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MÀSTER UNIVERSITARI EN OPTOMETRIA I CIÈNCIES DE LA VISIÓ

TREBALL FINAL DE MÀSTER

BIBLIOGRAPHIC REVIEW ABOUT MICROSACCADES IN OPTOMETRY

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30 OCTUBRE 2024

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REVISIÓ BIBLIOGRÀFICA SOBRE ELS MICROSACÀDICS EN OPTOMETRIA

RESUM

INTRODUCCIÓ. Els moviments oculars microsacàdics són canvis ràpids i coordinats en la fixació ocular que tenen un paper fonamental en l'exploració i l'estabilització visual. Aquests moviments són essencials en les activitats com la lectura i la navegació en entorns visuals. Des del punt de vista clínic, l'avaluació dels microsacàdics proporciona informació valuosa sobre la salut del sistema visual i l'oculomotor. Les anomalies en els microsacàdics poden indicar trastorns visuals, com l'ambliopia i la insuficiència de convergència.

MÈTODES. S'ha dut a terme una revisió sistemàtica de la literatura utilitzant les pautes PRISMA-NMA. Els articles científics es van obtenir de les plataformes PubMed i Google Scholar, i es van fer anàlisis qualitatives i quantitatives.

RESULTATS. S'han identificat un total de 3079 articles, dels quals, després d'aplicar els criteris d'inclusió i exclusió, se'n van seleccionar 7 per a l'anàlisi final. Els estudis seleccionats es centren en la relació entre els moviments microsacàdics, els trastorns visuals i les intervencions terapèutiques rellevants.

DISCUSSIÓ. Els moviments microsacàdics es veuen afectats notablement en alteracions com l'ambliopia i la insuficiència de convergència. Aquests trastorns solen estar relacionats amb canvis en els paràmetres microsacàdics, com ara la freqüència i la precisió. L'anàlisi dels moviments microsacàdics proporciona informació diagnòstica i pot servir com a biomarcador de la progressió dels trastorns. No obstant això, existeixen buits en la comprensió dels efectes terapèutics a llarg termini, la qual cosa indica la importància de dur a terme més investigacions.

CONCLUSIONS. Els moviments microsacàdics tenen potencial com a biomarcadors dels trastorns visuals. Tot i els avenços, cal més investigació per abordar els buits en la literatura, en particular en la variabilitat dels patrons de moviment ocular i els mecanismes visuals. Els futurs estudis haurien d'apuntar a estandarditzar els protocols i aprofitar els avenços tecnològics per millorar tant el diagnòstic i el tractament dels trastorns.

PARAULES CLAU. Moviments oculars microsacàdics, microsacades, trastorns visuals, ambliopia, convergència.

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REVISIÓN BIBLIOGRÁFICA SOBRE LOS MICROSACÁDICOS EN OPTOMETRÍA

RESUMEN

INTRODUCCIÓN. Los movimientos oculares microsacádicos son cambios rápidos y coordinados en la fijación ocular que desempeñan un papel fundamental en la exploración y estabilización visual. Estos movimientos son esenciales en las actividades como la lectura y la navegación en entornos visuales. Clínicamente, la evaluación de los movimientos microsacádicos proporciona información sobre la salud del sistema visual y oculomotor. Las anomalías en los microsacádicos pueden indicar trastornos visuales, como ambliopía e insuficiencia de convergencia.

MÉTODOS. Se ha realizado una revisión sistemática de la literatura utilizando las pautas PRISMA-NMA. Los artículos se han obtenido de PubMed y Google Scholar, y se han realizado análisis cualitativos y cuantitativos.

RESULTADOS. Se han identificado un total de 3079 artículos y, después de aplicar los criterios de inclusión y exclusión, se han seleccionado 7 para el análisis final. Los estudios seleccionados se centran en la relación entre los movimientos microsacádicos, los trastornos visuales y las intervenciones terapéuticas relevantes.

DISCUSIÓN. Los movimientos microsacádicos se ven afectados notablemente en afecciones como la ambliopía y la insuficiencia de convergencia. Estos trastornos suelen estar relacionadas con cambios en los parámetros microsacádicos, como la frecuencia y la precisión. La evaluación de los movimientos microsacádicos proporciona información diagnóstica y puede servir como biomarcador de la progresión de los trastornos. Sin embargo, existen vacíos en la comprensión de los efectos terapéuticos a largo plazo, lo que indica la importancia de llevar a cabo más investigaciones.

CONCLUSIONES. Los movimientos oculares microsacádicos tienen potencial como biomarcadores de los trastornos visuales. A pesar de los avances, se necesita más investigación para abordar los vacíos en la literatura, en particular en la variabilidad de los patrones de movimiento ocular y los mecanismos visuales. Los futuros estudios deberían apuntar a estandarizar los protocolos y aprovechar los avances tecnológicos para mejorar el diagnóstico y el tratamiento.

PALABRAS CLAVE. Movimientos oculares microsacádicos, microsacadas, trastornos visuales, ambliopía, convergencia.

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BIBLIOGRAPHIC REVIEW ABOUT MICROSACCADES IN OPTOMETRY

ABSTRACT

INTRODUCTION. Microsaccadic eye movements are rapid, coordinated shifts in eye fixation that play a crucial role in visual exploration and stabilization. These movements are key in activities like reading and navigating visual environments. Clinically, evaluating microsaccades provides insight into the visual and oculomotor systems' health. Abnormalities in microsaccades can signal visual disorders, such as amblyopia and convergence insufficiency.

METHODS. A systematic literature review was conducted using PRISMA-NMA guidelines. Articles were sourced from PubMed and Google Scholar, and qualitative and quantitative analyses were performed.

RESULTS. A total of 3079 articles were identified, and after applying inclusion and exclusion criteria, 7 were selected for final analysis. The selected studies focused on the relationship between microsaccadic eye movements, visual disorders, and relevant therapeutic interventions.

DISCUSION. Microsaccadic movements are notably affected in conditions like amblyopia and convergence insufficiency. These pathologies often correlate with changes in microsaccadic parameters such as frequency and accuracy. Assessing microsaccades provides diagnostic information and may serve as a biomarker for disorders` progression. However, there are gaps in understanding long-term therapeutic effects, indicating the need for further research.

CONCLUSIONS. Microsaccadic eye movements hold potential as biomarkers for visual disorders. Despite advancements, more research is needed to address gaps, particularly in the variability of eye movement patterns and visual mechanisms. Future studies should aim to standardize protocols and leverage technological advancements to enhance diagnosis and treatment.

KEYWORDS. Microsaccadic eye movements, microsaccade, visual disorders, amblyopia, convergence.

CONTENTS

INTRODUCTION

Saccadic movements and visual function

Saccadic movements are rapid, simultaneous eye movements of both eyes that allow a change in the point of fixation on the retina (Bahill & Stark, 1979). These movements are essential for visual exploration of the environment, enabling the eyes to quickly shift from one point to another to scan the visual field. In clinical practice, saccadic movements are crucial for assessing ocular health and the efficiency of the visual system. These movements are fundamental in everyday vision, facilitating reading, visual exploration, and perception of our environment in a smooth and coordinated manner (Land & Tatler, 2012; Leigh & Zee, 2015).

In the realm of clinical optometry, saccadic movements play a vital role in the evaluation of visual function and the oculomotor system. The precision, speed, and coordination of saccadic movements are indicative of a healthy visual system. Abnormalities in these movements can be a sign of visual dysfunctions, such as amblyopia and convergence insufficiency (Horn & Leigh, 2011; Ciuffreda, 2002). Thus, the assessment of saccadic movements is an integral part of the optometric examination, providing valuable information about the state of the patient's visual system.

Saccadic movements are among the fastest oculomotor functions in the human body, reaching speeds of up to 900 degrees per second. These movements are controlled by a complex network of neural circuits involving the brainstem, cerebellum, and various cortical areas (Sparks, 2002; Munoz & Everling, 2004).

The primary function of saccadic movements is to quickly redirect the line of sight to a new target of interest, enabling the brain to efficiently and continuously gather visual information. The execution of these movements depends on the coordinated activation of several extraocular muscles, which work in synergy to move the eyes precisely and controllably (Scudder et al., 2002).

In addition to their role in visual exploration, saccadic movements have a crucial function in image stabilization on the retina. During a saccadic movement, vision is temporarily suppressed in a phenomenon known as "saccadic suppression" (Ross et al., 2001). This suppression prevents the blurred or smeared images produced during the rapid eye movement from being perceived by the brain, allowing for a smooth transition between fixations and preventing the perception of a "jump" in the visual field. This ability to maintain visual stability is essential for activities that require high visual precision, such as reading and navigating visually complex environments (Dorr et al., 2010).

Saccadic movements are essential for visual function, allowing efficient exploration of the environment and stabilization of images on the retina. Their relevance in clinical optometry is undeniable, as their evaluation can reveal important indicators of the patient's visual health.

Microsaccadic movements and visual function

Since late 1950s, when the researchers began investigating the microsaccades, it appeared that their function was considered irrelevant with numerous article titles concluding that there is “no useful purpose of small saccades” (Rolfs, 2009). Recent investigations provide evidence to the contrary, demonstrating the undeniable significance of microsaccades in the functioning of visual system.

Microsaccades are high-velocity, small-amplitude eye movements that occur when attempting to fixate on a stationery object (Sinn & Engbert, 2016). They are characterized by size, amplitude and frequency. Microsaccade amplitudes, and frequencies can vary according to the experimental conditions. Microsaccade characteristics can also vary across observers, but the reason for the individual variability is unclear (Rucci & Poletti, 2015). Typically, they occur at a rate of 1-3 times per second and have a duration between 6 and 30 milliseconds. In comparison to other ocular movements, as tremors and drifts, microsaccades have higher velocity, averaging between 6 and 120 degrees per second, and present larger amplitudes, extending from 30 min arc up to 1 degree of visual angle (Gu et al., 2024; Martinez-Conde et al., 2013).

These movements have an important role of maintaining the acuity of the image on the retina, as they enhance the visual perception and improve special resolution (Martinez-Conde et al., 2009).

To evaluate microsaccades, eye-tracking technology is used, enabling researchers to differentiate saccadic and microsaccadic movements and analyse their properties and impact on visual processing.

In order to execute a microsaccade, a coordinated contraction of the extraocular muscles is required, therefore these movements can be a relevant indicator in clinical optometry (Collewijn & Kowler, 2008). The ability to perform adequate microsaccadic movements is indicative of the integrity of the oculomotor pathways connecting the brain to the extraocular muscles. Consequently, it is crucial to investigate how different disorders can affect these movements to improve diagnosis and treatment in clinical practice.

In clinical optometry, the evaluation of microsaccadic movements can be used to identify and characterize visual disorders. Microsaccadic dysfunctions, may indicate problems in oculomotor coordination and may reflect a disturbance in the neural pathways responsible for controlling these movements. Therefore, microsaccadic movements hold significant clinical relevance in optometric practice due to their ability to reflect the health of the visual system. The precise evaluation of these movements not only facilitates the diagnosis of a wide range of visual disorders but also provides a means to monitor the progression of these conditions and the efficacy of therapeutic interventions.

Microsaccades in visual attention

Microsaccades, the rapid, small-amplitude eye movements occurring even during periods of visual fixation, have been implicated in the complex interplay between visual perception and attentional mechanisms, acting as a fundamental component in optimizing the processing of visual information (Rosenbaum, 2010). These movements, although involuntary and minute, serve as an essential mechanism for maintaining visual stability and preventing perceptual fading. Their role in visual attention extends beyond simple fixation maintenance, contributing to higher-order cognitive processes such as attentional focus, visual exploration, and perceptual integration (Engbert, 2006).

The modulation of microsaccade frequency in response to visual cues and specific task demands underscores their involvement in attentional dynamics. For instance, during tasks requiring heightened visual acuity or fine motor control - such as threading a needle, reading fine print, or shooting a rifle - microsaccades are often suppressed. This suppression likely serves to enhance visual stability, ensuring that the central vision remains as steady as possible for precision tasks. Such instances demonstrate the brain's ability to prioritize stability over movement when clarity is critical. This sophisticated balancing act between the need for dynamic visual input and the necessity for visual stability reflects a fundamental aspect of visual attention, where microsaccades are modulated to meet task demands in real-time (Hicheur et al., 2013). Interestingly, while microsaccades are suppressed in high-precision tasks, their frequency tends to increase in less demanding visual tasks, suggesting a link between the activation of the oculomotor system and attentional allocation. The frequent, small-amplitude movements help maintain visual attention by continually refreshing the retinal image and providing constant sensory input, which prevents the brain from losing focus on static visual stimuli. In less precise tasks or when attention is less tightly focused on a particular point, microsaccades allow the visual system to more freely explore the environment (Otero-Millan et al., 2008; Sinn & Engbert, 2016), facilitating shifts in attention to different parts of the scene without overt, deliberate saccadic eye movements. This capacity for the unconscious "sampling" of visual information, without overt movement, is particularly useful in dynamic or complex visual environments where rapid reallocation of attention is necessary (Parkhurst et al., 2002).

Microsaccades also play a crucial role in spatial cuing paradigms, where the presence of a visual cue can modulate microsaccade rates. Research has shown that visual cues can enhance the likelihood of microsaccades occurring in a specific area of the visual field, indicating that the brain engages in a subtle but effective mechanism of attentional shifting in response to environmental stimuli. This increase in microsaccade frequency correlates with a heightened state of attentional engagement, suggesting that microsaccades not only serve to maintain visual fixation but are actively involved in the processing of visual information related to changes in the environment. For instance, in visual tasks requiring rapid detection of visual features or changes, microsaccades have been shown to enhance the brain's ability to integrate these inputs effectively, facilitating the rapid assessment of visual information (Dorr et al., 2010).

Recent research has also illuminated the connection between microsaccades and attentional shifts in response to endogenous and exogenous cues(Gu et al., 2024). The enhanced microsaccadic activity observed in spatial cuing experiments indicates that these movements are linked to both top-down and bottom-up processes of attentional control. Exogenous cues, such as a sudden flash of light or the appearance of a moving object, can trigger an increase in microsaccades as the brain reallocates attention toward the new stimulus. Conversely, in tasks involving more sustained or endogenous attention, where participants need to maintain focus on a specific target, microsaccade rates may be modulated to optimize visual performance. This dynamic modulation reinforces the idea that microsaccades serve as an active mechanism for enhancing visual attention and perception (Gu et al., 2024).

The role of microsaccades in enhancing visual processing is particularly relevant in contexts where rapid assessment of visual information is required, such as reading, driving, or navigating through complex environments. In these scenarios, microsaccades contribute to the efficiency of visual processing by allowing the visual system to continuously sample the scene without the need for large, overt eye movements. For example, while reading, microsaccades play a critical role in ensuring the smooth flow of visual information, helping to integrate characters and words seamlessly, while also preventing perceptual fading that might occur if the eyes remained fixed on a specific spot for too long (Hopp & Fuchs, 2004).

Saccades vs microsaccades

The primary distinction between these two movements lies in their fundamental function. From one perspective, saccades help in gathering visual data from the surroundings, allowing the brain to build a coherent representation of a scene. Conversely, there are microsaccades which help maintain visual stability and enhance contrast sensitivity during fixation, preventing visual fading. Another distinction between these two types of movements is that saccades are typically voluntary motor actions, while microsaccades are considered as involuntary (Sinn & Engbert, 2016). Most of the times, microsaccades cannot be differentiated from saccades according to their magnitude alone, as voluntary saccades can be the same size as microsaccades (Otero-Millan et al., 2008). Compared to voluntary saccades, microsaccades have smaller amplitudes and a proportionally larger overshoot (Nyström et al., 2016). Microsaccades' amplitudes are smaller than the diameter of the foveal region, typically less than 1 degree.

As for their similarities, saccades and microsaccades are generally binocular and conjugate, and both movements are correlated to shifts in spatial attention. They are also generated by the same brainstem neural circuitry (Tian & Chen, 2015).

Relation with specific disorders

Microsaccadic movements are critical for efficient visual exploration and image stabilization on the retina, playing a fundamental role in normal visual function. However, various disorders can significantly alter these movements, affecting fixation ability, precision, and visual stability. Among the most relevant disorders affecting microsaccadic movements are amblyopia and convergence disorders. These conditions can modify both the amplitude and velocity of microsaccadic movements, negatively impacting the efficiency of the visual system. Consequently, the analysis of microsaccadic movements constitutes a valuable tool in the comprehensive care of patients in the field of clinical optometry.

Amblyopia, commonly known as "lazy eye," is a developmental visual condition characterized by reduced visual acuity in one eye due to abnormal visual experiences during childhood. Amblyopia affects up to 4% of the population, and is usually associated with anisometropia, strabismus, or both conditions concurrently (Chung et al., 2015). This condition affects not only visual acuity but also ocular motility. There is frequently an alteration in the precision and speed of microsaccadic movements (Kelly et al., 2015). These abnormal movements can be used to monitor the effectiveness of visual rehabilitation therapies in patients with amblyopia (Ciuffreda, 2002).

Patients with amblyopia often present hypometric saccades, meaning eye movements that fail to reach the desired visual target, reflecting decreased precision and coordination of the oculomotor system

(Niechwiej-Szwedo et al., 2010). Additionally, it has been demonstrated that saccadic movements in patients with amblyopia tend to be slower and require multiple corrections to reach a target, indicating a deficiency in the programming and execution of these movements (Kelly et al., 2015). When amblyopia is associated with strabismus, it is frequently linked to oculomotor anomalies that include eccentric and unsteady fixation, low pursuit gains and abnormal saccadic and microsaccadic eye movements, such as increased frequency of microsaccades, reduced saccadic amplitudes, increased saccadic latencies and increased number of corrective saccades (Chow et al., 2022) .

Recent studies have shown that amblyopia affects not only the amblyopic eye but also the function of the dominant eye and binocular coordination. This alteration in saccadic function is attributed to changes in neural plasticity and an altered cortical representation of visual areas, which can be measured and monitored through clinical evaluation of saccadic movements (Bui Quoc et al., 2023). Therefore, the assessment of saccadic movements can be a useful tool for evaluating the severity of amblyopia and monitoring the response to treatment. Also, studies indicate that while the primary goal of treatment is to restore visual acuity, improving saccadic and microsaccadic movements can enhance overall visual performance and reduce residual visual deficits.

Convergence disorders, such as convergence insufficiency, are oculomotor dysfunctions that affect the ability of the eyes to work together during near vision tasks. The precision of microsaccadic movements is crucial for proper binocular alignment and the fusion of images perceived by each eye into a single three-dimensional image. Convergence disorders are characterized by difficulty maintaining binocular alignment and, therefore, difficulty maintaining fixation on a near object. Convergence insufficiency is particularly relevant in the context of saccadic movements, as patients with this condition may present with abnormal saccadic movements when attempting to switch fixation between near and distant objects.

In individuals with convergence insufficiency, saccadic movements may be inaccurate or uncoordinated, resulting in additional visual effort and symptoms such as eye strain, blurred vision, and diplopia. Studies have shown that visual therapy exercises can improve the accuracy of saccadic movements in these patients, indicating that the evaluation and training of saccadic movements are crucial for the clinical management of convergence disorders (Antoniades & Kennard, 2015).

JUSTIFICATION

The necessity for a profound understanding of how specific visual disorders affect mirosaccadic movements from a clinical perspective is fundamental in optometry and other related medical disciplines. Microsaccades play a crucial role in visual perception and processing. Analysing their role helps us understand how visual perception can be altered due to visual dysfunction.

Microsaccadic movements are essential for efficient visual exploration and for maintaining image stability on the retina. These movements are vital for numerous everyday tasks, such as reading, navigating the environment, and detecting moving objects. Given their crucial role in visual function, microsaccadic movements serve as a significant biomarker for a wide range of clinical conditions.

Despite their importance, research on how various disorders affect microsaccadic movements has been fragmented and occasionally inconsistent. Isolated studies have documented microsaccadic dysfunction in conditions such as amblyopia and convergence disorders, but there is no clear synthesis that allows fully understand the common patterns and differences in how these conditions affect ocular movements. This creates a significant knowledge gap that may limit healthcare professionals' ability to diagnose, treat, and manage these conditions effectively.

Amblyopia. In patients with amblyopia, studies have shown that saccades are often less precise and slower, and the microsaccades present an increased frequency, which may indicate dysfunction in the programming of eye movements due to abnormal visual development (Niechwiej-Szwedo et al., 2010). However, research varies in terms of the severity and types of saccadic dysfunction observed, and research on microsaccadic dysfunction is limited, suggesting the need for a systematic review to consolidate these findings and provide more coherent clinical guidelines.

Convergence disorders. Convergence disorders, such as convergence insufficiency, can significantly impact saccadic movements, especially when rapid and precise adjustment between different focal distances is required. Although treatments such as visual therapy have shown improvements in saccadic function, there is limited information available regarding the advances in microsaccadic movements (Alvarez & Kim, 2013). Therefore, more research is needed to fully understand how these movements are affected and how they can be optimized through clinical interventions.

The evaluation of microsaccadic movements provides a non-invasive and highly informative window into a patient's visual health. Alterations in these movements can offer crucial insights into the presence and progression of various clinical conditions. For instance, in optometric practice, microsaccadic movement tests can help to identify early visual problems in children, which might otherwise go unnoticed until more obvious symptoms appear. Similarly, in adult patients, microsaccadic tests can reveal changes in the central nervous system before other clinical symptoms become evident, allowing for earlier and potentially more effective interventions.

Moreover, microsaccadic movements can also serve as a marker of the effectiveness of various therapeutic interventions. For example, improvements in the accuracy and speed of microsaccadic movements following visual therapy can indicate significant functional recovery, thus providing clinicians with a means to objectively assess the success of their treatments.

METHODS

A Systematic Literature Review of the scientific literature on the topic was conducted. The guidelines of the Preferred Reporting Items for Systematic Review and Network-Analysis (PRISMA-NMA 2020) statement were followed in its preparation.

First, a primary research question was formulated using the PICO format (Patients, Interventions, Comparisons, and Outcomes) as proposed by PRISMA-NMA for systematic reviews; the resulting question was: "In patients with visual disorders (amblyopia or convergence disorder) how does the evaluation of microsaccadic eye movements compare to healthy individuals in detecting alterations and their impact on visual function?"

Here is the development of a research question for this project based on the PICO format:

- **Population (P).** Patients with specific visual disorders (e.g., amblyopia, convergence disorders).
- **Intervention (I).** Evaluation of microsaccadic eye movements.
- **Comparison (C).** Comparison with healthy individuals or patients without these disorders (control group).
- **Outcome (O).** Detection of alterations in microsaccadic movements (e.g., decreased accuracy, slower speed) and their impact on visual function.

The initial hypothesis supporting the research question was as follows: “In patients with visual disorders, such as amblyopia or convergence disorders, it is hypothesized that microsaccadic eye movements exhibit deviations from normative patterns observed in healthy individuals. These deviations are expected to manifest as reduced accuracy, prolonged latency, and decreased velocity, reflecting underlying disruptions in the neural circuits responsible for ocular motor control. Furthermore, the extent of these microsaccadic alterations is hypothesized to correlate with the severity of the disorder, offering potential diagnostic and prognostic value in clinical settings”.

This hypothesis posits that a systematic evaluation of microsaccadic parameters can provide critical insights into the impact of these disorders on visual function and may serve as a non-invasive biomarker for disorder progression, in conditions where early detection is crucial for optimal therapeutic intervention.

OBJECTIVES

Primary objective

To systematically evaluate and synthesize the current evidence on how various visual disorders such as amblyopia and convergence disorders affect microsaccadic eye movements, with a focus on identifying specific alterations in microsaccadic accuracy, velocity, and latency, and their clinical relevance in optometric practice.

Specific objectives

- To analyse and compare the characteristics of microsaccadic eye movements (e.g., accuracy, velocity, latency) in patients with amblyopia and convergence disorders, relative to healthy individuals.
- To evaluate the clinical utility of microsaccadic movement assessment as a diagnostic tool in optometry, specifically in the early detection of visual disorders.
- To assess the potential for microsaccadic eye movements to serve as a biomarker for monitoring treatment efficacy in patients undergoing therapeutic interventions, such as vision therapy.
- To identify gaps in the current literature and propose future directions for research that could further elucidate the role of microsaccadic eye movements in clinical diagnosis and management of these disorders.

A selection of the databases used was made.

- PubMed, for being a free-access search engine to the MEDLINE database of citations and abstracts of medical research articles.

- Google Scholar, for indexing content from a wide range of disciplines, including optometry and neurology, which ensures access to up-to-date research relevant to saccadic eye movements and associated pathologies.
- Scopus, for including records from MEDLINE database.

Appropriate keywords were chosen using Boolean or Logistic Operators, AND-OR-NOT, which logically connect concepts or groups of terms to expand, limit, or define the bibliographic search.

Table 1: Keyword combinations used.

Database	Search combination
PubMed and Google Scholar	(Microsaccades) AND (Optometry) AND (Eye movements)
	(Microsaccades) AND (Optometry) AND (binocular vision)
	(Microsaccades) AND (Optometry) AND (vergence)
	(Microsaccades) AND (Optometry) AND (accommodation)
	(Microsaccades) AND (Optometry) AND (amblyopia)
	(Microsaccades) AND (Optometry) AND (visual perception)

An initial screening of the articles selected using the combination of databases and keywords was carried out, eliminating duplicates, those that did not focus well on the main topic of interest, as well as those with unclear methodologies and inconsistent results.

Article selection process

The eligibility criteria, inclusion and exclusion were established. The inclusion and exclusion criteria are carefully selected to ensure the quality and relevance of the studies analysed.

The chosen criteria are deemed appropriate to provide a comprehensive and up-to-date assessment of the scientific literature (Table 2).

Table 2: Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Study type	
Randomized controlled trials (RCTs), cohort studies, case-control studies, quantitative observational studies, and relevant systematic reviews with high-quality criteria.	Expert opinions, letters to the editor, single case studies, and non-quantitative studies (e.g., qualitative studies that do not provide measurable data).
Study Population	
- Patients diagnosed with amblyopia, convergence disorders, or neurodegenerative diseases. - Participants with known visual disorders affecting microsaccadic eye movements. - Both adult and pediatric populations.	- Studies conducted on animal models.
Intervention	
- Evaluations of saccadic eye movements, including microsaccades, using clinical and experimental techniques. - Studies examining the role of microsaccades in relation to binocular vision, accommodation, and visual perception. - Interventions that include microsaccadic testing for the diagnosis or monitoring of visual and neurological conditions.	- Studies focusing solely on surgical or pharmacological interventions without evaluating microsaccadic movements. - Research examining only other eye movements without specific focus on microsaccades.
Comparison	
- Comparisons between patients with specific disorders (e.g., amblyopia, convergence disorders) and healthy individuals or control groups. - Comparisons based on the severity of the disorder and its impact on microsaccadic movement alterations.	- Studies without a comparison group or lacking an appropriate control group. - Comparisons between treatments unrelated to microsaccadic movement evaluation.
Measured Outcomes	
- Outcomes evaluating the impact of microsaccadic dysfunction on visual perception or binocular function.	- Studies that do not include quantifiable measures or qualitative assessments of microsaccadic performance. - Outcomes related only to other ocular functions not connected to microsaccadic movements.
Language	
- Articles published in English.	- Articles in languages for which adequate translation is not available.
Publication date	
- Articles published between 2015 and 2024 to ensure relevance of the data.	- Articles that are too old to reflect current practices and knowledge.

RESULTS

The search was conducted in several stages. Initially, a preliminary exploration of key sources was carried out, followed by a refined search focused on relevant works. The second phase involved expanding the search to electronic databases and a thorough review of bibliographic references. The final phase was dedicated to consolidating and organizing the collected information and identifying potential gaps in knowledge.

The results obtained from the various databases totalled 7611, based on the established databases and keywords for the search: 43 in PubMed, 7568 in Google Scholar. Initially, 4532 publications were removed due to duplication.

Subsequently, the remaining articles underwent screening for the inclusion and exclusion criteria. Only articles written in English were included. Only systematic reviews, experimental studies, randomized controlled trials, clinical trials, and observational studies were included. Letters to the editor, editorials, narrative reviews, expert opinions, or did not meet methodological rigor were excluded. Studies not meeting rigorous methodological standards were excluded. This included the clarity of objectives and methods.

Following this screening, 50 articles remained. These were examined and selected based on their relevance to the main topic of the review. Specifically, those that established a clear relationship between the studied conditions and microsaccadic movements or addressed the chosen variables were considered. Articles lacking relevant information on microsaccadic movements, visual perception, binocular vision, or the impact of specific disorders on these movements were excluded. Studies that did not provide data on important variables related to microsaccadic movements, such as the impact of visual disorders on microsaccadic accuracy, velocity, or latency, were excluded.

The results of the application of the inclusion and exclusion criteria are detailed in the flow diagram presented.

As shown in the diagram (Figure 1), seven articles were included in the review.

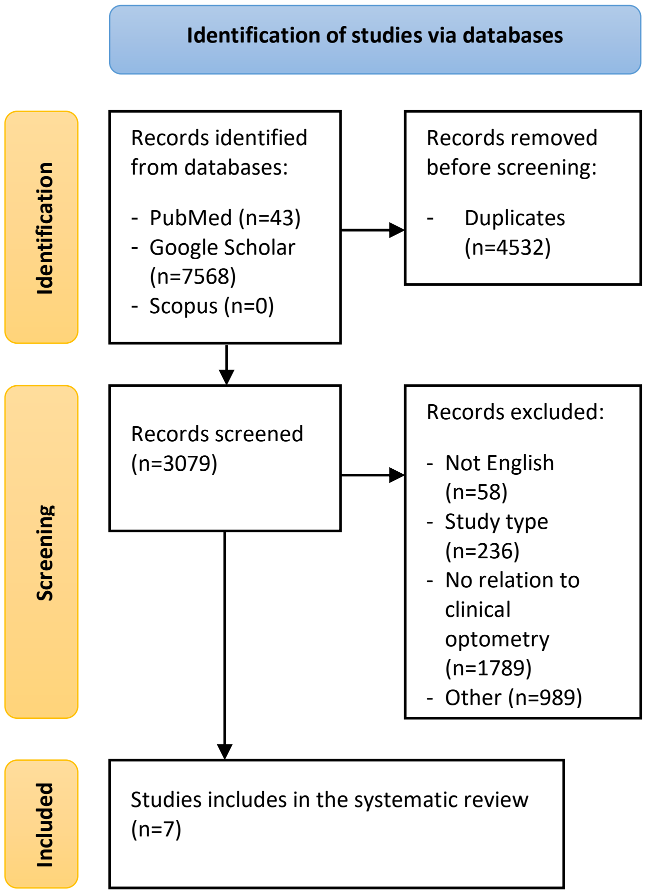

Figure 1: Flow diagram.

The data presented in the Table 3 were extracted from each of them.

Table 3: *Review of the relevant articles. It contains data on authors, title, year, objectives of the work and main findings.*

Authors and year	Title of study	Study type	Objective	Key findings
C. Amy et al. (2022)	Increased saccadic latency in Amblyopia: Oculomotor and attentional factors	Experimental study	To investigate whether oculomotor or attentional factors contribute to increased saccadic latencies in individuals with amblyopia.	-Saccadic latencies were significantly longer when targets were viewed with the amblyopic eye. -Oculomotor factors were ruled out, as saccadic gain and velocity were similar across groups. -Delayed saccadic latencies may be due to impaired attentional disengagement from a fixation target when viewed by the amblyopic eye.
Chung et al. (2015)	Characteristics of fixational eye movements in Amblyopia: limitation on fixation stability and Acuity?	Experimental study	To compare the characteristics of frequency, magnitude of landing errors, amplitude and speed of microsaccades, and the speed of slow drifts in four different groups. The investigated groups were control eyes, non-amblyopic fellow eyes, amblyopic eyes of anisometropic and strabismic amblyopes.	-Fixational eye movements are comparable in fellow eyes of individuals with amblyopia and those with normal vision. -Microsaccades and drifts are abnormal in eyes with strabismic amblyopia. -Fixation is less stable in amblyopic eyes compared to both fellow eyes and control eyes. -Errors in microsaccade amplitude and frequency can affect fixation stability due to their impact on acuity. -Microsaccade error and size, drift size and fixation stability affect acuity limits.
C. Mestre et al (2021)	Characteristics of saccades during the near point of convergence test	Research study	To analyse the saccadic characteristic when testing the near point of convergence. To see the difference of fixation in the dominant and non-dominant eye.	-Saccadic Characteristics: specific metrics of saccades and microsaccades during the near point of convergence test. -Differences in saccadic characteristics between participants with normal convergence and those with convergence insufficiency or other visual disorders. -How saccadic movements contribute to visual processing and fixation stability during convergence tasks.
Dennis M. Levi (2020)	Rethinking amblyopia 2020	Review	To understand amblyopia es a complex condition influenced by neural plasticity and not only as a visual deficit and to highlight the importance of early intervention.	- Amblyopia should be viewed in terms of the underlying neural mechanisms rather than just a visual deficit. - Early intervention and treatment can lead to significant improvements.

				- Understanding microsaccades can provide insights into the visual processing differences in individuals with amblyopia.
R. Alexander et al (2018)	Microsaccade Characteristics in Neurological and Ophthalmic Disease	Clinical study	To explore how microsaccades are affected in individuals with various neurological and ophthalmic conditions compared to healthy individuals.	- Microsaccadic dynamics change in neurological and ophthalmic disease. - The effects of ophthalmic disease on fixational eye movement features could provide an objective to evaluate visual impairment. - The fixational eye movement system is disrupted in patients with neurological and neurodegenerative disorders. - Microsaccadic affectations in hemianopic patients. - An objective evaluation of oculomotor functions in amblyopia involves the assessment of microsaccades. - Studies addressing microsaccadic impairment have valuable implications for clinical research.
C. Gambacorta et al (2018)	Both saccadic and manual responses in the amblyopic eye of strabismics are irreducibly delayed	Experimental study	To investigate and qualify the delays in saccadic responses in individuals with amblyopia associated with strabismus.	- Saccadic responses in the amblyopic eye of individuals presenting strabismus are consistently delayed. - The delays in saccadic movements a characteristic feature of amblyopia associated with strabismus.
Suzanne P. McKee et al (2016)	Saccadic latency in amblyopia	Experimental study	To investigate the timing of saccadic eye movements in a large sample of individuals with amblyopia, strabismus or anisometropia and analyse the interocular correlation with saccadic latency and visual acuity.	- Longer saccadic latencies in individuals with amblyopia compared to control subjects. - Saccadic responses are particularly delayed in the amblyopic eye, regardless of the dominance. - Importance of considering saccadic latency in the assessment and treatment of amblyopia.

DISCUSION

The findings of this study provide critical insights into the impact of various visual disorders on microsaccadic eye movements. As outlined in the primary and specific objectives, it has been systematically evaluated and synthesized the current evidence concerning alterations in microsaccadic movements associated with conditions such as amblyopia and convergence disorders. Understanding these alterations is not only essential for the accurate diagnosis and management of these disorders but also highlights the clinical relevance of microsaccadic eye movement assessments in optometric practice. This discussion will delve into the implications of the findings, examine the correlations between microsaccadic movement parameters and the visual disorders. Additionally, gaps in the existing literature will be identified and directions for future research that could further elucidate the role of microsaccadic eye movements in clinical contexts will be proposed.

Microsaccadic eye movements in visual disorders

The assessment of microsaccadic eye movements holds considerable promise as a diagnostic tool in optometry. This subsection will synthesize the impact of microsaccade eye movements on visual disorders and evaluate their clinical utility in the early detection of visual disorders. By discussing the relevance of microsaccadic evaluations in clinical practice, we can highlight their potential to enhance diagnostic accuracy and improve patient outcomes through timely interventions.

Microsaccades have been identified as critical to maintaining visual stability in patients with amblyopia, strabismus, and macular degeneration. Amblyopia, characterized by reduced visual acuity in one eye, leads to increased drift and irregular microsaccadic patterns during fixation, particularly in the amblyopic eye. The increased frequency and larger amplitude of microsaccades in amblyopic eyes contribute to fixation instability, as these movements tend to shift the eye further from the intended fixation point and are less accurate in their landing positions. The lack of stable fixation and the resultant increased microsaccade frequency may influence the dynamics and spatial allocation of selective attention in individuals with amblyopia, potentially affecting their overall visual processing. Amblyopic eyes demonstrate a higher proportion of large amplitude microsaccades compared to fellow fixing and control eyes, indicating the necessity to further investigation.

In individuals with amblyopia, the treatment could be a training method to target minimizing the landing errors of microsaccades and/or reducing the size of the microsaccades. Also, the correlation between microsaccadic behaviour and visual acuity in amblyopia underscores their potential use as biomarkers for assessing the efficacy of therapeutic interventions, such as orthoptics or optical correction.

In individuals with convergence insufficiency, it is hypothesized that a greater frequency of microsaccades is required to compensate the limitation in the convergence ability.

In hemianopia or macular disease, microsaccades may reflect compensatory mechanisms that enhance residual vision, contributing to visual restoration efforts. These findings suggest that oculomotor assessments could complement visual function tests in providing a more refined understanding of visual impairment and recovery, making microsaccades an integral biomarker for evaluating treatments in ophthalmic disease.

The rehabilitation of ocular and cognitive function could greatly benefit from the understanding of how saccadic patterns correlate with neural plasticity. The compensatory increase in microsaccadic amplitude observed in patients with hemianopia suggests a role for microsaccades in fostering neural plasticity and visual compensation. Thus, microsaccadic behaviour could serve as a window into the brain's ability to reorganize and adapt, particularly in response to therapies aimed at improving sensory or cognitive function. By studying the changes in microsaccadic patterns during recovery, researchers can evaluate the success of rehabilitation programs to compensate for visual and motor deficits.

Microsaccadic eye movements as biomarkers

Saccadic eye movements, including both microsaccades and larger saccades, have emerged as promising biomarkers in the context of visual disorders.

By examining their role as indicators of treatment response, we can better understand how these movements can inform clinical decision-making and optimize patient care. Their dynamic properties, such as amplitude, frequency, velocity, and precision, may help differentiate between disorder states, monitor disorder's progression, and assess the efficacy of therapeutic interventions.

Implications of microsaccadic dysfunction for visual perception and rehabilitation

Although microsaccades have long been thought to play a crucial role in maintaining visual perception by preventing perceptual fading, the specific relationship between altered microsaccadic dynamics and visual dysfunction has not been fully explored. In conditions like amblyopia, macular degeneration, and hemianopia, patients often exhibit increased drift and changes in microsaccadic dynamics, yet the functional consequences of these alterations-particularly in terms of perceptual fading, visual acuity, and field of view-are still poorly understood. Moreover, while microsaccades have been proposed to help compensate for visual deficits, such as in hemianopia, the mechanisms by which they do so remain speculative.

Future directions. Investigating the precise relationship between microsaccadic behaviour and visual perception in patients with visual dysfunctions will provide insights into the compensatory mechanisms that help mitigate visual deficits. Functional studies using real-time visual tracking, along with eye movement analysis, would help elucidate how microsaccades interact with visual inputs to maintain perceptual stability. Furthermore, therapeutic interventions aimed at improving microsaccadic control should be explored to determine whether they can enhance visual function or reduce perceptual fading in patients with degenerative retinal conditions or cortical blindness. Additionally, understanding how microsaccadic dysfunction contributes to visual disturbances could lead to the development of new treatment strategies for individuals with visual impairment.

Technological advancements in eye movement tracking

The evolution of eye tracking technology over the past decade has greatly enhanced the ability to study microsaccades and saccadic intrusions with high precision. However, there are still technical limitations that hinder the application of these tools in clinical settings. For instance, many current eye tracking systems require a fixed laboratory environment, which may not be feasible in real-world clinical settings. Additionally, most studies of fixational eye movements focus on monocular eye movements, neglecting the potential importance of binocular coordination and interocular differences in the dynamics of microsaccades.

Future directions. The development of portable, non-invasive eye tracking systems that can operate in a variety of clinical settings, would facilitate more widespread use of microsaccadic analysis in clinical practice. Furthermore, the integration of binocular eye tracking technology could provide a more comprehensive understanding of fixational stability and its relationship with visual acuity. Advances in machine learning and artificial intelligence also hold promise for automating the analysis of large-scale eye movement data, enabling more efficient and objective assessment of microsaccadic dynamics in clinical populations.

Literature gaps and future research directions

Despite the significant findings in this study, there remain gaps in the current literature regarding the role of microsaccadic eye movements in different visual disorders. Specifically, there is a gap in literature focusing on visual disorders regarding convergence, accommodation and binocular vision. There is a considerable number of studies about microsaccadic eye movements focusing on amblyopia, whereas research on other visual disorders is relatively limited.

There is a lack of investigation about the mechanism of microsaccades and their role in visual disorders as well as their effect on different patient population. Crucial gaps in the literature remain, underscoring the need for further investigation to enhance our understanding of these movements. This subsection will identify these gaps and propose future research directions that could further elucidate the importance of microsaccadic assessments in clinical settings. By addressing these areas, we can advance our understanding of microsaccadic eye movements and their relevance in the diagnosis and management of visual disorders.

One of the most significant challenges in the study of fixational eye movements, particularly microsaccades and saccadic intrusions, lies in the diversity of these eye movement patterns across different optic conditions. While some studies have successfully identified specific microsaccadic features - such as increased microsaccade rates or altered directionality - as characteristic of conditions like strabismus or amblyopia, these findings are often not universally applicable across all patients within these diagnostic categories. The variability in ocular fixation instability across individuals with the same diagnosis suggests that additional symptom-specific, and individual-specific factors contribute to microsaccadic dynamics.

Future directions. Studies that utilize high-precision tracking of eye movements in both longitudinal and cross-sectional designs are required to determine whether there exist distinct, reproducible microsaccadic biomarkers for specific visual disorders. It is critical to assess how age, disorder progression, and co-diagnosis influence the dynamics of microsaccades, and to determine whether there are identifiable clusters of eye movement abnormalities that correlate with clinical outcomes. Moreover, the potential influence of treatments, such as visual therapies, on these eye movement patterns should be explored to assess whether microsaccadic dynamics can serve as sensitive markers for treatment efficacy.

CONCLUSIONS

The investigation into microsaccadic eye movements has significantly advanced our understanding of their potential as biomarkers for various visual disorders. Through the review of the existing literature, it is clear that these involuntary, yet highly coordinated eye movements offer insights into the underlying processes associated with a range of conditions, such as amblyopia, convergence disorders and strabismus. However, despite these promising findings, substantial gaps remain in our knowledge, particularly regarding the precise mechanisms driving microsaccadic dysregulation and their broader implications for diagnosis and management of the disorders.

The characteristics of microsaccades could serve as potential biomarkers for various visual disorders, suggesting their utility in clinical optometry. There is a lot of potential of investigation including microsaccades mechanisms. The understanding of eye movements and their physiology may improve the diagnosis, treatment and outcome of visual abnormalities such as amblyopia and convergence disorders.

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