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Eye Tracking Technology in Mathematics Education Research: A Literature Review

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Abstract: *Eye Tracking technology (ET) has been increasingly used in educational research in recent years as it facilitates precise and non-invasive tracking of eye movements, providing valuable information about cognitive processes and visual behaviour. In terms of mathematics education research, ET has been employed in various fields and contexts to investigate students' thinking and learning process. This study entails a literature review of 64 articles focused on the integration of ET technology in mathematics education, published between 2020 up to February 2025. Our first objective is to classify the domains and topics in which ET technology was used. Most studies revolve around arithmetic, algebra, geometry and statistics with the following topics: fractions, number line estimation, representations, problem solving, geometric shapes and data interpretation. In addition, the considered articles relate to various psychological concepts such as eye-mind hypothesis, processes of perception and determination, cognitive load, math anxiety, judgement accuracy and process, mental rotation. Our second aim is to analyse the limitations and challenges faced by researchers while using ET in mathematics education as well as their suggestions for further research. Considering that a vast percentage of the studies are centred on the eye-mind hypothesis (EMH), it is imperative to further investigate the relationship between eye movements and cognitive processes. Bearing in mind the inconsistent set of measurements gathered for data interpretation in these articles, from duration and count of fixations and transitions, number of horizontal and vertical saccades, pupil dilation, and dwell time, a clear need for future methodological research surfaces. In conclusion, we highlight the need and the potential of future research in mathematics education using Eye Tracking technology.*

Keywords: *eye tracking; mathematics education; literature review; cognitive processes; visual attention.*

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Introduction

Eye Tracking technology in education research

The interest in Eye Tracking technology (ET) has increased in the last ten years, including the field of education research. ET provides a clear method to see which segments of the visual stimulus captured the participant's attention and how long that attention was held (Rehder & Hoffman, 2005).

Eye tracking – what is it and how does it work?

Eye tracking is a technology based on sensors that detect, measure and record the gaze's position and movement. It is made of the following distinct elements(Carter & Luke, 2020): a light source that creates patterns on the eye, a camera that captures those reflected patterns on the cornea and pupil and a processor with ET specific packages. It can be implemented with specialised devices – ET glasses or desk-mounted apparatus.

The use of ET technology follows these steps, thus facilitating precise and non-invasive tracking of eye movements:

1. An infrared light illuminates the eyes, generating patterns on the cornea and pupil
2. A camera captures images of the eyes and the reflection
3. Using specialised algorithms, the captured images lead to a 3D representation of the eye, enabling accurate gaze point identification (Paskovske&Kliziene, 2024).

Eye tracking in mathematics education research

In mathematics education research, ET technology was used in various fields and contexts, mainly to investigate students' thinking and learning processes (Strohmaier et al., 2020).

ET technology, supported by complementary research methods, offered valuable insight into students' attention and thinking processes (Norqvist et al., 2023), means to engage students in conceptual thinking and development (Solstad et al., 2024), visual strategies used in the process of interpreting graphs (Thomaneck et al., 2022), strategies used while problem solving (Türkoğlu & Yalçınalp, 2024), teachers' professional vision of classroom management (Stahnke & Friesen, 2023), mathematics anxiety (Blini et al., 2024).

A vast amount of studies are based on the eye-mind hypothesis (EMH) that assumes the existence of an adjacent connection between fixations and cognitive processes (Just & Carpenter, 1976).

Nonetheless, several studies proved the limitations of EMH as Strohmaier et al. (2020) and Schindler & Lilienthal (2019) have noted, inferring that the connection between eye movements and cognitive processes must be closely investigated to decrease ambiguity and inconsistency in data interpretation.

Previous literature reviews

Strohmaier et al. (2020)conducted an extensive systematic literature review about ET methodology in mathematics education research and they revised 161 studies issued over the span of 1921 - 2018. Their work assessed domains, topics, the implementation of the ET method and how eye movements were connected to mathematical thinking.

Another systematic review by Paskovske & Kliziene (2024)focussed on ET technology on children's mathematical education and analysed 17 studies. The review detailed how elementary school students' problem-solving skills had been studied with ET technology.

The literature review of Bairral and Aldon (2024)investigated three ET studies in the field of geometry where digital technology was integrated in task design. Their examination revolved around geometry domains where digital technology was integrated and the ET methods used in the three studies.

The present study offers a literature review of Eye Tracking Technology studies in mathematics education research between the years 2020 and 2025 revealing the recent focus on emerging tendencies in research such as AI integration(Ruf et al., 2024), machine-learning (Schindler et al., 2022), incentive system design for digital game-based learning (Lomos et al., 2023)and ET for collaborative creative process (Schindler & Lilienthal, 2022).We highlight ET's role in teacher training (Schnitzler et al., 2020), teacher metacognition (Da Silva Soares et al., 2021), classroom management (Stahnke & Friesen, 2023), math anxiety and emotion recognition (Lal et al., 2024).

The interdisciplinary insights of this review include connecting ET with functional magnetic resonance imaging data – fMRI (Moen et al., 2020), AI(Ruf et al., 2024), digital learning environments (Lal et al., 2024)and VR (Kosko et al., 2024). We also examined articles with understudied population such as infants (Viktorsson et al., 2023), development coordination disorder (Gomez & Huron, 2020)and deaf or hard hearing students (Schindler et al., 2022), participants with Down and Williams syndromes (Ranzato et al., 2020). In addition, this study summarises the ET software used by researchers and catalogues the limitations, challenges and further suggestions provided in the studies in order to offer an overview of ET technology potential.

Present study – objectives, research questions

We conducted a literature review of studies from the Web of Science database about ET technology in mathematics education research from 2020 to 2025. Our study concentrated on the following two aims and associated research questions.

The main aim was to identify and classify the domains and themes related to mathematics education research where ET technology was used.

RQ1: What are the domains and themes related to mathematics education research where Eye Tracking technology was used?

Our second aim was to analyse the limitations and challenges that researchers encountered and their suggestions for further studies.

RQ2: What are the limitations and challenges that researchers encountered in their studies?

RQ3: What are the suggestions proposed in order to further research ET technology in mathematics education research?

Methodology – PRISMA

Our paper selection process can be divided in three steps (see Figure 1):

1. We searched the Web of Science database for studies in mathematics education domain that employed ET technology. The years of publication ranged from 2020 to February 2025. The search was conducted on 16 February 2025. The search query we used was (eye OR gaze) AND (movement* OR track* OR record*) AND (math*) and revealed a total of 1008 studies, which were integrated in Zotero software.

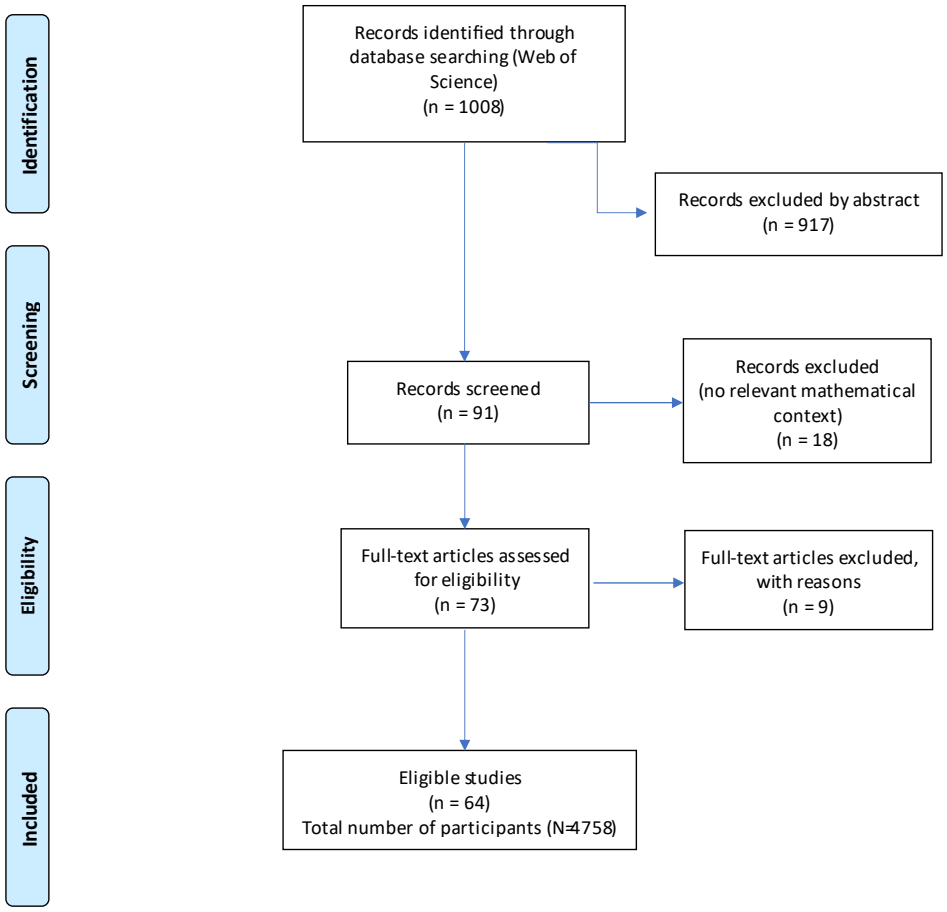
2. We screened titles and abstracts searching for studies that were printed in journal articles, conference proceedings or in book chapters, in English and their theme was related to ET technology. This process generated an exclusion of 917 articles with titles and abstracts that did not respect the conditions.

3. The remaining 91 articles were filtered by eliminating the ones that had no relevant mathematical context and the ET data was not broadly connected to mathematics. After this step, 18 articles were excluded.

4. From the remaining 73 articles we excluded theoretical and review articles and studies that didn't report the results in an extensive manner, thus eliminating 9 studies.

The final selection included 64 eligible studies which will be discussed in the following sections.

Figure 1. Prisma flow diagram



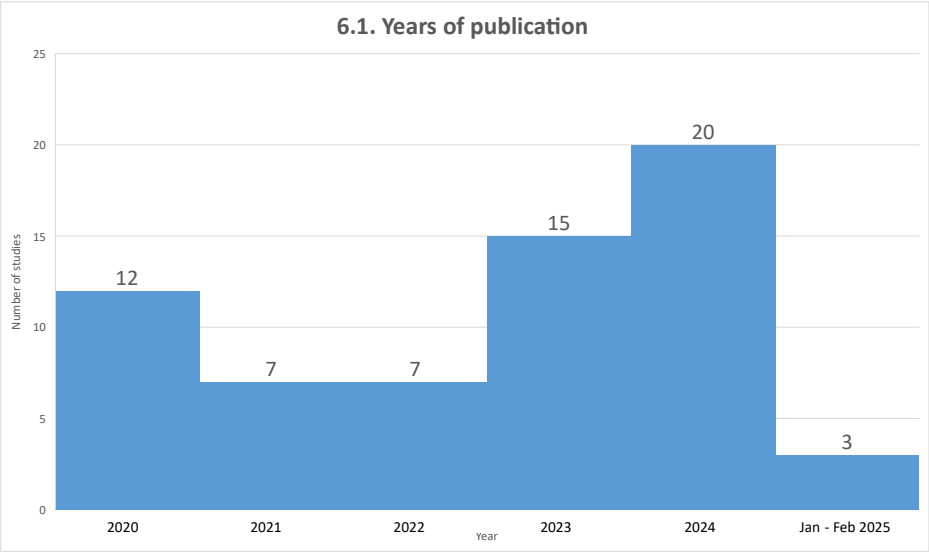
Source: the authors' own conception

Results

Years of publication

This literature review analysed studies from 2020 to February 2025. In 2020 a total of 12 studies concerning mathematics education were published, in 2021 and 2022 only 7 articles appeared each year and in 2023 there was a noteworthy upsurge to 15 articles. The highest number of studies (20) were conducted in 2024 and 3 studies were published between January and mid-February 2025, suggesting that ET technology is increasingly used in mathematics education research (see Figure 2).

Figure 2. Years of publication

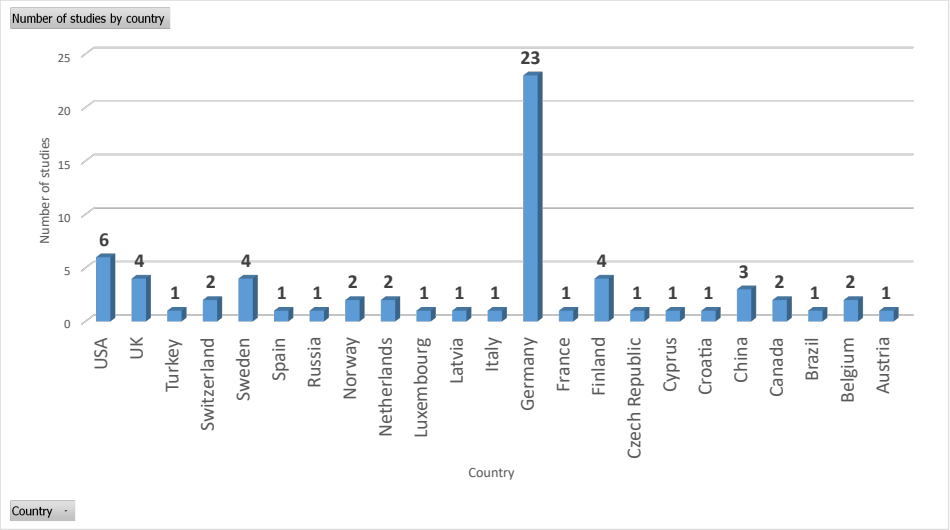


Source: the authors' own conception

Country of origin

A number of 52 studies selected in this review originated from Europe (Austria, Belgium, Croatia, Czech Republic, Finland, France, Germany, Italy, Latvia, Luxembourg, Netherlands, Norway, Russia, Spain, Sweden, Switzerland, United Kingdom), 5 studies from Asia (China, Cyprus, Turkey), 8 from North America (Canada and USA) and 1 article from South America (Brazil).The majority of studies originated in Germany (23). Two studies mentioned two countries of origin. Klein et al. (2020) and Becker et al. (2022) conducted research in Germany and Switzerland (see Figure 3).

Figure 3. Country of origin

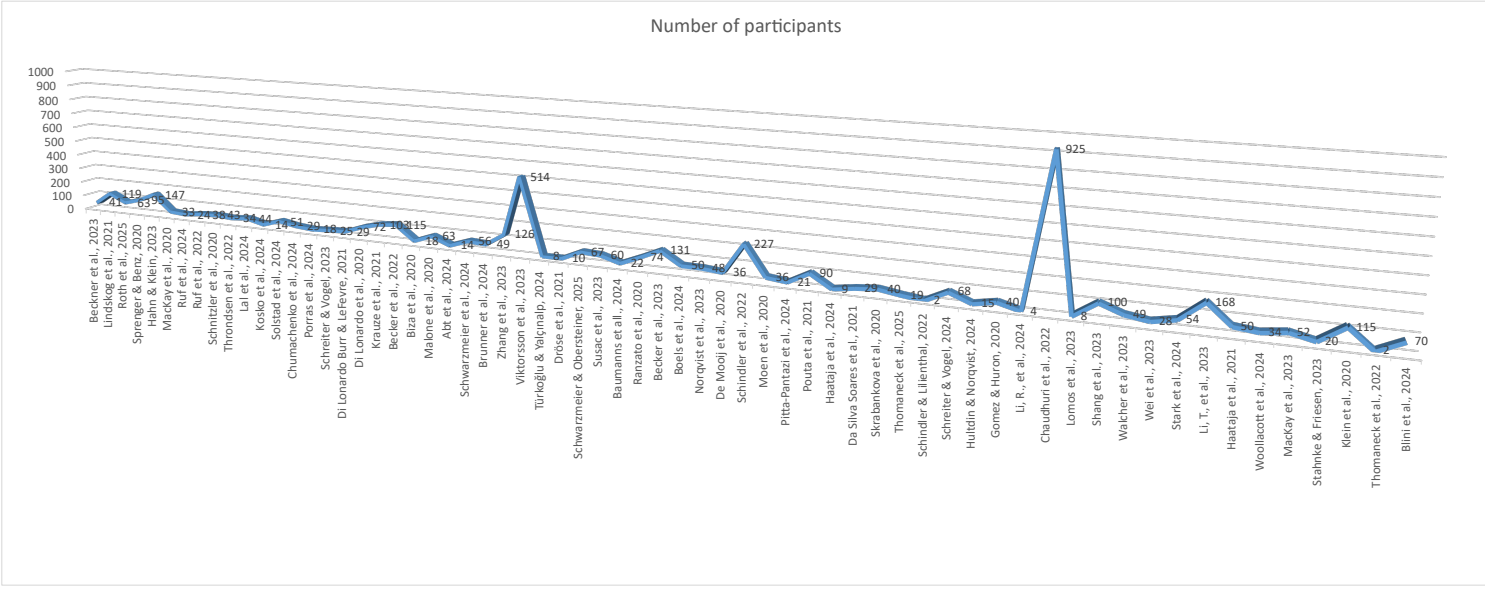


Source: the authors' own conception

Participants

The number of participants ranged from 2 to 925. Schindler and Lilienthal (2022) and Thomaneck et al. (2022) worked with only 2 participants, graduate university students. Viktorsson et al. (2023) examined a sample of 514 five months old twins and Chaudhuri et al. (2022) conducted a study with 925 participants (46 teachers and 879 first grade students). The average number of participants is 74 (see Figure 4).

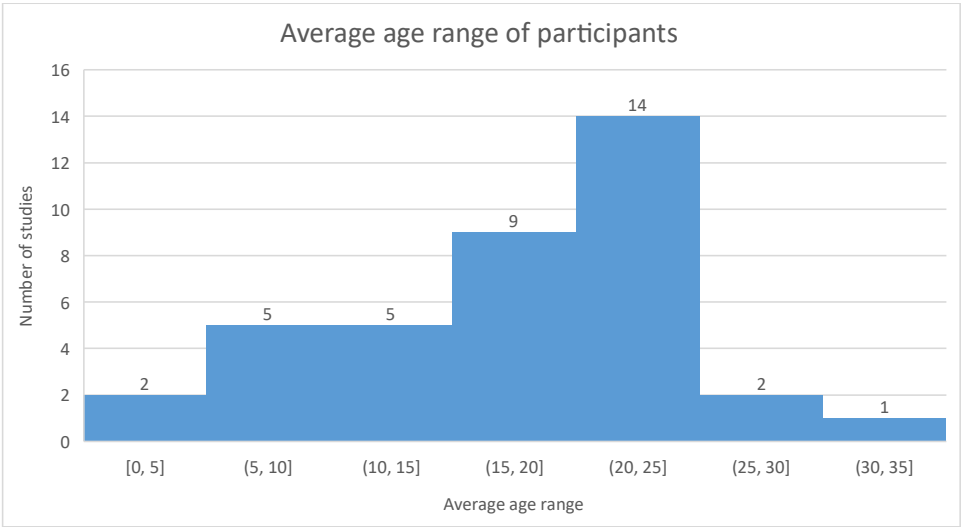
Figure 4. Number of participants per study



Source: the authors' own conception

The average age range of participants as shown in the following histogram illustrates that the mean age from all the studies is 17.74. It is noteworthy to mention that not all articles presented this information about their participants (see Figure 5).

Figure 5. Average age of participants

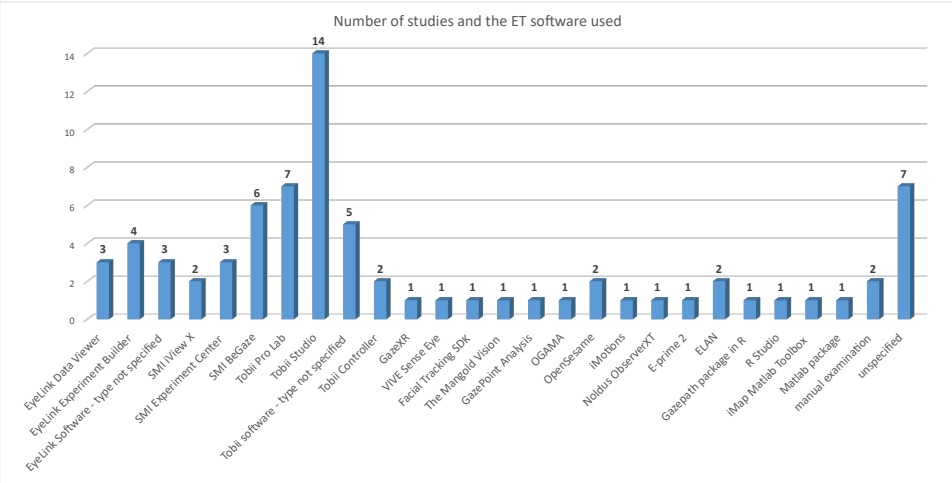


Source: the authors' own conception

Eye tracking software

The majority of studies operated with ET software from Tobii (28), SMI (11) and EyeLink (10). However, it is noteworthy to mention that some articles used open-source software such as OpenSesame (2) and OGAMA (1) and approximately 11% of research papers didn't clearly state the employed ET software. The lack of a detailed name for the employed ET software or the ET apparatus encountered in some studies is an important drawback (see Figure 6).

Figure 6. Eye Tracking Software

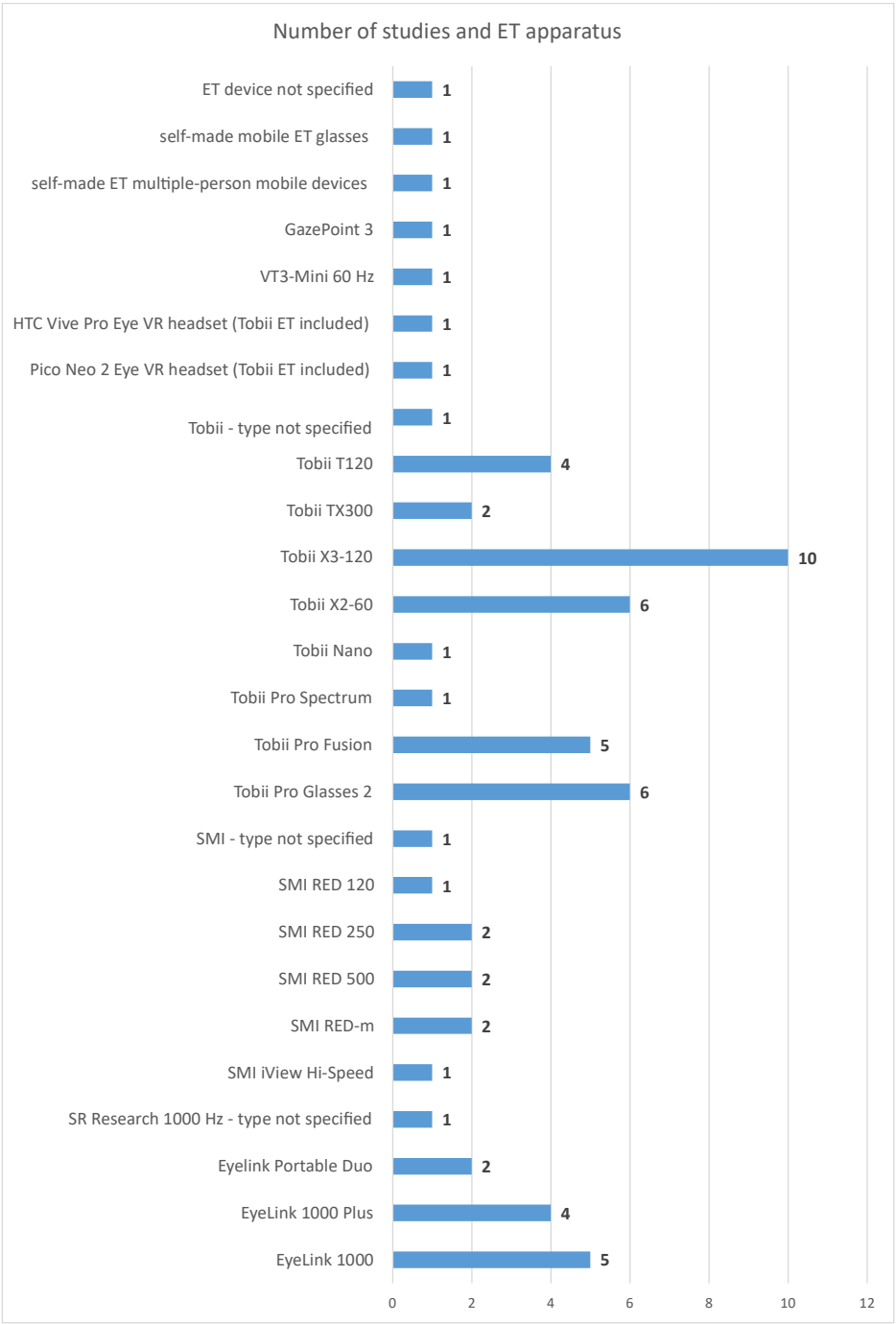


Source: the authors' own conception

Eye tracking apparatus

Concerning the ET equipment, the majority of the studies operated with Tobii (36), EyeLink (12) and SMI (9) static or mobile devices to capture and measure eye movements (see Figure 7). One study doesn't specify the ET device that was used and 2 studies are based on self-made ET apparatus (Haataja et al., 2024; Haataja et al., 2021). The most frequently employed ET device was Tobii X3-120 (approximately 15% of the studies).

Figure 7. Eye tracking apparatus

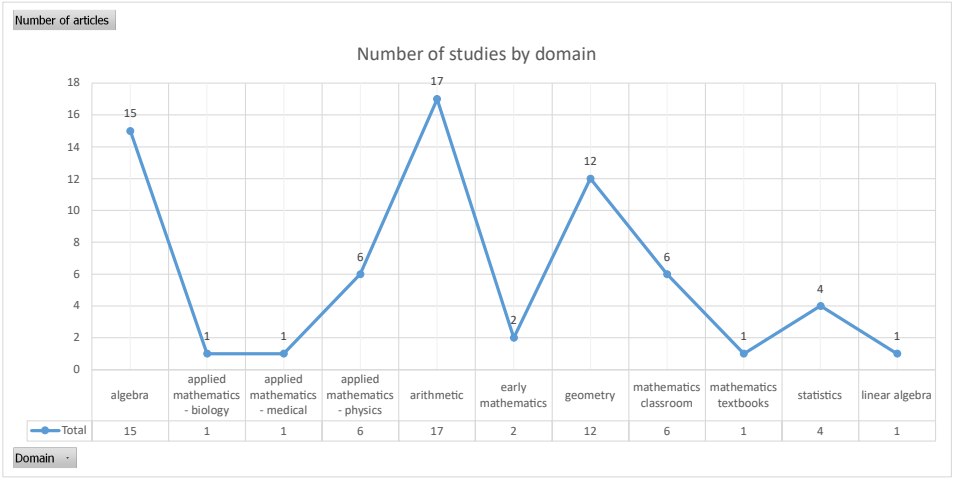


Source: the authors' own conception

Domains and themes related to mathematics education

The 64 studies analysed in this review were focussed on arithmetic (17), algebra (15), geometry (12), applied mathematics – physics (6), mathematics classroom (6), statistics (4), early algebra (2), linear algebra (1), mathematics textbooks (1), applied mathematics – biology (1), applied mathematics – medical (1). The majority of studies revolved around arithmetic and algebra (see Figure 8).

Figure 8.Mathematical domains discussed in studies



Source: the authors' own conception

In terms of mathematics related topics that were addressed, the studies were first organised by context: geometry, arithmetic, representations, algebra, statistics, cognitive processes, digital learning, mathematical writing and mathematics classroom. Several topics were registered for each context as shown in the table above. Some studies were associated with a single topic - Schwarzmeier & Obersteiner (2025) investigated fractions and the skill to visually compare fractional values, whereas other studies were linked to several topics - researchers Da Silva Soares et al. (2021) examined student's perspective and teacher's metacognition, exploring the teachers' interpretation of ET videos where students worked on mathematical tasks (see Table 1).

The frequently discussed themes were fractions and rational numbers (7), graphical representations (7), 2D and 3D geometrical shapes (6), problem solving (6), number line estimation (4) and the use of Geogebra platform (4).

Table 1. Mathematical topics

Mathematical context	Topics	Number of studies	Studies
Geometry	coordinate geometry	1	Lal et al., 2024
	mental rotation and spatial thinking	3	Beckner et al., 2023; Moen et al., 2020; Stark et al., 2024
	shape matching	1	Lal et al., 2024
	2D and 4D geometric shapes	6	Solstad et al., 2024; Chumachenko et al., 2024; Krauze et al., 2021; Schindler & Lilienthal, 2022; Haataja et al., 2024; Stark et al., 2024
Arithmetic	approximate number system	3	Viktorsson et al., 2023; Gomez & Huron, 2020; Lindskog et al., 2021
	fractions and rational numbers	7	Schwarzmeier et al., 2024; Brunner et al., 2024; Schwarzmeier & Obersteiner, 2025; Pouta et al., 2021; Shang et al., 2023; MacKay et al., 2023; Stahnke & Friesen, 2023
	mental arithmetic	3	Porras et al., 2024; Walcher et al., 2023; Blini et al., 2024
	subitizing and counting	2	Gomez & Huron, 2020; Ranzato et al., 2020
	multiplication and other operations	3	Throndsen et al., 2022; Kosko et al., 2024; De Mooij et al., 2020
	number line estimation	4	MacKay et al., 2020; Di Lonardo Burr & LeFevre, 2021; MacKay et al., 2023; Di Lonardo et al., 2020

	small number enumeration process	1	Schindler et al., 2022
	number processing, numerical cognition, number system	2	Lindskog et al., 2021; Roth et al., 2025
Statistics	data distribution	2	Schreiter & Vogel, 2023; Schreiter & Vogel, 2024
	interpreting statistical data	2	Skrabankova et al., 2020; Schreiter & Vogel, 2024
	statistical diagrams - boxplot, dot plot, histograms	3	Abt et al., 2024; Boels et al., 2024; Schreiter & Vogel, 2024
Representations	diagrams	2	Woollacott et al., 2024; Ruf et al., 2022
	graphical representations	7	Hahn & Klein, 2023; Ruf et al., 2024; Ruf et al., 2022; Brunner et al., 2024; Susac et al., 2023; Skrabankova et al., 2020; Becker et al., 2023
	graphs of position, velocity, and acceleration versus time	2	Becker et al., 2022; Klein et al., 2020
	vector field plot	2	Ruf et al., 2022; Hahn & Klein, 2023
	contextual graphs	2	Thomaneck et al., 2025; Thomaneck et al., 2022
Algebra	functions and covariation	2	Thomaneck et al., 2025; Thomaneck et al., 2022
	equations and linear systems of equations	3	Hahn & Klein, 2023; Ruf et al., 2022; Malone et al., 2020

	quadratic sequences	1	Biza et al., 2020
	sets	1	Sprenger & Benz, 2020
Cognitive processes	problem solving	6	Türkoğlu & Yalçınalp, 2024; Dröse et al., 2021; Norqvist et al., 2023; Schindler & Lilienthal, 2022; T. Li et al., 2023; Roth et al., 2025
	collaborative problem solving	1	Haataja et al., 2024
	collaborative creative process	1	Schindler & Lilienthal, 2022
	math anxiety and math performance	3	T. Li et al., 2023; Blini et al., 2024; Throndsen et al., 2022
	pattern recognition	2	Baumanns et al., 2024; Pitta-Pantazi et al., 2024
	problem posing	1	Zhang et al., 2023
	word problems and text processing	2	Roth et al., 2025; Dröse et al., 2021
	learner emotions recognition	1	Lal et al., 2024
Digital learning	digital game-based learning	2	De Mooij et al., 2020; Lomos et al., 2023
	Geogebra	4	Lal et al., 2024; Türkoğlu & Yalçınalp, 2024; Haataja et al., 2024; Haataja et al., 2021
	online math learning environment	1	De Mooij et al., 2020

	online word problem solving	1	Wei et al., 2023
	SmartPens	1	Haataja et al., 2024
Mathematical writing	multiple external representations (MER)	2	Malone et al., 2020; Susac et al., 2023
	mathematics textbooks	1	Woollacott et al., 2024
	alternative arrangements of mathematical symbols and words representations	1	Hultdin & Norqvist, 2024
Mathematics classroom	teacher's judgment process and accuracy	1	Schnitzler et al., 2020
	math learning difficulties (MLD)	1	Wei et al., 2023
	teachers' scaffolding behaviour	1	R. Li et al., 2024
	student's perspective	1	Da Silva Soares et al., 2021
	teacher's metacognition and competence	2	Da Silva Soares et al., 2021; R. Li et al., 2024
	teachers' individual support for students	1	Chaudhuri et al., 2022
	professional vision of classroom management	2	Stahnke & Friesen, 2023; Kosko et al., 2024
	teacher's visual focus and teacher-student interaction	2	Chaudhuri et al., 2022; Haataja et al., 2021

Source: the authors' own conception

Psychological context

While analysing the psychological context we focussed on attention, emotions, memory and cognition, cognitive processes, teachers and classroom management and digital learning. As shown above, the majority of studies investigated attention with topics of attention control theory (ACT), visual attention, attention-bias induced by stimulus control and perception and determination (19), teachers and classroom management in terms of student engagement, teachers' professional noticing, teachers' judgement accuracy and judgement process, prediction of student response behaviour, student learning style and pedagogical content knowledge (19) and cognitive processes with following underlying concepts: development of mental rotation, mathematics cognition, problem solving behaviour, problem posing, collaborative process, coordination strategies, statistical thinking and number estimation (21) (see Table 2).

Table 2. Psychological context

Context category	Psychological context	Number of studies
attention	visual attention	19
	attention control theory (ACT)	
	attention-bias induced by stimulus control	
	perception and determination	
emotions	math anxiety	4
	real-time emotion detection	
memory and cognition	working memory	6
	cognitive load	
	cognitive effort	
cognitive process	development of mental rotation	9
	number estimation	
	math cognition	
	comprehension skills	
	conceptual / non-conceptual thinking	
	statistical thinking	12
	problem posing	
	problem solving behaviour	
	collaborative process	
	coordination strategies	
teachers and classroom management	pedagogical content knowledge	19
	student engagement	
	teachers' professional noticing	
	teachers' judgement accuracy and process	
	prediction of student response behaviour	
	student learning style	
digital learning	machine learning	7
	digital learning environments	
	VR systems	
	incentive system design	

Source: the authors' own conception

Eye tracking methodology

As previous literature reviews have stated, we have identified an abundance of measurements associated with ET. A clear and concise methodology of using this technology in education research is yet to be defined.

The most frequent measurements used in the analysed studies were fixation count (number of fixations), fixation duration (gaze duration, fixation time), dwell time (total fixation duration), saccade count, areas of interest (AOIs) defined and mean fixation duration. Several researchers employed various metrics specifically defined for their particular study: transitions count (number of direct gaze shifts between two areas of interest - Malone et al., 2020), between-tape saccades (saccades that take place between the two visualizations - Schwarzmeier et al., 2024), within-tape saccades (saccades that take place within a visualization -Schwarzmeier et al., 2024), net dwell time (the duration of students' gaze on words associated with syntactic structures - Dröse et al., 2021), time of interest TOI (points in time when the teacher's eye movements was fixated in an AOI - Pouta et al., 2021).

Various studies investigated and interpreted gaze plots, heatmaps and scan paths generated by ET software in relation to the targeted mathematics domain, topics and psychological context. Heatmaps indicate the density or duration of the fixations from a group of participants by alternating colours or opacity (Drusch et al., 2014). A scan path is a general name for the pattern of fixations and saccades an individual makes while viewing something and it describes the trajectory of their eye movements over time (Kosel et al., 2021), whereas a gaze plot is a specific visual representation of a scan path where fixations are represented as circle sand saccades as lines for saccades, showing the sequence of eye movements (see Table 3).

This inconsistency in ET methodology makes it difficult to understand the connection between ET measurements and cognitive processing.

Interpretation of eye movements

The eye movements data generated by specialised software is translated into ET measurements that need careful interpretation. Based on other conducted studies and in relation to their mathematical topics and psychological context, researchers assigned different interpretations as shown below (see Table 4).

The data listed in Table 4 has been reproduced as reported in the original studies by the researchers presented in the first column in order to preserve the integrity and intended meaning of their analyses.

By analysing this data (see Table 4) and considering, for example, the fixation count measurement, we have observed that Schreiter & Vogel (2023) understand it as the amount of attention on an area of interest (AOI) and Chaudhuri et al. (2022) state that the fixation count indicated how visible and important a certain target was considered (an element that is more important is related to a higher number of fixations). Chumachenko et al. (2024) interpreted that adults have a lower fixation count as opposed to children. In addition, since adults and some of the children can distinguish a figure without directly looking at it, the same researchers concluded that fixations may even be absent as extrafoveal analysis can support perception. Porras et al. (2024) view the fixation count as an indicator of the level of overt visual attention or depth in information processing; interpreting longer fixations as indicators of greater cognitive effort, or greater task difficulty. Malone et al. (2020) gathered that a higher number of fixations corresponds to more attention focussed on a certain area of interest and this AOI increases in visibility, difficulty or relevance to a certain task. If the AOI doesn't register any fixation on then that part of the stimuli is entirely disregarded for the task solution. Schreiter and Vogel (2024) use the same ET measurement to infer that a global view of data is generally associated with fewer fixations, lengthier saccade amplitudes and higher saccade count in horizontal direction, as opposed to local view.

Table 3. Eye Tracking measurements

ET measurements	Number of studies
first gaze / fixation	6
point of gaze / fixation point	2
duration of fixations / fixation duration / gaze duration / fixation time	23
mean fixation duration	8
total fixation duration / dwell time / total visit duration	19
median fixation duration	1
dwell time slope	1
mean dwell time across all participants	1
net dwell time	1
number of fixations / fixation count	30
mean fixation count	1
total fixation frequency (count)	2
fixation sequence	1
order of fixations	1
fixation dispersion	1
average gaze distribution density of each or all participants	1
patterns of fixations	2
number of fixating figures	1
number of fixating numbers	1
number of consecutive fixations	1
absolute saccadic angle	1
saccade duration	1
saccade length	1
saccade amplitude	5
saccade count	16
saccade count between objects	1
saccade direction	2
saccade latency time	2
between-tape saccades	1
within-tape saccades	1
count of regressions	2

number of gaze switches	1
count of transitions	6
two-way transitions	1
Pair wise transitions	1
vertical transitions	1
GazePlot	6
HeatMap	8
Cluster	2
AI Cluster	1
ScanPath	5
ScanPath length	1
video of eye-gaze trajectories	3
raw gaze points	3
areas of interest (AOIs)	15
sweeps between AOIs	1
sweep length	1
order of visited AOI	1
number of revisiting target	4
pupil dilation	3
pupil diameter	2
pupil size	3
blink count	2
blink duration	1
response time	1
time on task	1
time of interest (TOI)	2
sequence of gaze shifting from material to student's face and back to material	1
percentage of total gaze time on each AOI relative to the total time the AOI was on screen	1
timestamp	1
off task duration ratio	1

Source: the authors' own conception

Table 4. Interpretation of ET measurements

Research paper	ET measurements	Interpretation
Schreiter & Vogel, 2023	fixation count	amount of attention on this area
	saccade amplitude	indicator for local (short saccades) compared to global (long saccades) strategies in information retrieval and integration
	saccade direction	indicator for search strategy / reading strategy of a diagram
Hahn & Klein, 2023	horizontal and vertical saccades	indicates procedural, representation-specific handling and processing of the vector field diagram
	saccade length	can be used as an indicator for local strategies in information retrieval, associated with expertise
	mean fixation duration	is calculated by dividing the total fixation duration on the diagram by the number of fixations on the diagram, representing the cognitive effort of visual information intake
	pupil dilation	the pupil dilated more with harder problems, so cognitive effort measured by pupil dilation was affected by the level of arithmetic problem difficulty
Lal et al., 2024	fixations, blinks and saccades characteristics	shorter fixations, fewer blinks, and more, slower and larger saccades indicate frustration and low arousal-positive valence emotions
		more and shorter fixations, and more, slower and longer saccades, longer blink durations and higher fixation dispersion, fewer blink counts and lower tonic skin conductance indicate low arousal-negative emotions such as boredom
		higher fixation dispersion, the highest number of blinks count and higher blink duration indicate high arousal-negative emotions

Solstad et al., 2024	fixations and saccades	used just to estimate where the participants focused their attention. When people use external mediating tools, often characterised by non-conceptual thinking, their eyes will fixate on those physical objects. In contrast, when the mediating tools are mental, often characterised by conceptual thinking, the eyes have nothing physical to fixate on.
Chumachenko et al., 2024	saccade	seen as an act of positioning the environment on the retina so that upcoming sensations can be best compared with a relevant-to-task-at-hand anticipatory image.
	fixation	serves the previous comparison and enables an extrafoveal choice of the next landing position.
	fixation count	the number of fixations decreases for adults compared to children and fixations can even disappear as perception is accomplished by extrafoveal analysis. Adults and some children could recognize a figure without glancing at it even once.
Porras et al., 2024	fixation count	indicator of the level of overt visual attention or depth in information processing; interpreting longer fixations as indicators of greater cognitive effort, or greater task difficulty.
Di Lonardo et al., 2020	first fixation	the best indicator of strategy choice
Krauze et al., 2021	average gaze distribution of all participants	with increasing distance between two elements, the gaze is more directed towards the objects and is less located in the area between the objects.
Biza et al., 2020	HeatMap	to gain a sense of where the eyes were looking on the screen as a proportion of a specific time interval
	saccades	a rich source of data since they could be interpreted as comparing or relating values

Malone et al., 2020	fixation length	can either reflect how relevant the respective stimulus is for the task to be performed or reflect how difficult it is to process (for math problems or for text reading)
	fixation duration	If single representations are given, longer fixation durations might speak for higher difficulty, and thus processing times, because the participants will have no choice but to work with the only provided representation. In contrast, with multiple (informationally equivalent) representations, longer fixations on one representation rather speak to its relevance to task performance: It can be assumed that the representation, which is fixated upon the longest, is the one primarily used to complete the task
	visit duration	might reflect the participants' efforts to integrate several stimuli within one representation.
	fixation count	more fixations are associated with more attention dedicated to a particular AOI, which classifies this area as either particularly visually salient, difficult, or relevant to the task. No fixation on an AOI means that a stimulus is completely ignored for the task solution.
	time to first fixation	it allows one to identify the one representation that attracts the students' attention first.
	number of visits to a specific AOI	more visits are related to frequent revisits of a stimulus (having inspected others in the meantime), which speaks to the relevance of the respective stimulus
	transitions count	more transitions are assumed to reflect more intense actual or attempted integration processes taking place between the two stimuli.
	fixation time	can also predict cognitive load and cognitive processing. It can also be used to validate the subjective cognitive load scale

Schwarzmeier et al., 2024	saccades	indicate strategy use and cognitive processes
	total number of saccades	can indicate whether a visual representation is processed efficiently
	between-tape saccades	indicate efficient, holistic processing of the tape diagrams because these eye movements represent the actual estimation and comparison of the fraction magnitudes.
	within-tape saccades	indicate less efficient, componential processing, because those eye movements are typical for looking at and counting individual segments, which is not necessary for solving the task.
	saccade count	to further examine inefficient processing and to find out whether participants really count individual segments
Brunner et al., 2024	fixation duration	an indicator of perceptual processing depth.
Zhang et al., 2023	total fixation duration	refers to the sum of the duration for all fixations. This metric is very sensitive to longer cognitive processing; the longer the fixation duration, the more information extraction and more effortful the cognitive processing produced.
	HeatMap	is calculated by averaging the fixation duration on any location in each stage at the pixel level, which is a data-driven approach to investigate which area of information is the most important for the participants throughout the entire process.
Dröse et al., 2021	net dwell time	the time that students look at the words indicating syntactic structures.
	ScanPath	allow deeper insights into students' reading processes when considering the different reading cycles.
Susac et al., 2023	transitions between AOIs	a measure of the integration of information from multiple representations.

Moen et al., 2020	saccades between objects	participants could require fewer cycles through the encode–rotate–compare process, suggesting that they may have encoded a more complete representation.
	dwell time slope	suggest that training on a mental rotation task may not be increasing the efficiency of the rotation process.
Pouta et al., 2021	time of interest (TOI)	manually marking time points (events) in the data when the teacher's gaze was in an area of interest.
Haataja et al., 2024	HeatMap	to illustrate the momentary formation of attention during teacher gestures
Da Silva Soares et al., 2021	HeatMap	show the spatial distribution of where the student looked at the screen during the task. The red spots in the heatmaps represent areas where the information was processed for a longer time by the participants, while the blue/purple colour represents locations minimally explored.
Skrabankova et al., 2020	ScanPath	used to determine whether the stimulus was read differently, for example, by men or women or by experts or novices.
Thomaneck et al., 2025	GazePlot	show the temporal sequence of gazes by plotting the fixations and the time spent looking at that particular point on the stimulus by the diameter of the fixation circle. This approach was used to combine the advantages of quantitative and qualitative evaluation methods of ET data
Schreiter & Vogel, 2024	fixation count	students with a global view, compared with those with a local view of data, exhibited on average fewer fixations (H1), longer saccade amplitudes (H2), and a higher relative number of saccades in the horizontal direction (H3).
Hultdin & Norqvist, 2024	total time of fixations	a measure of the time a reader spends focusing on the text and receiving visual impressions; a longer time spent on matching of content could indicate difficulties in the process, while a shorter time could indicate an easier process.

	total amplitude of saccades	enables comparison of the length of gaze paths (reading paths) when reading and searching the text
	average duration and number of fixations	can reveal differences associated with depth of the interpretation, and difficulties in the interpretation process. They are also associated with information density.
R. Li et al., 2024	time of interest (TOI)	created by selecting a start event – when the teacher's eyes are drawn to the object from one group – and an end event – when the teacher's eyes leave the group – to identify the interval of interaction fragments.
Chaudhuri et al., 2022	total fixation duration and average fixation duration	the longer the fixation duration on a target, the deeper was the information processing.
	fixation count	showed the noticeability and importance of a specific target; for example, higher fixation counts indicated greater importance of the target.
Walcher et al., 2023	pupil diameter (baseline and task-evoked)	measure of subjective and objective workload
T. Li et al., 2023	first fixation	an indicator of initial orienting attention to stimuli in that area
	fixation count and dwell time	indicate one's overall level of attention to stimuli within that area

Source: the authors' own conception

The data listed here has been reproduced as reported in the original studies by the researchers presented in the first column in order to preserve the integrity and intended meaning of their analyses.

Additional / Complementary methods that were paired with ET

Since there are various interpretations that can originate from a large amount of ET measurements, most of the researchers felt the need to complement ET technology with additional methods to strengthen the identified results.

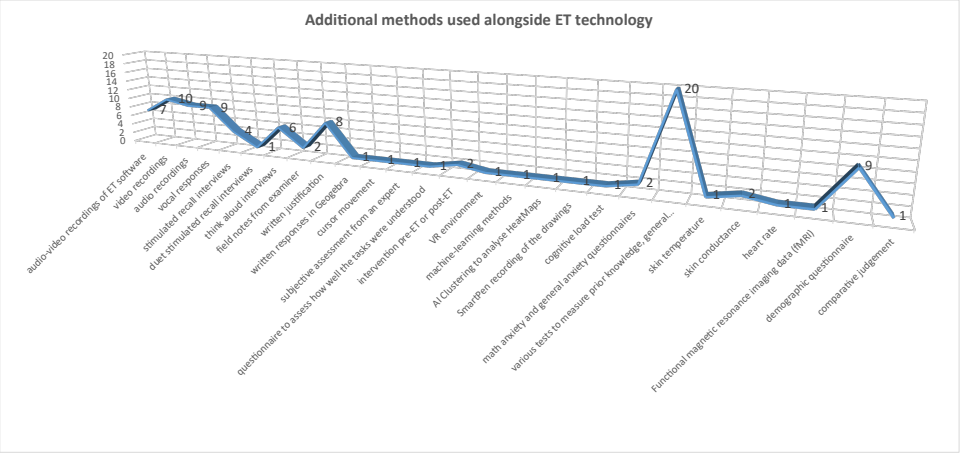
Among these methods, researchers successfully paired ET technology with audio-video recordings during the eye movements gathering that were amply analysed, stimulated recall interviews, think aloud interviews, the participants' written justification, the examiner's field notes, various questionnaires and even skin temperature and heart rate records.

Lomos et al. (2023) suggests that supporting ET with semi-structured interviews encompassing open-ended retrospective questions enables a wider view regarding the experience of students.

Schindler and Lilienthal (2022) employed due to stimulated recall interviews (SRI), an innovative method in mathematics education that generated a thorough understanding of the collaborative creative process. The two students that took part in the study collaborated while wearing eye tracking glasses for dual ET and were separately involved in a stimulated recall interview where they examined ET videos from their collaborative effort. This enabled the researchers to discover the stages of the collaborative creative process.

Another noteworthy study (Moen et al., 2020)employed ET and functional magnetic resonance imaging data (FMRI) to observe the developments in attention distribution and neural activity determined by training for complete representation and the ability of mentally rotating the representation (see Table 5 and Figure 9).

Figure 9. Additional methods that complement ET by number of studies



Source: the authors' own conception

Table 5. Additional methods that complement ET

Additional methods	Number of studies
audio-video recordings of ET software	7
video recordings	10
audio recordings	9
vocal responses	9
stimulated recall interviews	4
duet stimulated recall interviews	1
think aloud interviews	6
field notes from examiner	2
written justification	8
written responses in Geogebra	1
cursor movement	1
subjective assessment from an expert	1
questionnaire to assess how well the tasks were understood	1
intervention pre-ET or post-ET	2
VR environment	1
machine-learning methods	1
AI Clustering to analyse HeatMaps	1
SmartPen recording of the drawings	1
cognitive load test	1
math anxiety and general anxiety questionnaires	2
various tests to measure prior knowledge, general intelligence, working memory, verbal memory, cognitive development, math achievement and performance	20
skin temperature	1
skin conductance	2
heart rate	1
functional magnetic resonance imaging data (fMRI)	1
demographic questionnaire	9
comparative judgement	1

Source: the authors' own conception

Results of using ET in mathematics education

In the following section we are going to discuss the results of the 64 studies organised by mathematical context as seen in Table 1 (Mathematical topics). The main themes considered were geometry, arithmetic, representations, algebra, statistics, cognitive processes, digital learning, mathematical writing and mathematics classroom with their attached subtopics.

Geometry

Mental rotation. The study of Beckner et al. (2023) suggests that the staircase procedure may be useful for understanding mental rotation from infancy through early childhood, while Moen et al. (2020) used ET and fMRI to elucidate the attentional and neural mechanisms associated with mental rotation skill development.

Using VR laboratory and by comparing fixations, saccades, pupil dilation and head movements, Stark et al. (2024)concluded that the encoding of spatial information with visual 3D figures was lower-effort and participants may have utilised egocentric transformations and perspective changes.

Geometric shapes. The study of Solstad et al. (2024)showed that ET is a feasible technology for studying whether and when individuals employ conceptual thinking when classifying geometric shapes. The results of Chumachenko et al. (2024)reveal the narrowing of eye movements: with increasing knowledge, foveal analysis (noticing by looking directly) is replaced by extrafoveal analysis (observing without glancing at the geometric shape).

Krauze et al. (2021) considered eye tracking metrics for analysing geometric shapes with ambiguous features. The results of eye movement analysis indicate that gaze distribution is more probable to be unimodal when two objects are situated in close proximity of one another and the visual stimuli appear as rather single items. As the distance increases, the gaze distribution becomes multimodal and both objects are attended separately.

Arithmetic

Approximate number system. Lindskog et al. (2021) debated whether attentional bias induced by stimulus control (ABC) affect tasks regarding the approximate number system. Results indicated that students fixate the initial gaze on the set with larger items, biasing their response towards these sets. In addition, Viktorsson et al. (2023)assessed approximate number system (ANS) in 5-months old infant twins and concluded that the sense of approximate numerosity is inherited and not positively related to cognitive, motor or concurrent attentional skills.

Subitizing and counting. The study of Gomez & Huron (2020)determined that children with developmental coordination disorder were less accurate and slower in enumeration tasks providing evidence that this disorder impairs counting and subitizing.

Analyses of the eye movements from another study (Ranzato et al., 2020) showed that individuals with Williams syndrome and Down syndrome were using inefficient scanning strategies when counting.

Fractions and rational numbers. Schwarzmeier et al. (2024) perceived that adults as well as children are more likely to compare graphically represented fraction values when the visualizations are continuous rather than discrete. Another study (Schwarzmeier & Obersteiner, 2025)revealed the complexity of the connection between fraction knowledge, strategy use and performance in the task of comparing visually represented fractions.

Pouta et al. (2021) observed that both student teachers and experienced teachers attended to mathematical and fraction-related aspect similarly but differed in interpreting and instructing students' fraction understanding.

Shang et al. (2023) found that structured stepwise presentation has a significant contribution in supporting attention guidance during fraction lessons. Another study on fractions (MacKay et al., 2023)using ET found that processing fractions requires more time compared to other notations, natural numbers and decimals.

Number line estimation. MacKay et al. (2020) investigated patterns of fixation and cursor response in tasks related to number line estimation and discovered that answers were quicker and less precise when responding with the eyes than when they responded with the cursor.

Di Lonardo Burr & LeFevre (2021)revealed that the adults' struggle in atypical number lines estimation tasks is caused by errors in calculating the midpoint's value. In another study, Di Lonardo et al. (2020)observed that adults address conventional as well as atypical range number lines with benchmark strategies, but limited numerical ability lowers the effectiveness of said strategies on the atypical case.

Mental arithmetic. Porras et al. (2024) found that performance results in mental arithmetic and number of fixations in areas of interest are negatively correlated. Another study (Walcher et al., 2023) concluded that both the quantity and the type of mental resources employed during an internal mental arithmetic task influence perceptual decoupling.

Small number enumeration process. Schindler et al. (2022)revealed that students who are deaf and hard hearing (DHH) do not register delays in

small number enumeration in comparison to normal hearing students and their math difficulties are not linked to small number enumeration.

Representations

Graphic representations. Ruf et al. (2024)determined that students of physics and medicine use similar visual strategies to solve graph tasks, suggesting that visual behaviour is a strong indicator of graph comprehension. Additionally, the ability to work with graphs in physics was studied by Skrabankova et al. (2020) and the results showed that students from all three groups assigned by the teacher (plus, average and minus) encountered difficulties while reading graphs. Eye-movement data identified several students who had been incorrectly assigned to their groups.

The results of another study (Becker et al., 2022) indicate that only specific AOIs are vital to a correctly extracting data from diagrams. The understanding of graphs for physics quantities critically depends on applicating correct mathematical procedures. Furthermore, Becker et al. (2023) discovered that students' ET behaviour registers meaningful differences in mathematic versus kinematic settings.

Brunner et al. (2024)found that recognising significant task characteristics regarding graphs can be evaluated with eye movements and is connected to deep cognitive processes.

Visual attention while answering tasks of interpreting graphs in kinematics was investigated by Klein et al. (2020), who concluded that increased visit durations on highly interfering distractors and decreased duration on correct options are linked to incorrect responses while correct answers indicate a reversed relationship.

Contextual graphs. Thomaneck et al. (2022)conducted an investigation into methodological approaches on eye-mind hypothesis applied in the field of functions. They concluded that eye movements were frequently linked to cognitive processes, though sometimes in an indirect manner with minimal ambiguity in the interpretation of ET data. In another study, Thomaneck et al. (2025)found a total of nine strategies to detent changes in contextual graphs.

Vector field plot – diagram and equation. Ruf et al. (2022) observed that students following verbal instructions show better performance than students receiving written instructions when expected to coordinate between diagram and equation for vector field plots in physics education. In addition, Hahn and Klein (2023) concluded that vertical and horizontal oriented saccades are related to executive perception in tasks involving vector field coordination.

Algebra

Equations. The study of Malone et al. (2020) showed that multiple external representations are better than single representations for students with basic familiarity but insufficient exercise in dealing with linear systems of equations. MERs that contain graphical representation are of greater utility for beginners.

Quadratic sequences. Biza et al. (2020) investigated strategies in finding the nth term rule for simple quadratic sequences and the qualitative analysis of ET data offered several strategies.

Sets. Sprenger & Benz (2020) found that children who are 5 years old have perception of structures and utilise them when determining cardinality of sets and found that 5-year-old can already perceive structures and use them to identify the number of elements.

Statistics

Data distributions. Schreiter & Vogel (2023) found that students displaying a global view of data in comparison those with a local view presented a lower number of fixations, extended saccade amplitudes, and a larger quantity of horizontal saccades. Furthermore, Schreiter & Vogel (2024) showed that there were no substantial variations depending on grade level in the gaze behaviour or in the students' kill to process global characteristics while comparing distributions.

Statistical diagrams. Abt et al. (2024) discovered that students utilising different diagrams show distinct gaze patterns, divergent both in fixations count and duration on relevant box plot areas. Another study (Boels et al., 2024) relayed that performance on case-value plot tasks was high, in contrast to the low performance on histogram tasks.

Cognitive processes

Problem solving. Türkoğlu & Yalçınalp (2024) concluded that the effort invested in the comprehension and planning phases of problem-solving are important aspects leading to success. Besides, Norqvist et al. (2023)remarked that the presence of a solution method determined the students to revisit it each time they answered the task at hand, paying close attention exclusively to the illustration with details strengthening mathematical reasoning.

Collaborative geometry problem solving. Haataja et al. (2024) used self-made eye tracking devices to investigate the distribution of visual attention throughout group instruction for collaborative problem solving in the field of geometry. The study concluded that teacher gestures can communicate mathematical content and guide students' focus, encouraging mathematical thinking in problem solving.

Problem posing. In the study of Zhang et al. (2023) students who appeared to be competent posers demonstrated better comprehension of the problem-posing task and revealed considerably increased fixation duration in order to complete the problem-posing activity.

Learner Emotion recognition. Lal et al. (2024) concluded that the following parameters can be used to differentiate between emotions: frequency of skin conductance response peak, tonic skin conductance, number of fixations, duration and dispersion of fixations, number, duration and amplitude of saccades and number and duration of blinks.

Collaborative creative process. Schindler & Lilienthal (2022) conducted an explorative study about the collaborative creative process of students and its stages in mathematics education. They employed an innovative approach with dual eye tracking and duet stimulated recall interviews and established a framework of the collaborative creative process.

Math anxiety (MA). Blini et al. (2024) conducted a study finding the negative correlation between competence and performance in arithmetic tasks and MA using the variation in pupil size. In addition, (Li et al., 2023) concluded that students with higher math anxiety exhibited more enhanced attentional processing of distractors during math problem solving than students with lower math anxiety and that lower math performance connected to math anxiety is partially intermediated by impaired attentional control in problem solving tasks.

Through ET data, Throndsen et al. (2022) found that MA does not increase cognitive effort during multiplication tasks.

Word problems and text processing. One of the articles (Dröse et al., 2021) helped in understanding that revisits and scanpaths are more appropriate for detecting changes in students' processes of perceiving syntactic language characteristics, as opposed net dwell time.

Roth et al. (2025) found that the numbers from an arithmetic word problem capture attention and concluded that there is no advantage to a firm delimitation of text and number processing.

Pattern recognition and structure sense. Baumanns et al. (2024) conducted an explorative ET study about pattern-recognition processes of first-grade students and observed that the students used four distinct processes to identify patterns. Another study on first-graders (Pitta-Pantazi et al., 2024) analysed, through ET, the students' use of structure sense and the variety of strategies they used.

Digital learning

Online math learning environment. De Mooij et al. (2020) found that arithmetic performance (and dealing with online learning environments) might improve by adapting the display of time limit during tasks, while considering individual cognitive profiles.

Digital game-based learning. Lomos et al. (2023) concluded, through ET data, that students paid minimal visual attention to the incentive system (remarkable through points, stages and feedback) independent of game performance or age range. However, the feedback at the end captured more attention, offering performance information.

Online word problem solving. Wei et al. (2023) specified that students with math learning difficulties benefited from visual cueing as it decreased the time they spend on task-unrelated activities. Still, it didn't seem to enable deep thinking or improve performance.

Mathematical writing

Textbooks. Woollacott et al. (2024) observed that participants allocated less attention to representations in the margins than those situated in the main body. Therefore, the spatial contiguity principle should be considered for designing mathematics textbooks.

Multiple representations. Susac et al. (2023) suggested that students who fittingly respond to PISA items involving the data from multiple representations need more time and transition more between representations than students who are not capable of answering correctly.

Alternative arrangements of mathematical symbols and words representations. Hultdin & Norqvist (2024) observed that the reading process becomes less focused when text connections are based on language semantics, as opposed to when the key connections are highlighted by visual structure. Thus, integrating graphical representations to evoke vital relationships between formulas and variables can give more focus to the reading process, but it may lead to missing certain details.

Mathematics classroom

Judgment process and accuracy of teachers. Schnitzler et al. (2020) discovered that student teachers displayed notable variation in their judgment accuracy and those with a higher accuracy demonstrated gaze movement patterns specific to experienced teachers (bigger fixation count and lower fixation duration).

Teachers' Scaffolding Behaviour. In the study of Li et al. (2024) the teachers acknowledged students' understanding by noticing the material

through scanning patterns. On the other hand, during scaffolding, teachers directed their attention to the students and material.

Teachers' metacognition and students' perspective. Da Silva Soares et al. (2021)concluded that a percentage of more than 90% of the teachers demonstrated precision in foreseeing whether students responded correctly or not, exclusively using information from the eye tracking videos.

Professional vision of classroom management. Stahnke & Friesen (2023) observed that biology teachers were more focussed on alternative classroom management approaches, whereas mathematics teachers assessed the events and concentrated on behavioural management or facilitating students' engagement.

In addition, Kosko et al. (2024) concentrated on professional noticing and identified significant contrast between expert and beginner teachers.

Teachers' visual focus of attention and teacher-student interaction. Haataja et al. (2021) used multiple-person mobile gaze tracking that facilitated gathering data of nonverbal interaction and determined that the rate and duration of teachers' and students' visual interaction is influenced by teacher agency.

Another study (Chaudhuri et al., 2022) discovered that teachers' visual attention (analysed by number of fixations) is associated with students' basic academic abilities and the degree of individual support that teachers offer to their students in literacy and math.

Limitations and challenges mentioned in the studies

Our review identified several limitations and challenges that researchers had to face in their studies. We have organized these data in the table below indicating at least one study that mentions each limitation (see Table 6).

Table 6. Table of limitations identified in studies

Limitations	Example of study that mentioned the limitation
ET hardware and software related - calibration, equipment malfunction, data loss	the majority of studies
the use of only one type of ET device	Porras et al., 2024
participants limitations - lack of engagement, eye conditions, emotional state	Beckner et al., 2023; Skrabankova et al., 2020
insufficient / limited sample size	the majority of studies
eye-mind hypothesis	the majority of studies
relying exclusively on eye-tracking data	Shang et al., 2023
lack of physiological data	Kosko et al., 2024
lack of analysis for peripheral vision	Thomaneck et al., 2022
inconsistencies in ET methodology	Porras et al., 2024
ambiguity in the interpretation of ET data	Thomaneck et al., 2022
laborious analysis of ET data manually	Pitta-Pantazi et al., 2024
analysing too many metrics in eye-tracking as a possible threat to the validity of the results	Malone et al., 2020
the sensitivity of the ET measurement, depending on the equipment used	Throndsen et al., 2022
limited math context or limited number of items	Dröse et al., 2021
controlled lab-setting that eliminated several distractions which would normally appear in a real classroom	Lal et al., 2024
the language of instruction could cause misinterpretations of the tasks	Krauze et al., 2021
the head placed in a chinrest could impact the ability to concentrate	Norqvist et al., 2023
technical error - wireless connection malfunction	Pouta et al., 2021
wearing the ET glasses may influence participants' interactions or cause discomfort	Haataja et al., 2024; Li et al., 2024
SRI interviews are subjective, based on the student's statements	Thomaneck et al., 2025
limited stimulus	Schnitzler et al., 2020
eye tracking measures capture only overt attention not covert attention	Li et al., 2023

Source: the authors' own conception

Suggestions for further research from the studies

The studies we have analysed brought to our attention a large set of suggestions for further research. The data that proposed impact on future research was organised in the table below, thus illustrating that ET technology can make unique contributions in mathematics education research (see Table 7).

Table 7. Table of suggestions identified in studies

Suggestions	Example of study that made the suggestion
ET consistent methodology	Zhang et al., 2023
study-design guidelines for the use of ET technology	Lal et al., 2024
use additional methods to strengthen the ET findings, including electroencephalography (EEG) and functional magnetic resonance imaging (fMRI)	Solstad et al., 2024
adjust the sample size - number, age	the majority of studies
study connection between verbal and gaze data	Hahn & Klein, 2023
study connection between mouse and eye responses - mouse tracker	MacKay et al., 2020
more consistent task format	Hahn & Klein, 2023
broaden the mathematical context / diverse math context	Susac et al., 2023
more studies in real world classrooms	Lal et al., 2024
ET implemented in intelligent tutoring systems to use student gaze data to continuously adapt learning environments and thus personalize the learning process	Becker et al., 2022
ET measurements as inputs for adaptive learning systems	Ruf et al., 2024
ET as a step towards emotion-aware learning systems	Lal et al., 2024
real-time eye-tracking guided instruction and feedback in mathematics classroom	Solstad et al., 2024
comparison with other STEM disciplines	Ruf et al., 2024
conduct intervention studies pre-ET or post-ET	Schwarzmeier et al., 2024
large genome-wide association studies (GWASs) on mathematical ability	Viktorsson et al., 2023
the adequacy of ET research method as tool for teacher training	Pouta et al., 2021
include additional factors such as visual impairment, occupation and other observer-based factors	Krauze et al., 2021
include participants with severe difficulties in learning mathematics and gifted children	Porras et al., 2024

Source: the authors' own conception

Discussion

Eye-mind hypothesis – challenging perspectives encountered in the studies

A vast amount of the studies investigated in this review are based on the eye-mind hypothesis (EMH) that assumes the existence of an adjacent connection between fixations and cognitive processes (Just & Carpenter, 1976). Nevertheless, as mentioned before, several studies proved the limitations of EMH as Strohmaier et al. (2020) and Schindler & Lilienthal (2019) have noted.

It is essential to explore several potential competing or alternative perspectives in relation to EMH, debated in the reviewed articles such as covert attention, perceptual decoupling, EMH inferences beyond external objects, extrafoveal analysis, attentional bias induced by stimulus control, emotion-driven attentional biases, visual cueing and information-reduction hypothesis

Covert attention

Pitta-Pantazi et al. (2024) reiterated that covert attention is related to distinguishing information by engaging peripheral vision based on extrafoveal processes. This type of attention is a key factor when students recognise a repeating object without visually fixating it. This study observed several participants who glanced at the top part of a shape and employed peripheral vision to distinguish the rest of the figure.

Norqvist et al. (2023) argued that EMH is not entirely appliable in mathematics education as ET follows foveal ranges and it is unable to register a participant's capacity to perceive and process information in peripheral areas. However, individuals are capable of preserving a mental representation of an image while processing information in additional areas by employing peripheral vision.

Li et al. (2023) mentioned that ET has certain limitations as it captures information about overt not covert attention.

Perceptual decoupling

Mind wandering or concentrating on internal affairs reduces the resources allocated for external activities and generate slower less accurate reactions hindering perceptual thinking(Walcher et al., 2023). This process is called perceptual decoupling and its cognitive basis is not well understood. In contrast to EMH, perceptual decoupling implicates that eye fixations aren't necessary an indication of cognitive processes. The study of Walcher et al. (2023)investigated how task type (e.g. arithmetic) and workload level (e.g. low

or high) of an internal task impacts voluntary saccades. Temporal restraints of this process were explored by manipulating the interval between internal cues regarding the tasks at hand and saccade stimulus. Results indicated that internal cues delayed saccades but had no influence over spatial planning.

EMH inferences beyond external objects

Solstad et al. (2024)proposed an innovative view on EMH, implying that disconnecting a fixation on an external object (an example, a formula) could show concentration on an internal representation of the object. This alternative perspective on EMH can potentially detect changes in thinking processes as they take place. Transitioning to conceptual thinking can be observed using ET technology by analysing scan paths and noticing how fixations discontinued on certain visual stimulus.

Extrafoveal analysis

Chumachenko et al. (2024)discussed about a theoretical alternative to EMH by viewing eye movements as components of problem-solving during environmental interaction. Since in their study, adults could properly identify a geometrical figure without looking at it directly, they observed that eye movements are not necessary when a connection is established between an anticipatory image and upcoming sensory data without positioning the geometrical figure in the foveal area. Their study concluded that the lack of fixations does not fundamentally mean disregarding a visual stimulus, as it often points to extrafoveal analysis. Though EMH limits eye movements to fixations for the cognitive processing of information in the foveal area, saccades serve the purpose of aligning the stimuli from the environment on the retina to support the connection between incoming sensations and the anticipatory image of a current task.

Consequently, theoretical perception does not always depend on direct fixations on a geometrical figure. With increasing knowledge, foveal analysis (by directly looking at a visual stimulus) is replaced by extrafoveal analysis (distinguishing figures without glancing at them).

Attentional bias induced by stimulus control (ABC)

EMH might not be appliable when attentional bias induced by stimulus control is taken into consideration, as attention can register involuntarily shifts unconnected to eye movements. Lindskog et al. (2021) observed that stimulus type influences attention. There was clear indication of attentional bias induced by stimulus control when the participants first looked at a group of larger items at the expense of sets with smaller items,

during an ET experiment for assessing overt attention, proving that decisions are influenced by object size.

Emotion-driven attentional biases

Sprenger and Benz (2020) commented that EMH does not hold in intense emotional situations (stress, panic). Schindler & Lilienthal (2019) concluded that gaze movements are not only connected to cognitive process but to affective processes as well. Thus, ET technology should be supported by additional methods.

Visual cueing

Visual cueing refers to directing attention to a certain part of the visual stimuli and it offers information about restrictions and extensions of EMH. Wei et al. (2023)established that this process has a positive impact on directing attention and minimizes the time spent on irrelevant activities. However, visual cueing does not necessarily lead to improved learning outcomes.

Information-reduction hypothesis

Ruf et al. (2024)found that experts concentrate on important information for the task at hand filtering all irrelevant facts, thus their fixations on important details are longer, even though they process them more efficiently than non-experts.

All in all, EMH should be approached with caution and its constrains should be considered when dealing with interpretation and validation of ET metrics. In addition, ET technology should be supported by complementary methods for a better interpretation and validation.

Benefits of using ET in mathematics education

Since ET can quantify human attention, this technology has the means to complement conventional research methods with a better understanding of attention and cognitive processes (Norqvist et al., 2023).

Furthermore, eye tracking technology is capable of detecting changes in thinking modes as they arise in real time. According to Solstad et al. (2024) this technology can lead to new interpretations about thought processes in mathematics and enable research on means to involve students in conceptual thinking.

Several studies demonstrated that ET data taken during the problem-solving process is useful for gaining insight into the visual strategies used in interpreting kinematic diagrams (Becker et al., 2022), students' graph

interpretation (Thomaneck et al., 2022) processes and predicting the correctness of responses.

ET can help teachers receive relevant feedback about students' problem-solving behaviour and can facilitate the investigation of teachers' cognition (Da Silva Soares et al., 2021). In addition, it offers new perspectives about teacher's gestures in real time classroom (Haataja et al., 2024).

The use of mobile ET devices allows video recordings from a teacher's viewpoint of realistic teaching-learning situations. Complemented by cued retrospective reporting, ET can gather extensive information on teachers' professional vision (Pouta et al., 2021). Along the same lines, combining ET and think-aloud interviews data can have a positive impact on research into teachers' professional vision and classroom management (Stahnke & Friesen, 2023).

ET measurements viewed as strong indicators of students' data interpretation approaches in statistics education across diverse grade levels was demonstrated by Schreiter & Vogel (2024). Moreover, eye tracking data was found to help further understand cognitive processes when comparing statistical representations (Abt et al., 2024).

Last but not least, ET metrics can serve as inputs for developing adaptive learning systems. ET could support an extensive online adaptive learning framework for developing mathematical skills, that adapts to children's abilities, cognitive strengths and limitations(De Mooij et al., 2020). In addition, personalised machine-learning applications can lead teachers to identify students having difficulties with mathematical content(Ruf et al., 2024).

Contributions of this review

The current review has analysed 64 peer-reviewed articles published between the years 2020 – 2025. The studies were selected from the Web of Science reputable database ensuring academic rigor and the screening process was systematic, following PRISMA guidelines with Zotero's assistance supporting reproducibility. The selection criteria were well-defined, we included English-only, theme related to ET technology, relevant mathematical context, ET data broadly connected to mathematics studies and excluded theoretical and review articles and papers that didn't report the results in an extensive manner.

As far as the place of origin is concerned, the studies involved multiple countries from Europe (52), North America (8), Asia (5), South America (1) and with a majority of articles initiated in Germany (23).

Where specified, the participants varied from infants of5 months old(Viktorsson et al., 2023) to adults with average age of 31 years old(MacKay et al., 2020). In addition, this review identified understudied populations such as infants (under one year old), DCD - development coordination disorder(Gomez & Huron, 2020)and DHH - deaf or hard hearing students(Schindler et al., 2022), participants with Down and Williams syndromes (Ranzato et al., 2020).

The 64 studies examined in this review were centred on numerous mathematical domains such as arithmetic, algebra, geometry, statistics, applied mathematics in physics, biology and medicine, mathematics classroom and textbooks with the majority concentrated on arithmetic and algebra (32).

Considering the wide span of countries of origin, age groups and mathematical domains, this review illustrates a diverse and complex sample limiting potential bias.

This review highlights Eye Tracking's role in teacher training with educator-focussed studies about teacher's judgment process and accuracy (Schnitzler et al., 2020), teachers' scaffolding behaviour (R. Li et al., 2024), their individual support for students (Chaudhuri et al., 2022) and teacher-student interaction (Haataja et al., 2021). In addition, with the help of ET, Da Silva Soares et al. (2021) and R. Li et al. (2024) investigated teacher's meta cognition and competence, Stahnke and Friesen (2023) and Kosko et al. (2024)discussed professional vision of classroom management.

Blini et al. (2024),T. Li et al. (2023) and Throndsen et al. (2022)illustrated another practical application of ET in math anxiety research and Lal et al. (2024) examined learner's emotion recognition with this technology.

From a technological advancement point of view and interdisciplinary approach, we have included ET studies that are connected to machine-learning (Schindler et al., 2022), AI-based prediction(Ruf et al., 2024), digital learning environments (Lal et al., 2024), incentive system design for digital game-based learning (Lomos et al., 2023) and functional magnetic resonance imaging data – fMRI (Moen et al., 2020).Along the same lines, Kosko et al. (2024) and Stark et al. (2024) used VR environments combined with ET.

On the subject of innovation in research, it is noteworthy to mention how Schindler and Lilienthal (2022) used dual eye tracking and duet stimulated recall interviews for investigating the collaborative creative process of problem solving for a geometry task. On a similar note, Haataja et al. (2021) used multiple-person mobile ET, an original approach in educational research, for gathering data on nonverbal teacher-student interaction.

The problem of relying exclusively on eye tracking data (Shang et al., 2023), which generates questions regarding the validity and interpretation of ET measurements, was addressed in other articles by complementing this technology (the quantitative ET data) with additional qualitative methods. A substantial number of studies included stimulated recall interviews, think-aloud interviews, audio-video recordings. Other articles relied on cursor movement (MacKay et al., 2020), VR environment (Stark et al., 2024), AI Clustering (Schindler et al., 2022), and functional magnetic resonance imaging data – fMRI (Moen et al., 2020).

On a different note, the clarity of ET data interpretation can be enhanced by visualisations such as Heatmaps and Gazeplots which have been used in a significant number of the studies.

All in all, by offering insight into the use of ET technology as a tool for teacher training, classroom management and emotional regulation, into the technological development, interdisciplinary and innovative approaches for mathematical education research, this study differentiates its contributions from prior reviews on the same subject.

This study incorporated an extensive list of limitations and gaps in ET research in mathematics education. The majority of studies noted the constraints of eye-mind hypothesis validity, ET data loss or equipment malfunction and participant limitations. As far as ET settings are concerned, the issues encountered were related to inconsistencies in ET methodology (Porras et al., 2024), ambiguity in interpretation of ET data and lack of investigation for peripheral vision (Thomaneck et al., 2022), analysing too many ET metrics (Malone et al., 2020),the sensitivity of the ET metrics, depending on the equipment (Throndsen et al., 2022), the placement of the head in a chinrest possibly altering concentration (Norqvist et al., 2023)and the possible influence or discomfort caused by ET glasses (Haataja et al., 2024). Other notable concerns were the controlled lab-setting removing distractions (Lal et al., 2024),the limited math context or number of mathematical items (Dröse et al., 2021) and the fact that ET captures only overt attention not covert attention (Li et al., 2023).

This review identified certain important suggestions for future research from the analysed studies. A significant number of articles proposed future longitudinal design with Et technology and larger and more diverse sample population. Ruf et al. (2024)suggested that ET metrics could serve as inputs for adaptive learning systems. On a similar note, Becker et al. (2022) recommended ET technology employed in intelligent tutoring systems for continuously adapting learning environments and personalize the teaching-learning process and Lal et al. (2024) proposed using ET technology for emotion-aware learning

systems. Additional recommendations were to elaborate guidelines for the use of ET technology (Lal et al., 2024) leading to consistent ET methodology (Zhang et al., 2023), using electroencephalography (EEG) and functional magnetic resonance imaging – fMRI (Solstad et al., 2024), studying the connection between mouse and eye movements (MacKay et al., 2020), comparison articles with other STEM disciplines (Ruf et al., 2024) and offering extensive insight into the quality of ET data. In addition, Solstad et al. (2024)and Lal et al. (2024) suggested studies in actual mathematics classrooms and real-time ET directed learning and feedback.

Limitations of this review

This review has certain drawbacks that need to be considered. Since only articles from the Web of Science reputable database have been investigated, there is a potential publication bias that can be remediated by including preprints and grey literature. Furthermore, there is a geographic restriction generated by the prevalence of European studies (52 out of a total of 64). Including more Asian or African research papers could help diversify the perspective.

A second limitation that suggests interpretative caution is the reliance on eye-mind hypothesis (EMH), despite the criticism it received (Schindler & Lilienthal, 2019).Additionally, another constraint of this review, connected to EMH, is the theoretical gap generated by the limited discussion of alternate hypotheses such as perceptual decoupling, covert attention or extra foveal processing.

The articles analysed in this study use a wide-range of ET measurements (fixation duration, fixation count, dwell time, saccade amplitude, between-tape saccades and many others) and varied ET apparatus (EyeLink, Tobii, SMI, VR headset and self-made ET devices), as shown in the previous chapters. This methodological heterogeneity complicates cross-study comparisons.

The lack of standardised guidelines for applying ET in mathematics education research, particularly no optimal ET metrics for specific math topics (specific ET measurements for fractions or number line estimation or mental rotation), limit the general applicability. Further research should be conducted in order to design a framework with recommended ET metrics for domains and themes in mathematics education and consistent ET guidelines.

Questions about the statistical power of this review could be raised considering the small sample population in various articles, such as the studies of Schindler and Lilienthal (2022) and Thomaneck et al. (2022)with only two participants each, and R. Li et al. (2024) with 4 participants.

Conclusion

The present study intended to offer a literature review of Eye Tracking Technology studies in mathematics education research between the years 2020 and 2025. A total of 64 eligible articles were classified and analysed regarding mathematical domain and themes. Furthermore, we catalogued the limitations, challenges and further suggestions provided in the studies in order to offer an overview of ET technology potential.

Overall, our review indicates that the possibilities of using ET technology in mathematics education research are endless, from further insights into students' and teachers' cognitive processes while solving a mathematical task to implementing adaptive learning systems, emotion-aware learning systems and even real-time eye tracking guided instruction and feedback in classroom.

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