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CIVIL ENGINEERING

A methodological framework for evaluating ADAS training for older drivers: Feasibility and user perception

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Abstract. The rapid introduction of Advanced Driver Assistance Systems (ADAS) poses a unique challenge for older drivers, who often face barriers in adopting these technologies. This study evaluates the effectiveness of a practical, simulator-based training concept designed specifically for drivers aged 50+. The empirical analysis of a research group of 25 people focused on verifying four research hypotheses regarding the suitability of the simulator, trust calibration, user awareness, and training utility. The results confirmed that the high-fidelity simulator is an appropriate training environment for this demographic; analysis of the Revised Simulator Sickness Questionnaire (RSSQ) revealed a statistically significant reduction in symptoms during the adaptation process, validating the physical feasibility of the training (H1). The intervention led to a measurable increase in trust towards ADAS, with a strong effect size, confirming positive behavioral adaptation (H2). Furthermore, participants demonstrated raised awareness of system benefits, primarily identifying enhanced safety and speed control (H3). The proposed training model achieved high internal consistency and received positive subjective usability ratings (H4). These findings support the deployment of simulator-based practical training as an effective tool for preventing digital exclusion among older drivers. Key words: driver training; ADAS; simulation sickness; older drivers; trust calibration.

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1. INTRODUCTION

1.1. Literature review

Demographic analyses unequivocally indicate an unprecedented acceleration of the aging process in OECD (Economic Co-operation and Development) populations, driven in part by the aging of large demographic cohorts, such as the post-war generation, which significantly impacts current transport systems. Information on population aging contained in the latest Eurostat analyses [1] indicates that the old-age dependency ratio in the EU reached 34.5% on 1 January 2025, which reflects a significant long-term trend compared to 29.0% recorded a decade earlier. Future projections assume this ratio will nearly double, reaching 59.7% by 2100, while the total age dependency ratio is expected to rise to 83.9% [1]. In the automotive context, a key qualitative change concerns not only the number of seniors themselves, but primarily the prevalence of holding driving licenses in this age group. According to current road safety research, a "saturation" of the senior population with drivers is observed, as current generations maintain their mobility significantly longer and treat the car as a primary guarantor of independence and social inclusion [1]. Demographic and transport forecasts point to the phenomenon of gender convergence in the structure of senior drivers. Studies by Sivak and Schoettle [3] demonstrate that, as a result of the cohort effect, the gender gap is rapidly diminishing. This phenomenon, supported by the paradigm of active aging and the extension of working life [1], will result in the presence on the roads of an unprecedented number of drivers aged 75+.

This group, despite better general health status than in previous decades, is characterized by increased physical vulnerability and age-related functional limitations, including declines in peripheral vision and divided attention, which necessitate the specific adaptation of road infrastructure and the implementation of advanced driver support systems [2,4]. Numerous studies highlight that maintaining mobility by persons over 50 is the foundation for counteracting social exclusion and preserving mental well-being, which directly correlates with savings in healthcare systems [5,6]. This is confirmed by reports from Mobilizing Justice [7], indicating transport as a key "social driver of health". However, a significant influence of age on the manner of learning and functioning behind the wheel should be noted. Ucińska *et al.* [8] indicate that the physiological decline in performance (regression of fluid intelligence) does not necessarily disqualify older drivers, provided it is compensated by experience (crystallized intelligence). Nevertheless, as noted by Czaja *et al.* [9], the senior population is characterized by immense cognitive diversity, which necessitates the application of User-Centered Design in technology development.

In light of the above challenges, the impact of ADAS (Advanced Driver Assistance Systems) and driving automation on the mobility of persons over 50 is perceived as a key factor capable of delaying driving cessation. Publications (including in

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BMC Public Health) suggest that these technologies can compensate for psychophysical deficits [10,11]. Studies indicate the potential for accident reduction [6]; however, the introduction of automation generates new threats resulting from improper environmental monitoring [12]. In this context, it is crucial to distinguish between full automation and Advanced Driver Assistance Systems (ADAS). While the coexistence with autonomous vehicles (SAE Levels 4–5) is a future challenge, the immediate safety concern for older drivers lies in the correct usage of ADAS (SAE Levels 1–2) in mixed traffic. Razmi Rad *et al*. [13] observe that the introduction of dedicated lanes for autonomous vehicles may influence the behavior of drivers of traditional vehicles, which also has implications for the general level of safety.

However, a critical problem remains the knowledge of ADAS among older persons (over 50) and their willingness to use them. Rodak and Pełka [14], in research published in Archives of Transport, identify a systemic educational gap: drivers' knowledge often stems from a trial-and-error method, which may lead to suboptimal system usage among senior populations. Kaye *et al*. [15] and DeGuzman and Donmez [16] prove that users do not distinguish between supportive functions and full autonomy, which leads to erroneous mental models. This is closely related to the issue of trust among older persons – those over 50 – in new technologies, including technologies ranging from active assistance systems (ADAS) to emerging autonomous vehicles (AVs). It is noted that trust calibration requirements differ significantly between these levels of automation. Charness *et al*. [10] and Liu *et al*. [17] identify age as a predictor of a higher level of anxiety and mistrust. However, this trust is not static – Jing *et al*. [18] point to determinants of acceptance, and Haghzare *et al*. [19] emphasize that exposure to technology can change seniors' attitudes, provided the systems are transparent in their operation.

In response to competence gaps, a broader use of driving simulators for driver training, including ADAS training, is postulated. Wallace *et al*. [20] demonstrate the utility of simulation in assessing drivers with cognitive impairments, indicating that traditional methods are insufficient. Therefore, dedicated ADAS driver training that goes beyond theoretical explanation is essential. Murtaza *et al*. [21] demonstrate that virtual training enhances performance in highly automated scenarios; such findings are increasingly relevant for ADAS education, where drivers must manage the transition between manual and assisted control. Crucially, a direct impact of ADAS training on trust levels has been empirically proven. Zahabi *et al*. [22] showed that practical simulator training reduces cognitive workload and allows for proper trust calibration, preventing phenomena of misuse and disuse of technology by seniors. However, methodological limitations must be borne in mind, such as the issue of simulator sickness. Simulator sickness, resulting from a conflict between visual stimuli and the vestibular system, manifests similarly to motion sickness (e.g., nausea, dizziness). Although typically milder in presentation, it is estimated to affect 30–80% of the population, potentially impeding participation in training sessions. Pędzierska *et al*. [23] analyzed differences in symptom occurrence in 2D and 3D simulations, pointing to the necessity of careful scenario calibration to minimize sensory conflict, which could distort research results on technology acceptance in the older adult group.

Given the varying degrees of driving automation, it is essential to distinguish Advanced Driver Assistance Systems (ADAS), which correspond to SAE Levels 1–2 and require the driver to remain fully engaged, from autonomous vehicles (SAE Levels 4–5), where the system performs all driving tasks. While autonomous cars represent a future paradigm, this study focuses specifically on ADAS, as these systems pose the most immediate challenge for older drivers in terms of proper trust calibration and the maintenance of manual driving skills.

The purpose of this research is to evaluate the feasibility, physical tolerability, and subjective acceptability of a simulator-based practical ADAS training concept specifically designed for drivers aged 50 and over. By focusing on trust calibration and simulator sickness, this study aims to establish a methodological foundation for preventing digital exclusion among senior road users. This article is organized as follows: Section 2 describes the research group, experimental methodology, and technical equipment; Section 3 presents the empirical results of the training evaluation; Section 4 provides a discussion of the findings, including gender-based analysis and study limitations; and Section 5 concludes the research with implications for future studies.

1.2. Preceding study – Motor Transport Institute

This research is presented since it represents a methodological continuation of our prior work conducted within the Trustonomy consortium, which established foundational ADAS training protocols and culminated in Pełka's fuzzy logic evaluation framework. The subsequent analysis represents a significant empirical extension of these preliminary methodologies, incorporating enhanced assessment parameters and validation procedures as delineated in the following excerpt. The study analyzed data from 49 participants (aged 27–65), allocated to three training modalities: Practical Training ($n = 16$), E-learning ($n = 17$), and Brief Manual Instruction, where participants independently studied written materials ($n = 16$). Participants possessed valid driver's licenses but limited or no prior experience with ADAS.

Research was conducted using a high-fidelity AS 1200-6 driving simulator configured to emulate a Highway Chauffeur system. The protocol included six stages, culminating in a test drive featuring three planned emergencies requiring manual takeover.

Training effectiveness was evaluated using a proprietary fuzzy logic model (Mamdani-type), which generated standardized quantitative scores (scale 1.64–5). Representing a methodological shift from previous aggregate analyses, this study adopted a scenario-based approach. Key input variables, number of attempts, takeover reaction time, and full control handover time were calculated independently for each critical event. This disaggregated methodology allowed for a direct, quantitative measurement of performance progression between the initial and subsequent emergencies.

Following the test drive, participants underwent an instructor evaluation, a digital knowledge test with immediate feedback, and an electronic self-assessment. Both evaluations utilized a five-point scale to rate holistic driving performance, facilitating a comparative analysis of trainer and trainee perceptions. The survey assessed general simulator proficiency, adaptation time, overall system competence, and the level of difficulty concerning:

- System activation, interface operation, and speed regulation
- Monitoring driving modes and comprehending system messages or takeover requests
- Executing control takeovers, reaction time sufficiency, and subsequent vehicle stabilization

The research unequivocally establishes practical, simulator-based training as the superior method for preparing drivers to operate ADAS. Statistical analysis utilizing the Kruskal-Wallis test revealed significant performance disparities across training modalities, with the practical training cohort achieving a mean score of 4.0, markedly outperforming both the e-learning ($M = 3.11$) and manual instruction ($M = 3.01$) groups. Participants in the practical session exhibited superior reaction times and required fewer attempts to master system operations, underscoring the critical necessity of hands-on experience for adapting to complex vehicle automation.

A central contribution of this study was the development and validation of a proprietary, fuzzy logic-based evaluation model, which demonstrated high efficacy and a strong correlation with objective driving data. Within the practical training group, 81% of participants achieved performance ratings of "acceptable" or "very good." Furthermore, the model proved capable of granularly tracking the learning curve, with performance scores improving significantly from the initial hazard to the final event ($M = 4.88$). However, when juxtaposing these objective outputs with subjective evaluations, significant discrepancies were identified; notably, in 14 instances, instructors awarded scores exceeding the model calculation by more than one point.

Qualitative analysis of these divergences elucidates the fundamental limitations of human assessment in this context. The primary factors contributing to the variance between objective model data and subjective trainer ratings include:

- **Recency and progression bias:** While the automated model calculated performance based on aggregate averages across all trials, human evaluators tended to prioritize the outcome. Consequently, drivers who initially performed poorly but improved their results over time were rated highly by trainers, disregarding early errors that the mathematical model strictly penalized.
- **Leniency and the "halo effect"**: Analysis detected a distinct "leniency bias", where instructors awarded inflated scores based on a driver's general competence rather than specific system operation. Furthermore, ratings fluctuated based on the individual evaluator, indicating a lack of standardization.
- **Inconsistency in criteria application**: Instructors frequently adjusted scores based on contextual factors such as perceived "learning potential" or "visible progress" rather than adhering to the strict, standardized parameters measured by the objective model.
- **Lack of instrumentation precision**: Subjective assessment inherently lacks the capacity to accurately measure critical micro-metrics, such as specific reaction times (ms), which are essential for evaluating safety but can only be captured via objective instrumentation.

The unreliability of subjective measures was further substantiated by participant self-assessments, which exhibited a marked optimism bias. The majority of participants (34 out of 49) rated their performance higher than the objective model would indicate, with several assessments directly contradicting both the model and the instructor. This finding reinforces that self-perception is often skewed and cannot serve as a standalone reliability metric for safety-critical skills.

In conclusion, while expert trainer evaluation remains valuable for capturing behavioral nuances, it is insufficient on its own for a reliable and reproducible assessment. The developed model provides a robust tool that eliminates subjectivity and ensures a standardized evaluation methodology. Consequently, the study advocates for a hybrid evaluation framework, where objective data-driven assessment is complemented and verified by qualitative expert evaluation. This combined methodology leverages the precision of the model alongside the contextual insight of the trainer, creating a comprehensive framework essential for enhancing training quality and promoting road safety.

2. AN UPDATED CONCEPT FOR EVALUATING THE EFFECTIVENESS OF PRACTICAL TRAINING

Analysis of preliminary research findings (Section 1.2) revealed substantial limitations in traditional subjective assessment, highlighting its susceptibility to cognitive biases and a lack of standardized criteria. A distinct inconsistency in evaluation strategies was observed: whereas some trainers exhibited a tendency to "forgive" initial difficulties provided the final maneuver was executed correctly, others rigorously downgraded the entire session based on errors committed in the initial scenario. These discrepancies resulted in significant deviations from the objective telemetry data. In response to these observations, a decision was made to revise the expert assessment methodology by introducing modernized evaluation sheets based on Behaviorally Anchored Rating Scales (BARS). This new instrument compels the evaluator to assess each experimental scenario independently, thereby preventing holistic averaging and ensuring precise insight into the driver's actual competence level at each measurement point. When testing an updated concept for evaluating the effectiveness of practical training, the authors decided to restrict the study cohort exclusively to individuals aged 50 and over, due to their specific needs regarding adaptation to emerging technologies. This group is most susceptible to digital exclusion within the transport sector, yet simultaneously demonstrates the greatest benefit from active training methodologies. As earlier phases of the experiment unequivocally established the superiority of simulator-based training over passive methods (such as e-learning or manual instruction), control groups were eliminated in this study to ensure all participants received the most effective intervention. This approach facilitated a deeper analysis of the learning process within the cohort at highest risk of operational errors, thereby maximizing the practical research value of the project [24].

2.1. Research group

The study sample was composed of 25 participants aged 50 and over, consisting of 13 females and 12 males. The study sample consisted of drivers aged 50 and over, a group characterized by significant cognitive and physical heterogeneity. According to Murman [27], age 50 marks the period where the decline in fluid intelligence (e.g., processing speed) begins to diverge significantly from stable crystallized intelligence (experience). This specific threshold is scientifically justified as an optimal point for proactive intervention; while the most pronounced psychophysical declines are typically recorded after age 65 [28], research by Svetina [29] demonstrates that reaction times during divided attention tasks exhibit measurable deficits already in the 50–60 age bracket. By initiating training at this stage, drivers can leverage their high level of crystallized intelligence to develop compensatory strategies, such as those observed in simulated driving environments [30], before steeper cognitive degradation occurs. Furthermore, since older drivers often exhibit a disconnect between their self-assessed and actual driving performance [31], early exposure to simulator-based ADAS training serves to calibrate trust and awareness at a stage where executive functions—which are more precise predictors of fitness to drive than chronological age alone—are still largely preserved [32].

This specific demographic was recruited to enable an in-depth analysis of their adaptation to new technology and to assess the effectiveness of the practical, simulator-based training module. To ensure the validity of the data, all participants were required to meet strict inclusion criteria, including the possession of a valid category B driving license, a minimum of one year of active driving experience (defined as covering approximately 2000 km annually), and limited or no prior exposure to the ADAS functionalities under investigation. This minimum threshold is consistent with established research protocols aimed at ensuring that participants have passed the novice phase and possess stable, automated driving skills [33]. In accordance with the principles of gerontology in transport, no maximum limit on driving experience was set. Extensive driving history is recognized as a key compensatory asset (crystallized intelligence) that enables older drivers to maintain safety despite age-related declines in processing speed [34]. Conversely, exclusion criteria were rigorously applied to disqualify individuals with conditions capable of impairing safe simulator operation, such as significant psychomotor or cognitive disorders.

The research protocol received formal approval from the Scientific Research Ethics Committee at the Motor Transport Institute in Warsaw (Resolution No. 4/2025, dated June 3, 2025). All procedures were conducted in strict adherence to the ethical principles outlined in the Declaration of Helsinki. Prior to participation, every individual was fully briefed on the study's objectives, provided written informed consent, and received a nominal voucher as compensation for their time.

2.2. Research equipment

All experimental sessions and training were conducted using the AS 1200-6 high-fidelity driving simulator, located at the Motor Transport Institute (ITS) in Warsaw, Poland. This specific configuration was chosen for its ability to provide kinesthetic cues that synchronize with visual stimuli, thereby minimizing simulator sickness in senior participants. The authors declare full commercial independence, as the manufacturer had no role in the study design or data analysis. A detailed technical specification of the simulator has been presented in previous work [24].

The simulator is built around a fully-functional, full-cockpit cabin of an Opel Astra IV passenger vehicle, providing participants with a highly realistic and immersive tactile environment. To replicate the kinesthetic sensations of driving, the entire cabin is mounted on a six-degrees-of-freedom (6-DoF) motion platform. This system accurately reproduces vehicle dynamics, including angular movements (roll, pitch, yaw) and linear accelerations (surge, sway, heave), which are crucial for simulating credible responses to braking, acceleration, and cornering maneuvers.

The visual environment is rendered on a large, cylindrical screen that offers a seamless 200-degree horizontal and 30-degree vertical field of view. The high-resolution display is powered by a system of four overhead projectors, ensuring a wide and coherent visual field that minimizes edge distortions and enhances peripheral awareness. In place of standard rear-view mirrors, the simulator utilizes three strategically placed high-definition monitors that display a live feed from the virtual environment, accurately mimicking the driver's natural use of mirrors.

All simulation parameters, scenario events, and data logging are managed from a dedicated operator's station. This setup allows for precise control over the experiment and the nonintrusive recording of a wide array of driver performance metrics, which formed the basis for the objective evaluation model developed in this study.

2.3. Research methodology

The research protocol (Fig. 1) was rigorously structured into six sequential phases, creating a repeatable 100-minute assessment environment. The procedure commenced with Phase 1, which encompassed participant briefing, informed consent, and baseline screening for simulator sickness. To ensure validity, Phase 2 facilitated acclimatization through a seven-minute standardized drive, allowing subjects to familiarize themselves with the vehicle dynamics prior to a secondary health verification. The protocol then advanced to Phase 3, where participants underwent practical training on the high-fidelity AS 1200-6 simulator; this session focused on the "Highway Chauffeur" system, placing specific emphasis on engagement procedures and the execution of takeover maneuvers. Immediately following instruction, Phase 4 utilized a custom-developed, multi-faceted questionnaire to capture subjective evaluations regarding instructional quality, satisfaction, and the perceived impact on driver confidence.

The assessment culminated in Phase 5, an experimental test drive featuring four unannounced critical events designed to evaluate reaction times and situational awareness. These scenarios included three system-prompted hazards: a static obstacle, sudden braking, and an aggressive merge; the fourth was an adverse weather condition (dense fog) that required proac-

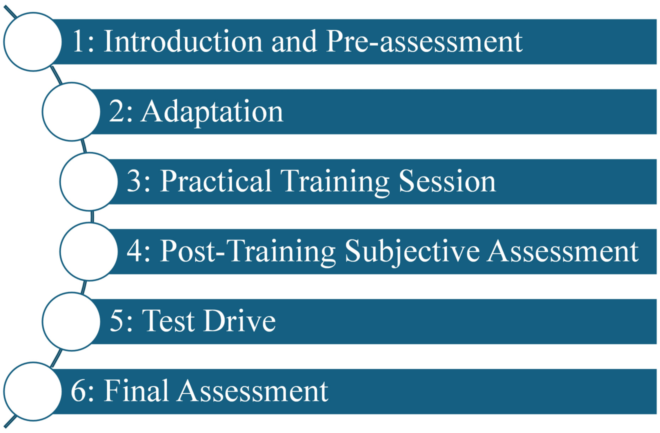

Fig. 1. Research methodology

tive manual intervention without a system alert. Finally, Phase 6 integrated the findings by benchmarking objective performance data against subjective trainer and participant ratings. This dual-methodological approach was employed to highlight the superior precision of the scenario-based evaluation framework compared to traditional aggregated metrics.

2.4. Research hypotheses

Based on the literature review and the research objectives concerning the adaptation of older drivers to ADAS technologies, the following four hypotheses were formulated and operationalized:

H1: The severity of simulator sickness symptoms, as measured by the Revised Simulator Sickness Questionnaire (RSSQ) total score, is sufficiently low so as not to disrupt the training process, thereby validating the high-fidelity simulator as a suitable environment for the 50+ demographic.

H2: Participation in the practical training session leads to a statistically significant increase in subjective trust levels towards ADAS, measured on a five-point Likert scale before and after the intervention.

H3: The training intervention results in increased participant awareness of specific system benefits, as identified through a standardized multiple-choice perception survey.

H4: The proposed practical training model is perceived as highly usable and professional, achieving high scores in the subjective usability and instructional quality assessment (Training Assessment Questionnaire).

3. RESULTS

The empirical analysis focused on verifying the hypotheses presented in Section 2.4. Data were collected from 25 participants using the hybrid model described in the methodology.

To verify the first hypothesis (H1), the Revised Simulator Sickness Questionnaire (RSSQ) was employed. This instrument comprises 28 symptoms categorized into three domains: nausea (N), oculomotor disturbances (O), and disorientation (D). Participants rated symptom severity on a four-point scale (0 – none, 3 – severe) immediately before and after each session. The absence of health contraindications permitted the commencement of an adaptation drive on a virtual expressway, enabling participants to familiarize themselves with the simulator operating characteristics.

In the analysis of RSSQ results, numerical values are assigned to individual symptoms. Appropriate conversion values are utilized for this purpose, where 0 corresponds to no symptoms, 1 to slight symptoms, 2 to moderate symptoms, and 3 to severe symptoms. Subsequently, the scores obtained for each scale are summed according to their classification. To calculate the total score, the sums obtained from each scale are aggregated. It is important to note that data not assigned to a specific symptom category are excluded from the numerical analysis.

Comparative analysis of the results is facilitated by multiplying the raw scores by specific weight factors. These factors are 9.54 for nausea, 7.58 for oculomotor symptoms, 13.92 for disorientation, and 3.74 for the total score. The numerical analysis of coefficients for individual symptom categories conducted in this manner allows for an assessment of the impact of various exposure factors on the participant during driving simulation. Figure 2 presents the results obtained from successive RSSQ questionnaires, categorized by symptom domain.

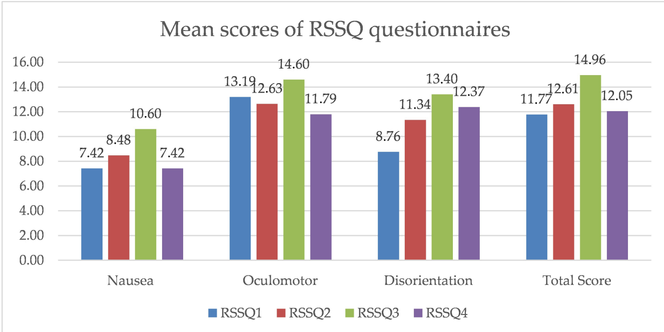

Fig. 2. Mean scores of RSSQ questionnaires

Subsequently, a statistical analysis was performed to determine whether statistically significant differences existed across individual items. An analysis of symptom variations between RSSQ1 (pre-adaptation) and RSSQ4 (following the final experimental drive) revealed that a statistically significant change occurred in two out of the 28 investigated items. These changes pertained to the following symptoms: fatigue ($p = 0.033$) and somnolence ($p = 0.02$). No statistically significant differences were observed for the remaining items. A Wilcoxon signed-rank test was conducted to compare fatigue levels between the two measurement points (RSSQ1 vs. RSSQ4). The results indicated a statistically significant difference between the measurements ($Z = -2.13$, $p = 0.033$). This implies that the participants' fatigue levels significantly decreased over time (Fig. 3, Fig. 4).

The Wilcoxon signed-rank test was employed to compare somnolence levels between the first (RSSQ1) and fourth (RSSQ4) measurements. The results revealed a significant difference, $Z = -2.33$, $p = 0.020$. This implies that the participants' somnolence levels significantly decreased over the course of the study (Fig. 5, Fig. 6).

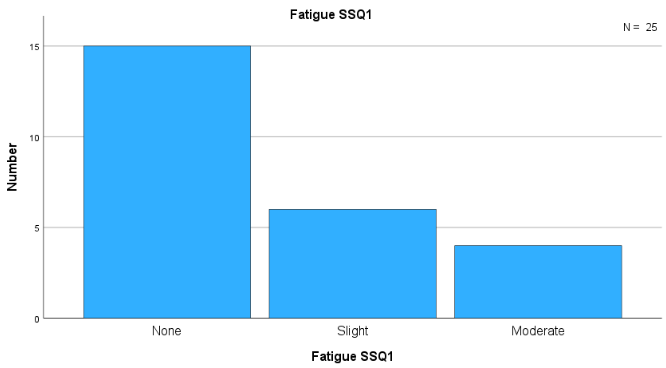

Fig. 3. Distribution of fatigue levels before adaptation (RSSQ1)

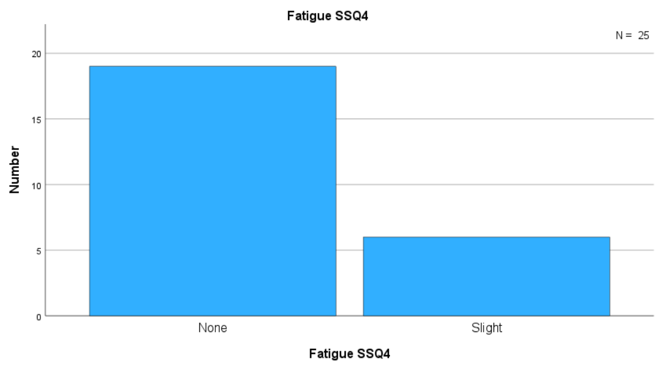

Fig. 4. Distribution of fatigue levels after the final test drive (RSSQ4)

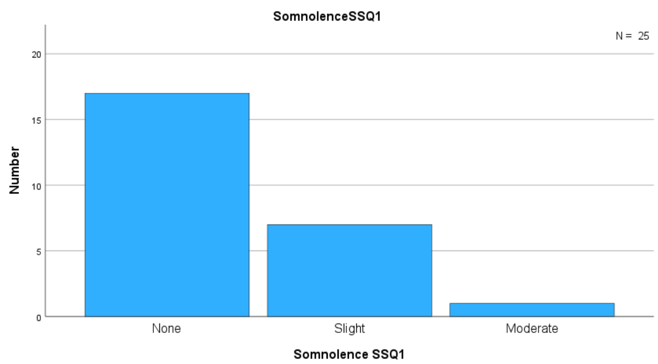

Fig. 5. Distribution of somnolence levels before adaptation (RSSQ1)

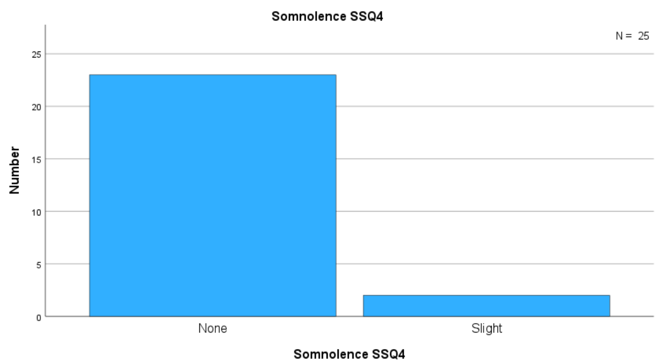

Fig. 6. Distribution of somnolence levels after the final test drive (RSSQ4)

The results suggest that the simulator did not induce an exacerbation of simulator sickness symptoms, thereby confirming its suitability as a training tool for individuals over the age of 50.

To verify the assumptions of the second and third hypotheses, the evolution of participant responses was examined. A key component of the analysis involved comparing the baseline state (initial survey) with the assessment provided by the drivers following the completion of the training. The study utilized a closed-ended questionnaire, requiring participants to quantify their level of trust on a scale of 1 to 5. The detailed distribution of responses is presented in Figs. 7 and 8.

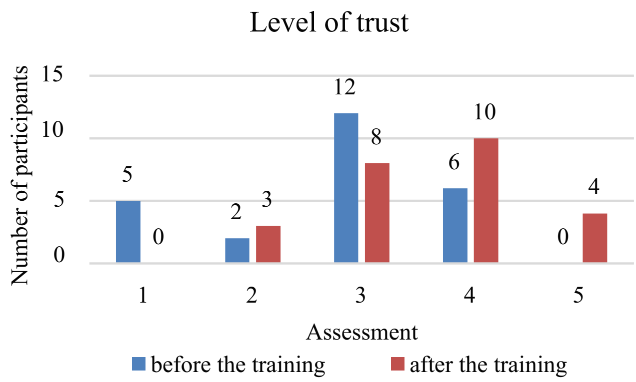

Fig. 7. Distribution of self-reported trust in ADAS before and after simulator-based practical training

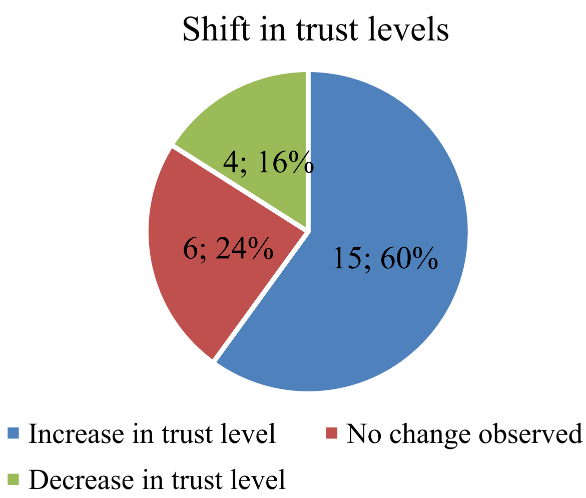

Fig. 8. Direction of change in self-reported trust in ADAS after completion of practical simulator-based training

The symptom structure reported by participants upon completion of the full training cycle (RSSQ-4 measurement) was subjected to a detailed analysis. The objective was to determine the impact of the six-degrees-of-freedom (6-DoF) platform on the psychophysical comfort of the drivers.

Analysis of descriptive statistics for the individual subscales revealed a specific symptom profile. The lowest mean score was recorded for the Nausea subscale ($N = 7.24$), while higher values were observed for the Oculomotor (O = 12.40) and Disorientation (D = 13.32) subscales.

To evaluate the temporal dynamics of participant well-being during exposure to the virtual environment, the Revised Simulator Sickness Questionnaire (RSSQ) Total Score was analyzed across four measurement points (N = 25). Descriptive statistics indicated that the severity of simulator sickness symptoms remained at a relatively low and stable level throughout the experiment. The mean RSSQ Total Scores for the consecutive measurement points were as follows: M1 = 12.72 (SD = 17.48), M2 = 13.61 (SD = 13.82), M3 = 16.16 (SD = 15.97), and M4 = 13.02 (SD = 15.08). An analysis of mean ranks revealed a negligible upward trend during the intermediate phase of the study (rising from a mean rank of 2.26 at T1 to 2.78 at T3), followed by a decline in the final phase (mean rank 2.32), suggesting the occurrence of a habituation effect.

Statistical verification using the nonparametric Friedman test for related samples confirmed the absence of statistically significant differences in the RSSQ Total Score across the simulation stages ($\chi^2 = 3.917$; $p = 0.271$). The obtained result ($p > 0.05$) supports the null hypothesis regarding the stability of symptom distribution over time. This indicates that prolonged exposure to the simulation scenario did not result in a cumulative effect of negative symptoms; thus, no significant temporal escalation of sickness was observed. The stabilization of scores and the absence of significant deterioration in well-being during the final stage confirm the ergonomic quality of the simulation environment and the effective synchronization of visual and vestibular stimuli.

The analysis of simulator sickness symptoms across gender groups showed no significant disparities in tolerance. While female participants exhibited a higher mean total symptom score at the final measurement point (M = 15.27, SD = 15.42) compared to male participants (M = 10.93, SD = 14.61), the difference did not reach statistical significance (U = 68.5, p = 0.603). Furthermore, the rate of change in symptoms from pre-adaptation (RSSQ1) to post-test drive (RSSQ4) followed a similar pattern for both genders, suggesting that the 6-DoF motion platform effectively mitigated gender-based susceptibility to simulator sickness.

To evaluate the impact of the conducted training on the level of trust in ADAS, the Wilcoxon signed-rank test for dependent samples was employed. Statistical analysis revealed a significant difference between the baseline and final measurements (p = 0.016). The direction of this relationship indicates an increase in participant trust levels following the completion of the training.

Notably, the calculated effect size was $r = 0.48$. According to Cohen's classification, this result is interpreted as a medium effect size, approaching a large effect.

Gender-specific analysis revealed that both groups experienced a positive shift in trust levels. For male participants (n = 13), the median trust level increased from 3.0 to 4.0, while for female participants (n = 12), the median rose from 2.5 to 3.0. Although male participants reported higher absolute trust scores at the end of the training (M = 3.08, SD = 1.04) compared to females (M = 2.33, SD = 0.89), this difference was not statistically significant (Mann-Whitney U = 51.5, p = 0.168).

Figure 7 illustrates absolute trust levels, whereas Fig. 8 highlights the direction of trust calibration, including both increases and decreases. A specific group of respondents (16%), for whom a decrease in trust levels was observed, requires particular attention (Fig. 7, Fig. 8). This phenomenon should not be interpreted negatively. In the relevant literature, this is referred to as "trust calibration." The training likely rectified the drivers' excessive and unrealistic expectations regarding the system, adjusting trust to a level commensurate with the actual capabilities of the technology. No significant gender-based differences were observed regarding trust or RSSQ scores in this sample ($p > 0.05$).

The quantitative analysis was complemented by the identification of the perceived benefits resulting from the operation of ADAS (Fig. 9). The advantages most frequently enumerated by the subjects included: enhanced road safety, more precise control of driving parameters (speed, distance), and driver support under difficult road conditions.

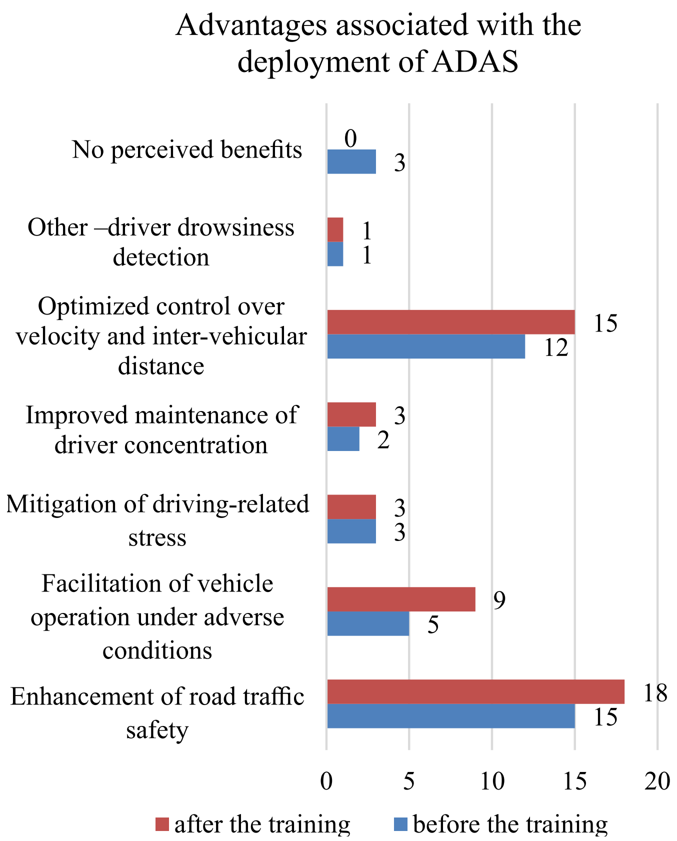

Fig. 9. Advantages associated with the deployment of ADAS

The fact that "increased safety" was the most frequently cited benefit correlates with the Technology Acceptance Model (TAM). Users are more inclined to adopt ADAS solutions when they perceive a direct impact on accident risk reduction, rather than viewing them merely as a convenience.

Prior to analyzing the results verifying the fourth hypothesis, the internal consistency of the applied evaluation questionnaire (questions 1–8) was assessed. The conducted statistical analysis revealed that Cronbach's Alpha coefficient for the entire scale amounted to $\alpha = 0.76$.

This result exceeds the threshold value of 0.7 accepted in social research methodology, confirming the correct construction of the research tool. This indicates that respondent answers were consistent and that the survey reliably measured a single, common construct: the subjective assessment of training quality and usability.

Verification of the fourth research hypothesis was based on the analysis of subjective participant assessments collected via an eight-item evaluation questionnaire (Fig. 10). The Likert scale used (1–5) allowed for a quantitative assessment of satisfaction.

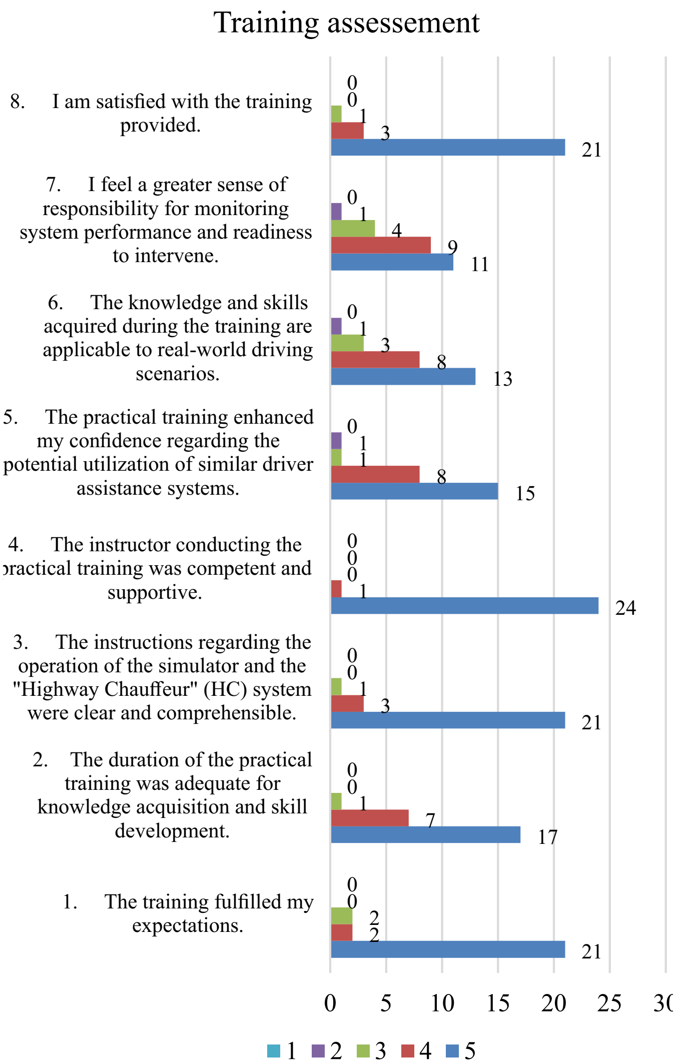

Fig. 10. Training assessment results

Analysis of the response distribution and descriptive statistics (Fig. 10) indicates a high level of acceptance for the proposed training model. Regarding the assessment of instructor professionalism and competence (Question 4), 24 out of 25 respondents (96%) awarded the highest possible score (mean ≈ 4.9). The degree to which the training fulfilled participant expectations (Question 1) also achieved a modal response of 5 (21 indications). In terms of perceived impact, a large majority of participants reported increased self-confidence in operating ADAS (Question 5), with a mean score exceeding 4.5. However, Question 7 ("I feel more responsible for monitoring system performance. . . ") exhibited the greatest variance in responses, with several participants providing "moderate" ratings compared to the consistently high scores in other categories.

The quantitative analysis was complemented by the categorization of statements provided by participants in the open-ended section of the survey. In response to the inquiry regarding the most valuable elements of the training, respondents most frequently highlighted three areas:

- **Understanding system limitations** – the opportunity to safely test situations in which the system disengages or requires intervention (cited by 35% of the subjects).
- **Practical skill verification** – e.g., "testing one's own reaction time," "mastering reflexes."
- **Educational value** – the acquisition of knowledge regarding functionalities of which drivers were previously unaware.

Regarding recommendations for training improvement, the most frequently recurring suggestion was to increase the difficulty level of the scenarios (e.g., "more challenging situations," "driving in fog," "extending driving time"). This suggests high participant engagement and a desire to further refine driving techniques under simulated conditions.

Correlation analysis between well-being and training assessment

To verify whether negative physiological sensations (simulator sickness symptoms) result in reduced satisfaction with the training, a Spearman's rank correlation analysis was conducted. The relationship between the total symptom severity score following the final drive (variable RSSQ_Total) and the declared level of satisfaction with the training (Question 8) was examined.

The analysis revealed no statistically significant relationship between the variables ($rho = -0.152$; $p = 0.470$). This indicates that the occurrence of somatic symptoms did not determine the participants' final assessment. It is worth noting that even individuals for whom a relatively high discomfort index was recorded (RSSQ > 30) rated the training with the highest possible score (5).

4. DISCUSSION

The results of this study provide several important insights into the feasibility of ADAS training for older drivers. Firstly, the symptom structure reported by participants (where $N < O$) confirms the high ergonomic validity of the research station. In accordance with sensory conflict theory, the low level of nausea demonstrates that the kinesthetic stimuli generated by the 6-DoF platform were congruent with the visual stimuli, thereby effectively minimizing the risk of vegetative symptoms.

Regarding behavioral adaptation, the calculated effect size ($r = 0.48$) implies that the training intervention had a measurable and significant impact on modifying the attitudes of the surveyed drivers. This is particularly evident in the increase of self-confidence and trust, which was not hindered by minor physiological discomfort.

An important aspect raised during the review process was the potential "gender gap" in technology adoption. Our analysis (Mann-Whitney U test) showed that while men reported slightly higher trust ($M = 3.08$) than women ($M = 2.33$), this difference was not statistically significant ($p = 0.168$). Similarly, gender did not significantly impact simulator sickness susceptibility ($p = 0.603$). This suggests that for the 50+ demographic, extensive driving experience may act as a unifying factor that outweighs gender-specific differences in technology acceptance.

From the perspective of transport psychology, the high scores in self-confidence (Question 5) and the increased sense of responsibility (Question 7) suggest that the training effectively raised awareness of the "human factor". The fact that participants rated the training highly even when experiencing moderate symptoms (RSSQ > 30) attests to the high substantive value of the intervention, which outweighed physical discomfort in the participants' perception.

Regarding the "gender gap" mentioned in the literature review, our findings suggest that in the 50+ age group, gender is not a dominant factor in ADAS acceptance or simulator tolerance. The lack of significant differences in trust levels ($p = 0.168$) aligns with the cohort effect theory, suggesting that for senior drivers, years of manual driving experience may act as a stronger determinant of technology perception than gender. Although female participants showed a nonsignificant trend toward higher simulator sickness sensitivity, the overall stability of the RSSQ scores across both groups confirms the suitability of the training environment for all users, regardless of gender.

Despite the positive outcomes, this study has limitations that must be acknowledged. The findings are primarily constrained by the relatively small sample size ($n = 25$), which reduces the statistical power to detect subtle disparities between age subgroups. Consequently, while this study serves as a successful proof-of-concept for the proposed training methodology, the broad "50 and over" demographic may not fully account for the increasing cognitive and functional diversity of older drivers. As emphasized by Murman [27], cognitive aging involves a complex shift where declining fluid abilities are often balanced by stable crystallized intelligence. Research by Svetina [29] and Wood *et al.* [35] confirms that these age-related changes significantly impact specific driving metrics, particularly reaction times during divided attention tasks, which exhibit measurable deficits already in the 50–60 cohort. Furthermore, the lack of decade-by-decade differentiation (e.g., 50 s vs. 70 s) limits the analysis of how mental workload and HMI usability requirements evolve as functional capacities change with advanced age [12]. Additionally, the current reliance on subjective measures may be influenced by the potential disconnect between older drivers' self-assessments and their actual performance [31]. Future research should involve larger, age-stratified cohorts to allow for a more nuanced understanding of how cognitive aging affects the learning curve and trust calibration in the context of driving automation [28].

The high ratings regarding instructor competence observed in the results highlight the critical role of expert support and the human factor in the process of adapting senior drivers to new technologies in a simulated environment. The positive outcomes in self-confidence (Question 5) suggest that practical exposure is an effective tool for overcoming psychological barriers to ADAS adoption. However, the variance observed in the responses to Question 7 regarding the sense of responsibility is particularly revealing. It suggests that while senior drivers quickly gain confidence in the system's operation, the full internalization of the division of responsibility between the human driver and the machine is a more complex cognitive process. This finding indicates that achieving a stable awareness of system monitoring duties may require a longer adaptation period or repeated training sessions.

5. CONCLUSIONS

This study provides empirical evidence supporting the effectiveness of practical, simulator-based training in preparing older drivers (50+) for the use of Advanced Driver Assistance Systems. The research successfully validated the proposed evaluation concept, demonstrating that a high-fidelity driving simulator is an appropriate and safe training environment for this demographic. Analysis of the Revised Simulator Sickness Questionnaire (RSSQ) confirmed that while physiological symptoms occur, they significantly decrease with adaptation (H1), allowing for effective learning without compromising participant well-being.

The training intervention resulted in a measurable increase in participants' trust in ADAS technologies (H2) and a deeper awareness of the benefits associated with their use, such as enhanced safety and driving comfort (H3). Participants rated the utility and quality of the practical training highly (H4), indicating a strong demand for hands-on experience over passive learning methods.

The study reaffirms the fundamental limitations of subjective assessments in safety-critical contexts, as evidenced by the variance between trainer ratings and objective data. The comparison between the objective fuzzy logic model and trainer ratings revealed that human evaluators are susceptible to cognitive biases, including the "recency effect" and "leniency bias." Trainers tended to overlook initial errors if the outcome was positive, whereas the objective model strictly penalized all deviations. Consequently, this study argues that subjective rating alone is insufficient for certifying safety-critical skills.

Instead, the paper proposes a hybrid evaluation framework. This approach leverages the precision of objective telemetry to measure micro-metrics (e.g., reaction times, control inputs) while utilizing Behaviorally Anchored Rating Scales (BARS) for the qualitative assessment of situational context. Such a model ensures a standardized, reproducible, and diagnostically valid assessment of driver competence, bridging the gap between technological potential and user safety.

It is important to note that while the current publication focuses on the validation of the conceptual framework and subjective metrics, the detailed analysis of objective data acquired during the simulator drives (telemetry) will be published in a separate article.

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