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A NARRATIVE REVIEW OF EYE-TRACKING RESEARCH ON SELF-REGULATED LEARNING FROM MULTIMEDIA LEARNING MATERIALS IN HIGHER EDUCATION

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ABSTRACT

This study provides a narrative review of current eye-tracking research on self-regulated learning from multimedia learning materials in higher education. The main aim of the review is to explore how eye tracking is used in self-regulated learning research when learning from multimedia materials in university students. Other specific aims were established: 1) to identify what self-regulated learning processes are explored with eye tracking while learning from multimedia materials, 2) to determine what methods are used to explore self-regulated learning processes with eye tracking, 3) to find what structures and stimuli are used in eye-tracking experiments when studying self-regulated learning processes, and 4) to investigate what eye-tracking metrics are used to study self-regulated learning processes in learning from multimedia materials. To accomplish these aims, we analyzed 11 empirical studies published between 2012 and 2021. The results show that 1) current studies focus on self-regulated learning processes, such as judgments of learning, metacognitive monitoring, meta-comprehension, and learning strategies, 2) studies are quantitative and use experimental designs, specific stimuli, and distinct structures, and 4) studies are mainly focused on the fixations, saccades, and transitions between selected areas of interest in the data analyses. The results of this narrative review can indicate new directions for future research in this field.

KEYWORDS

self-regulated learning, self-regulatory processes, multimedia learning materials, eye tracking, narrative review

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Introduction

Self-regulated learning has become a recognized and well-established subject of educational research in recent decades (Boekaerts et al., 2000; Zimmerman & Schunk, 2011). It can be described as a learning process that is comprised of cognitive strategies, motivation, and metacognition and is based on student independence and responsibility for their learning (Carneiro et al., 2011). Students' abilities to regulate their own learning are particularly important in the context of online learning since there is a lower teacher presence and therefore higher demands on student autonomy and their ability to study actively and independently (Wong et al., 2019). In the context of online learning and online educational systems, multimedia materials are one of the main modes of information presentation. Research of multimedia learning materials is therefore of great importance because the form and the content of the multimedia materials can enhance or hinder students' self-regulation and thus lead to better or worse learning outcomes.

One of the current and promising approaches to studying student learning from different types of multimedia materials consists of utilizing eye-tracking technology. This approach focuses on the learning strategies that are reflected in where and in what sequence the students are looking while learning from presented materials. Thus, the analysis of student eye movements recorded by an eye-tracking device can provide useful information about student learning from various types of multimedia materials (Alemdag & Cagiltay, 2018). The aim of the current study is to provide a review of recent literature on the use of eye-tracking technology in the context of self-regulated learning and multimedia learning research.

1. Theoretical background

1.1 Self-regulated learning

Self-regulated learning (SRL) is an important concept and area of research within educational and psychological research. Self-regulated learning can be seen as a broad conceptual framework encompassing cognitive, metacognitive, motivational, emotional, and behavioral aspects of learning (Panadero, 2017; Zeidner & Stoeger, 2019). Although different definitions and models of self-regulation and self-regulated learning have been proposed over the last few decades of research, most of the definitions and models agree that SRL is a cyclical process divided into three main phases: the preparatory phase, the performance phase, and the reflective phase (Zimmerman, 2000). Within these phases, specific processes such as selection, strategic planning, and time management take place, shaping the overall approach to learning (Panadero, 2017). In addition to cognitive and metacognitive processes and strategies, most current conceptualizations of SRL also pay attention to the affective and motivational aspects of learning and self-regulation. These include self-motivational beliefs such as self-efficacy, goal orientation, and the subjective value of learning (Wong et al., 2019; Zimmerman & Schunk, 2011).

One of the main reasons the SRL concept has gained increased attention in educational research over the years is its connection to learning outcomes. It has been found that the extent to which learners are able to regulate their learning significantly enhances their learning outcomes. Thus, the relation between SRL and learning outcomes and academic success is a primary focus among researchers in this area, and a large number of studies have presented evidence of the contribution of SRL to student outcomes (Carneiro et al., 2011; Zimmerman & Schunk, 2011). Nonetheless, the research is not yet entirely conclusive; for example, a highly cited meta-analysis by Sitzmann and Ely (2011) did not find a significant relationship between self-regulatory processes and learning outcomes. The conflicting results of research on SRL and learning outcomes are often attributed to the many heterogeneous measurement approaches employed in different studies on this topic. The measurement of SRL is currently one of the most discussed issues in SRL research. So far, most researchers have relied on self-reports and questionnaires, but these measurement methods seem to capture student learning preferences rather than actual learning behavior. There has thus been a shift toward new approaches to measuring SRL in recent years, with eye-tracking technology being one of them (Panadero, 2017; Zeidner & Stoeger, 2019).

Focusing on self-regulated learning in the context of online learning and learning from multimedia materials, it can be argued that research of SRL in an online setting is of high importance due to increased demands on student autonomy and thus on their ability to self-regulate (Wong et al., 2019). However, despite recent developments in SRL research, only limited attention has been paid to the specific context of learning in online environments. At the same time, a specific focus on online learning processes seems to be indispensable for understanding self-regulation in online learning, because existing research findings suggest that online learning involves different regulatory processes than learning in a traditional setting (Broadbent & Poon, 2015).

1.2 Learning from multimedia materials

Learning from multimedia materials is an essential part of online learning and learning in online environments. Multimedia learning materials can present information through a variety of formats. Including text, illustrations, photos, audio, videos, and animation. In order for learning material to be considered multimedia material, it has to incorporate both words and pictures. Accordingly, multimedia learning can be defined as "building mental representations from words and pictures" (Mayer, 2005). A long line of research has identified the benefits of using multimedia learning materials with multiple forms of representations of information. Aside from positive effects on student engagement, multimedia learning materials can facilitate knowledge acquisition and thus lead to more meaningful learning (Mayer, 2014). On the other hand, a considerable number of studies have demonstrated that simply presenting information in different modes or formats does not necessarily lead to a better understanding of the information or to better learning in general (Hegarty, 2004; Mayer et al., 2005; Moreno, 2004; Ploetzner & Lowe, 2004).

There seems to be a lack of detailed research that would provide a deeper insight into the link between individual cognitive processes, various forms of multimedia learning materials, and learning outputs (Liu & Chuang, 2011). According to Chuang and Liu (2012), this lack of sufficiently detailed research stems from methodological limitations and the difficulty of measuring cognitive processes such as visual attention and cognitive load. Some researchers have therefore turned their attention to eye tracking as a new and promising technology that can be useful for studying cognitive and metacognitive processes during learning from multimedia materials (van Gog & Jarodzka, 2013).

1.3 Eye tracking in self-regulated learning from multimedia research

Eye-tracking technology is based on recording the movement of participants' eyes in relation to a stimulus. This allows researchers to determine which part(s) of the stimulus were interesting for the participant and how the visual attention of the participant was distributed among different parts of the stimulus (Duchowski, 2007). Thus, using an eye-tracking device can enable inferences about the attention processes of the participants and about the stimulus itself (van Gog & Jarodzka, 2013).

In the context of multimedia learning, the stimulus takes the form of materials presented on a computer monitor. A wide variety of measures can be obtained by eye-tracking technology (Holmqvist et al., 2011; Lai et al., 2013), but the two main types are fixations and saccades (van Gog & Jarodzka, 2013). Fixation means a relatively stable gaze at one point in the stimulus. Measurements of the location and duration of the fixations indicate what information is attended to and how intensively that information is being processed. Saccades are the quick eye movements between the individual fixations. They provide information about the changes in the focus of visual attention (Holmqvist et al., 2011; van Gog & Jarodzka, 2013).

Even though eye-tracking technology has become more and more affordable and easier to employ and despite its apparent benefits, the use of eye tracking by researchers in the field of education is still rather rare, and many researchers have only recently started to use it. Nevertheless, a considerable number of studies have investigated eye movements in the context of learning from multimedia materials, as is evident from a recent systematic review focused specifically on eye-tracking technology in multimedia learning (Alemdag & Cagiltay, 2018). On the other hand, the number of studies that analyze eye movements during learning from multimedia materials with regard to self-regulatory and metacognitive processes is still very low. A useful overview of this area was provided by van Gog and Jarodzka (2013), but the research mentioned in the overview is older. Alemdag and Cagiltay (2018) identified the topic of metacognition as one of the research gaps in the context of eye-tracking research dealing with multimedia learning materials. In their systematic review, only 4 out of 58 studies had investigated the metacognitive processes in multimedia learning. Mayer (2017) similarly found metacognition to be an understudied area in multimedia learning research.

2. Methods

The main aim of the presented narrative review is to analyze and summarize existing empirical research dealing with eye-tracking technology in the context of self-regulated learning and learning from multimedia learning materials. To achieve this aim, we defined the following main research question: "How is eye tracking used in research on self-regulated learning in university students learning from multimedia materials?"

To further elaborate on the issue in question, we determined four specific research questions:

1. What self-regulated learning processes are explored with eye tracking in the context of learning from multimedia learning materials?
2. How are self-regulated learning processes in the context of learning from multimedia learning materials examined with eye-tracking technology, from a methodological perspective?
3. What structure and stimuli are used in the eye-tracking experiments when studying self-regulated learning processes?
4. What eye-tracking metrics are used to study self-regulated learning processes in learning from multimedia learning materials?

2.1 Data sources and search terms

This review was created based on the methodology described by Gregory and Denniss (2018), Ferrari (2015), and, among others, Gasparyan et al. (2011). The steps for conducting the review include: "define topic and audience, search and re-search the literature, be critical, and find a logical structure"

(Gregory & Denniss, 2018). To conduct the presented narrative literature review, the following four databases were searched: Web of Science, Scopus, APA PsycInfo/PsycArticles, and ERIC. Our search terms focused on eye tracking, self-regulated learning strategies, and multimedia learning materials in the higher education environment. For detailed information about the key concepts and the search terms used in all four database searches, see Table 1. The search was conducted on February 9, 2022.

Table 1
Key concepts and search terms used for the search

Key concepts	Search terms
Eye tracking	(eye-tracking OR (eye AND track*) OR (gaze AND track*) OR gaze-tracking OR eye-movement* OR (eye AND movement*))
Self-regulated learning	AND (((learn AND strateg*) OR (cognitive AND engagement) OR (critical AND thinking) OR (effort AND regulat*) OR elaborat* OR (goal AND orient*) OR (goal AND set*) OR (help AND seek*) OR monitor* OR (motivational AND beliefs) OR organisat* OR plan* OR rehearsal* OR (resource AND management) OR self-efficacy OR (self AND efficacy) OR (task AND value AND beliefs) OR (time AND management) OR (self-regulated AND learn*) OR self-regulat* OR metacognit* OR (self AND regulat* AND learn*)))
Multimedia learning materials	AND (multimedia OR audio-visual OR learn* OR (learn* AND material*))
Higher education	AND ((higher AND education) OR (tertiary AND education) OR (post-secondary AND education) OR (post AND secondary AND education) OR (third-level AND education) OR universit* OR college* OR (higher AND education AND student*) OR (universit* AND student*) OR undergraduate* OR (college* AND student*) OR bachelor* OR master*)

2.2 Inclusion and exclusion

We limited the search to original peer-reviewed research articles published in the English language between 2012 and 2021 and we retrieved only articles that dealt specifically with eye tracking, self-regulated learning, and multimedia learning materials. Articles were excluded if they did not focus on all three topics (especially self-regulated learning) or if they studied the topic in a different environment than higher education. Inclusion and exclusion criteria are summarized in Table 2.

Table 2
Summary of inclusion and exclusion criteria.

Inclusion criteria	**Exclusion criteria**
• Eye tracking • Self-regulated learning • Multimedia learning materials • Higher education	• Language other than English • Document type other than "article" • Documents published before 2012 • Environment other than higher education • No self-regulated learning or self-regulated learning processes

2.3 Screening

Our initial search identified 449 studies. After removing duplicates, 174 studies were included in the screening phase. Subsequently, we screened the titles and abstracts, resulting in 18 records that seemed appropriate. We were unable to retrieve the full text of one article, therefore only 17 articles were assessed for the specified eligibility criteria. After the assessment, a total of 11 articles were suitable for inclusion in the review. A detailed document workflow using a flow diagram of the literature selection process is shown in Figure 1.

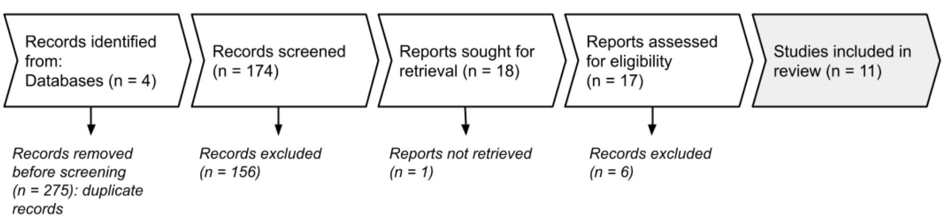

Figure 1
Flow diagram of literature selection process.

2.4 Data Analysis

The analysis of the articles started with an examination of the research goals and questions, the methodologies, and the study results. The relevant data were extracted from the articles and are summarized in Table 3. These data included research goals and questions, study design and methods, sample size, and variables measured (see Table 3). The authors then synthesized all the included papers and presented a narrative description of the findings with regard to the three research questions.

Table 3
Methodological details of empirical studies included in the review.

Authors (year)	**Aims**	**Sample size**	**Design**	**Variables/Measures**	**Eye-tracking metrics**
Antonietti et al. (2015)	investigating students' metacognitive monitoring and control when exploring a multimedia presentation with new information	*n* = 20	experimental + questionnaires	eye movements, psychophysiological measures, learning outcomes, metacognition	visual exploration, fixation length, number of fixations, time to the first fixation
Catrysse et al. (2018)	clarifying students' processing learning contents and its relation to their self-report of learning strategies	*n* = 20	quantitative approach + questionnaires	self-report measures, learning strategies, eye movements	first-pass fixation duration, second-pass fixation duration, total fixation duration in areas of interest
Eitel (2016)	investigating multimedia effect on across study-test cycles and which (meta) cognitive processes are associated with it	*n* = 79 (experiment 1); *n* = 55 (experiment 2)	experimental + questionnaires	study times, judgment of learning, learning outcomes, eye movements	fixation count, mean fixation duration, total fixation time
Fiorella and Pilegard (2020)	investigating how writing an explanation after studying a multimedia lesson influences restudy behavior (eye movements) and learning	*n* = 126 (experiment 1); *n* = 65 (experiment 2)	experimental + questionnaires	learning outcomes, eye movements	dwell time, number of integrative saccades, fixations
Mudrick et al. (2019)	investigating the influence of discrepancy in the learning materials on participants' metacognitive judgments and eye-movement behaviors	*n* = 32	experimental + questionnaires	eye movements, metacognitive judgments, learning outcomes, sequence mining	fixation duration, number of fixations, sequence of fixations
Park et al. (2020)	validating the use of Thinking-Aloud Protocols in learning studies	*n* = 120	experimental + questionnaires	learning success, eye movements, cognitive load, prior knowledge	proportion of fixation duration, transitions between areas of interest

Ruf and Ploetzner (2014)	investigating the effect of presenting cognitive learning aids, self-monitoring questions on the frequency of use of cognitive learning aids in multimedia materials	$n = 60$	experimental + questionnaires	learning performance, use of learning aids, usability of learning environment, eye movements	transitions between areas of interest, sequence of fixations
Scheiter et al. (2018)	investigating the effect of eye movement modelling on improving self-regulated learning from multimedia materials	$n = 50$	experimental + questionnaires	learning outcome, eye movements, domain-specific cognitive prerequisites	fixation time, transitions between areas of interest
Taub and Azevedo (2019)	investigating the impact of prior knowledge on students' fixations in self-regulated learning-related areas of interest and on the sequences of engaging in cognitive and metacognitive self-regulated learning processes with e-learning material	$n = 194$; $n = 30$ (eye-tracking part)	experimental + questionnaires	prior knowledge, proportional learning gain, fixation sequence of SRL, eye movements, sequence mining	proportions of fixations in areas of interests
Trevors et al. (2016)	investigating the relations between epistemic cognition and self-regulated learning	$n = 42$; 20	multi-study; mixed method design	prior knowledge, metacognition, eye movements, study time allocation, connotative aspects of epistemological beliefs	sequence and frequency of two transitions between fixations
Tsai et al. (2019)	investigating the influence of metacognitive intervention supported by eye tracking on the scientific evidence-based reasoning performance during online computer-based scientific reasoning tasks	$n = 80$	experimental	metacognitive intervention, visual attention, eye movements	number of fixations, total inspection time, mean fixation duration, number of saccades, total and mean saccade distance, number of re-readings, total re-reading time, mean re-reading duration

3. Results

A total of 11 empirical studies published between 2012 and 2021 were included in the presented narrative review. The selected empirical studies were originally published in the United States, Germany, Netherlands, Italy, and Taiwan. The outcomes of the narrative review were divided into four thematic areas based on the specific research questions: 1) self-regulated learning processes studied using eye-tracking technology, 2) methodological approaches used to study self-regulated learning processes, 3) structures and stimuli used in eye-tracking research of self-regulated learning processes, and 4) eye-tracking metrics in the study of self-regulated learning processes in the context of learning from multimedia learning materials. These thematic areas will be described in more detail in the following sections.

3.1 Self-regulated learning processes studied using eye-tracking technology

The goal of the first part of this section is to focus on the aspects of self-regulated learning processes that authors included in empirical studies. The authors of selected empirical studies are not unified in this respect; for this reason, the self-regulated learning processes of the given studies will be presented individually.

Antonietti et al. (2015) focused on the use of eye tracking and psychophysiological patterns to investigate self-regulated learning strategies, metacognitive monitoring, overall metacognitive awareness with a focus on memory index, and learning performance in multimedia processing depending on the type of multimedia learning materials (i.e., the differences between learning materials containing only text and images and materials supplemented by sound recording). According to Antonietti et al. (2015), eye tracking and psychophysiological measures can reveal when and why self-regulated decisions are made with respect to the multimedia materials. In addition, the authors anticipated a positive connection between the metacognitive processes and learning outcomes.

A different approach was chosen by Taub and Azevedo (2019) who extended their previous studies and focused on the effects of various levels of prior knowledge on the way learners fixate on authentic multimedia materials. In more detail, the authors focused on sequences in metacognitive and cognitive processes while studying, proportional learning gain, and prior knowledge level in relation to fixation proportions. Taub and Azevedo (2019) also included in their analyses the influence of prompts that appeared to participants during measurements. Catrysse et al. (2018) explored learning strategies during combinations of online and offline measurements using eye tracking technology to observe comprehension processes. In more detail, the authors aimed to investigate whether learning strategies are reflected in eye-tracking patterns.

A different direction was chosen by Mudrick et al. (2019) and Trevors et al. (2016), who focused on specific self-regulated learning processes such as judgment of learning, metacognitive monitoring processes, and meta-comprehension while learning from multimedia materials with a focus on the appearance of discrepancy in these materials (contradictory information in the materials). According to Trevors et al. (2016), discrepancies can induce epistemic cognition, which can have a consequent effect on self-regulated learning. Eitel (2016) focused on judgments of learning and learning outcomes while studying from various versions of multimedia material across a study-test cycle. Eitel (2016) expected higher levels of judgments of learning and learning outcomes when learning from text-and-picture learning materials and reduced learning time in repeated study material observations.

Tsai et al. (2019) focused on metacognitive intervention, specifically how metacognitive intervention can affect visual attention and scientific reasoning performance. Similarities with Tsai et al. (2019) can be found in the study by Scheiter et al. (2018) who focused on eye movement modelling during learning, i.e., on the influence of professional eye movements while learning on the learning outcomes of tested students. Ruf and Ploetzner (2014) concentrated their investigation on learning aids and the impact of self-monitoring questions on the use of learning aids. Ruf and Ploetzner (2014) assumed that students often did not use these learning aids because they were not aware of their own needs. Thus, self-monitoring questions should help identify student comprehension gaps and lead to enhanced use of learning aids.

In this part of our narrative review, we focused on self-regulated learning processes that can be investigated with eye-tracking technology. Based on the selected studies, researchers mainly investigate metacognitive processes and awareness of them, such as judgments of learning, metacognitive monitoring, and meta-comprehension. Studies were oriented on different learning strategies, the sequence of self-regulated learning processes while studying from various types of multimedia learning materials, and subsequent learning outcomes.

3.2 Methodological approaches used to study self-regulated learning processes

The empirical studies included in the narrative review had, in terms of methodology, quantitatively oriented designs. Most researchers used experimental designs to study self-regulated learning and self-regulatory processes, both between-subject designs (e.g., Fiorella & Pilegard, 2021; Scheiter et al., 2018) and within-subjects designs (e.g., Mudrick et al., 2019). The form of the experiment was subsequently adapted to the researched aspects and the authors of the selected empirical studies were thus not very unified in this respect in most cases. For this reason, this section of the narrative review is divided into three parts, in terms of the course of the procedure of the whole data collection, the structure of the eye-tracking experiment, and the topic of multimedia material.

With respect to the course of the data collection procedure, it is necessary to mention that the studies differed significantly, especially when using additional questionnaires or tasks other than an eye-tracking experiment. In general, the eye-tracking measurement was preceded by a set of questionnaires, which were usually initiated by a demographic questionnaire and followed by a metacognition questionnaire or self-regulated learning questionnaires. For example, Park et al. (2020) used a series of questionnaires that focused on prior knowledge of the topic used in experimental multimedia materials, study motivation, spatial skills, and visual-spatial memory, and then a test of academic success as a post-test. Catrysse et al. (2018) used a self-report questionnaire (Inventory of Learning Patterns-Short Version) that was partially focused on self-regulation in learning. Due to the experimental design of these studies, the authors in some studies created pre-tests (previous knowledge) and post-tests (learning performance) consisting of a series of multiple -choice questions related to the topic of multimedia material designed to verify the learning performance of selected participants (e.g., Fiorella & Pilegard, 2021; Mudrick et al., 2019; Taub & Azevedo, 2019). Catrysse et al. (2018) chose only one open question to explain the content of the learning materials the participants had completed. Antonietti et al. (2015) enhanced their eye-tracking experiment with psycho-physiological measurements, such as skin conductivity and temperature and pulse volume, while assuming better study performance in a group that had completed multimedia materials supplemented by audio recordings that were part of the experiment. Trevors et al. (2016) added log files to the eye-tracking data collection, supplementing the information about the passage through the multimedia learning material. Ruf and Ploetzner (2014), besides using pre-tests and post-tests to monitor learning performance, added a usability questionnaire composed of the ten statements focused on the subjective usability of the learning environment.

When focusing on the eye-tracking experimental procedure itself, the authors selected various approaches in terms of both experimental aims and the procedures. For example, a unique approach to the experimental procedure was adopted by Tsai et al. (2019), whose research group consisted of university students (science majors). Their aim was to complete five online study modules with hyperlinks that linked to each other. The metacognitive intervention took place in the second read of the multimedia materials. In the second part of the measurement, students were shown their own eye movements so that they could cover the areas they had missed during the first part of the measurement. A similar approach was chosen by Scheiter et al. (2018) who focused on the influence of eye movement modelling on self-regulation and learning performance. The aim was to show the eye movements recorded from an expert learner while learning from text-and-picture learning material to the experimental group and let them study the same material afterward. Meta-cognitive intervention in other studies was created using inference questions on individual pages of multimedia materials (e.g., Mudrick et al., 2019; Trevors et al., 2016). Fiorella and Pilegard (2021) created an experiment that was based on prompts, which were included in the procedure in the form of explanations during the passage through the learning materials. Park et al. (2020) focused on the effect of multiple factors, i.e., think-aloud protocols and the effect of seductive details; thus, they created four groups for the experimental purpose. Ruf and Ploetzner (2014) used three types of learning aids – static (support area is always in the fixed position), dynamic (support area is animated after a certain amount of time) and collapsed (to make the support area visible, learner must click on a start button). Furthermore, in experimental groups, the self-monitoring questions appeared after each learning unit. However, Ruf and Ploetzner (2014) used the eye-tracking device only to monitor whether the learner visited certain learning units and also how many times these learning units were visited.

From a methodological point of view, the majority of the authors decided to design their research quantitatively and used an experimental design for both between-subject and within-subject designs. The experimental procedure in most cases consisted of multiple parts: the questionnaires (e.g., demographic questionnaires, questionnaires focused on self-regulatory and metacognitive processes or learning performance, i.e., pre-tests and post-tests) and additional measurements (e.g., psychophysiological measurements or log-files).

Structures and stimuli used in the eye-tracking research of self-regulated learning processes

Regarding the structures of the experiments and the stimuli used in them, such as the topic of the multimedia learning materials or the graphic design, both artificial learning materials created for the purpose of the experiment (e.g., Antonietti et al., 2015; Catrysse et al., 2018; Mudrick et al., 2019; Trevors et al., 2016) and authentic learning materials (Taub & Azevedo, 2019) have been used. Multimedia materials (both artificial and authentic) were made up of a grouping of a different number of pages, one side of the material then contained a text part, a picture or graph, or an inference question (e.g., Mudrick et al., 2019; Park et al., 2020; Trevors et al., 2016). The number of pages and the position of the text, image, or additional stimuli were always individually spaced, but frequently the text was positioned on the left side of the page and the graph or image was on the right (e.g., Antonietti et al., 2015).

Thematically, the multimedia materials diverged. Antonietti et al. (2015) and Fiorella and Pilegard (2021) decided to create material on a topic for they assumed low knowledge in the studied population. Park et al. (2020) created multimedia material for a study group (psychology students) based on a biochemical topic. A similar approach can be seen in the experimental learning materials of Scheiter et al. (2018), in which university students of study areas other than biology were measured in the multimedia materials on the topic of cell division. Ruf and Ploetzner (2014) decided to create multimedia learning material based on the two textbooks about sailing. The final version of the learning material consisted of text, images, and animations focused on the mechanisms of sailing. Eitel (2016) created multimedia material thematically focused on a toilet flushing system consisting of text and/or a combination of text and picture.

In contrast, Taub and Azevedo (2019) took advantage of an authentic e-learning multimedia environment from a thematic area that was relatively close to the selected measured population. The structure was also adapted to an experimental condition. Mudrick et al. (2019) and Trevors et al. (2016) adapted the multimedia material structure to create content disparity on each side of the material. The experiment thus contained three types of material (without a discrepancy, with a discrepancy between text and text, or with a discrepancy between text and graph). Different types of discrepancies can induce different metacognitive decision-making responses, which will also affect eye movements during learning from multimedia materials (Mudrick et al., 2019). Park et al. (2020) used seductive details, which were made up of additional and highly interesting information, but irrelevant to the learning material.

In conclusion, when focusing on the structure of the eye-tracking experiment and chosen stimuli topic, two methods of experimental preparation appeared: 1) creating artificial learning material adjusted to the research purposes or 2) using authentic (e-learning) material. Thematically, topics both known and unknown to the participants were used. The structure of the multimedia material (i.e., number of pages, amount of text, and number of pictures per slide) varied widely depending on the research questions.

3.3 Eye-tracking metrics in the study of self-regulated learning processes

When using eye tracking to investigate self-regulatory and metacognitive processes during learning, it is also necessary to focus on eye-tracking metrics that enter subsequent data analyses. The selection of eye-tracking metrics may vary according to the chosen methodological approach, but the empirical studies included in the presented analysis were mainly quantitatively oriented studies. In general terms, the authors of the studies focused primarily on the two fundamental metrics that enter eye-tracking analyses most frequently:

fixation and saccades. Fixation is an eye movement during which the eye gaze is maintained in one location and the perception and processing of the observed scene (e.g., reading a text or watching a picture) occurs (Ciuffreda & Tannen, 1995). Saccades are very rapid eye movements that aim to direct the visual axes so that the image of the observed object hits the point of sharpest vision (fovea) (Duchowski, 2007). During saccadic eye movements, a saccadic suppression occurs and no visual information is processed (Ciuffreda & Tannen, 1995).

A key element to mention before analyzing eye-tracking metrics themselves are the areas of interest. These are self-made areas within stimuli that were part of eye-tracking measurements. For example: one slide of multimedia learning material contains a title, a paragraph of text, and a picture. Individual areas of interest (with respect to research purposes) can be created on the title, the paragraph of text, and the picture. These areas of interest make it possible to perform a deeper analysis of eye-tracking metrics (e.g., fixations, saccades, or transitions between each area of interest). Most of the authors of the selected empirical studies worked in their analyses precisely with the areas of interest created, which included key elements for input into the analysis in the stimulus created (e.g., Antonietti et al., 2015; Catrysse et al., 2018; Mudrick et al., 2019). For example, Mudrick et al. (2019) created areas of interest in places that were key to analyzing eye-tracking data (sections with text, graph, and inference questions) within a given stimulus (e.g., tutorial slides). Trevors et al. (2016), whose areas of interest delimited the text and the graph, followed a similar pattern. Scheiter et al. (2018) created two areas of interest on each slide, one area of interest on the picture and the second on the text. The form of experiment and chosen stimuli were discussed in the previous section.

Within the presented areas of interest, it is possible to focus on a deeper analysis of selected eye-tracking metrics. Many authors dealt with the total time spent on the slide (Catrysse et al., 2018) and the time repeatedly spent on the slide (Tsai et al., 2019). The authors also considered the dwell time, which is the total time spent in a given area of interest (Fiorella & Pilegard, 2021; Scheiter et al., 2018). Increased time spent on the site or in a specific area of interest may indicate an increased cognitive load (Scheiter et al., 2018).

Fixations can be considered a key eye-tracking metric for most authors of the selected studies, who subsequently focused on the detailed parameters of fixations. The most recurrent parameter was the fixation duration in given areas of interest (e.g., Antonietti et al., 2015; Catrysse et al., 2018; Fiorella & Pilegard, 2021; Mudrick et al., 2019; Tsai et al., 2019). The fixation duration is related to the cognitive processing of the observed object; excessive fixation duration may indicate the complexity of processing the stimulus for the observer (Antonietti et al., 2015). Depending on the research and analysis needs, the authors worked with the average fixation in interest or with the total fixation duration in the given areas of interest (Mudrick et al., 2019; Tsai et al., 2019) or on the whole stimulus (Catrysse et al., 2018). Catrysse et al. (2018) and Antonietti et al. (2015) focused on detailed values of fixation duration and distinguished this metric into first-pass fixation duration; Catrysse et al. (2018) also considered second-pass fixation duration in the areas of interest. The ability to orientate oneself in each environment can also be shown by the total number of fixations, both in the given area of interest and on the whole stimulus (Antonietti et al., 2015). The total number of fixations in their analyses was used, for example, by Antonietti et al. (2015), Mudrick et al. (2019), and Tsai et al. (2019). To be able to work with fixations in different areas of interest, the frequency of fixations in these areas was also used. Mudrick et al. (2019) extended their analysis with a sequence of fixations in individual areas of interest, i.e., the order of fixations, which shows how the participant worked and proceeded with the learning material. A different approach was suggested by Taub and Azevedo (2019), who worked with the proportions of fixations, which were calculated from a multiple of the average fixation duration and the fixation frequency divided by the total duration of the experiment. Park et al. (2020) also worked with the ratio of fixation duration to total learning time, with the percentage serving as an indicator of visual attention. Eitel (2016) focused on the number of fixations in specified areas of interest, mean fixation duration on a text, and overall fixation time.

As in the case of fixations, the authors focused on a deeper analysis of the transition between the two fixations (i.e., saccades), although the incidence of this metric was lower than the fixations. Saccades and their more detailed parameters were used only in the analyses by Tsai et al. (2019) and Fiorella and Pilegard (2021). Tsai et al. (2019) focused on the number of saccades and the total and average distance of the saccades. Fiorella and Pilegard (2021) then used the so-called integrative saccades in their analysis, which they described as saccadic transitions between multimedia stimuli on the page (e.g., between text and image). These long saccades between individual areas of interest were also used by other authors who referred to this movements as transitions. Transitions between different areas of multimedia materials (e.g., text and image/graph) can provide more detailed information on learning strategies and are also a suitable indicator of cognitive activity (Park et al., 2020; Trevors et al., 2016). Transitions between different areas of interest (texts and pictures) were used also by Scheiter et al. (2018).

As all the empirical studies included in this review were based on using eye-tracking technology, it is also necessary to summarize the eye-tracking metrics used in them. The focus was mainly concentrated on the fixations, saccades, and transitions between selected areas of interest. In order to analyze the fixations, some detailed parameters were chosen (e.g., fixation duration, number of fixations, and order of fixations). The occurrence of saccadic parameters was lower than the fixations. However, some authors decided to analyze specific parameters of saccades (e.g., number of saccades, total and average distance of saccades). With longer saccades, the authors also mentioned the transitions, which are basically the saccade between two fixations. This metric measured the number of skips from one area of interest (e.g., text) to another (e.g., picture, graph, or inference question) and can show the different approaches of students to multimedia learning material.

Conclusion

Our narrative review was dedicated to the actual field of using eye-tracking technology to investigate the relation between eye movements and self-regulated learning from multimedia materials. In our review, we discovered that research using eye-tracking technology in the field of self-regulated learning is a new area and the related empirical studies showed a broad spectrum of different methodological approaches to studying this topic.

The presented narrative review has considerable limits. The review includes a limited number of studies published between 2012 and 2021, providing only a bounded insight into the research of using eye-tracking technology to study self-regulated learning processes while learning from multimedia materials. The inclusion and exclusion criteria of empirical studies were relatively strict. However, the criteria make it possible to present a clear view of the selected thematic area.

This narrative review provides a summary of current directions in eye-tracking research dealing with self-regulated learning from multimedia materials. In particular, the results show which self-regulatory and metacognitive processes in learning from multimedia materials are currently the main focus of investigation, how these processes are measured using eye-tracking technology with a special focus on the methodological perspective and experimental structure and stimuli, and what eye-tracking measures are considered useful for data analysis.

The results of our narrative review can offer new insights for investigators researching self-regulated learning from multimedia materials with the use of eye-tracking technology. Future research may explore in more depth the relations among various concepts (e.g., learning strategies, judgments of learning, and learning outcomes) while studying from multimedia materials in connection to recorded eye movements. This may provide further information about self-regulatory processes. This information could in turn improve the quality of the multimedia materials and subsequently help university students with learning processes.

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