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Review article

Emerging applications of eye-tracking technology in dermatology

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ABSTRACT

Eye-tracking technology has been used within a multitude of disciplines to provide data linking eye movements to visual processing of various stimuli (i.e., x-rays, situational positioning, printed information, and warnings). Despite the benefits provided by eye-tracking in allowing for the identification and quantification of visual attention, the discipline of dermatology has yet to see broad application of the technology. Notwithstanding dermatologists' heavy reliance upon visual patterns and cues to discriminate between benign and atypical nevi, literature that applies eye-tracking to the study of dermatology is sparse; and literature specific to patient-initiated behaviors, such as skin self-examination (SSE), is largely non-existent. The current article provides a review of eye-tracking research in various medical fields, culminating in a discussion of current applications and advantages of eye-tracking for dermatology research.

Contents

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1. Emerging applications of eye-tracking technology in dermatology

Eye-tracking technology has been used within a multitude of disciplines to provide data that link subject visual patterns to stimuli (see Table 1). Medical researchers have used eye-tracking extensively in fields such as psychiatry and radiology. Within psychiatry, research has examined visual behavior of patients with depression [1], schizophrenia [2], and autism [3]. The field of radiology has examined how physicians visually process output from magnetic resonance imaging [4], ultrasounds [5], computed tomography [6], and other imaging machines [7]. Outside of these, other medical disciplines, like surgery [8,9] and pathology [10] have also utilized eye-tracking in training capacities, though to a lesser degree than those noted above. Despite the benefits of eye-tracking in allowing for the identification and quantification of visual attention and visual information processing, the field of dermatology has yet to see broad application of the technology. Given the visual dominance of many identification tasks in dermatology, and previous research suggesting eye movements can be predictive of expertise [11], competence [12], and learning [13,14], the increased application of eye-tracking in dermatological work is important to consider. As discussed in the present review, there is limited use of eye-tracking in dermatology and great potential for integrating the research technology into dermatology training and practice.

Visual attention is a primary means of gathering information about one's environment. It serves an orienting role and, through both active and passive processing, allows for perception and action to be linked [15]. While visual attention and gaze are not always connected [16], the ability to track where an individual is looking is a strong indicator of where his/her focus may lie [17]—especially in scenarios where one is directed to perform a specific task [18].

Eye-tracking technology refers to any of a multitude of devices designed to quantify the visual attention of subjects across a stimulus. The most commonly used measures in eye-tracking research are *fixations*, or points where the subject's eye stops in order to process information [19] and *saccades*, the short visual shifts that exist between fixations, and during which information encoding is suspended [20]. The majority of currently-available eye-tracking devices rely on a corneal-reflection/pupil-center method [21]; using an infrared camera and infrared light to generate reflections from the subject's pupil and cornea.

A comprehensive review of the history and functionality of eye-tracking is available in the literature courtesy of Kowler [22]. For the purposes of this review, focus will be maintained on the application-specific benefits that eye-tracking provides in medical applications. Just like in non-medical applications, where eye-tracking has been used in advertising [23], aviation [24], usability testing [25], and various other capacities—applications of eye-tracking in medical settings have been similarly varied, providing context in areas that would otherwise remain unquantifiable.

2. Applications of eye-tracking in other disciplines

2.1. Radiology

As radiologists review medical imagery, diagnostic errors are acknowledged and documented [26], even if the underlying causes aren't entirely understood [27]. Reportedly, errors in diagnosis occur during one of two stages: the visual perception stage (e.g., inspecting an image) or the cognition stage (e.g., the thought processes that ultimately lead to diagnosis) [28]. Both stages have been thoroughly researched, and eye-tracking has made a unique contribution to the inspection stage—breaking it down further into failures of search and failures of recognition [29].

Eye-tracking has been applied to radiology through examining radiographs or chest nodules [30], training of radiologists [31], and analyzing breast lesions in mammograms [32], among other applications. In each of these capacities, eye-tracking has been used to analyze visual search patterns, and to discriminate by experience level. For example, Leong and colleagues [30] discovered that experienced radiologists not only had greater true-positive detections than less-experienced radiologists, but they required significantly shorter fixation times for diagnosis; indicative of an inverse relationship between expertise and time to diagnosis. Kundel, Nodine, and Krupinski [13] also found significant accuracy benefits for radiologists who were given eye-tracking feedback during training. Furthermore, eye-tracking has also shown utility when paired with computer-assisted detection (CADe) systems, to aid radiologists during mammography screening. Specifically, Tourassi and colleagues [33] gave radiologists eye-tracking glasses to wear while using CADe, which made the CADe system context sensitive, and, in turn, increased its accuracy and the accuracy of the radiologists.

Overall, applications of eye-tracking in radiology have provided the capability to examine the correlation between gaze duration and correct diagnosis [12], how to predict diagnosis through spatial frequency representation [34], how conspicuous lesions impact search patterns in mammography [35], and the correlation between detection and lesion subtlety [36]. Eye-tracking also provides feedback for trainers and trainees in isolating perceptual and cognitive problems, allowing for discrimination between experts and non-experts, and determining the perceptual or cognitive origins of processing deficiencies.

2.2. Surgery

Applications of eye-tracking in the surgical discipline, while not as wide-spread as those in radiology, nevertheless offer insight into its instructional/training potential. Chetwood and colleagues [8] found that showing an instructor's gaze during training resulted in faster completion times, fewer errors, and significantly reduced visual latency. Additionally, Tomizawa and colleagues [9] used mobile eye-tracking units to record extracorporeal circulation (ECC) tasks performed during surgery, and discovered that the most experienced perfusionist spread his visual attention more widely across all key areas of information than his less-experienced counterparts.

Beyond training applications, Zheng et al. [37] used eye-tracking to measure blinks among surgeons, and then correlated these items with the National Aeronautics and Space Administration Task Load Index (NASA TLX). Results indicated that surgeons who blinked infrequently reported higher levels of frustration and higher overall workload—providing support for eye-tracking as a possible measure of cognitive workload.

Use of eye-tracking in the field of surgery is still growing. Early applications have shown potential for the technology to contribute in optimizing training procedures, process efficiency and expert discrimination, outcomes [38], evaluation of workload, and, increasingly, integration with surgical robotics [39]. Future applications will undoubtedly expand upon these areas.

3. Dermatology and eye-tracking

For dermatology, there are lessons to be learned from reviewing eye-tracking applications in radiology, surgery, and other medical disciplines. Notably, each of these disciplines has benefitted from using eye-tracking, and new research lines have been opened.

Table 1
Selected Eye-Tracking Applications by Medical Discipline

Discipline	Year	Authors	Overview	Metrics Used
Dermatology	2012	Dreiseitl, Pivec, & Binder [42]	Participants ($N = 16$) with varying levels of diagnostic expertise (little, intermediate, superior) were recorded via eye-tracking while examining and diagnosing 28 digital images of pigmented skin lesions (PSLs). Results showed that experience level had a significant impact on the way in which images are examined (the more experience, the fewer and shorter the fixations).	Fixations
Dermatology	2014	Krupinski, Chao, Hofmann-Wellenhof, Morrison, & Curiel-Lewandrowski [43]	In this phased study, board-certified dermatologists ($n = 2$) and dermatology residents ($n = 2$) viewed a series of 20 PSLs and rated each as benign or malignant while eye position was recorded. Results determined that dermatologists had more efficient searches than residents, generating fewer fixations and shorter dwell times.	Dwell time Fixations
Dermatology	2017	John, Jensen, King, Ratcliff, & Grossman [14]	The researchers proposed a visual skill acquisition model (VSAM) that identifies eye-tracking metrics as measures of visual processing efficiency. With a sample of laypersons ($N = 92$), the study examined the impact of photorealistic vs. illustrated visuals on skin self-examination (SSE) training effectiveness. Overall, illustrated training was found to increase sensitivity, while photorealistic training increased specificity. Moderated-mediation analysis showed that, in certain circumstances, training using photorealistic or illustrated visuals increased accuracy by first increasing total time viewing the atypical moles.	Fixations
Psychiatry	2011	Sears, Newman, Ference, & Thomas [1]	This eye-tracking study looked for evidence of attention and memory biases in individuals with a self-reported history of depression compared to individuals with dysphoria and individuals with no history of depression. Previously depressed and dysphoric individuals spent significantly less time attending to positive images than never depressed individuals. Previously depressed individuals also attended to anxiety-related images more than never depressed individuals.	Dwell time Fixations Saccades
Psychiatry	2004	Tregallas, Tanabe, Miller, Ross, Olincy, & Freedman [2]	Researchers used functional magnetic resonance imaging (fMRI) to compare brain response during a smooth pursuit eye movement task in patients with schizophrenia. Smooth pursuit deficits in patients with schizophrenia included lower gain (eye velocity relative to target velocity) and a higher percentage of total eye movements due to anticipatory saccades compared with healthy subjects. Patients with schizophrenia also exhibited greater activity in both the posterior hippocampi and the right fusiform gyrus during smooth-pursuit eye movements, suggesting inhibitory function in the hippocampus.	Fixations Saccades
Psychiatry	2013	Wagner, Hirsch, Vogel-Farley, Redcay, & Nelson [3]	This study examined the neural, behavioral, and autonomic responses of adolescents with autism spectrum disorder (ASD) and individuals with typical development (TD) while viewing a series of faces. Adolescents with ASD showed an atypical pattern of emotional face processing, with reduced neural differentiation between emotions and a reduced relationship between gaze behavior and processing.	Fixations Pupil size
Radiology	1997	Niimi, Shimamoto, Sawaki, Ishigaki, Takahashi, Sugiyama, Nishihara [4]	Researchers evaluated the effectiveness of three kinds of display methods for magnetic resonance (MR) image interpretation using eye-tracking. After analyzing fixation points and dwell time, researchers determined that a multiple-series display with selected key series of slices was the most suitable.	Dwell time Fixations
Radiology	2013	Andreoni, Mazzola, Zambarbieri, Forzoni, D'Onofrio, Viotti, San-tambrogio, & Baselli [5]	Usability tests of two portable ultrasound scanners with different user interfaces (touchscreen and classic physical keyboard) were conducted and measured using eye-tracking.	Scan path
Radiology	2015	Samadani, Ritlop, Reyes, Nehrbass, Li, Lamm, Schneider, Shimunov, Sava, Kolecki, & Burris [6]	Eye-tracking was used to measure the eye movements of subjects who had suffered a brain injury ($n = 75$) and noninjured control ($n = 64$) subjects in order to determine whether tracking would reveal disconjugate gaze associated with both structural brain injury and concussion. Results suggest that eye tracking may help quantify the severity of ocular motility disruption associated with concussion and structural brain injury.	Fixations Saccades
Radiology	2014	Rubin, Roos, Tall, Harrawood, Bag, Ly, Seaman, Hurwitz, Napel, & Roy Choudhury [7]	Researchers examined radiologist ($N = 13$) search patterns, recognition, and diagnosis of lung nodules using a remote eye tracker. They used a metric called gaze volume (GV) to refer to the portion of lung parenchyma within 50 pixels of the radiologists' gaze, and found that nodules within the radiologist's GV stood a greater chance of being detected accurately. Overall, sensitivity held a moderate correlation with the percentage of the lung that was reviewed.	Fixations Scan path
Radiology	2006	Manning, Ethell, Donovan, & Crawford [30]	Eye tracking measures were used to investigate differences in search strategies in detecting pulmonary nodules between radiologists ($n = 8$), radiographers ($n = 5$), and undergraduate radiographer students ($n = 8$). Performance measures showed the experienced group of radiologists and radiographers after training were better at the task than the undergraduates. Results also indicate distinct search patterns between the groups, suggesting a theoretical model of measuring expert performance.	Fixations Saccades Scan path
Radiology	1990	Kundel, Nodine, & Krupinski [31]	Using previous eye-tracking results, an algorithm was developed to determine places on a chest radiograph where pulmonary nodules are likely to be missed. The study was conducted in order to determine whether using visual feedback that highlighted these easily-missed areas was an effective aid to pulmonary nodule detection. Results show a 16% improvement in accuracy in those who received visual feedback.	Fixations Scan path
Radiology	2011	Lång, Zackrisson, Holmqvist, Nystrom, Andersson, Förnvik, Tingberg, & Timberg [32]	This study evaluated 4 different viewing procedures of breast tomosynthesis (BT) image volumes in order to determine the greatest time efficiency and accuracy. Visual search behavior was measured using eye-tracking. Results indicate no differences between the 4 types of procedures, but suggested the use of medium loop speed.	Fixations Scan path
Radiology	2010	Tourassi, Mazurowski, Harrawood, & Krupinski [33]	This study measures the use of a context-sensitive computer-assisted detection system (CADe) in assisting radiologists when screening for malignant masses. Results indicate that context-sensitive CADe, or a system with variable decisions	Dwell time

Table 1 (*Continued*)

Discipline	Year	Authors	Overview	Metrics Used
			based on the radiologists' eye dwelling data, reduced errors and improved radiologists' sensitivity more effectively than conventional CADe.	
Radiology	2006	Mello-Thoms [34]	This eye-tracking study examined the effect that the observation of a malignant mass had on the background sampling strategy of experienced mammographers. Results indicated that while there was no significant difference between background sampling before and after their eyes first hit a correctly-reported malignant mass, there was a significant difference in spatial frequency when a mammographer didn't see a mass, or when lesion-free areas were incorrectly reported as containing a mass (false positives).	Dwell time Spatial frequency
Radiology	2002	Mello-Thoms, Dunn, Nodine, Kundel, &Weinstein [35]	This study measured mammographers' attention and spatial frequency in order to model areas on mammograms that attracted visual attention. Mammographers read 40 mammogram cases, during which their eye positions were recorded. Results indicated that different decision outcomes yielded different spatial frequencies.	Fixations Spatial frequency
Radiology	2005	Krupinski [36]	The eye movements of radiologists ($N = 6$) were tracked during visual mammogram searches in order to determine whether lesion subtlety influenced accuracy and visual search behaviors. Results indicated that subtle lesions were detected later than more obvious lesions, and false negatives were detected later than true positives, garnering fewer fixations.	Dwell time Fixations
Surgery	2012	Chetwood, Kwok, Sun, Mylonas, Clark, Darzi, & Yang [8]	This study projected the eye movements of a supervisor onto a laproscopic screen to aid surgical instruction. Results indicated that projected eye-gaze of the supervisor on a screen significantly reduced the number of errors and completion time.	Fixations Latency Scan path
Surgery	2012	Tomizawa, Aoki, Suzuki, Matayoshi, & Yozu [9]	A pilot study was conducted in which eye-tracking was applied to the analysis of extracorporeal circulation (ECC) performed by perfusionists during cardiovascular surgery. Results indicated that perfusionists with greater expertise dispersed his or her attention more widely.	Fixations Spatial frequency
Surgery	2012	Zheng, Jiang, Tien, Meneghetti, Panton, & Atkins [37]	Surgeons' mental workload was evaluated using a paper assessment and blink rates via eye-tracking. Surgeons who blinked infrequently reported a higher level of frustration and higher level of workload than those who blinked more frequently.	Blink duration Blink frequency Level of workload
Surgery	2011	Kim, Burgess, Waters, Reece, Beahm, Crosby, Basen-Engquist, & Markey [38]	The researchers examined the potential of eye-tracking technology to explicate plastic surgeon subjective assessments of breast reconstruction surgery outcomes. Dwell time and transition frequency were measured using eye-tracking. Results showed that surgeons spent the most time on the anterior-posterior views.	Dwell sequence Dwell time Transition frequency
Surgery	2010	Ahmidi, Hager, Ishii, Fichtinger, Gallia, & Ishii [39]	This paper identified two methods of determing the skill level of surgeons: motion data of surgical tools and eye-tracking. Results suggest that eye-gaze data can indicate skill; furthermore, by adding eye-tracking information to surgical tool motion data, skill assessment improved by 13.2% for expert levels and 5.3% for novice levels.	Fixations Scan path

These lessons apply directly to dermatology because, above all, dermatology still relies primarily on the human eye and brain to render judgment on atypical lesions. Diagnoses may increasingly be aided by dermatoscopes [40], computers [41], and other imaging tools, but the final decision to excise or ignore is a human one, based on visual indicators. Using eye-tracking, these visual indicators could be identified, quantified, codified, and applied for future practice. Furthermore, training of new dermatologists could be enhanced by allowing gaze patterns to be corrected early on. With the dermatologist's reliance on visual processes to render diagnosis, application of eye-tracking to the discipline is a natural fit. However, thus far, only a handful of studies have utilized eye-tracking to examine visual patterns in the diagnosis of nevi.

3.1. Current applications

Dreiseitl and colleagues [42] grouped 16 participants by diagnostic experience, and presented them individually with a series of pigmented skin lesion (PSL) images to diagnose. Their gaze patterns were tracked and, as variables of interest, the researchers measured visual coordinates, gaze track length, total time to diagnosis, fixation duration, and total number of fixations. Results indicated that, on average, experts arrived at diagnosis 70% quicker than non-experts. Additionally, both total fixation time and total number of fixations were 50% lower for experts compared to non-experts, meaning that experts required less time and fixation points on the lesion to come to a more accurate diagnosis, compared to non-experts [42].

These conclusions are supported by a second study, performed by Krupinski and colleagues [43], which used eye-tracking to measure the success of an online dermoscopic training program. In particular, the researchers presented the subjects with 20 cases of PSLs that were either malignant melanoma (MM) ($n = 10$), or benign lesions with characteristics of MM ($n = 10$). In each case, subjects viewed both a standard photo of the lesion, centered and surrounded by normal skin, and a dermoscopic image of the same lesion for comparison. Lesions were rated on a scale from 1 to 10, with 1–5 considered benign and 6–10 considered highly atypical. The sample consisted of two board-certified dermatologists and two dermatology residents, and these individuals repeated their assessment three months after the initial assessment. Results indicated that the two dermatologists had more efficient search patterns than their resident counterparts, evidenced by lower numbers of total fixations and shorter dwell times. Furthermore, in instances where decisions changed between the photograph and the dermoscopic image, total fixations and dwell times were observed to be significantly higher across all subjects, indicative of increased cognitive processing driving these decisions.

These two studies represent foundational dermatological applications of eye-tracking, but they are inherently limited. Both studies included relatively small samples, which ultimately restricts generalizability, therefore, additional studies that measure similar variables with larger samples are necessary. Furthermore, both of these studies relied upon groups of individuals who were either experts, or aspiring experts, in dermatology. Focusing on experts has left skin self-examination (SSE) and laypeople drastically under-represented. There are limitations to SSE effectiveness [44,45]; however, application of eye-tracking to this line of research would open the door for deficiencies in training to be quantified and improved—in similar manner to expert-focused studies.

One such study, performed by John, Jensen, King, Ratcliff, and Grossman [35], used eye-tracking to measure SSE training accuracy gains among a sample of 96 laypersons. Specifically, John and colleagues [14] proposed and tested a Visual Skill Acquisition Model (VSAM), which claimed that eye-tracking metrics may serve as quantifiable measures of skill acquisition in visual tasks like SSE. To test this model, they employed a 2×2 factorial design exploring how training that includes particular visual presentations (illustrated vs. photorealistic training) and patterns (ABCDE vs. ugly duckling sign training) impacts sensitivity and specificity outcomes following a mole identification task. Results indicated that illustrations and photos yielded higher sensitivity and specificity scores, respectively—with the UDS × photo condition providing the greatest gains in specificity. Furthermore, for individuals with self- efficacy at the mean or lower, fixation-based eye-tracking metrics mediated the relationship between training and specificity. Overall, these findings provide early empirical support for VSAM, and early evidence that eye tracking metrics may be suitable to quantify gains in SSE visual processing efficiency.

3.2. Future directions

Despite its limited application, eye-tracking has yielded unique insights for dermatology research; however, specific questions need to be addressed before the technology's full potential for the discipline can be discerned. First, do fixation-based metrics serve as consistent skill discriminators among dermatologists, residents, and students? While early research has shown that the visual search patterns of more experienced dermatologists are more efficient than their less-experienced peers [42,43], these claims come from only two studies with admittedly small sample sizes. Further research needs to be performed, preferably with larger sample sizes, to support this claim. Second, how can eye-tracking be used to enhance layperson training and SSE performance? Only a single study has applied eye-tracking to layperson samples [14], and while illustrated and photorealistic training both increased accuracy under certain circumstances, in both cases it resulted in higher total fixation time on the atypical nevi—which runs counter to the efficiency gains seen in trained dermatologists. It is possible that, due to their lack of experience, laypersons must expend greater cognitive resources to apply the principles of their training—resulting in less efficiency that, nevertheless, begets greater accuracy. Third, how can other eye-tracking metrics—like blink rates and saccadic frequency—be used to enhance training in lesion classification? The disciplines of radiology and surgery have integrated eye-tracking technology into training scenarios, and have found significant benefits [8,37,38]. Would the same hold true for dermatological instruction? Finally, what efficacy does eye-tracking hold for further research beyond pigmented lesions in the context of melanoma screening? To offer a handful of suggestions, other potential applications may include evaluation of *distribution* of lesions that are characteristic of various skin diseases that may be restricted to or spared from particular anatomic sites. For example, some papulosquamous (e.g. psoriasis) disorders commonly involve the extensor rather than flexor surfaces and spare the face while some blistering diseases (e.g. dermatitis herpetiformis) typically are restricted to the elbows and buttocks. Allergic contact dermatitis induced by air-borne allergens commonly involves the eyelids and the dorsal hands, while photo-dermatoses (induced by UV exposure, e.g. porphyria cutanea tarda) usually spare the eyelids and involve the dorsal hands. Thus, eye-tracking could be used to study how dermatologists and trainees focus on particular body sites in the evaluation of a patient with a new skin eruption. Another example would be using fixation-based metrics to study how the initial lesion (herald patch) is identified in a patient with a widespread papulosquamous eruption suspicious for pityriasis rosea that would be a key diagnostic clue. Similarly, eye-tracking could be applied to studying how physicians examine patients with pre-existing conditions who are being evaluated for response to therapy, where some areas would be predicted to respond faster or slower than others. As a final example, evaluating the evolution of a cutaneous eruption, where lesions arise at one site and then progress to other sites may also be amenable to eye-tracking studies. For example, drug rashes typically begin centrally and may be concentrated in dependent areas and then these areas improve as lesions begin to develop on the extremities.

3.3. Fixation-based metrics

Arguably, future innovations in dermatology eye-tracking research will hinge heavily on the efficacy of fixations—the most commonly used eye-tracking metric—to yield relevant data. Fixation-based metrics derive information about subject attention and cognition by examining areas where the subject's gaze stops momentarily over the stimulus, and the meaning behind fixation behavior is context-dependent, in that variations in task (e.g., encoding vs. search) can ascribe very different meaning to the observed behaviors. For example, in an encoding scenario, such as looking at a melanoma pamphlet, a greater number of total fixations may indicate greater interest in the stimulus. However, in a searching task, where a subject is asked to identify an atypical nevus among many nevi, a greater number of fixations may be indicative of confusion or uncertainty in locating the item of interest [19]. Despite these context-dependent differences in interpretation, researchers are consistent in their claims that fixations are an indicator of some level of cognition [19]. The following fixation-derived metrics are commonly used in eye-tracking literature, and may hold utility for dermatology research applications.

3.3.1. Total fixations

This is the total number of fixations recorded as the subject looks across the stimulus/stimuli. A greater number of fixations can be indicative of interest during encoding tasks, or indicative of confusion during searching tasks [19]. In mole identification applications, for example, researchers could assign subjects a task to identify an atypical mole on a patient's back, and total fixations could serve as a metric of confusion across subjects.

3.3.2. Fixation duration

This is the total time that the subject spent either on a single fixation, or the total fixation time across all fixations. Greater fixation duration can be indicative of uncertainty or difficulty in deciphering the stimulus, or it could mean that the stimulus was particularly appealing to subjects, depending on context [46].

3.3.3. Fixation density

High fixation density manifests in eye-tracking data as clusters of fixation points, tightly grouped together. Fixation density can be indicative of search efficiency—where greater density indicates effective searching, and lower density indicates unstructured or inefficient searching [47].

3.3.4. Fixations within a lookzone/area of interest (AOI)

Lookzones (AOIs) are defined areas of interest that the researcher has marked for further analysis, which are invisible to subjects. For example, if a researcher was interested in how many subjects observed an atypical nevus on a patient's body, he/she could place a lookzone around that nevus. During analysis, fixations within the lookzone could then be tracked separately from fixations on the remainder of the nevi. Typically, greater fixations within the lookzone means one (or both) of two things: Either the objects within the lookzone were more conspicuous than those in the remainder of the stimulus, or the objects in the lookzone were more important to the subject compared to competing elements in the stimulus [48].

It is important to note that, when dealing with a lookzone around text, it is recommended that the average number of fixations in that lookzone be divided by the total number of words in the lookzone [48]. This is done to discriminate between an inflated fixation count elicited due to simple reading, versus a higher fixation count due to interest/difficulty in recognizing the target.

3.3.5. Dwell

This is the total time that the subject spends fixating, either across the entire stimulus, or within a particular lookzone of interest. This is a useful measure to contrast how visual attention was spread between two or more targets in the stimulus (e.g., a lookzone versus the remainder of the stimulus). Additionally, it can be a measure of anticipation, when gaze precedes a particular action within the stimulus (e.g., a subject visually anticipating a window popping up after clicking on a button) [34].

3.3.6. Time to lookzone/AOI

This metric relies on the total time elapsed before arriving at the lookzone or area of interest, to determine that element's relative importance to other competing elements within the stimulus [49]. Greater time equals less importance.

Related to this metric are *post-target fixations*, which refer to the number of fixations that take place outside of the lookzone after encountering it. Higher numbers of post-target fixations imply that the object(s) within the lookzone are of low priority compared to other elements of the stimulus [19].

3.3.7. Percent of subjects who fixated within the lookzone/AOI

This metric represents a simple calculation of what portion of subjects actually fixated within the desired lookzone(s). Low percentages mean that the elements in the desired lookzones need to be emphasized or relocated (especially in the case of usability testing) [23,25].

A closely related metric was used by Goldberg and Kotval [19], who took the number of fixations within the lookzone, and divided it by the total number of fixations (overall), providing a ratio of fixations on and off target. A lower ratio indicates ineffective design/presentation.

3.4. Challenges

While eye-tracking technology can open lines of research for dermatology, these do not come without difficulties. First, eye-tracking equipment is expensive—for some, prohibitively so—creating an initial entry barrier. Lower cost options are slowly becoming available, but these cheaper alternatives often do not have the precision or integration with software to suit academic or medical research. Second, there is a knowledge gap with eye-tracking measures and logistics that must be crossed. These can be mitigated through review of foundational eye-tracking literature [17,20,22]; though expert-guided exposure to the equipment and methods is also a desirable alternative for those with eye-tracking labs in their vicinity. When publishing eye-tracking research in a discipline unfamiliar with the technology, the researcher must provide the audience with a basic knowledge of the measures used. This will allow for conclusions to be evaluated objectively by reviewers and readers. Third, eye-tracking equipment is very sensitive to calibration errors and environmental factors. Tall and colleagues provide an excellent overview of variance that can be introduced into eye-tracking research through these factors [50]. Without careful consideration to calibration, equipment configuration, and environment (at onset and throughout tracking), eye-tracking results run the risk of being marred with error—leading to spurious findings. Acceptance of eye-tracking as an appropriate addition to any discipline requires evidence of effective measures and scientific processes; and the mantle of responsibility for valid eye-tracking research in dermatology rests squarely on the shoulders of its earliest adopters.

4. Conclusion

This review calls for a closer examination of eye-tracking and the benefits that it can provide to the discipline of dermatology. Eye-tracking provides the capability of quantifying visual search patterns; allowing for the analysis of visual attention and for inferences about cognition to be made. In application to dermatology, eye-tracking affords access to data that have henceforth been uncapturable in the analysis of atypical nevi, and provides a means of measuring training impact on visual processes (e.g., why training works). Capitalizing on eye-tracking capabilities, dermatology can begin to share the benefits that other disciplines—such as psychiatry, radiology, and surgery—have already seen from the technology. Current eye-tracking research in dermatology represents initial steps in building a foundation, and future research should look to other disciplines for examples of potential applications.

Conflict of interest

None.

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