and user expertise (Krejtz et al., 2018; Holmqvist et al., 2011).
- **Saccadic patterns and microsaccades**
  Saccades are rapid eye movements between fixations. Changes in saccadic amplitude, velocity, and direction can reflect shifts in attention and cognitive strategy. Microsaccades—tiny, involuntary eye movements during fixation—have also been linked to cognitive load, particularly in tasks requiring sustained attention or working memory (Krejtz et al., 2018; Di Stasi et al., 2013) (Krell et al., 2022).
- **Scanpath complexity**
  The sequence and structure of fixations and saccades—known as a scanpath—can be analyzed for complexity. More erratic or nonlinear scanpaths may indicate cognitive overload or inefficient information processing. Metrics such as transition entropy or Levenshtein distance are sometimes used to quantify scanpath variability (Goldberg & Helfman, 2010).

Eye openness

Eye openness is the distance between the upper and lower eyelids. The eye openness signal, which is available for the Tobii Pro Fusion and the Tobii Pro Spectrum eye trackers, is advantageous for measuring blink dynamics beyond basic measures such as rate and duration (Nyström et al., 2024)

Explore more about how capturing eyelid movements can enrich and improve gaze signal quality in eye tracking experiments.

Learn article: Eye openness - less noise, more signal

Multimodal approaches

Recent research highlights the benefits of using multiple methods to enhance the validity and reliability of cognitive load measurements. Combining eye tracking with self-report tools, EEG, or additional physiological metrics such as galvanic skin response (GSR) and facial expression analysis has proven to offer a more cohesive understanding of cognitive states (Krell et al., 2022).

Eye tracking does far more than simply reveal where users direct their attention. It provides a dynamic, moment-by-moment window into the cognitive processes underpinning mental effort, decision-making, and learning. For instance, metrics such as pupil dilation, fixation duration, and saccadic patterns serve as direct indicators of cognitive load. Pupil dilation, often referred to as the task-evoked pupillary response (TEPR), is one of the most reliable physiological markers. As cognitive demands intensify, pupil size increases, reflecting heightened mental effort. Similarly, fixation metrics—such as duration and frequency—offer insights into the depth of information processing and task complexity. Longer fixations often correlate with higher processing demands, while frequent fixations can indicate scanning behavior or task uncertainty.

Additional eye tracking metrics, such as scanpath complexity and microsaccades, delve deeper into cognitive strategies and states. Erratic or nonlinear scanpaths frequently emerge during cognitive overload, providing a quantitative measure of inefficient information processing. Microsaccades, tiny involuntary movements during fixation, reflect the interplay between sustained attention and working memory demands. These subtle eye behaviors have been shown to correlate with mental workload in high-stakes environments, such as aviation, medical diagnostics, and industrial decision-making.

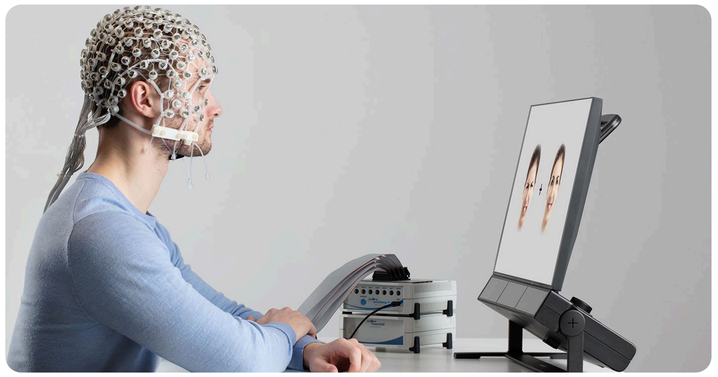
Importantly, eye tracking allows researchers to go beyond observable behavior and infer internal cognitive states. For example, gaze patterns during decision-making tasks reveal not only which options are visually considered but also the hesitation, comparison, or overload experienced by the user. In educational settings, eye tracking can map when a student struggles with integrating new information, even before errors manifest. These capabilities make it invaluable for real-time interventions, such as adaptive learning platforms that adjust difficulty based on student engagement and cognitive load.

When paired with other data streams, the power of eye tracking is amplified. Physiological methods such as EEG offer high-resolution insight into brain activity, while GSR tracks emotional arousal, and facial expression analysis identifies engagement or frustration. Together, these multimodal approaches create a detailed picture of cognitive load. Furthermore, Tobii products are compatible with a range of different tools, making integration easier across research and applied environments. Click here to see a list of our partners.

Learn how researchers used eye tracking, HRV, and GSR to measure cognitive load in human-robot collaboration.

Scientific Publication: Robots reducing workers' cognitive load

Method	Advantages	Limitations
Eye tracking	Real-time, non-invasive, applicable in naturalistic settings, sensitive to subtle changes in cognitive state	Sensitive to lighting and calibration, requires specialized equipment
Heart rate variability (HRV)	Easy to measure, continuous data	Influenced by physical and emotional states (Novak et al., 2017)
Galvanic skin response (GSR)	Reflects arousal and stress	Less specific to cognitive load (Novak et al., 2017)
EEG	Direct measure of brain activity, high temporal resolution	Intrusive, sensitive to movement artifacts (Chen et al., 2011)
fNIRS	Non-invasive, usable in real-world settings	Lower spatial resolution, slower response time (Chen et al., 2011)
Self-report (e.g., NASA-TLX)	Easy to administer, widely validated	Subjective, not real-time (Chen et al., 2011)



Learn how multimodal research can enhance your understanding of user behavior and mental effort.

Read More: How to combine eye tracking with other biometric data

Tailored solutions for measuring cognitive load

Eye tracking technology has advanced significantly, offering powerful tools to investigate cognitive load with precision and adaptability. Tobii's cutting-edge products are specifically designed to address the nuanced requirements of cognitive load research, enabling researchers to explore mental effort, attention allocation, and information processing in diverse contexts while offering the flexibility to extend their application to other areas.

Tobii Pro Glasses 3: Cognitive load in real-world scenarios

The **Tobii Pro Glasses 3** is an ideal tool for studying cognitive load in dynamic, real-world environments. Its wearable design allows researchers to measure gaze behavior, fixation durations, and blink dynamics in naturalistic settings such as surgery, driving, or industrial workflows. These insights are critical for understanding how users manage mental effort under stress or high-pressure conditions. While it excels at capturing real-time cognitive load metrics, its versatility also makes it valuable for other types of research into human behavior in real-world environments.

Tobii Pro Spectrum: Deep dive into cognitive processes

For controlled experimental research, the **Tobii Pro Spectrum**, a high-precision screen-based eye tracker, provides unparalleled precision, making it a cornerstone for cognitive load studies. Its high sampling rate of up to 1200 Hz enables researchers to analyze intricate eye behaviors like microsaccades and pupil dynamics, directly reflecting mental workload. Additionally, the device's ability to measure eye openness enhances the assessment of blink dynamics, offering a comprehensive view of cognitive and attentional states. While optimal for cognitive load experiments, it also supports studies on memory, attention, and learning.

Tobii Pro Fusion: Versatility for cognitive load across settings

The **Tobii Pro Fusion**, another versatile screen-based eye tracker, bridges the gap between lab-based precision and the portability required for applied cognitive load research. With its adjustable sampling rates (60 Hz to 250 Hz), it adapts to diverse research demands, whether in usability testing, training environments, or field studies. The inclusion of eye openness signals further supports nuanced analysis of cognitive effort and fatigue. Its flexible design ensures cognitive load researchers can rely on it for accurate data collection across a wide range of scenarios, while still benefiting from its applicability in general research contexts.

Tobii's screen-based eye trackers empower researchers to delve deeply into cognitive load metrics, offering targeted solutions for understanding how individuals allocate attention, process information, and manage mental effort. By choosing the right device for the task at hand, cognitive load studies can achieve unprecedented insights, fostering breakthroughs in education, safety, and usability.

Use cases for eye tracking in cognitive load research

Eye tracking is increasingly being used to assess cognitive load across a wide range of domains—from education and UX to healthcare and high-stakes operational environments. Its ability to provide real-time, non-intrusive insights into visual attention and mental effort makes it especially valuable in settings where traditional methods fall short.

Education and learning environments

In educational research, eye tracking helps evaluate how students interact with learning materials. For example, researchers can assess whether learners are focusing on relevant content or being distracted by extraneous elements. This is particularly useful in multimedia learning, where text, images, and animations must be carefully balanced to avoid cognitive overload.

See how a startup uses eye tracking and VR to assess cognitive load in education and healthcare.

Customer Story: Measuring cognitive load in VR – the power of three

User experience (UX) and human-computer interaction (HCI)

In UX and HCI, eye tracking is used to evaluate how interface design affects user attention and mental effort. For example, longer fixations or erratic gaze patterns may indicate a user is confused or overloaded. This information can guide the design of more intuitive interfaces, especially in complex systems like dashboards, control panels, or VR environments.

Explore how eye tracking supports usability testing, interface design, and situational awareness studies.

Learn More: Empowering UX design with attention data

Workplace training and safety-critical environments

In high-stakes environments—such as aviation, manufacturing, or emergency response—eye tracking can help identify when a trainee or operator is experiencing cognitive overload. This allows for adaptive training interventions or interface adjustments to improve safety and performance.

A practical guide to using eye tracking in applied settings like training, safety, and usability testing.

Explore: Eye tracking in human factors research

Healthcare and medical education

In medical training and practice, eye tracking is used to study how clinicians allocate attention during procedures. For example, expert surgeons tend to have more focused and efficient gaze patterns than novices. Eye tracking can also help identify moments of high cognitive load during complex tasks, supporting better training and decision-making.

Discover how eye tracking is used to assess attention and decision-making in clinical training.

Explore: How eye tracking is improving medical device safety

How do experts study cognitive load?

Using eye tracking to estimate cognitive load in limb prosthesis users

The study examined whether mobile eye tracking can measure cognitive load during motor tasks. The study participants were prosthetic users and able-bodied controls. Eye tracking data and body movements were recorded with Tobii Pro Glasses 3 while participants performed motor tasks (e.g., level ground walking, stairs up and down, etc.). Participant’s target fixation times and pupil diameters were measured and correlated to the subjective rating of cognitive load. The study results showed that target fixation time and pupil diameter correlate with subjective ratings of cognitive load. The study suggests that a mobile eye tracker could estimate cognitive load in prosthesis users during motor tasks, potentially offering a new, objective, practical, and simple assessment method.

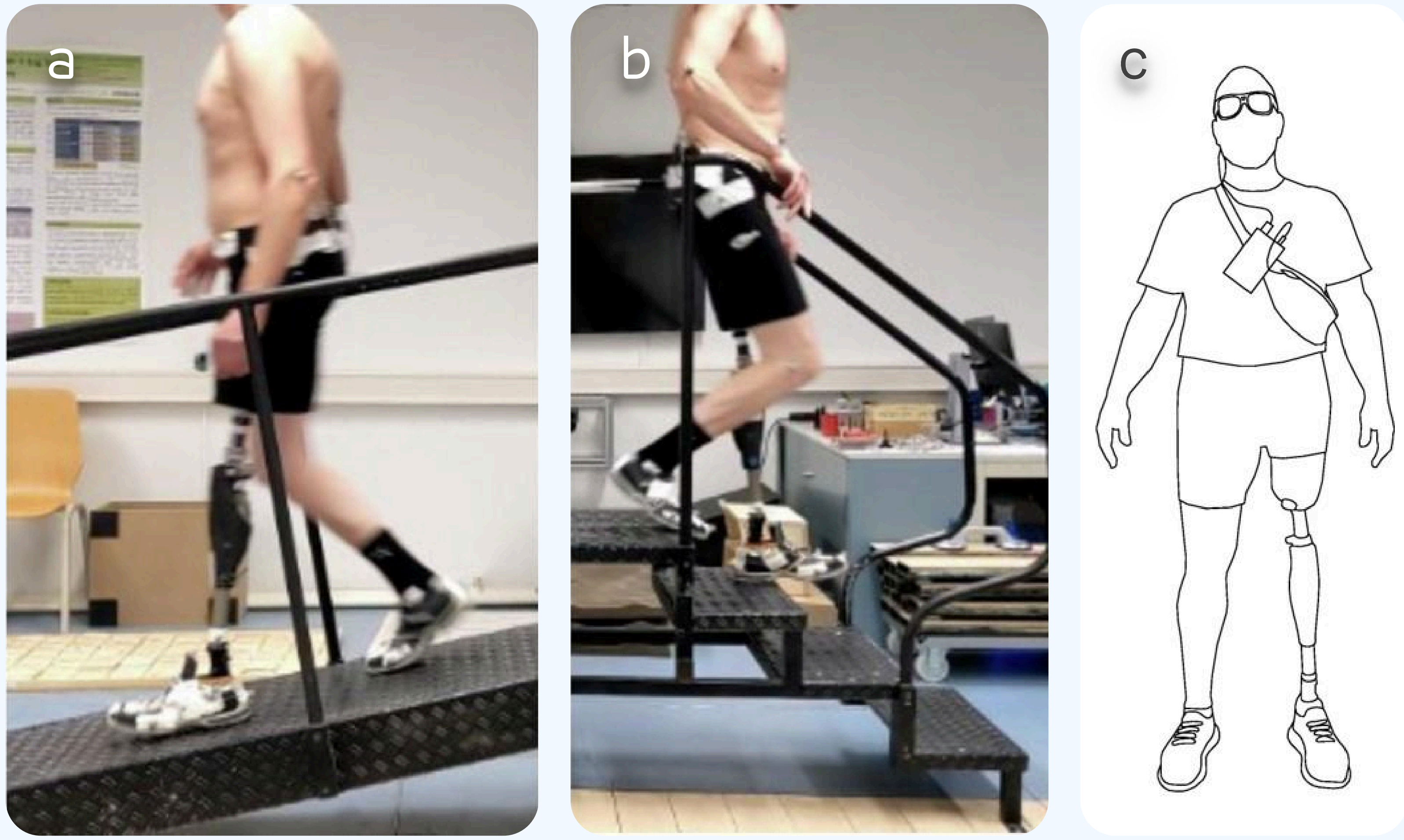


Figure 1 Photos of user testing during ramp descent (a), stair descent (b), and a schematic of a user wearing eye tracking glasses in Manz et al. (2024) study.

Participants: 15 (prosthetic users and able-bodied controls)

Task: Various walking tasks (e.g., ramp decent)

Eye tracking hardware: Tobii Pro Glasses 3

Eye tracking software: Tobii Pro Lab software

Motion capture system: Vicon

Key finding: Eye tracking provides objective cognitive load measures for prosthetic users and can be further developed to assess cognitive load inside and outside the lab.

Cited research:

S. Manz, T. Schmalz, M. Ernst, et al., Using mobile eye tracking to measure cognitive load through gaze behavior during walking in lower limb prosthesis users: A preliminary assessment, Clinical Biomechanics (2024), https://doi.org/10.1016/j.clinbiomech.2024.106250

How do experts study cognitive load?

Exploring sleepiness and fatigue risk of short-haul truck drivers with eye tracking

The research study explored the occupational fatigue risks among short-haul truck drivers, specifically analyzing how sleep patterns, driving tasks, and time-on-task influence driving behavior and eye movement metrics. Eleven professional short-haul truck drivers participated in the study. They underwent a three-day test involving different sleep conditions and two driving tasks (outbound and inbound). Violations of sleep-related legal requirements and insufficient sleep were found to negatively affect drivers' vigilance and driving performance. The interaction between sleep deprivation and the type of driving task exacerbated driver fatigue, indicating that both lack and quality of sleep significantly impact safety. Using eye tracking technology, the study quantified fatigue through metrics such as fixation duration on different areas of interest, pupil diameter, and saccadic velocity. These metrics illustrated how fatigue could impact a driver's ability to concentrate and react to road conditions. The study's conclusions emphasized the need for stricter driving schedule management and sleep patterns among truck drivers to mitigate fatigue-related risks.

Participants: 11 experienced drivers

Task: Outbound and inbound under three different sleep patterns

Eye tracking hardware: Tobii Pro Glasses 2

Key findings: Eye tracking metrics can reliably indicate drivers' fatigue related to lack of sleep on a short-haul drive. The study results inform recommendations for optimizing short-haul truck drivers' schedules and enhancing road safety.

Cited publication:
Zhang, C., Ma, Y., Chen, S., Zhang, J., and Xing, G. (2024). Exploring the occupational fatigue risk of short-haul truck drivers: Effects of sleep pattern, driving task, and time-on-task on driving behavior and eye-motion metrics. Transportation Research Part F: Traffic Psychology and Behaviour, 100, 37–56. https://doi.org/10.1016/j.trf.2023.11.012

Practical tips for cognitive load in indoor lab and real-world settings

Whether you're conducting a controlled lab study or evaluating performance in the field, measuring cognitive load effectively requires thoughtful planning. Below are practical tips for using eye tracking and complementary methods in both experimental and applied contexts.

In indoor lab settings

1. **Control for lighting conditions**
   Pupil dilation is a sensitive indicator of cognitive load, but it's also affected by ambient light. Use consistent lighting or include a baseline calibration to account for these effects.
2. **Establish individual baselines**
   People vary in their natural gaze behavior and pupil size. Collect baseline data under low-load conditions to better interpret changes during more demanding tasks.
3. **Use high-precision equipment**
   For detailed studies—such as those involving microsaccades or rapid attention shifts—devices like the **Tobii Pro Spectrum** or **Tobii Pro Fusion** offer the temporal resolution needed for fine-grained analysis.
4. **Combine with other measures**
   Triangulate eye tracking data with self-reports (e.g., NASA-TLX) or physiological signals (e.g., HRV, EEG) to increase validity and capture different dimensions of cognitive load.

In real-world settings

1. **Use wearable eye trackers**
   Devices like the **Tobii Pro Glasses 3** allow for naturalistic data collection in environments such as classrooms, hospitals, or industrial sites.
2. **Minimize intrusion**
   Ensure that the eye tracking setup does not interfere with the task. Lightweight, unobtrusive equipment helps maintain ecological validity.
3. **Automate data processing**
   Real-world studies often generate large volumes of data. Use software tools to automate fixation mapping, heatmaps, and pupil analysis to streamline interpretation.
4. **Account for contextual factors**
   In applied settings, cognitive load may be influenced by stress, multitasking, or environmental noise. Consider these variables when designing your study and interpreting results.

A guide to 15 lab paradigms using eye tracking to study attention, memory, and learning.

Download: Eye tracking – a window to cognitive processes

Conclusion

Cognitive load is a crucial factor in shaping how individuals learn, make decisions, and perform under pressure. Although the concept has been studied for decades, accurately measuring cognitive load remains a challenge, particularly in real-world environments where traditional methods may fall short.

This whitepaper has examined various approaches to cognitive load measurement, ranging from self-reports and performance metrics to physiological and biometric tools. Among these methods, eye tracking stands out for its ability to provide realtime, non-intrusive insights into visual attention and mental effort. Whether applied in controlled lab settings using high-precision systems like the Tobii Pro Spectrum, or in the field with wearable solutions such as the Tobii Pro Glasses 3, eye tracking enables researchers and practitioners to estimate cognitive load with greater nuance and contextual relevance.

As cognitive technologies continue to progress, measuring mental effort will become increasingly vital—not only in academic research but also in fields like UX design, training, healthcare, and more. Eye tracking offers a scalable, flexible, and scientifically grounded method to address this need effectively.

If you're interested in exploring more publications, be sure to visit our publication database or resource center. Ready to get started with eye tracking? Reach out to us through our contact form.

By combining eye tracking with complementary methods and applying it thoughtfully across various contexts, we can move closer to designing systems, environments, and experiences that genuinely support human cognition.

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