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Exploring eye-tracking in orthopedics: Potential uses and perspectives

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ABSTRACT

Eye-tracking technology has emerged as a promising tool in the medical and surgical field, offering significant potential for improving diagnostic accuracy, enhancing training, and assessing clinical skills across various disciplines. This article focuses on the current and potential applications of eye-tracking in orthopedic practice, including its role in diagnostic imaging, surgical training, and measuring cognitive workload. Eye-tracking can objectively evaluate visual attention, identify expertise levels, teach trainees, and optimize decision-making during high-pressure scenarios. In addition, it provides real-time feedback that can enhance surgical performance and teamwork. While its use in orthopedics is still evolving, this article highlights the need for further research, particularly in real-world clinical settings, to realize its benefits for orthopedic education and clinical practice.

Keywords: Artificial intelligence, Eye-tracking, Gaze behaviors, Medical education, Orthopedics

INTRODUCTION

In contemporary medical practice, technological advancements have significantly enhanced the precision and efficiency of diagnostic and therapeutic approaches. Among these innovations, eye-tracking technology, defined as "an experimental method of recording eye motion and gaze location across time and task,"[1] has emerged as a promising tool. This technology tracks the focus and movement of the eye during specific tasks. It was initially used in fields such as marketing and psychology and has been increasingly found in applications in medicine and surgery.[1] In this article, we will discuss studies in non-orthopedic uses of eye tracking that may have implications for orthopedic practice. It aims to review the current and potential applications of eye-tracking technology in orthopedic surgery. While its current use in orthopedics remains limited, the technology has proven valuable in other medical fields, such as radiology and surgery.[2]

EYE-TRACKING: HISTORY

Charles Bell first linked eye movement control to the brain in 1823, establishing a connection between eye motion and the nervous system.[1] Early 20th-century research was limited by high costs and complexity, but technological advancements have since made eye-tracking more accessible, with publications rising from under 50 annually before 2000 to over 1,000 by 2018 in

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spanning fields such as neuroscience (18%), medicine (33%), and psychology (58%).[1]

EYE-TRACKING: RATIONALE FOR ITS USE

Eye-tracking technology captures eye motion and gaze location during tasks, enabling the study of visual attention. Gaze location and duration are influenced by cognitive processes such as perception, language, memory, and decision-making.[1] The fovea, the area of highest visual acuity, must align with the desired stimulus, reflecting the "eye-mind link," which connects visual attention to mental processing. By analyzing gaze patterns, eye-tracking provides insights into cognitive functions.[1]

A scanpath, composed of saccades and fixations, represents the sequence of eye movements made when viewing an image.[3] A fixation corresponds to a period during which the eyes are fixed on a visual target and collect visual information.[4] Due to the small size of the fovea, the eye must move frequently to gather information, resulting in numerous short fixations lasting between 180 and 330 ms.[4] Typically, the eye makes about four voluntary movements per second.[3] Saccades are ballistic movements of the eyes from one fixation to the next.[4] During saccades, there is no visual information gathered. The most common method for recording eye movements involves using a near-infrared camera.[5]

Medical imaging plays a crucial role in diagnosis, requiring careful interpretation to ensure accuracy. This includes 2D radiological images, such as radiographs, and volumetric modalities such as computed tomography or magnetic resonance imaging, which must be processed to guide appropriate patient treatment. Training novices to adopt expert-like strategies remains a primary goal of this field.[6] Eye tracking aids in understanding the acquisition of radiological expertise. Diagnostic errors in radiological readings remain significant, with an estimated rate of 30%, which has remained essentially unchanged in recent decades.[7] Studying the gaze patterns of radiologists through eye-tracking technology helps to identify common perceptual errors.[6] The ability to interpret radiological images is essential for all physicians, with orthopedics particularly demanding strong image interpretation skills. In addition, surgeons must often interpret visual information in real-time during live procedures, whether directly or through camera-assisted techniques such as laparoscopy or arthroscopy. To help researchers design studies in eye-tracking research, Dunn *et al*. developed guidelines with a checklist to improve data comprehension and reproducibility.[8]

Radiology, essential for orthopedic diagnosis, offers valuable insights, while general surgical studies can also be extrapolated to orthopedic procedures. Integrating these findings provides a broader perspective on advancements beneficial to orthopedics.

EYE-TRACKING USE IN THE RADIOLOGICAL FIELD

There are two types of interpretation errors in radiology: Cognitive and perceptual.[9] Cognitive errors occur when a lesion is detected but misinterpreted due to incorrect reasoning or insufficient knowledge.[6,9] Perceptual errors involve failing to notice a perceptible lesion.[9] They are more common (78% of cases) and are the leading cause of legal actions against radiologists.[10]

Although guidelines exist for interpreting radiographs, their effectiveness is not well-proven.[9] Research shows that "systematically viewing" radiographs is less beneficial than expected, as even experts rely on non-systematic search patterns.[9] The optimal strategy for interpreting medical imaging remains unknown.[9]

A suggested model explaining expert visual search is the global-focal model.[11] It indicates that experts form a quick global impression of an image, comparing it to prior knowledge to identify abnormalities.[9] Thereafter, they focus on suspicious areas, repeating the process if no decision is reached. This fast global processing, which is absent in novices, enables experts to detect more abnormalities more efficiently with fewer eye movements.[9]

In their meta-analysis about expertise differences in the comprehension of visualization, Gegenfurtner *et al*. observed that experts, compared to non-experts, have shorter fixation durations, more fixations on task-relevant areas, fewer on redundant areas, longer saccades, and faster fixation on relevant information.[12] Table 1 summarizes the main differences between experts' and novices' eye-metrics during medical image interpretation.

The extent to which replicating experts' eye metrics improves diagnostic accuracy remains uncertain. Eye-tracking studies suggest that gaze patterns, such as time-to-first fixation[13] or saccade ratios,[14] develop before diagnostic accuracy. Thus, replicating expert gaze patterns alone does not necessarily improve diagnostic performance.[6,15] However, integrating experts' visual patterns into broader training approaches shows promise. For instance, Aufferman *et al*.[16] demonstrated that gaze training significantly improved trainees' ability to detect pulmonary nodules compared to a control group. These results suggest that eye-tracking, when used as part of a comprehensive strategy, could enhance image perception and diagnostic performance. Additional factors, such as clinical information and disease prevalence, influence diagnostic accuracy.[6]

Further research is needed to identify the optimal strategy for enhancing image perception.

EYE-TRACKING USE IN THE SURGICAL FIELD

Eye-tracking technology is widely used in surgical research. In their systematic review, Gil *et al*. identified its main applications as skill assessment (41%), visual attention (22%), workload (17%), and skill training (19%), along with others such as team cognition, fatigue, and vigilance.[17] The applications of eye tracking in surgery are summarized in Table 2.

Eye-tracking technology enables comparisons between novices and experts, helping train novices on where and when to focus during procedures. Fichtel *et al*. found that when participants viewed surgical videos, fixation times varied by expertise,[18] suggesting eye-tracking can differentiate expertise levels.

A study by Dilley *et al*.[19] examined the correlation between eye metrics and performance using the Global Evaluative Assessment of Robotic Skills and the Numeric Psychomotor Test Score during simulated and real-tissue robotic surgery. Significant correlations were found between eye metrics (e.g., pupil size, rate of change, and entropy) and performance in both novices and proficient surgeons. This suggests that eye-tracking aligns with established assessment methods and is useful in robotic surgery.

Table 1: Experts versus novices eye-tracking differences in medical image interpretation.

Criterion	Experts	Novices
Fixation duration	Shorter fixations on relevant areas	Longer fixations, including on irrelevant areas.
Number of fixations	Fewer overall fixations, with more focus on relevant areas	Greater number of fixations, often on redundant or irrelevant areas.
Saccade length	Longer saccades due to broader parafoveal processing and extended search areas	Shorter saccades with less efficient visual coverage
Time to first fixation (relevant)	Faster detection of relevant areas, with quicker focus on anomalies	Slower detection of relevant areas, often distracted by irrelevant features
Fixations on redundant areas	Few fixations on irrelevant areas	Significant fixation time wasted on irrelevant or redundant areas
Search patterns	Initial global search followed by a detailed focal exploration	More random and systematic search without efficient prioritization

Comparison between experts' and novices' metrics during medical image interpretation. Adapted from previously published studies.

Table 2: Eye-tracking in surgery: Applications, workload, and performance.

Application	Key usefulness	Metrics used	Impact on surgical practice
Skill assessment	Tracks gaze to evaluate surgical performance and skill acquisition	Fixations, saccades, gaze patterns, gaze entropy	Provides objective evaluation of surgical skills and helps novice surgeons adopt expert-like gaze patterns.
Visual attention	Analyzes surgeons' focus areas during critical tasks	Gaze patterns, fixation duration, task-specific regions	Optimizes visual attention strategies for better management of critical events and task success.
Workload measurement	Assesses mental workload by tracking eye movements and pupil dilation	Pupillometry, blink rates	Provides objective metrics for workload, informs training to reduce cognitive overload, improves performance
Skill training	Teaches novices expert gaze strategies for improved performance	Gaze behavior, fixation duration, visual attention patterns	Enhances skill acquisition through feedback on gaze behavior, improves performance retention.
Team cognition	Examines team members' visual attention and interaction	Gaze patterns, shared focus areas	Improves teamwork and communication within the surgical team, optimizing overall procedure success
Fatigue and vigilance	Detects fatigue or lapses in attention that can affect surgical performance	Gaze entropy, pupil dilation	Helps detect fatigue or lapses in attention that could affect performance, leading to better scheduling and breaks during surgery

Surgical eye-tracking applications include skill assessment, workload evaluation, and performance optimization. Adapted from previously published studies.

Eye-tracking technology can provide direct feedback and assist in training novices for technical skills. For instance, Melnyk *et al*.[20] found that students who adopted expert gaze patterns demonstrated more efficient movements during a virtual reality robotic suturing task.

A recent systematic review Bapna *et al*.[21] noted that most eye-tracking studies in surgery were conducted in simulated environments (n = 72), with few in operating theaters (n = 20). While simulations provide controlled conditions and easier data interpretation, translating gaze behavior to real-world surgery remains challenging. Live surgical studies are recognized as crucial for bridging this gap, offering insights into clinical practice and the complexities of real-world surgical interventions.

MEASURE OF COGNITIVE WORKLOAD WITH EYE-TRACKING

Eye-tracking technology has been used to measure cognitive workload during surgery. The operating theatre is a complex environment that requires constant multitasking, such as multidisciplinary communication, rapid decision-making, and technical skills execution. The notion of a mental load linked to allocated cognitive resources required to do a task is described as "cognitive load theory."[22] The measure of cognitive workload has traditionally been measured subjectively with self-reported questionnaires, such as the Surgery Task Load Index. However, this method does not reflect real-time assessment during surgery.[22] Ocular metrics are a more reliable indicator of cognitive workload. In their systematic review, Naik *et al*.[22] emphasized the importance of ocular parameters such as pupil size, blinking, and gaze metrics as effective indicators of cognitive workload. Another systematic review further supports eye-tracking as a valid workload indicator, demonstrating metric variations based on task difficulty.[23]

EYE-TRACKING USE IN THE ORTHOPEDIC FIELD

Eye-tracking technology applications in orthopedics remain underexplored. The following section highlights recent studies on eye-tracking in orthopedics.

Several studies in orthopedics have compared eye-tracking differences between experts and novices during radiograph analysis. For instance, Giovinco *et al*.[24] found that when rating deformities in bunion radiographs, experts spent less time per image and were quicker to assess deformities than novices.

In a study where observers were asked to identify fractures on an anteroposterior pelvis radiograph,[25] more experienced observers demonstrated faster response times and fewer fixations, indicating greater efficiency in interpreting plain films. Eye-tracking metrics were recorded during a simulated hip arthroscopic procedure[26] revealing a correlation with expertise levels. Unlike the intermediate group, novices exhibited longer dwell times, more saccades, more fixations, and longer saccade durations. However, the number of participants was low (n = 12).

Galuret *et al*.[27] found that visual behaviors could be related to technical skills assessment during a simulated environment. They quantified gaze distribution in simulator-specific areas of interest within an arthroscopic simulator, showing that gaze behavior can assess surgical expertise and track the learning curve.

These studies show that there are differences in eye-metrics between experts and novices during imagery interpretation but also simulated arthroscopic procedures.

These findings underscore the potential of eye-tracking technology in orthopedics for evaluating expertise, improving training, and optimizing diagnostic accuracy. With further research, particularly in real-world clinical settings, eye-tracking could become an essential tool for advancing both education and practice in orthopedics.

CONCLUSION

Eye-tracking technology shows promise in orthopedics, following its application in radiology and surgery to enhance diagnostics, training, and skill assessment. While there is a paucity of eye-tracking research in orthopedics, insights can be drawn from other fields. Future studies, especially in live surgical settings, are needed to explore its benefits and drive innovation in orthopedic practice and education.

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REFERENCES

1. Carter BT, Luke SG. Best practices in eye tracking research. Int J Psychophysiol 2020;155:49-62.
2. Ashraf H, Sodergren MH, Merali N, Mylonas G, Singh H,

Darzi A. Eye-tracking technology in medical education: A systematic review. Med Teach 2018;40:62-9.
3. Wu CC, Wolfe JM. Eye movements in medical image perception: A selective review of past, present and future. Vision (Basel) 2019;3:32.
4. Rayner K. The 35th Sir Frederick Bartlett lecture: Eye movements and attention in reading, scene perception, and visual search. Q J Exp Psychol 2009;62:1457-506.
5. Holmqvist K, Nyström M, Andersson R, Dewhurst R, Jarodzka H, Van de Weijer J. Eye tracking: A comprehensive guide to methods and measures. Oxford: Oxford University Press; 2011. p. 16.
6. Waite S, Grigorian A, Alexander RG, Macknik SL, Carrasco M, Heeger DJ, *et al*. Analysis of perceptual expertise in radiology - current knowledge and a new perspective. Front Hum Neurosci 2019;13:213.
7. Berlin L. Accuracy of diagnostic procedures: Has it improved over the past five decades? AJR Am J Roentgenol 2007;188:11738.
8. Dunn MJ, Alexander RG, Amiebenomo OM, Arblaster G, Atan D, Erichsen JT, *et al*. Minimal reporting guideline for research involving eye tracking (2023 edition). Behav Res 2023;56:4351-7.
9. Waite S, Farooq Z, Grigorian A, Sistrom C, Kolla S, Mancuso A, *et al*. A review of perceptual expertise in radiology-how it develops, how we can test it, and why humans still matter in the era of artificial intelligence. Acad Radiol 2020;27:26-38.
10. Baker SR, Patel RH, Yang L, Lelkes VM, Castro A. Malpractice suits in chest radiology: An evaluation of the histories of 8265 radiologists. J Thorac Imaging 2013;28:388-91.
11. Nodine CF, Kundel HL. Using eye movements to study visual search and to improve tumor detection. Radiographics 1987;7:1241-50.
12. Gegenfurtner A, Lehtinen E, Säljö R. Expertise differences in the comprehension of visualizations: A meta-analysis of eye-tracking research in professional domains. Educ Psychol Rev 2011;23:523-52.
13. Kelly BS, Rainford LA, Darcy SP, Kavanagh EC, Toomey RJ. The development of expertise in radiology: In chest radiograph interpretation, "expert" search pattern may predate "expert" levels of diagnostic accuracy for pneumothorax identification. Radiology 2016;280:252-60.
14. Kok EM, De Bruin AB, Robben SG, Van Merriënboer JJ. Looking in the same manner but seeing it differently: Bottom-up and expertise effects in radiology. Appl Cogn Psychol 2012;26:854-62.
15. Van der Gijp A, Ravesloot CJ, Jarodzka H, van der Schaaf MF, van der Schaaf IC, van Schaik JP, *et al*. How visual search relates to visual diagnostic performance: A narrative systematic review of eye-tracking research in radiology. Adv Health Sci Educ Theory Pract 2017;22:765-87.
16. Auffermann WF, Little BP, Tridandapani S. Teaching search patterns to medical trainees in an educational laboratory to improve perception of pulmonary nodules. J Med Imaging (Bellingham) 2015;3:011006.
17. Gil AM, Birdi S, Kishibe T, Grantcharov TP. Eye tracking use in surgical research: A systematic review. J Surg Res 2022;279:774-87.
18. Fichtel E, Lau N, Park J, Henrickson Parker S, Ponnala S, Fitzgibbons S, *et al*. Eye tracking in surgical education: Gaze-based dynamic area of interest can discriminate adverse events and expertise. Surg Endosc 2019;33:2249-56.
19. Dilley J, Singh H, Pratt P, Omar I, Darzi A, Mayer E. Visual behaviour in robotic surgery-demonstrating the validity of the simulated environment. Int J Med Robot 2020;16:e2075.
20. Melnyk R, Campbell T, Holler T, Cameron K, Saba P, Witthaus MW, *et al*. See like an expert: Gaze-augmented training enhances skill acquisition in a virtual reality robotic suturing task. J Endourol 2021;35:376-82.
21. Bapna T, Valles J, Leng S, Pacilli M, Nataraja RM. Eye-tracking in surgery: A systematic review. ANZ J Surg 2023;93:2600-8.
22. Naik R, Kogkas A, Ashrafian H, Mylonas G, Darzi A. The measurement of cognitive workload in surgery using pupil metrics: A systematic review and narrative analysis. J Surg Res 2022;280:25872.
23. Tolvanen O, Elomaa AP, Itkonen M, Vrzakova H, Bednarik R, Huotarinen A. Eye-tracking indicators of workload in surgery: A systematic review. J Invest Surg 2022;35:1340-9.
24. Giovinco NA, Sutton SM, Miller JD, Rankin TM, Gonzalez GW, Najafi B, *et al*. A passing glance? Differences in eye tracking and gaze patterns between trainees and experts reading plain film bunion radiographs. J Foot Ankle Surg 2015;54:382-91.
25. Hanley J, Warren D, Glass N, Tranel D, Karam M, Buckwalter J. Visual interpretation of plain radiographs in orthopaedics using eye-tracking technology. Iowa Orthop J 2017;37:225-31.
26. Cai B, Xu N, Duan S, Yi J, Bay BH, Shen F, *et al*. Eye tracking metrics of orthopedic surgeons with different competency levels who practice simulation-based hip arthroscopic procedures. Heliyon 2022;8:e12335.
27. Galuret S, Vallée N, Tronchot A, Thomazeau H, Jannin P, Huaulmé A. Gaze behavior is related to objective technical skills assessment during virtual reality simulator-based surgical training: A proof of concept. Int J Comput Assist Radiol Surg 2023;18:1697-705.