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Anna WARCHOŁ-JAKUBOWSKA[1*], Krzysztof KREJTZ[2], Patryk SZCZECIŃSKI[3], Katarzyna WISIECKA[4], Andrew T. DUCHOWSKI[5], Izabela KREJTZ[6]

VISUAL ATTENTION OF TRAM DRIVERS AS A STEP TOWARDS INCREASING SAFETY IN PUBLIC TRANSPORT: A COMPARATIVE EYE-TRACKING STUDY BETWEEN NOVICE AND EXPERT TRAM DRIVERS

Summary. This paper presents an eye-tracking study capturing the dynamics of ambient and focal attention of tram drivers as an application of modern technology in improving their training. Twenty-three experts and twenty-four novices were invited to take part in the eye-tracking study. We explored the visual attention dynamics of tram drivers while they were watching tram-driving simulation videos. The tram driver's view: The windshields and control panel were defined as areas of interest (AOIs). In line with expectations, experts were more focused than novices and maintained their concentration for a longer time than novice tram drivers. This difference was significant for regions crucial for monitoring the driving environment (the windshields AOIs). Monitoring drivers' visual attention gives new insights into the process of gaining expertise in scanning the driving environment.

1. INTRODUCTION

The human factor continues to be the main cause of road accidents [1, 2]. Accident rates are particularly high for less experienced drivers (driving less than a year) [3]. Road safety is a problem both in Poland and worldwide [4]. A survey conducted with 640 Polish respondents [5] showed that they evaluated the level of road safety in Poland as low and indicated that human factors are the greatest factor in road accidents.

As a field of science that allows for non-invasive registration of visual attention in real-time [6], eye tracking, along with other psychophysiological measurements (e.g., EEG, galvanic skin response, and face tracking), has become one of the new techniques for examining operators of motor vehicles.

[1] SWPS University, Institute of Psychology; Chodakowska 19/31, 03-815 Warsaw, Poland; e-mail: awarchol-jakubowska@swps.edu.pl; orcid.org/0000-0002-0550-289X
[2] SWPS University, Institute of Psychology; Chodakowska 19/31, 03-815 Warsaw, Poland; e-mail: kkrejtz@swps.edu.pl; orcid.org/0000-0002-9558-3039
[3] SWPS University, Institute of Psychology; Chodakowska 19/31, 03-815 Warsaw, Poland; e-mail: pszczecinski@st.swps.edu.pl; orcid.org/0009-0001-8099-058X
[4] SWPS University, Institute of Psychology; Chodakowska 19/31, 03-815 Warsaw, Poland; e-mail: kwisiecka@swps.edu.pl; orcid.org/0000-0002-7839-4068
[5] Clemson University, School of Computing; 821 McMillan Rd, Clemson, SC 29631, USA; duchowski@clemson.edu; orcid.org/0000-0003-1681-7878
[6] SWPS University, Institute of Psychology; Chodakowska 19/31, 03-815 Warsaw, Poland; e-mail: ikrejtz@swps.edu.pl; orcid.org/0000-0002-9827-8371
* *Corresponding author*: e-mail: awarchol-jakubowska@swps.edu.pl

(a) Ambient fixation of novice driver

(b) Focal fixation of expert driver

Fig. 1. Exemplary scenes from tram driving simulation videos: (a) presents exemplary ambient fixation of a novice tram driver, and (b) presents exemplary focal fixation of an expert tram driver. (*Note*: red circles indicate fixations. The radius of the circle reflects relative fixation duration; the bigger the circle, the longer the fixation)

Initially, eye movements were treated as a physiological reaction of the body. Currently, eye-tracking information is recognized as an accurate portrayal of the interplay between cognitive functions and external visual cues [7]. Eye-tracking studies expose new details about drivers' visual attention processes and thus contribute to improving road safety. For example, Le et al. [8] determined that examining differences between anticipated and actual unintentional eye movements can reveal new information about cognitive distraction. First, monitoring drivers' eye movements can help to understand how novices differ from experienced drivers in terms of visual attention distribution and concentration maintenance. Second, based on experts' eye movement patterns, new training tools can be developed [9] to more effectively teach novices and, in the long run, prevent driving accidents.

Eye-tracking studies in drivers originated in the 1970s. [10]. Since then, an increasing number of eye-tracking studies involving drivers [11] and machine operators [12] have been conducted. In the driving domain, eye trackers are used to train drivers [13], construct vehicles [14], design roads and their surroundings [15], and design automatic driver support systems [16]. A significant achievement is the utilization of eye tracking for research aimed at improving safety. So far, there are only a few reviews of studies using eye tracking for research on road safety [17]. For instance, through studies conducted in urban areas, we can assess drivers' behavior and the quality of the infrastructure concerning road safety [18]. To our knowledge, studies focusing on eye-movement characteristics of tram drivers are scarce [19].

This article aims to demonstrate differences in visual attention between tram-driving experts and novices by analyzing the interplay between ambient and focal visual attention while watching tram-driving simulations (see Fig. 1). There are two novel aspects of our study. First, by including the relatively understudied sample of tram drivers, we contribute to eye-tracking studies in public transport. Second, we concentrate on depicting differences between novices and experts in tram driving in their ability to maintain focal attention. Our general prediction was that experts would be more focused than novices and would concentrate on the critical road safety visual aspects of the driving environment (e.g., windshield) rather than on aspects related to controlling the vehicle (control panels).

We believe that the analysis of focal attention in passive driving (watching driving simulation) can provide new insights into the behavior of drivers and help plan preventive actions to avoid accidents they might cause. The present work is an extension of the analysis presented in a position paper by Warchoł-Jakubowska et al. [19]. Our research exemplifies the use of modern technologies to work on improving road safety and is a milestone in shaping the safety culture of a public transport company.

2. BACKGROUND

Operating a vehicle is a multifaceted task demanding visual, cognitive, and motor capabilities [20]. Consequently, drivers need to possess adequate levels of alertness, responsiveness, executive function, visual acuity, and physical coordination [21]. Foveal and peripheral visual attention have been recognized as an important predictor of traffic accidents [22]. Better visual attention, along with automotive expertise, leads to fewer driving mistakes and fewer accidents [23].

2.1. Visual Attention of Expert and Novice Drivers

The visual attention distribution of experienced and inexperienced drivers has been systematically studied, suggesting that novice and expert drivers differ in their scanning paths while driving [23].

Novice drivers focus more on the dashboard area, whereas expert drivers focus more on the front and center than other areas, which may lead to better driving control [23]. These results suggest that inexperienced drivers exhibit distinctions from their seasoned peers in their interactions with in-vehicle technology [24].

A driver's field of view is positively related to their driving history—drivers with more driving experience make better use of their field of view. Inexperienced drivers use mirrors less than experienced drivers [25] and make more fixations along the vertical axis [26]. Scanning the left and right field of view suggests inspecting for different road safety risks. This implies that the attentional bias acquired with driving experience allows a driver to scan their visual field for unexpected vehicles and pedestrians.

Scanning strategies of experienced drivers are more flexible than those of inexperienced drivers, and these drivers adjust their strategy to the dynamics of the driving environment [26]. Comparative studies have also shown differences in directing visual attention depending on the type of vehicle (e.g., motorcyclists and car drivers) [27]. There is a lack of research on tram drivers in the literature, motivating the current focus on this multi-thousand professional group.

2.2. Eye Movement Characteristics: Ambient and Focal Attention

Through the recording of eye movements (e.g., fixations and saccades), we can obtain new information about drivers' visual attention [6]. Fixations are understood as the relative stopping of eye movements on a selected object to maintain focus on it. The typical median of fixation duration is 200–250 ms, and the average duration is 300–350 ms [28], but while viewing a scene, shorter fixations (> 100 ms) or longer (< 500 ms) can also be observed [6]. It is assumed that fixations naturally reflect the volitional gazing at a selected part of the visual field.

Saccades are rapid eye movements between successive fixations by which visual attention is quickly relocated to a different region in the visual environment [6]. Saccades represent a switch to a new point of visual interest The joint analysis of fixations and saccades characteristics gives an insight into how a visual scene is inspected. Visual scene exploration starts with shorter fixations and saccades of greater amplitude; meanwhile, in the later stages of processing, the longer duration of fixations corresponds to shorter saccades [29]. These changes in eye-movement characteristics map to two types of visual processing: ambient (exploration) and focal (elaboration) [30].

The two modes of visual information processing [30] can be captured by the ambient-focal attention K-coefficient [31]. Positive K-coefficient values indicate focal attention, whereas values of K-coefficient values below zero suggest ambient attention. When the K-coefficient is plotted over time, it represents dynamical changes between ambient and focal attention. In this paper, we analyze the differences between experts and novices in tram driving in their ability to maintain focal attention while observing simulation driving. Previous research indicated differences in visual attention distribution between novice and expert drivers [32]. To our knowledge, the dynamics of ambient and focal attention have not been analyzed in the context of tram driving.

2.3. The Present Study

In the current study, we examined tram drivers' visual attention while watching short clips from simulation-based tram driving. Simulation-based training has been used for years in such fields as aviation [33] and medicine [34]. Driving simulators are a modern solution for training vehicle operators, including pilots, sailors, and tram drivers, in which difficult situations are simulated, requiring immediate reaction of the operator, transferred from the real environment to simulation conditions. Before candidates for tram drivers start practical driving on a wagon, they undergo several weeks of training using a tram-driving simulator.

Tram simulators reflect the city traffic environment as faithfully as possible, taking into account the different types of wagons used in traffic on a daily basis. Training with the use of a simulator is aimed at teaching trainees how to use control panels and improve the efficiency and safety of driving by learning automatic reactions, thus minimizing errors. The advantage of using a simulator in the training process is that it presents the possibility of constructing various types of potential hazards that are difficult to create in real conditions and may pose a threat to safety [35].

Mixed-design eye-tracking study was conducted to expose the scanning strategies of experienced and inexperienced drivers. Experts and novices watched four 90-second-long videos from a tram-driving simulator while their visual attention was captured. The videos presented rides prepared by driving instructors. They included various risks (pedestrians running out, vehicles forcing the right of way), times of the day, weather conditions (fog, rain), and traffic intensities (monotonous sections and busy intersections). Additionally, we controlled for potential differences in personality traits (e.g., sense of social responsibility, self-control, mental stability, and risk avoidance) and cognitive functions (e.g., logical reasoning, visuomotor coordination, ability to estimate the speed and direction of moving objects) by administering the DRIVE-PL battery from Vienna Test System Schuhfried [36]. This battery is commonly used for psychological assessments of drivers and is mandatory for all tram drivers and other professional drivers in Poland.

The first between-subjects independent variable was the group (experts vs. novices in tram driving). The second within-subjects independent variable was time on task. To capture the dynamics of ambient and focal attention, we divided the video time into ten time-on-task epochs (see Fig. 3a). We formulated two main hypotheses. First, we predicted that experts would exhibit more focused attention than novices due to their expertise (hypothesis 1) and would maintain their focus for a longer time than novices (hypothesis 2). The third hypothesis predicted different patterns of focal attention; experts would be more focused on the more important areas of interest from a safety perspective than novices (hypothesis 3).

3. EMPIRICAL STUDY METHOD

3.1. Participants

Forty-seven tram drivers participated in the study, consisting of 23 experts (four females), including driving instructors (M_{age} = 44.5, SD = 7.58) with minimum of five years of experience ($M_{workexperience}$ = 15.4, SD = 8.88), and 24 novices (four females) with no more than one year of work experience (M_{age} = 39.3, SD = 8.25). Experts and novices were matched by sex and age. They were compared on the DRIVE-PL battery from Vienna Test System Schuhfried [36]. The DRIVE-PL was completed by the novices (n = 22) at the recruitment stage and by experts (n = 22) during periodic examinations. Novices showed higher self-control (M = 6.27, SD = 0.94) than experts (M = 4.81, SD = 2.29), $t(26, 220) = 2.72$, $p = 0.012$. A higher score in self-control may be due to the desire to present oneself in the best possible way to the future employer. The lack of significant differences in the other tests shows that such functions as reaction time, coordination, and attention do not change with the acquisition of experience. The selection criterion for the study groups was the length of work experience as a tram driver and accident-free driving in the case of expert tram drivers. Tram drivers participated in the study voluntarily. The IRB commission approved the study protocol (Opinion no. 28/2022). The participant population is the same as that considered in our previous paper [19]. Data from two outlying participants were omitted from the analyses.

(a) Experimental settings

(b) Definition of AOIs

Fig. 2. Experimental settings with a participant during an eye-tracking data collection procedure (a) and Areas-of-Interest (AOIs), the blue squares constitute the windshield AOIs group, and the red ones are related to the control panel AOIs group (b)

3.2. Study Procedure

This study was conducted at the Warsaw Tram Training Centre and consisted of the observation and evaluation of rides recorded using a tram-driving simulator. The experimental task began with familiarizing the subject with the operation of the eye tracker (see Fig. 2a), followed by standard nine-point calibration of the eye tracker and then validation of the measurement. Then, four approximately 90-second-long videos depicting tram simulator driving were presented in random order on a 21-inch computer screen with a 1920×1080 resolution. Before each video was played, a fixation cross was presented for 600−1200 ms.

Participants watched the videos and then answered the NASA-TLX survey questions about mental demand, effort, and frustration level after each video [37]. The NASA-TLX survey was completed after each video. No between-group differences were detected in the answers to any of the questions ($p > 0.05$). At the end of the experimental procedure, a demographic survey was filled out, including questions related to age, gender, position in work, and years of experience.

3.3. Eye-tracking equipment

While each participant watched the rides, their gaze behavior was captured with a Gazepoint GP3 HD 150Hz eye tracker. The eye tracker was mounted under a 21-inch computer monitor with a 1920×1080 screen resolution. Participants were seated in front of the computer monitor at a distance of approximately 57 cm. The experimental procedure was prepared using PsychoPy v2022 software. Two groups of areas of interest were drowned around the tram driver view: windshields (left-side vs. middle vs. right-side) and the control panel (left-side, middle, right-side) (see Fig. 2b).

4. RESULTS

Eye-tracking data preprocessing and all data analyses were conducted using the R programming language for statistical computations [38]. To detect events (fixation and saccades), we used the *gazepath* algorithm, which estimates velocity thresholds per person and uses the minimal duration threshold specified to 80 ms. Successive fixations that overlap in space were also combined. All fixations whose duration was longer than $Mean + 1.58 \times IQR$, where IQR stands for "inter-quartile range," were considered as outlying. Then, following the capping procedure, these were replaced with the maximum non-outlying value. The statistical analyses employed the linear mixed modeling (LMM) approach following [39]. Two LMM analyses were performed to test hypotheses related to the differences in ambient-focal attention in expert and novice drivers. The first LMM tested the differences between experts and novices in focal attention depending on the time-on-task independent variable. The second LMM focused on differences between experts and novices while looking at more important (windshields) and less important (driving control panel) AOIs of the tram cockpit. In both analyses, two random effects were used in the model for participants and for stimuli videos.

4.1. Ambient-Focal Attention during Time on Task in Experts vs. Novice Tram Drivers

The first analysis tested the hypothesis related to the longer sustainability of focal attention while watching tram driving scenarios in experts in comparison to novice tram drivers. In the first analysis, time-on-task (the independent within-subjects variable) was treated as a fixed factor with ten levels corresponding to 10 segments of each stimuli duration. We also treated the participant group as the independent between-subjects variable, a fixed factor (experts vs. novices). The K-coefficient was the dependent variable (see model equation[7]).

The null model with random effects of participants and stimuli only showed the significant intercept $\beta = -0.16$, $t(37.47) = -2.83$, $p = 0.01$. The *SD* for participants was 0.36 ($ICC = 0.05$), and the *SD* for stimuli was 0.04 ($ICC = 0.00$). The residual $SD = 1.65$. The null model fit was evaluated with $AIC = 71164.13$, $BIC = 71195.42$, and $Pseudo\text{–}R^2_{(total)} = 0.05$. The final model with independent variables, group, and time-on-task was significantly better fitted than the null model, $BIC = 71239.40$, and $Pseudo-R^2_{(total)} = 0.06$.

The effect of the time-on-task segment significantly improved the model fit, $\chi^2(9) = 187.41$, $p < 0.001$. The model coefficients for time-on-task showed that, in general, the participants' attention tended to be more focal as the time on task increased. The impact of the group was also statistically significant, $\chi^2(1) = 6.32$, $p = 0.012$. Novices' attention was significantly more ambient than experts' attention while watching stimuli videos (*z.ratio* = 2.56, $p = 0.011$). In general, expert tram drivers were significantly more focused while watching simulator tram driving videos than novices (hypothesis 1).

Finally, the analysis showed the significant interaction of time-on-task and participants' group, $\chi^2(9) = 18.81$, $p = 0.027$ (see Fig. 3a). The detailed pairwise comparisons with Tukey's HSD correction showed that novices and experts were no different in ambient-focal attention during the first segments of time; moreover, the difference was consistently significant or marginally significant in the last four time segments (hypothesis 2).

4.2. Ambient-Focal Attention on Important and Less Important AOIs in Experts vs. Novice Tram Drivers

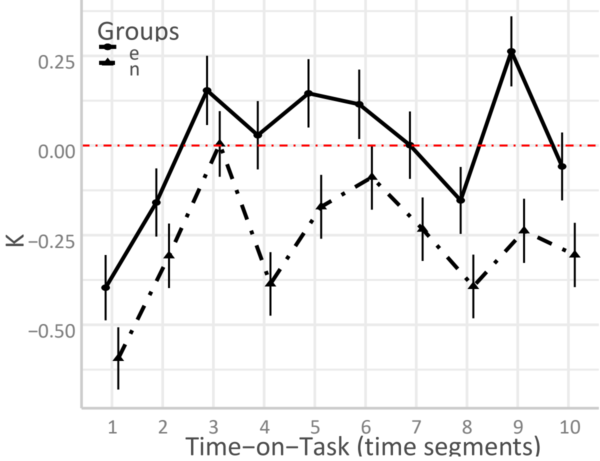
The second LMM analysis tested if experienced tram drivers' attention is more focal when gazing at AOIs important for road safety and windshields in comparison to control panel AOIs, whci are relatively unimportant for driving safety. The analysis treated the K-coefficient as a dependent variable, the AOI group (windshields vs. control panel), and drivers expertise (experts vs. novice) as fixed factors, independent variables. Similar to the first LMM, we included random effects for participants and stimuli videos (see the model equation[8]).

Note that for this analysis, eye-movement data within windshields and driving panel AOIs were selected. The null model showed a statistically significant intercept, $\beta = -0.15$, $t(34.98) = -2.59$, $p = 0.01$. The parameters for the null model are as follows: $AIC = 69699.62$, $BIC = 69730.82$, and $Pseudo - R^2_{(total)} = 0.05$. The *SD* for participants was equal to 0.36 ($ICC = 0.05$), and the *SD* for stimuli video was 0.05 ($ICC = 0.00$). The final full model fit was significantly better in comparison to the null model with $AIC = 69107.91$, $BIC = 69162.51$, and $Pseudo - R^2_{(total)} = 0.08$. In the final model, expertise significantly

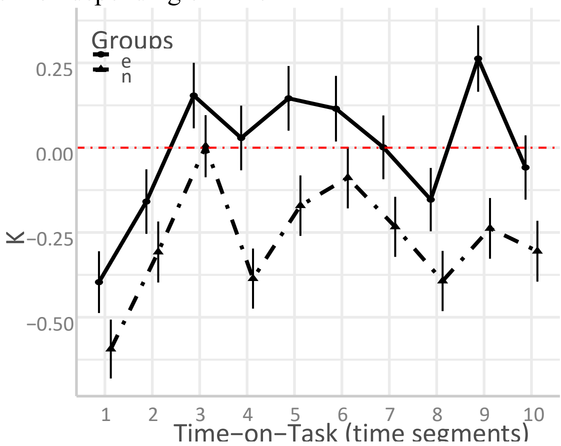
[7] $K = \beta_{time\text{-}on\text{-}task} + \beta_{group} + \beta_{time\text{-}on\text{-}task \times group} + \Upsilon_{participant} + \Upsilon_{stimuli}$

[8]1 $K = \beta_{AOIgroup} + \beta_{expertise} + \beta_{AOIgroup \times expertise} + \Upsilon_{participant} + \Upsilon_{stimuli}$

improved the model fit over the null model, $\chi^2(1) = 5.96$, $p = 0.01$, with novice drivers, in general, being more ambient ($M = -0.57$, $SE = 0.07$) than experts ($M = -0.40$, $SE = 0.08$).



(a) Ambient-focal attention depending on time



(b) Ambient-focal attention depending on AOIs

Fig. 3. Differences between expert and novice tram drivers in ambient-focal attention (K-coefficient is measured standard deviation units) (a) depending on time on task and (b) important (window) and less important (driving panel) areas of interest. Note: Whiskers indicate ±1*SE*. The red dotted horizontal line represents the numerical threshold between ambient-focal attention

Also, the main effect of the AOI group significantly improved the model fit, $\chi^2(1) = 598.32$, $p < 0.001$. Visual attention, in general, was significantly more ambient when gazing at the driving control panel ($M = -0.95$, $SE = 0.07$) vs. the windshield's AOIs ($M = -0.02$, $SE = 0.06$).

The most interesting results were revealed by the statistically significant interaction between participants' expertise and AOIs, $\chi^2(1) = 4.47$, $p = 0.03$ (see Fig. 3b). The pairwise comparisons with Tukey's HSD correction showed that experts' attention was more focal when they were gazing at windshields AOIs ($M = 0.10$, $SE = 0.08$) than novice drivers looking at the same AOIs ($M = -0.15$, $SE = 0.07$) (hypothesis 3). Furthermore, when looking at the control panel, experts' attention ($M = -0.91$, $SE = 0.09$) was similar to the novices' ($M = -0.99$, $SE = 0.08$).

5. DISCUSSION

The eye-tracking comparison of experienced and inexperienced tram drivers while observing a third-party ride on the tram simulator allowed us to verify the differences in ambient-focal attention dynamics over different AOIs. Focal attention is related to greater analytical cognitive processes, while ambient attention suggests more visual skimming [31]. As predicted, experts were more focused than novices (hypothesis 1), especially toward the end of driving simulation viewing, which may suggest that they were more attentive than novices. Importantly, they were able to maintain focal attention in the trials (the entire stimuli watching time) significantly longer than novice tram drivers (hypothesis 2). Additionally, the analysis of attention distribution over different AOIs showed that experts were significantly more focused when they looked through the tram windshields, which presumably contain more important information for driving safety than tram control panels (hypothesis 3).

Another possible interpretation of the experts' focal attention relates to differences in peripheral perception ability between experienced and novice study participants. This interpretation corroborates previous research [40] reporting a positive correlation between car drivers' peripheral perception ability and their driving expertise. However, Deng et al. [40] did not collect eye-tracking data. The hypothesis of a wider peripheral perception ability in tram-driving experts needs further testing with a specially designed study to capture differences in peripheral vision.

Previous eye-tracking research on the influence of expertise on observation techniques in driving used rather traditional eye-movement metrics, such as fixation count or scan path length. The present research extends the analysis spectrum with a quantitative second-order metric of ambient-focal attention captured by K-coefficient [31] to discern the depth of attention concentration among experts and novices.

In the present study, tram drivers passively watched tram simulator driving. Future studies should focus on monitoring visual attention during tram-driving simulations. The precise emulation of authentic working conditions for tram drivers within the simulator setting provides an optimal research environment. For scientific analysis purposes, the simulator enables the examination of behaviors under various motion conditions for individuals with diverse psychophysical characteristics [35]. For instance, it enables an evaluation of driving style and the tram driver's reaction time in response to variables like physical fatigue, the time of day, distractions, or stress-inducing circumstances. Despite the advantages of the simulation environment, the utilization of a simulated environment evidently introduces substantial simplifications in scrutinizing the situation [18]. The final step should be the observation of visual attention during real-world tram driving. In the course of such research, the deployment of mobile eye-tracking technology permits the comprehensive analysis of subjects' visual behaviors across a spectrum of driving scenarios. We would also like to invite more women to participate in research so we can better assess gender differences in driving since most previous studies [41] did not study gender differences. Our results may also suggest that novice tram drivers may not have enough cognitive resources to pay attention to relevant driving stimuli. Acute stress, through the release of cortisol, may disrupt executive control functions in the frontal area [42]. Furthermore, stress is a factor that may affect attention in addition to expertise level [43]. Therefore, in future research, other physiological methods, such as skin conductance, may be used to control the effect of stress.

Analyses of visual attention distribution and focus could provide insights into visual field scanning skills, which are equally important for training novices (developing important scanning skills) and experts (expanding knowledge about one's own behavior) [33]. The characteristics of fixations change with acquired knowledge [44]. Scanning patterns can be a valuable source of information to further inform experts on how to adjust the training of novices to guide their attention toward key elements during tram driving.

Rudi et al. [45] presented an attention training program for novice pilots. Novice pilots were asked to solve a difficult emergency protocol in a simulator. Next, novices were presented with a clip in which an expert pilot solved the same problem. Half of them viewed the clip with the scan path of an experienced pilot. When retested, novices who watched the experts' scan path performed better than the other group of pilots. Rudi et al. [45] demonstrated the beneficial effects of including visualizations of experts' gaze in novice training.

6. CONCLUSION

As expected, unique patterns of dynamic interplay between focal and ambient attention were observed in expert and novice tram drivers. The present study is the first step toward designing supportive training tools based on expert tram drivers' eye movement patterns to facilitate the training process. Combining the possibilities offered by the simulator and the experience of eye-tracking tests could lead to the creation of a completely innovative approach to training candidates for tram drivers.

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