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ORIGINAL RESEARCH

Eye-Tracking Analysis of Attention Disruptions Under Realistic Interruptions During Trauma Management; A Cross-sectional Study in a Simulated Virtual Reality

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Abstract: **Introduction:** Distractions and interruptions may interfere with concentration, working memory, and timely decision-making. This study aimed to analyze the visual attention patterns of medical interns during the management of a multiple-trauma patient in a realistic virtual reality (VR) emergency scenario using eye-tracking technology integrated into VR simulation. **Methods:** This cross-sectional simulation-based study was conducted among 15 medical interns at Tehran University of Medical Sciences. Participants were exposed to a 242-second high-fidelity VR trauma scenario representing a crowded ED with multiple environmental distractions and interruptions. Eye-tracking data were collected using the HTC Vive Pro Eye headset. The scenario was divided into four predefined temporal intervals. Areas of interest (AOIs) were defined and classified as relevant (main patient, key treatment team members, and essential equipment) or distractors (nonessential environmental and emotional stimuli). Main outcome measures included cumulative gaze time on relevant and distractor AOIs, gaze time outside defined AOIs, and the Relevant/Distractor ratio. **Results:** A total of 253,075 gaze samples were obtained, with a mean of 16,871.7 ± 2,097.0 samples per participant. The mean duration of valid eye-tracking data was 238.5 ± 12.3 seconds per participant, corresponding to approximately 98.6% of the total scenario time. Across all intervals, gaze was predominantly directed toward relevant AOIs, and this pattern became progressively stronger over time. The Relevant/Distractor ratio increased from 3.41 ± 1.58 in the initial interval to 27.60 ± 26.12 in the final interval, while attention to distractor AOIs decreased from 19.2% to 4.7%. Spatially, the head and face of the main injured patient, the emergency medicine resident, and the patient monitor consistently attracted the greatest attention. **Conclusion:** Medical interns progressively adopted a more structured and goal-directed visual attention strategy, increasingly prioritizing vital clinical information over distracting stimuli. VR-based eye tracking appears to be a feasible and informative tool for assessing attentional behavior and may support targeted educational interventions in trauma training.

Keywords: Virtual reality; Eye tracking; Trauma management; Emergency department; Medical interns; Visual attention; Simulation-based education

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1. Introduction

The emergency department (ED) is considered one of the most complex and high-pressure clinical environments, where physicians must make critical and accurate decisions in the shortest possible time (1). This issue becomes even more important when they are faced with patients with multiple trauma, as these patients require rapid assessment, simultaneous interventions, and multidisciplinary coordination (2). Under such circumstances, the implementation of ATLS principles plays a vital role in standardizing initial assessments, identifying immediate life-threatening conditions, and appropriately prioritizing therapeutic interventions, and it is recognized as the reference approach in the management of trauma patients (3). However, the crowded emergency environment is full of distractions and various

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interruptions that can have substantial negative effects on the treatment process; these include environmental noise, equipment alarms, the arrival of patients' companions, telephone calls, sudden requests, and the unavoidable multitasking of staff (4–6). By disrupting concentration and working memory, these distractions and interruptions increase the likelihood of medical errors and delays in treatment, thereby affecting the quality of care (7). The results of one study indicate that physicians and nurses in the ED experience an average of approximately 11 interruptions per hour, amounting to a total of 1205 interruptions in their workflow over the course of the study (8). Therefore, training future physicians to function effectively in such crowded and chaotic environments is both essential and critical. Medical education should be designed in a way that strengthens students' ability to maintain concentration, make correct decisions, and interact effectively with other members of the healthcare team under stressful conditions (9). Existing evidence suggests that simulation is one of the effective methods for teaching the management of distractions and interruptions in emergency settings. This approach allows students to practice their skills in maintaining focus, making rapid decisions, and responding to interruptions in a safe environment, which consequently improves accuracy and safety in patient care (10). Simulation-based training should be designed so that students can strengthen their skills in critical situations through the use of realistic emergency simulations (11). In recent years, emerging technologies, particularly Virtual Reality (VR), have gained a special place in medical sciences education (12). VR–based simulators, by creating realistic and controlled emergency environments, enable medical students to practice vital skills such as crisis management, rapid decision-making, and effective performance under pressure (13). These environments are designed to reproduce the stressors and distractions present in real emergency situations and thereby enhance students' capacity to cope with complex and unpredictable clinical conditions (14, 15). Nevertheless, realistic simulation alone is not sufficient. To prevent medical errors and improve educational processes, it is essential that distracting factors be carefully identified and analyzed, especially in crowded emergency situations (10, 16). In this regard, eye-tracking technology, which has been specifically incorporated into VR headsets, can serve as a powerful tool for analyzing attention patterns and identifying distraction-inducing factors (17). By examining gaze pathways and users' points of focus, this technology enables researchers to analyze students' attentional patterns in simulated environments and investigate how their attention is distributed under crowded conditions (18, 19). Findings from previous studies have shown that the combination of realistic simulations and eye-tracking technology can play a significant role in improving decision-making skills and reducing clinical errors through precise analysis of attention patterns, identification of distracting factors, optimization of decision-making processes, and enhancement of cognitive abilities under high-pressure conditions (20 - 22). However, to the best of our knowledge, few studies have specifically analyzed and evaluated distracting factors in a simulated emergency environment with realistic interruptions through eye tracking. Therefore, the present study analyzes the attentional patterns of medical interns in a simulated emergency environment using VR equipped with eye-tracking technology. The aim of this research is to identify factors affecting impaired concentration and decision-making during the management of patients with multiple trauma. The results of this analysis may provide a basis for designing targeted educational interventions that ultimately lead to improved decision-making accuracy, reduced medical errors, and enhanced quality of patient management in crowded emergency settings.

2. Methods

2.1. Study design and setting

This was a single-group, descriptive pilot, simulation-based eye-tracking study conducted in a hospital emergency simulation environment using a high-fidelity virtual reality trauma management scenario. No intervention, control, or comparison group was included; therefore, assessment comparability between groups was not applicable. All participants were exposed to the same VR scenario and were assessed using the same headset, eye-tracking calibration procedure, temporal intervals, AOI definitions, data extraction protocol, and outcome measures. To design the scenario, common interruptions and distractions in the ED such as alarm sounds, background conversations, staff movement, family member interference, and the simultaneous presence of multiple patients were first identified based on a preliminary literature review and a review of emergency medicine experts' experiences; subsequently, the scenario script was developed accordingly. The scenario was performed in the emergency simulation setting by a trained group consisting of a standardized patient, a patient companion, nurses, medical students, an emergency medicine resident, ED staff, and a prehospital emergency team, and a 360-degree video recording of the scene was obtained. The camera was positioned at the location of the decision-making physician so that the participant's viewpoint in the VR environment would correspond to the real decision-making position in the ED. The visual content was converted into an interactive VR environment using 3DVista Virtual Tour Suite software, and a dedicated software application based on Unreal Engine and the official eye-tracking plugin was developed to record gaze trajectories. In this system, at each frame, the intersection point of the user's gaze ray with the displayed content surface was recorded, and its coordinates were stored after conversion into the display coordinate system. Ultimately, the eye-tracking output included temporal data, including timestamp, horizontal and vertical gaze coordinates (X, Y), and grayscale and colored heat maps for each time interval. The entire scenario lasted 242 seconds, during which each participant, in the role of the decision-making physician, encountered a multiple-trauma scene in a crowded ED.

2.2. Eligibility Criteria

The study population consisted of medical interns at Tehran University of Medical Sciences. Inclusion criteria were completion of at least 1.5 emergency medicine clerkship credits, passage of at least six months since the beginning of the internship period, and completion of at least one month of the emergency medicine internship rotation, in order to ensure that participants were familiar with the ED environment and the basic principles of trauma management. Exclusion criteria included visual impairment or low vision affecting the use of the VR headset or eye-tracking system, use of psychotropic or antidepressant medications with a potential impact on concentration and cognitive performance, severe sleep deprivation or insomnia within 24 hours prior to scenario execution, use of reflective eyeglasses or colored contact lenses that could interfere with eye-tracking registration, absence from the study session, or withdrawal at any stage of the research. Individuals meeting any of these exclusion criteria were not included in the final analysis, and only data from participants who met all inclusion criteria and had none of the exclusion criteria were analyzed.

2.3. Sample Size and Sampling Method

The study population given the pilot nature of the study, the implementation complexity of the VR scenario, and resource limitations (time, equipment, and manpower), the sample size was set at 15 participants. Sampling was performed using a convenience/feasibility-based method; thus, eligible interns who were present in the emergency medicine department during the study period and were willing to participate were voluntarily enrolled in the study. Owing to practical limitations, randomization and further increase in sample size were not feasible, and the study was designed and conducted with the aim of describing the preliminary pattern of visual attention in a simulated trauma scenario and assessing the feasibility of using an eye-tracking system in a VR environment.

2.4. Data Collection

After explaining the study objectives and providing initial instruction on headset use, multipoint eye-tracking calibration was performed for each participant using the HTC Vive Pro Eye headset to ensure that gaze recording accuracy was within an acceptable range. The participant was then positioned, either standing or sitting, in the role of the decision-making physician, and the VR content, consisting of a crowded ED with a patient with multiple trauma (traffic accident with lower-limb amputation and unstable vital signs), was presented for 242 seconds. Throughout the scenario, despite realistic interruptions and disturbances including alarm sounds, background conversations, people entering and moving through the environment, family member interference, the presence of other patients, and clinical changes in the main patient the participant was required to maintain focus on the primary patient and make critical decisions related to treatment priorities in four consecutive temporal stages, such as selection of the first airway management intervention, fluid resuscitation, respiratory measures, or intervention on the injured limb. For more precise analysis of the eye-tracking data, and considering the changing position and priority of areas of attention throughout the scenario, the entire scenario was divided by consensus of two emergency medicine specialists into four time intervals: 0–66, 66–101, 101–156, and 156–242 seconds. In each interval, areas of interest (AOIs) were defined based on two-dimensional gaze coordinates. In total, 14 AOIs were identified, including the head and face of the main injured patient (AOI1), the main patient monitor (AOI2), the emergency medicine resident (main colleague) (AOI3), the intervening medical student (AOI4), the intervening nursing student (AOI5), the emergency nurse (main colleague) (AOI6), prehospital nurse (AOI7), the distressed mother of the main patient (AOI8), the ambulatory trauma patient and companion (AOI9), ED staff (AOI10), the amputated lower limb of the main injured patient (AOI11), important equipment and devices (AOI12), the deceased patient and family (AOI13), and the emergency police officer (AOI14); the boundary coordinates of each AOI were determined on the real scene image. AOIs related to the main patient (head and face, amputated limb, monitor), key members of the treatment team (emergency medicine resident, emergency nurse), and vital equipment were classified as "relevant" AOIs, whereas the remaining AOIs were classified as "distractor" AOIs. This classification was performed a priori for each time interval based on the clinical decision-making objectives of that interval and by consensus of two emergency medicine specialists, and was adjusted in an interval-specific manner when necessary, according to scene changes and decision-making priorities. The eye-tracking output file for each participant included time (timestamp) and gaze coordinates (x, y) from second 0 to 242. For each temporal sample, it was determined whether the gaze point fell within the boundaries of any AOI; accordingly, each sample was assigned an AOI label or, if it did not match any AOI, was recorded as "outside AOI." The viewing duration for each AOI in each time interval was calculated by counting the number of samples within the AOI (n) and dividing it by the effective sampling rate of the device (f) (viewing time in seconds = n/f). Accordingly, for each participant and each time interval, cumulative gaze time on relevant AOIs, cumulative gaze time on distractor AOIs, gaze time outside AOIs (Outside_sec), and seconds with no valid data (Missing_sec) were extracted; in addition, eye-tracking heat maps were generated for visual comparison of attention patterns across different intervals.

2.5. Handling of missing eye-tracking data

Missing eye-tracking data were defined as time periods during which no valid gaze coordinate was recorded by the eye-tracking system. Invalid or missing samples were not imputed or replaced, because artificial interpolation could distort the true gaze allocation pattern. Instead, these periods were excluded from AOI-specific gaze time calculations and were reported separately as Missing_sec for each participant and each time interval. For each temporal interval, tracked time was calculated as the total interval duration minus Missing_sec. The proportions of gaze time directed toward relevant AOIs, distractor AOIs, and outside predefined AOIs were interpreted in relation to the available tracked data. Participants with valid calibration and usable gaze data were retained in the analysis, and the extent of missing data was reported descriptively in the Results section.

2.6. Sensitivity Analysis

To examine whether the main descriptive findings were influenced by the participant with the highest amount of missing eye-tracking data, a sensitivity analysis was performed by repeating the interval-level descriptive analysis after excluding this participant. The main attention indices, including Relevant_sec, Distractor_sec, Outside_sec, and the Relevant/Distractor ratio, were recalculated for the remaining participants and compared descriptively with the primary analysis including all participants. Because of the pilot and descriptive nature of the study, this sensitivity analysis was not used for hypothesis testing, but rather to assess the robustness of the observed temporal pattern of attention allocation.

2.7. Ethics statement

This study was reviewed and approved by the Ethics Committee in Research of Tehran University of Medical Sciences before implementation (ethics code: IR.TUMS.MEDICINE.REC.1402.058). All procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki. Participation was entirely voluntary. Before enrollment, all participants received sufficient information about the study objectives, procedures, duration of the VR scenario, eye-tracking data recording, potential discomfort related to VR headset use, confidentiality of data, and their right to withdraw from the study at any time without any educational or administrative consequences. Written informed consent was obtained from all participants prior to participation. Personal information was kept confidential, and each participant was assigned a unique code. No personal identifiers were included in the analytical dataset. Participants were also informed that if they experienced any physical or psychological discomfort during the VR scenario, including dizziness, nausea, visual discomfort, or anxiety, the session would be stopped immediately and they could withdraw from the study.

2.8. Statistical Analysis

The statistical analysis was planned according to the descriptive and pilot nature of the study. The main objective was to describe temporal and spatial patterns of visual attention during a single VR-based trauma scenario rather than to compare intervention groups or test the effectiveness of an educational intervention. For each participant and within each of the four predefined time intervals, the following eye-tracking indices were calculated: cumulative gaze time on relevant AOIs (Relevant_sec), cumulative gaze time on distractor AOIs (Distractor_sec), gaze time outside predefined AOIs (Outside_sec), the ratio of gaze time on relevant AOIs to distractor AOIs (Relevant/Distractor ratio), and seconds with no valid eye-tracking data (Missing_sec).

For each time interval, continuous variables were summarized using mean, standard deviation, minimum, and maximum values. At the AOI level, the mean and standard deviation of gaze duration for each AOI were calculated across participants to identify regions that attracted the highest and lowest levels of visual attention. Temporal changes in gaze allocation were presented descriptively using summary tables and trend graphs.

Because this was a single-group pilot study with a small sample size and no control or comparison group, no inferential statistical tests were performed. Accordingly, no regression modeling or statistical adjustment for potential confounding variables was conducted. Potential confounding was minimized at the design and measurement levels by exposing all participants to the same VR scenario, using the same headset and calibration procedure, applying identical AOI definitions and temporal intervals, and extracting the same outcome measures for all participants. The findings were therefore interpreted as preliminary descriptive patterns rather than causal or comparative effects.

3. Results

3.1. Data quality and eye-tracking performance

In this study, eye-tracking data were collected from 15 medical students at the internship level during a realistic trauma management scenario with a nominal duration of 242 seconds using the HTC Vive Pro Eye headset, yielding a total of 253,075 gaze samples. The mean number of recorded samples per participant was 16,871.7 ± 2,097.0, ranging from 9,658 to 18,275 samples. Considering the duration of the scenario, the mean availability of valid eye-tracking data for each participant was 238.5 ± 12.3 seconds (range: 194–242 seconds), indicating that most participants maintained stable tracking for nearly the entire 242-second period. In this analysis, the variable Missing_sec was defined as the number of seconds during which no valid eye-tracking sample was recorded. On this basis, a total of 52 seconds out of the 3,630 seconds of total simulation time (15 participants × 242 seconds) lacked valid data, corresponding to approximately 1.4% of the total study time. The distribution of Missing_sec showed that 11 participants had no missing seconds, two participants had only 1–2 seconds of missing data, and one participant experienced 48 seconds of data loss, indicating overall high tracking quality with a major defect occurring in only one case. In the sensitivity analysis excluding the participant with 48 seconds of missing data, the overall temporal pattern remained unchanged: gaze allocation continued to be predominantly directed toward relevant AOIs across all intervals, distractor-related gaze time decreased over time, and the Relevant/Distractor ratio showed a progressive increase throughout the scenario. The effective eye-tracking sampling rate, expressed as the number of samples per recorded second, was on average 70.45 ± 6.28 samples per second (range: 49.78–75.52 Hz), which is consistent with the technical specifications of the hardware used. In addition, all x and y coordinate values were within the normalized range of 0 to 1, and no samples were recorded outside the screen boundaries, confirming the geometric adequacy and overall stability of eye-tracking data quality in this sample (Figure 1 & 2).

3.2. Temporal pattern of attention allocation to critical and distracting regions

First time interval

In the initial interval of the scenario (0–66 seconds), the mean gaze time directed at critical regions was 34.69 ± 6.87 seconds, corresponding to approximately 52.6% of the total time in this interval. During the same interval, gaze time directed at distracting regions was 12.70 ± 6.47 seconds, equivalent to about 19.2% of the interval, whereas gaze time outside the defined AOIs was 17.54 ± 5.14 seconds, corresponding to 26.6% of the recorded time. The Relevant/Distractor ratio in this phase was 3.41 ± 1.58, indicating that although visual attention was predominantly focused on critical elements from the outset, a considerable proportion of attention was still allocated to distracting stimuli (Table 1).

Second time interval

In the second interval (66–101 seconds), the mean gaze time toward critical regions increased to 21.20 ± 4.03 seconds, equivalent to approximately 60.6% of the interval, whereas gaze time toward distracting regions declined to 4.73 ± 3.03 seconds, accounting for about 13.5% of the interval, and gaze time outside AOIs was 8.47 ± 4.71 seconds, equivalent to 24.2%. At this stage, the Relevant/Distractor ratio rose to 7.52 ± 6.98, suggesting greater participant focus on critical information and reduced sensitivity to nonessential environmental stimuli (Table 1).

Third Time Interval

In the third interval (101–156 seconds), the mean gaze time directed at critical regions was 29.69 ± 8.09 seconds, corresponding to approximately 54.0% of the interval. Gaze time directed at distracting regions was 4.74 ± 5.65 seconds (about 8.6%), while gaze time outside AOIs was 20.10 ± 8.65 seconds, equivalent to nearly 36.5% of the interval. The Relevant/Distractor ratio increased to 13.65 ± 9.49 in this interval, showing that despite an increase in overall scene scanning (Outside), the relative share of attention allocated to distracting regions declined even further (Table 1).

Final time interval

In the final interval of the scenario (156–242 seconds), the mean gaze time toward critical regions reached 47.71 ± 10.02 seconds, accounting for approximately 55.5% of the interval, whereas distracting regions attracted only 4.05 ± 5.35 seconds of gaze time, equivalent to about 4.7%, and gaze time outside the defined AOIs was 32.91 ± 7.63 seconds, corresponding to 38.3% of the interval. At this point, the Relevant/Distractor ratio reached its highest value, 27.60 ± 26.12, indicating a very strong concentration on critical regions and a minimization of attention to distracting stimuli toward the end of trauma management (Table 1).

3.3. Overall tracking coverage across intervals

Across all intervals, the mean Missing_sec was less than 1.5 seconds, and the mean tracked_sec values were 64.93, 34.40, 54.53, and 84.67 seconds, respectively, demonstrating valid data coverage in more than 98% of the seconds in each interval.

3.4. AOI-level analysis and spatial pattern of attention

At the level of individual AOIs, the spatial pattern of attention showed that participants' gaze was consistently concentrated on the main patient and key members of the treatment team. In the 0–66 second interval, the longest fixation time was observed for the emergency medicine resident (AOI3), with a mean of 12.47 ± 2.78 seconds, followed by the head and face of the main injured patient (AOI1) with 12.14 ± 3.38 seconds, whereas the intervening nursing student (AOI5) was viewed for only 0.31 ± 0.46 seconds. In the 66–101 second interval, this pattern was repeated; the emergency medicine resident and the head and face of the injured patient accounted for the longest gaze durations, with means of 10.44 ± 3.26 and 10.39 ± 3.65 seconds, respectively, while the emergency police officer (AOI14) had no recordable viewing time. In the 101–156 second interval, the greatest gaze duration was directed toward the head and face of the main injured patient (14.65 ± 5.55 seconds) and the patient monitor (AOI2) with 9.29 ± 5.47 seconds, whereas the ED staff (AOI10) were almost entirely ignored, with only 0.02 ± 0.09 seconds of observation. In the final 156–242 second interval, the head and face of the main injured patient, with 23.66 ± 7.59 seconds, and the emergency medicine resident, with 14.83 ± 5.52 seconds, once again ranked as the most frequently viewed regions, whereas the distressed mother of the main patient (AOI8) attracted only 0.03 ± 0.11 seconds of attention (Table 2).

3.5. Temporal trends in key AOIs

Examination of the temporal trend of several key AOIs also revealed a coherent pattern. Gaze time directed at the head and face of the main injured patient remained high across all intervals and increased from approximately 12 seconds in the initial interval to more than 23 seconds in the final interval, indicating sustained and progressively intensified focus on the principal source of life threat. Gaze time toward the emergency medicine resident was high during the first two intervals, decreased markedly in the 101–156 second interval (mean: 2.91 ± 2.00 seconds), and then rose again to a high level at the end of the scenario; this fluctuation likely reflects a change in the resident's role or spatial position within the scene. Attention to the patient monitor, in the intervals in which this AOI was present, particularly during the middle and final phases, accounted for a considerable share of total attention, suggesting that students repeatedly referred to the patient's vital signs. In contrast, attention to the distressed mother of the main injured patient was relatively high at the beginning of the scenario (4.88 ± 3.32 seconds) but declined sharply in subsequent intervals and became almost negligible in the final interval; this pattern may indicate a gradual reduction in the attentional weight of emotionally salient but nonessential stimuli during the more advanced stages of trauma resuscitation (Table 2).

3.6. Overall summary of the visual attention pattern

Overall, the findings indicate that students directed their attention predominantly toward critical regions from the very beginning of the scenario, and as time progressed, the relative share of attention allocated to distractor AOIs decreased while the Relevant/Distractor ratio increased progressively. In the final stages, the visual attention pattern was characterized by a very strong focus on the main patient, the emergency medicine resident, and the patient monitor, together with minimal attention to noncritical environmental stimuli. The high quality of the eye-tracking data across all intervals supports the validity of these patterns and provides a basis for the application of inferential tests to compare time intervals or different participant subgroups (Figure 3).

4. Discussion

The findings of this study indicate that, when confronted with a realistic trauma scenario in a VR environment accompanied by interruptions and environmental distractions in the ED, medical interns dynamically and temporally shift their visual attention allocation strategy toward clinically relevant stimuli. Specifically, gaze directed at critical AOIs remained predominant throughout the scenario and became more pronounced over time, whereas attention to distractor AOIs progressively declined, and the Relevant/Distractor ratio increased markedly from the beginning to the end of the scenario. From the perspective of situation awareness theory, this pattern may be interpreted as reinforcement of Level 1 situation awareness (i.e., the acquisition/extraction of relevant information from the environment), because eye tracking specifically captures the trace of visual information gathering and does not necessarily indicate comprehension or projection (Levels 2 and 3) (23).

In comparison with the existing literature, the predominant gaze concentration in the present study on the patient/head and face, followed by the monitor and a key team member, is consistent with eye-tracking findings from trauma simulation studies. For example, Damji et al., using a head-mounted eye tracker (Mobile Eye XG) and defining fixation (>0.2 seconds) within predetermined AOIs, demonstrated that in a trauma scenario, the greatest proportion of visual attention was allocated to the patient/manikin, followed by the monitor and team members, suggesting that even under high-pressure conditions, the core stimuli involved in clinical decision-making usually remain the main focus of gaze (24). Likewise, the increasing structure of attention over time is consistent with the idea that after an initial phase of broad scanning and the formation of a mental model of the patient's condition, the individual moves toward more goal-directed gaze strategies. Evidence from emergency education has shown that gaze metrics may be associated with performance evaluation in simulated resuscitation tests; therefore, changes in the ratio of relevant to irrelevant attention in the present study may represent a potential behavioral indicator of cognitive maturation and/or reduced non-purposeful visual search during task performance (25). Other studies have also shown that in critical situations, gaze distribution particularly toward monitoring components changes and adapts to the critical state. For instance, in the simulation study by Roche et al. in anesthesia, the visual attention of staff toward monitoring components differed between noncritical and critical conditions (26), which is conceptually consistent with our observed pattern regarding the prominence of the patient monitor across different intervals and the increasing concentration on critical elements.

On the other hand, the marked reduction in attention to emotional and environmental stimuli (such as the distressed mother, police officer, and secondary patients) may be interpreted in a dual manner. On the one hand, it may reflect effective filtering of distractions and preservation of xABCDE priorities in the crowded emergency environment. On the other hand, it also raises the possibility that some communicative or safety-related cues (for example, team interactions, environmental hazards, or information provided by family members) may receive less attention because of intense focus on core stimuli. Therefore, it is recommended that future studies correlate gaze indices with performance outcomes including decision-making accuracy, time to critical interventions, errors, and nontechnical skills to determine the point at which ignoring distractions shifts from being a cognitive advantage to becoming a risk, especially in scenarios in which some environmental stimuli deliberately carry clinical information (27).

From a methodological perspective, the very high quality of the data (high percentage of valid data) indicates that eye tracking in VR can be operationally feasible and reliable for emergency scenarios. However, the hardware literature on eye-tracking headsets, including the Vive Pro Eye, emphasizes that data quality depends on factors such as calibration status, head movement, and the spatial position of visual targets, and these factors should therefore be standardized and reported in future protocols (28, 29).

From an educational perspective, the growing literature suggests that patterns of visual attention can be used both for feedback and debriefing and for predicting performance/cognitive load. For example, in skill-based simulators, attentional patterns may predict novice performance and cognitive load (30), and in certain resuscitation domains, eye tracking has been used to explore cognitive processes and enrich simulation-based education (20, 31). Therefore, from the perspective of intervention design, our findings may contribute to the development of benchmark patterns for visual attention during different stages of a trauma scenario, and subsequently, through the use of gaze replay in debriefing, may help target the skill of selective attention while maintaining environmental awareness (20, 32).

Given the pilot nature and limited sample size of the present study, future research should employ multicenter designs with larger sample sizes and probabilistic (random) sampling in order to improve the generalizability of visual attention patterns during trauma management among interns and other professional groups, including residents, attending physicians, and emergency nurses, and to enable cross-level comparisons of skill. It is also recommended that future studies, in addition to descriptive analyses, use inferential tests and more advanced models such as mixed linear models or data-mining and clustering approaches based on fixation patterns to identify distinct attention profiles and examine their associations with clinical performance, speed and accuracy of decision-making, and diagnostic error. Investigating the effects of educational interventions based on eye-tracking feedback, such as presenting trainees with heat maps of experts' gaze patterns and comparing them with their own patterns, within randomized trials focused on educational outcomes and long-term retention of skills, may also represent an important direction for future research. Moreover, developing more diverse scenarios with different trauma patient profiles for example, penetrating trauma, multisystem injury, pediatric trauma—and varying levels of complexity and environmental distraction, together with examining the intra-individual stability of attention patterns across different situations, may lead to a deeper understanding of how visual attention skills generalize. Finally, integrating eye-tracking indices with other objective measures, such as physiological stress markers (heart rate and skin conductance), perceived cognitive load, and objective in-scenario performance, is recommended to better explain the relationship between attention, mental workload, and decision-making quality in trauma education.

5. Limitations

This study was a single-center pilot investigation with a small sample size (15 interns) and convenience sampling, and it included only medical interns from one university; therefore, the generalizability of the findings to other universities, experience levels, and professional groups is limited. The scenario was also implemented in a VR environment based on a 360-degree video and a single type of multiple-trauma injury; although it had high fidelity in relation to a real ED, it does not necessarily represent all trauma types and real clinical conditions. The definition of AOI boundaries, the labeling of regions as "relevant" or "distractor," and the division of the scenario into four intervals were all based on expert judgment, and alternative designs might yield somewhat different quantitative values. From a technical perspective, the data were collected using a specific headset model (HTC Vive Pro Eye) and were analyzed primarily on the basis of gaze duration; more detailed ocular micro-patterns and certain potential sources of error, such as calibration quality, head movement, and missing data in one participant, could not be fully controlled. In addition, the analyses were mainly descriptive, and because of the limited sample size, inferential tests and systematic assessment of clinical performance were not used to link attention patterns to performance outcomes. Furthermore, participants' awareness that eye tracking was being recorded may itself have influenced their gaze behavior to some extent.

6. Conclusions

The findings of this study demonstrated that the use of eye tracking in a high-fidelity VR–based trauma management scenario with the HTC Vive Pro Eye headset provides a detailed and objective depiction of the visual attention patterns of medical interns when confronted with a complex and distraction-rich scene, while data quality in practice was acceptably high; on average, approximately 98.6% of the total scenario time contained valid data. Analysis across the four temporal intervals of the scenario showed that, from the very beginning of the encounter, interns directed a substantial proportion of their attention toward critical regions, including the main patient, key treatment team members, and important equipment, and that this focus became stronger over time. Specifically, the ratio of gaze time directed toward relevant AOIs relative to distractor AOIs increased from approximately 3.4 in the first interval to more than 27 in the final interval, while the share of distractor regions declined from nearly one-fifth of the time in the initial interval to less than 5% by the end of the scenario. At the spatial level, the head and face of the main injured patient, the emergency medicine resident, and the patient monitor were identified as the primary attentional foci across most intervals, whereas environmental and emotional elements such as the distressed mother, secondary patients, staff, and police accounted for only a small fraction of total gaze time, and this fraction particularly for emotional stimuli decreased sharply as the scenario progressed. Taken together, these patterns suggest that when medical interns face a trauma scene in a realistic, crowded, and interruption-laden environment, they gradually move toward a more purposeful and structured visual attention pattern in which vital clinical information is increasingly prioritized over distracting stimuli. This characteristic may potentially serve as an objective marker for evaluating and improving decision-making skills in trauma education.

7. Declarations

7.1. Acknowledgments

None.

7.2. Ethics Approval

The study was reviewed and approved by the Ethics Committee in Research of Tehran University of Medical Sciences before implementation (ethics code: IR.TUMS.MEDICINE.REC.1402.058). All participants provided written informed consent before enrollment, and all procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki.

7.3. Competing interests

The authors declare that they have no competing interests.

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7.5. Authors contributions

Conceptualization: SFA, KB, AM, RM. Methodology: RM, AM, KB. Software: NE. Validation: RM, AM, KB. Formal analysis: AM. Project administration: AM. Supervision: SFA. Funding acquisition: none. Writing–original draft: NE, AM. Writing–review & editing: all authors.

7.6. Data availability

The datasets generated and analyzed during the current study were submitted to the journal during manuscript submission.

7.7. Using artificial intelligence

The authors utilized Grammarly® for language editing and grammatical refinement. This tool was not employed for generating scientific content, analyzing data, or influencing the interpretation of results. All content remains the sole responsibility of the authors.

References

1. Wears RL, Woloshynowych M, Brown R, Vincent CA. Reflective analysis of safety research in the hospital accident & emergency departments. Applied ergonomics. 2010 Sep 1;41(5):695-700.
2. Bouillon, B., Kanz, K. G., Lackner, C. K., Mutschler, W., & Sturm, J. (2004). Die Bedeutung des Advanced Trauma Life Support (ATLS) im Schockraum [The importance of Advanced Trauma Life Support (ATLS) in the emergency room]. Der Unfallchirurg, 107(10), 844–850. https://doi.org/10.1007/s00113-004-0847-2.
3. Kamau C, Chikophe I, Abdallah A, Mogere E. Impact of advanced trauma life support training on 30-day mortality in severely injured patients at a Kenyan tertiary center: a retrospective matched case-control study. International Journal of Emergency Medicine. 2024 Oct 10;17(1):153.
4. Forsyth KL, Hawthorne HJ, El-Sherif N, Varghese RS, Ernste VK, Koenig J, Blocker RC. Interruptions experienced by emergency nurses: implications for subjective and objective measures of workload. Journal of emergency nursing. 2018 Nov 1;44(6):614-23.
5. Berg LM, Källberg AS, Göransson KE, Östergren J, Florin J, Ehrenberg A. Interruptions in emergency department work: an observational and interview study. BMJ quality & safety. 2013 Aug 1;22(8):656-63.
6. Emadi N, Mojtahedzadeh R, Allameh SF, Basiri K, Mohammadi A. The primary sources of interruptions experienced by physicians and nurses in emergency departments: a scoping review. Arch Acad Emerg Med. 2026;14(1). doi:10.22037/aaem.v14i1.2919.
7. Göras C, Olin K, Unbeck M, Pukk-Härenstam K, Ehrenberg A, Tessma MK, et al. Tasks, multitasking and interruptions among the surgical team in an operating room: a prospective observational study. BMJ open. 2019;9(5):e026410.
8. Weigl M, Catchpole K, Wehler M, Schneider A. Workflow disruptions and provider situation awareness in acute care: An observational study with emergency department physicians and nurses. Applied Ergonomics. 2020 Oct 1;88:103155.
9. Beigzadeh A, Maroufi M. Medical Students' Learning in the High-Stress Clinical Environment of the Emergency Department. Journal of Surgery and Trauma. 2025 Sep 10;13(3):87-9.
10. Johnson KD, Alhaj-Ali A. Using simulation to assess the impact of triage interruptions. Journal of Emergency Nursing. 2017 Sep 1;43(5):435-43.
11. Hallikainen J, Niemi-Murola L. High-fidelity simulation in clinical education of emergency medicine and anaesthesiology: systematic review. inacta anaesthesiologica scandinavica 2013 aug 1 (vol. 57, pp. 7-7). 111 river st, hoboken 07030-5774, nj usa: wiley-blackwell.
12. Kaggwa MM, Agboinghale P, Marginean D, Chaimowitz GA, Olagunju AT. Embracing virtual reality in medical ed-

ucation. Discover Education. 2025 May 23;4(1):129.

13. Abbas JR, Chu MM, Jeyarajah C, Isba R, Payton A, McGrath B, Tolley N, Bruce I. Virtual reality in simulation-based emergency skills training: A systematic review with a narrative synthesis. Resuscitation plus. 2023 Dec 1;16:100484.
14. Mühling T, Späth I, Backhaus J, Milke N, Oberdörfer S, Meining A, Latoschik ME, König S. Virtual reality in medical emergencies training: benefits, perceived stress, and learning success. Multimedia Systems. 2023 Aug;29(4):2239-52.
15. Einloft J, Meyer HL, Bedenbender S, Morgenschweis ML, Ganser A, Russ P, Hirsch MC, Grgic I. Immersive medical training: a comprehensive longitudinal study of extended reality in emergency scenarios for large student groups. BMC Medical Education. 2024 Sep 9;24(1):978.
16. Westbrook JI, Coiera E, Dunsmuir WT, Brown BM, Kelk N, Paoloni R, Tran C. The impact of interruptions on clinical task completion. BMJ Quality & Safety. 2010 Aug 1;19(4):284-9.
17. Emadi N, Mojtahedzadeh R, Allameh SF, Basiri K, Mohammadi A. Virtual reality simulation with eye-tracking feedback versus mannequin-based training for situational awareness in trauma management under simulated emergency department interruptions in Iran: a pilot randomized controlled trial. J Educ Eval Health Prof. 2026;23:8. doi:10.3352/jeehp.2026.23.8.
18. Funk MP, Navab N, Schütz L. Eye Tracking-Based Adaptive User Interfaces in Virtual Reality Eye Surgery Training. InProceedings of the 2025 Mensch und Computer 2025 2025 Aug 31 (pp. 578-582).
19. Anton, N. E., Cha, J. S., Hernandez, E., Athanasiadis, D., Yang, J., Zhou, G., Stefanidis, D., & Yu, D. (2023). Utilizing Eye Tracking to Assess Medical Student Non-Technical Performance During Scenario-Based Simulation: Results of a Pilot Study. Global surgical education : journal of the Association for Surgical Education, 2(1), 49. https://doi.org/10.1007/s44186-023-00127-3
20. Zehnder EC, Schmölzer GM, van Manen M, Law BHY. Using eye-tracking augmented cognitive task analysis to explore healthcare professionals' cognition during neonatal resuscitation. Resusc Plus. 2021; 6:100119. Published 2021 Apr 12. https://doi.org/10.1016/j.resplu.2021.100119.
21. Lavoie P, Lapierre A, Khetir I, Doherty A, Thibodeau-Jarry N, Rousseau-Saine N, Benhannache R, Crétaz M, Mailhot T. Eye-Tracking for Examining Nurses' Attention During Cardiac Arrest Simulations: A Feasibility and Acceptability Study. Science of Nursing and Health Practices. 2024;7(1):17-33.
22. O'Meara P, Munro G, Williams B, Cooper S, Bogossian F, Ross L, Sparkes L, Browning M, McClounan M. Developing situation awareness amongst nursing and paramedicine students utilizing eye tracking technology and video debriefing techniques: a proof of concept paper. International emergency nursing. 2015 Apr 1;23(2):94-9.
23. Endsley MR. Situation awareness in dynamic systems: analysis, measurement, and implications. Human Factors. 1995;37(1):65-84.
24. Damji O, Lee-Nobbee P, Borkenhagen D, Cheng A. Analysis of eye-tracking behaviours in a pediatric trauma simulation. CJEM. 2019;21(1):138-140. https://doi.org/10.1017/cem.2018.450.
25. Szulewski A, Egan R, Gegenfurtner A, et al. A new way to look at simulation-based assessment: the relationship between gaze-tracking and exam performance. CJEM. 2019;21(1):129-137. https://doi.org/10.1017/cem.2018.391.
26. Roche TR, Maas EJC, Said S, et al. Anesthesia personnel's visual attention regarding patient monitoring in simulated non-critical and critical situations, an eye-tracking study. BMC Anesthesiol. 2022;22(1):167. Published 2022 May 30. https://doi.org/10.1186/s12871-022-01705-6.
27. Anton N, Chen H, Yu D, et al. Nontechnical Skills Assessment in Acute Care Trauma Simulations: A Mixed Methods Approach Using Eye Tracking and Behavioral Marker Systems Military Medicine. 2024;189(Supplement_3):719-727. https://doi.org/10.1093/milmed/usae240.
28. Sipatchin A, Wahl S, Rifai K. Eye-Tracking for Clinical Ophthalmology with Virtual Reality (VR): A Case Study of the HTC Vive Pro Eye's Usability. Healthcare (Basel). 2021;9(2):180. Published 2021 Feb 9. https://doi.org/10.3390/healthcare9020180.
29. Hanke LI, Vradelis L, Boedecker C, et al. Immersive virtual reality for interdisciplinary trauma management - initial evaluation of a training tool prototype. BMC Med Educ. 2024;24(1):769. Published 2024 Jul 18. https://doi.org/10.1186/s12909-024-05764-w.
30. Chan AHY, Lee WF, Van Gerven PWM, Chenkin J. Assessment of changes in gaze patterns during training in point-of-care ultrasound. BMC Med Educ. 2022;22(1):658. Published 2022 Sep 2. https://doi.org/10.1186/s12909-022-03680-5.
31. Chen LGR, Law BHY. Use of eye-tracking to evaluate human factors in accessing neonatal resuscitation equipment and medications for advanced resuscitation: A simulation study. Front Pediatr. 2023; 11:1116893. Published 2023 Mar 16. https://doi.org/10.3389/fped.2023.1116893.
32. Nakamura K, Sakai T, Abe T, et al. A team leader's gaze before and after making requests in emergency care simulation: a case study with eye-tracking glasses. BMJ Simul Technol Enhanc Learn. 2020;6(6):369-370. Published 2020 Nov 1. https://doi.org/10.1136/bmjstel-2019-000561

Table 1: General eye-tracking indices across four-time intervals

Time range (s)*	Relevant_sec	Distractor_sec	Outside_sec	Relevant/Distractor	Missing_sec
0–66	34.69 ± 6.87	12.70 ± 6.47	17.54 ± 5.14	3.41 ± 1.58	1.07 ± 4.13
66–101	21.20 ± 4.03	4.73 ± 3.03	8.47 ± 4.71	7.52 ± 6.98	0.60 ± 2.32
101–156	29.69 ± 8.09	4.74 ± 5.65	20.10 ± 8.65	13.65 ± 9.49	0.47 ± 1.81
156–242	47.71 ± 10.02	4.05 ± 5.35	32.91 ± 7.63	27.60 ± 26.12	1.33 ± 4.10

*Time in seconds. Data are presented as mean ± standard deviation.

Table 2: Gaze time on area of interests (AOIs) across four-time intervals (seconds)

AOI Type	0–66	66–101	101–156	156–242
Relevant				
Head & face – main patient (AOI1)	12.14 ± 3.38	10.39 ± 3.65	14.65 ± 5.55	23.66 ± 7.59
Amputated lower limb – main patient (AOI11)	1.53 ± 1.84	0.07 ± 0.20	0.07 ± 0.14	0.07 ± 0.15
ED nurse – main colleague (AOI6)	1.65 ± 0.79	0.03 ± 0.08	2.72 ± 1.73	0.96 ± 1.21
Monitor – main patient (AOI2)	6.13 ± 3.78	NA*	9.29 ± 5.47	8.13 ± 4.68
ED resident – main colleague (AOI3)	12.47 ± 2.78	10.44 ± 3.26	2.91 ± 2.00	14.83 ± 5.52
Important equipment and devices (AOI12)	0.77 ± 0.85	0.28 ± 0.72	0.06 ± 0.23	0.07 ± 0.16
Distractor				
Ambulatory trauma and companion (AOI9)	2.06 ± 1.43	0.04 ± 0.14	0.51 ± 1.33	0.71 ± 1.89
ED staff (AOI10)	1.10 ± 0.78	0.80 ± 1.49	0.02 ± 0.09	0.25 ± 0.94
Distressed mother – main patient (AOI8)	4.88 ± 3.32	0.05 ± 0.19	2.17 ± 4.59	0.03 ± 0.11
Prehospital nurse (AOI7)	2.12 ± 2.59	0.04 ± 0.08	NA*	NA*
Intervening nursing student (AOI5)	0.31 ± 0.46	0.69 ± 0.87	0.27 ± 0.38	1.45 ± 1.58
Intervening medical student (AOI4)	0.60 ± 0.87	3.09 ± 1.84	1.52 ± 1.42	0.95 ± 1.39
Deceased patient and family (AOI13)	1.16 ± 1.08	0.02 ± 0.07	0.21 ± 0.58	0.48 ± 1.21
ED police officer (AOI14)	0.47 ± 0.51	0.00 ± 0.00	0.03 ± 0.12	0.18 ± 0.60

*NA indicates that the AOI was not present in the scene during that time interval. Data are presented as mean ± standard deviation.

Figure 1: Areas of Interest (AOIs) were defined, and a heatmap was generated based on time intervals. 0-66 & 66-101 (A): Visualization of AOIs during the 0-66 & 66-101 second interval. Relevant AOIs are delineated by blue borders, while distractor AOIs are marked by white borders. 0-66 & 66-101 (B): This heatmap illustrates eye-tracking and gaze allocation from 0-66 & 66-101 seconds for 15 medical students, based on the distribution of AOIs.

Figure 2: Areas of Interest (AOIs) were defined, and a heatmap was generated based on time intervals. 101-156 & 156-242 (A): Visualization of AOIs during the 101-156 & 156-242 second interval. Relevant AOIs are delineated by blue borders, while distractor AOIs are marked by white borders. 101-156 & 156-242 (B): This heatmap illustrates eye-tracking and gaze allocation from 101-156 & 156-242 seconds for 15 medical students, based on the distribution of AOIs.

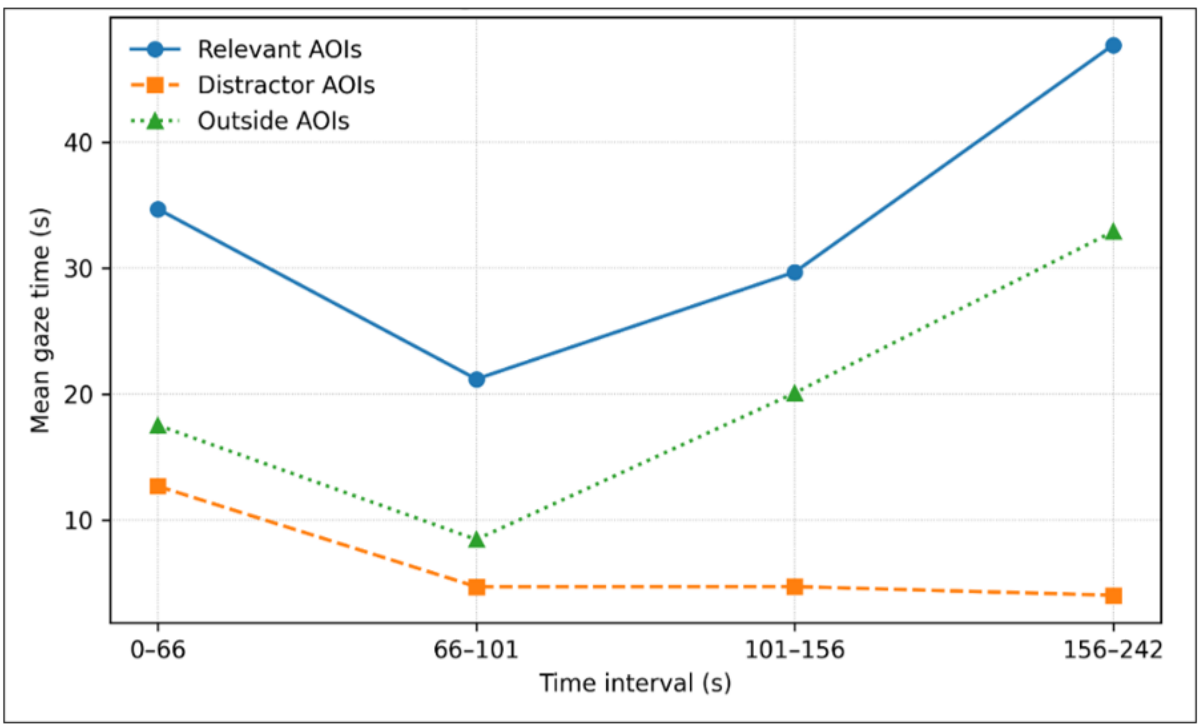

Figure 3: Time course of gaze allocation across scenario intervals.