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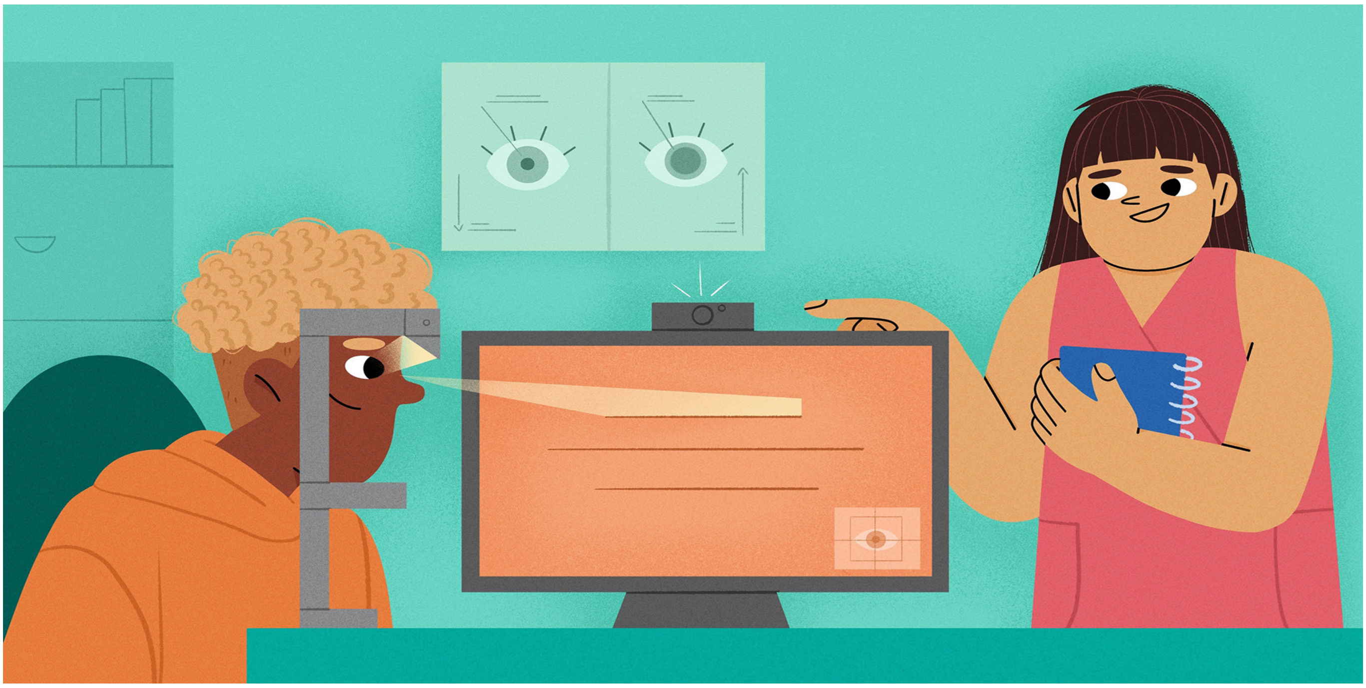
NEUROSCIENCE AND PSYCHOLOGY
Published: 25 June 2024
doi: 10.3389/frym.2024.1237161



UNCOVERING THE MENTAL EFFORT OF READING USING EYE-TRACKING TECHNOLOGY

Jennifer E. Martinez and Michael C. Hout *

Department of Psychology, New Mexico State University, Las Cruces, NM, United States

YOUNG REVIEWERS:

DANIEL
AGE: 14

DARREN
AGE: 14

VRISHAB
AGE: 14

Whenever we learn about new topics by reading, we use varying degrees of effort to process what we read. Many factors may affect how much effort you feel like you are using (called cognitive workload) to perform reading tasks—such as how long you have already been reading, your reading skill, and even how you feel that day. Understanding how much effort it takes to understand reading material is vital because scientists can use this information to create better reading experiences and programs—especially for those who find reading difficult. Scientists have explored the effects of cognitive workload on reading comprehension to better understand how readers process information and store it in memory. One of the ways scientists do this is by using tools called eye trackers to measure the cognitive workload a reader is experiencing as they read.

MEMORIES OF WHAT WE READ CAN STICK AROUND FOR A LONG TIME!

When we read, we store all types of information in our brains. For example, we may remember details about the lives of our favorite characters or key events that influenced a story's plot. The brain is an excellent storehouse of much—but not all!—of what we read. One of the most remarkable capabilities of the human brain is its ability to retain information over extended periods of time. This is known as **long-term memory (LTM)**. LTM enables us to remember our *experience* of reading (such as what it felt like to curl up under a blanket and enjoy a good story) and also the specific *information* we read (like the names of characters or facts from a science textbook). However, not all the information we read is automatically "saved" in our brains the way information is stored on a computer's hard drive. When we experience a high **cognitive workload**—that is, when reading is a particularly difficult or effortful mental process—the content of what we read might not be stored correctly (or at all). This can lead to memory errors when we try to "retrieve" and think about the information later.

LONG-TERM MEMORY (LTM)

The memory system that stores information in the brain for a very long time.

COGNITIVE WORKLOAD

A person's perceived level of mental effort required to perform some task (like reading or math).

WHAT FACTORS AFFECT COGNITIVE WORKLOAD?

There are many factors that influence cognitive workload and thus our ability to store information for later. Sometimes external (environmental) factors impact how much effort it takes for us to read (Figure 1). Environmental factors can range from a loud noise you hear down the hallway, to a bright ray of sunshine coming in through the window and hitting you in the face. These environmental factors can distract you and cause your brain to feel like it has gone "fuzzy" for a moment—making it hard to get back on track with your reading task. When these distractions occur, you may feel like too much information is coming in through your senses all at once, crowding your thoughts and concentration, and this makes your brain have to work harder to keep your concentration focused on the material you are reading, so that you can store it in LTM. Because of this, it is essential to try to read and learn in environments that fit your needs, such as a quiet, distraction-free location like your school's library.

External factors are not the only things that impact cognitive workload. Internal factors—the state of your own body—can also impact the ability to read effectively. Internal factors also come in a variety of forms, like a nagging headache, a tired or restless feeling, or even a growling stomach. Your parents have probably told you that breakfast is the most important meal of the day. Well, they were not kidding, and there is a good scientific reason supporting this idea. Eating well and keeping your hunger in check can make a big difference in learning. Just like loud noises or bright lights, internal sensations can distract us, pulling our attention away from what we are reading and forcing

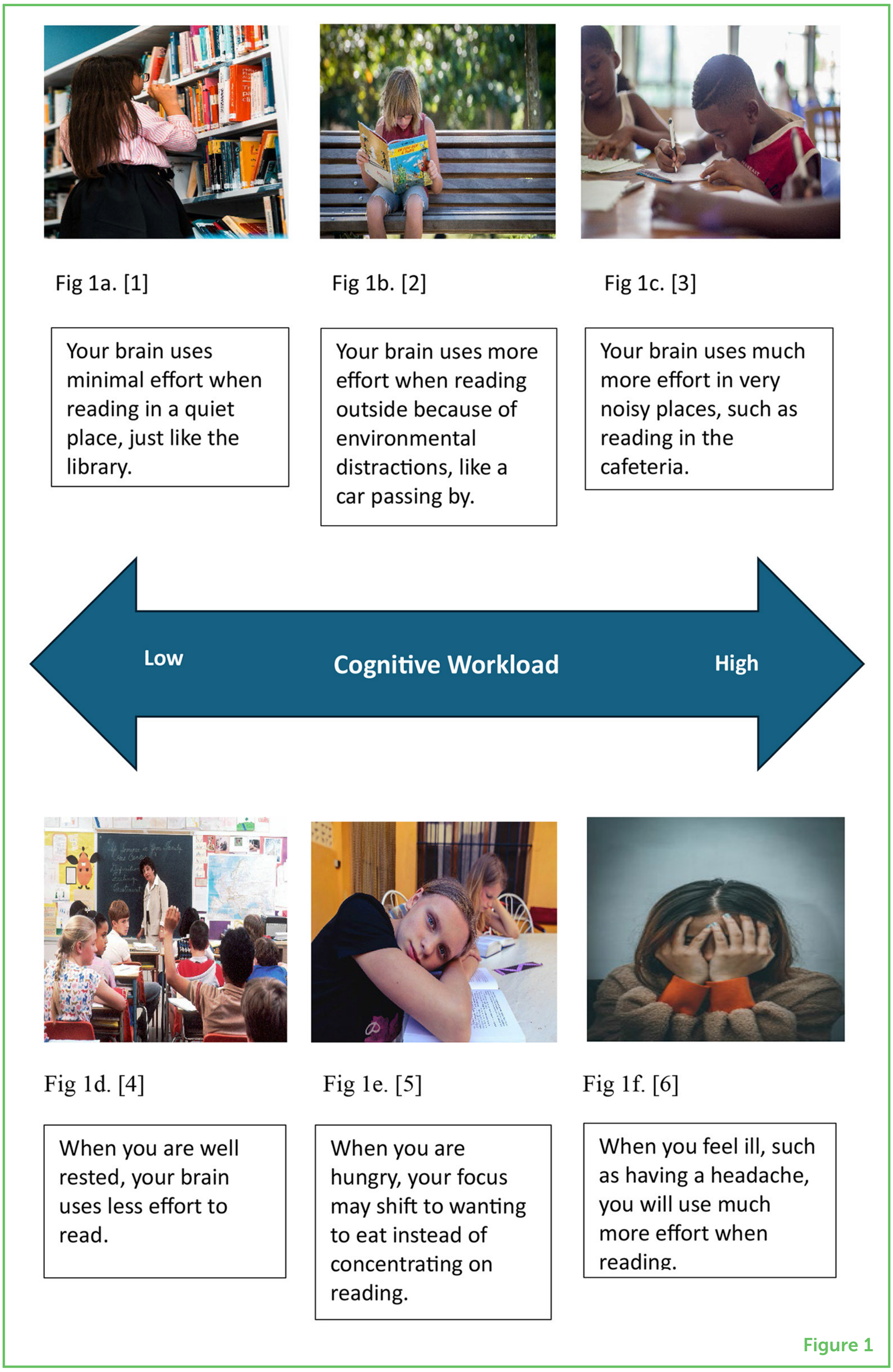


Figure 1

Example situations in which external **(top)** and internal **(bottom)** factors can impact your cognitive workload to varying degrees.

our brains to work harder to retain the material. Hunger can increase your cognitive workload because when you are feeling hungry, your brain is telling you that you need to pay more attention to feeding yourself than to studying (Figure 1). After all, your brain is always going to prioritize keeping you alive, and if it senses that you do not have enough food to create energy for your body, it is going to send out signals saying "feed me!". This means that when you are hungry, it takes more cognitive work to block out your internal feelings and sensations, therefore making it harder focus on learning and remembering what you are reading. When we do not meet our internal needs—such as having a good meal or getting a good night's rest—our brain gets "overloaded" and must work harder than it otherwise should to ensure we comprehend and remember what we read.

HOW DO SCIENTISTS MEASURE COGNITIVE WORKLOAD?

The cognitive workload we experience can significantly impact our memory and other brain processes, but it is important to realize that this is not an "all-or-none" situation. Cognitive workload does not operate like a light switch that is on or off at any given moment. For instance, sometimes we might feel like we are under a relatively low workload, such as when we are reading in a library with minimal background noise. Other times, reading might be more challenging and we might feel like we are under a medium workload, such as when we sit outside to read but get occasionally distracted by the breeze or loud cars driving by. In these situations, we might need to put in more effort to avoid distractions, to understand and remember what we are reading. Other times, it can get even harder. You might feel like you are under a high cognitive workload when you are trying to read something in a noisy, distracting environment, like a school cafeteria. The constant chatter of people talking and the clattering of kitchen utensils is likely to divert your attention, increasing your workload considerably. However, to truly understand cognitive workload and how it impacts performance, we need some way to accurately and consistently measure it. One of the ways scientists do this is to use an **eye tracker** to monitor how people's eyes move and what they are paying attention to.

EYE TRACKER

A device that typically uses a high-powered camera to take pictures of someone's eyes in order to figure out where they are looking, and how much their pupils are dilated or constricted.

Scientists who study cognitive workload sometimes use surveys to understand how people feel when they complete tasks such as reading, doing math problems, or various other things. The problem with using surveys, however, is that the measurements scientists get from them (that is, the responses of the survey participants) do not always give scientists an accurate picture of what the person is experiencing. People's responses to survey questions can sometimes be inconsistent or even inaccurate. For example, sometimes people may respond untruthfully because they feel embarrassed about something, or they may respond in a way that they think the experimenter *wants* them to respond. At other times, people simply might not have a particularly good awareness of what they are feeling in the first place.

For these reasons (and others), scientists have turned to alternative ways to measure cognitive workload, such as recording what a person does with their eyes. It is often said that the eyes are a window into the brain—they can give us clues about a variety of internal activities, such as whether we are paying attention to something, or how much effort is required to perform a certain task.

SACCADIC EYE MOVEMENT

Jumpy movements of the eyes that bring new pieces of information into focus, like focusing on one word in a sentence and then jumping to the next.

FIXATION

The period of time in which the eyes stay relatively still, allowing a person to process what they are looking at.

PUPIL DILATION

The degree to which the pupil is narrow or wide, allowing less or more light into the eyes and giving scientists clues about a person's cognitive workload.

EYE BEHAVIORS CAN REFLECT COGNITIVE WORKLOAD

There are three essential eye behaviors you need to understand in order to know how the eyes can tell scientists how much cognitive workload a person is experiencing (read more about why our eyes move in our earlier Frontiers for Young Minds article). The first behavior is called a **saccadic eye movement**. This is when the eyes rapidly move from one location to another, like reading one word and then "jumping" to the next one. The second behavior is called a **fixation**, which is when the eyes are relatively still, allowing us to process the information we are looking at. The last behavior is **pupil dilation**, and this is when the pupil (the small hole at the center of the eye that lets light in) gets bigger (or smaller, which is called pupil constriction; see Figure 2). This eye behavior is especially important because scientists have discovered that when our pupils dilate and let in more light, it is often a signal that we are experiencing a higher cognitive workload (read more about this interesting finding in our other Frontiers for Young Minds article). We are not even aware of this happening, because we cannot feel our pupils changing size, but by using an eye tracker to record pupil size, scientists can tell how much effort is required to process information during reading (or other tasks). Together, these three eye behaviors can help scientists understand the workload readers are under. But how exactly do scientists measure these eye behaviors?

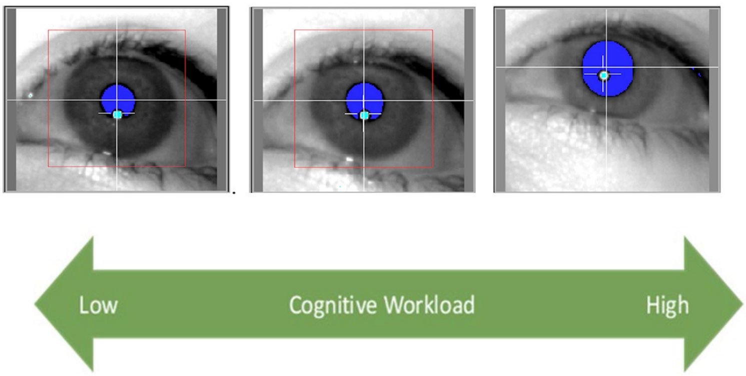


Figure 2

Figure 2

An example of a person's pupil at different levels of dilation, taken from an eye tracker in our laboratory. On the far left, the pupil is mostly constricted and is not letting much light into the eye. This signals that the person might not be experiencing much cognitive workload. On the right, the pupil is much more dilated, letting in a lot of light and possibly indicating that the person is experiencing a high cognitive workload.

HOW DO EYE TRACKERS WORK?

An eye tracker is an effective and safe way to record how the eyes move and how big a person's pupil is at any moment in time [7].

Eye trackers have been around since the 1900s, and they were first developed to study reading behavior! For instance, an eye tracker can tell scientists how long someone is looking at a particular word, or how many times a sentence is read and reread. This precise, numerical information (such as the pupil diameter, the number of re-reads, and reading time) can give scientists clues as to when someone has difficulty understanding a word (readers fixate longer on challenging words) or a sentence (readers make more eye movements to re-read when they have misunderstood something; [8]).

Figure 3 shows an eye tracker used to track a person's reading performance. The information gathered can be used to understand reading difficulties. By capturing the areas where someone is having difficulty, it might be possible to develop personalized reading programs that target areas in which a reader finds things especially difficult. This is particularly important for kids like you who spend a lot of time reading about new topics in school. Scientists have even used devices like this to study specific reading difficulties, like **dyslexia**, by comparing the eye movements of children with and without dyslexia while they read a passage. One of the key findings in a recent study [9] was that children with reading disabilities like dyslexia had more pupil dilation when they read complex sentences, indicating that these students were experiencing increased cognitive load during this task.

DYSLEXIA

A learning disorder that involves difficulty reading, and that arises due to differences in parts of the brain that process language.

Figure 3

Figure 3

An eye tracker being used to monitor a person's reading performance. The eye-tracking camera is located at the center of the desk. To ensure the accuracy of the results, a chinrest is used to prevent the person's head from moving around too much during the experiment.

REMEMBER TO TRY AND MINIMIZE THE EFFORT NEEDED WHEN YOU READ!

Understanding how much effort is required to read about new topics (or challenging sentences) is essential. Many external and internal factors, like loud classrooms or rumbly stomachs, can increase the cognitive workload we experience and impact how much information we are likely to store in LTM for later. To further understand these complex processes, scientists have turned to eye tracking to figure out where and when a reader is having a hard time. Further, measuring pupil dilation can help scientists understand how much mental effort the reader is using. These advances may someday lead to impressive, personalized reading programs, but for now, remember that it is always best to find an optimal learning environment and to make sure that your body is fueled up and ready to learn!

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SUBMITTED: 08 June 2023; **ACCEPTED:** 12 June 2024;
PUBLISHED ONLINE: 25 June 2024.

EDITOR: Casey Lew-Williams, Princeton University, United States

SCIENCE MENTORS: Vinod Venkatraman

CITATION: Martinez JE and Hout MC (2024) Uncovering the Mental Effort of Reading Using Eye-Tracking Technology. Front. Young Minds 12:1237161. doi: 10.3389/frym.2024.1237161

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

DANIEL, AGE: 14

Daniel is a freshman and is 14 years old. He is a baseball player—which he has been playing for his whole life—and hopes to join the high school team in the spring. He has a passion for history in class, especially World History in general. He knows a lot about history and geography which are things he wants to pursue in the future.

DARREN, AGE: 14

Darren is 14 years old and lives in Philadelphia. He enjoys math and science, and plays chess. He also runs track with his high school team.

VRISHAB, AGE: 14

Vrishab is 14 years old and a freshman in high school. His favorite subject in school is math, and he enjoys hanging out with his friends in free time. He enjoys watching many sports like baseball, football, and tennis, and he runs on his school's track team and plays violin in multiple orchestras.

AUTHORS

JENNIFER E. MARTINEZ

Jennifer E. Martinez is a graduate student at New Mexico State University. She is currently studying experimental psychology and minoring in engineering psychology and applied statistics. The focus of her research is on human-drone interaction, specifically using virtual reality to develop safety measures for drone operators and personnel through visual perception. Recently, she was awarded the New Mexico Space Grant Consortium—Graduate Research Fellowship (2023) to continue her work. During her leisure time, she enjoys hiking, spending time with her family, working out at the gym, and visiting her favorite coffee shop to keep up with the latest research on technological advancements.

MICHAEL C. HOUT

Michael C. Hout is a professor in the Department of Psychology at New Mexico State University, and an associate editor at the journal *Attention, Perception, & Psychophysics*. His research focuses primarily on visual cognition (including search, attention, eye movements, and memory) and the development of new methods, tools, and stimuli to be used in experimental research. He has won several awards for research and teaching, including the *Rising Star* award from the *Association for Psychological Science*. In his limited free time, he enjoys walking his dog, running, hiking, playing hockey, and going on road trips with his wife. *mhout@nmsu.edu.