

# Enhancing Occupational Road Safety through Virtual Reality—An Innovative OSH Training Approach from Italy: Preliminary Results

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**Abstract**—The widespread and increasingly diverse application of virtual reality technology offers significant opportunities for innovative training on both road and workplace safety and health. Key advantages include the ability to recreate realistic contexts, provide immersive learning experiences, and monitor participant performance through tracking and scoring systems. Such features enable more effective training, fostering the development of appropriate safety behaviours and activating systems of vigilance and accountability, also improving adherence to technical procedures across various activities. This paper presents a case study conducted through a multidisciplinary, multi-sectoral approach, focusing on the design and evaluation of an interactive virtual reality laboratory aimed at enhancing knowledge of work-related road risks. A specific emphasis was placed on drivers' psychophysical and health status, with the goal of promoting a culture of road safety in both personal and professional settings. The methodology involved the assessment of health, cognitive and behavioural aspects of driving through company case studies and the integration of best practices for road safety and health. Additionally, an interactive virtual reality application was developed, simulating a commute under varying conditions affecting psychophysical performance, including medication use, drowsiness, alcohol consumption, and distractions from mobile devices. The ultimate objective was to create a virtual-based training module capable of supporting participatory and immersive multimedia programs for worker information, education and training. By combining realistic simulation with interactive engagement, this approach aims to improve risk awareness, encourage preventive behaviours, and provide a replicable model for the integration of virtual reality into occupational health and safety training initiatives.

**Keywords**—virtual reality, training and education, occupational safety and health, road safety

## I. INTRODUCTION

Over the last decade, Road Safety (RS) has shifted from being a secondary issue, closely linked to transport, to a major global health and development priority, formalized

by the UN's Decade of Action for RS 2021–2030, which aims to halve road deaths by 2030. This issue impacts the general population and workers across various domains, including public health, economic development, education, and social equity, highlighting the need for integrated solutions in vehicles, infrastructure, legislation, and emergency care. Global data published by the World Health Organization (WHO) show that over 1 million people die each year worldwide due to Road Accidents (RA); two-thirds of road traffic fatalities occur among people of working age (18–65 years), and a significant proportion of deaths occur among vulnerable road users, including pedestrians, cyclists, and motorcyclists. Road traffic crashes cost most countries approximately 3% of their Gross Domestic Product (GDP) [1].

The European Transport Safety Council (ETSC) recognizes road use for working life, but it also has a considerable impact on the health and safety of workers. ETSC recognizes road use as essential and significant for working life, but it also has a considerable impact on the health and safety of workers, being the cause of a high number of injuries, disabilities, and deaths (most of the latter while commuting). The most recent major report (June 2025) [2] reveals that while some countries, such as Norway and Sweden, excel, the EU is off track to reach its 2030 target, with only a 2% drop in road fatalities in 2024. The year 2024, well below the 6.1% needed, and a total decline of 12% from 2019, indicating stagnation; so much that it developed the Road Safety Performance Index (PIN), a policy tool aiming to help EU Member States to improve road safety by comparing performance between countries and identifying best practices in areas such as user behaviour, infrastructure, vehicles, and safety policies. However, the true number of work-related road deaths is likely higher due to incomplete and inconsistent reporting and a lack of a common definition.

The European Commission (EC) also reports a similar data trend, noting progress towards achieving the main target set in the Strategic Action Plan on Road Safety and the EU Road Safety Policy Framework 2021–2030,

namely, to halve road deaths by 2030. The recently published preliminary data on road deaths for 2024 indicate around 19,800 fatalities, a decrease of 3% compared to 2023, equivalent to 600 fewer lives lost. While this represents a step in the right direction, the overall pace of improvement remains too slow, with significant disparities between Member States [3].

The situation concerning Italy in this context is not better: the number of road accident deaths reported by the National Institute of Statistics (ISTAT) for 2024 was 3030 (−0.3% compared to 2023), while the number of injuries was 233,853 (+4.1%), for a total of 173,364 RA (+4.1%). Compared to 2019, the number of fatalities and injuries decreased (−4.5% and −3.1% respectively), while road accidents showed a slight increase (+0.7%). Therefore, compared to 2023, the number of fatalities in 2024 remains almost stable, but still exceeds 3000: the road fatality rate increases from 51.5 to 51.4 deaths per million inhabitants. The social cost of RA resulting in personal injuries is still significant (calculated with parameters updated by ISTAT and ACI in 2023, based on data collected by the Italian Road Police, Italian Local Police and the Italian Carabinieri (national gendarmerie) amounts to just over 18 billion euros in 2024, almost 1% of the national GDP [4].

The first data made available by the National Institute for Insurance against Accidents at Work (INAIL) for the period January–December 2024 also shows a decrease in workplace accidents (−1.9%) compared to 2023. Conversely, commuting accidents increased by 5.0%, rising from 92,261 in 2023, 18% of total accidents reported during the year to 96,835 in 2024 (19% of the total). This increase is accompanied by a significantly higher number of fatalities than in 2023, with deaths rising by 41%, from 239 to 28 [5].

The issue of road accidents is still getting worse: data from the European Commission on RA fatalities in 2022 recorded 20,600 road deaths, marking a 3% increase compared to 2021 [6].

As previously mentioned, a significant feature of RA is its association with employment, as many people commute to and from work on the road. Business travel, commuter travel, and travel for work-related reasons are all considered work-related road trips in Italy. Work-related RA is a leading source of fatalities and disabilities in the workplace, even in the absence of systematic monitoring of work-related road deaths and serious injuries [7].

Within the complex “driving system”, consisting of multiple components in dynamic and mutual equilibrium, major RS studies indicate that an accident is considered a kind of “short circuit” in the interaction between man, vehicle and environment. Data indicates that 90% of all RAs are linked to human error and alterations in the human macro-factor: specifically, 30% of fatal accidents are due to excessive speed, while “distraction” causes 10–30% of road deaths and 25% of all road accidents in the EU are alcohol related [8]. Numerous physiological (e.g., advanced age) and pathological conditions (such as cardiovascular disease, diabetes, epilepsy, sleep disorders, etc.) can also affect driving performance, through alterations in motor activity and vigilance, as well as

impairments in an individual’s senses and intellectual function. The same factors, or similar ones, always cause or contribute to RA issues in both personal and working circumstances, including driving behaviour and psychophysical state, the environment and infrastructure, and the vehicle. Inappropriate drug and alcohol use, diseases and altered psychophysical conditions, poor vision, use of psychotropic substances, excessive daytime sleepiness, fatigue, drowsiness, using mobile devices while driving, and disregarding traffic laws are just a few of the many risks associated with human factors, which have a predominant influence [7].

In this context, especially considering that the human factor—namely, the driver’s behaviour and psychological state—is the primary one compared to other predisposing factors such as the availability and safety of transportation options, road traffic, and risks involved in transporting hazardous materials, it is crucial to emphasize the importance of effective training and information [7].

Digital technologies offer the potential to influence workers’ behaviour and/or attitudes: their usefulness and subsequent diffusion have recently been recognized as central within the new Italian regulatory framework. In particular, the 2025 State–Regions Agreement on mandatory Occupational Safety and Health (OSH) training formally acknowledges the effectiveness of advanced digital training tools. It distinguished three main categories: virtual and physical simulators, including machine-edge systems, consisting of virtual simulation software that is especially effective for the acquisition of manual and practical skills; gamification, defined as a pedagogical methodology that applies game-based and videogame-inspired mechanics to enhance learner engagement and to stimulate motivation and sustained attention during training activities; and augmented and virtual reality technologies, which rely on visual, auditory, and haptic devices to superimpose multimedia information onto the user’s naturally perceived environment. Their application enables the delivery of training activities without requiring physical presence in a specific workplace and allows the simulation of multiple operational scenarios for educational and practice-oriented purposes.

Overall, these technologies facilitate and enhance training processes by enabling real-time visualization of information, supporting repeated practice across multiple training sessions, and significantly reducing the potential consequences of errors during learning activities [9].

By combining the concept of road safety with preventive and educational approaches (individual “health”—psychophysical well-being, vehicle–environment safety), it is possible to develop case studies that can be considered risk reduction initiatives, aiming to promote a culture of road safety also in the workplace [7]. This article describes a research project based on the use of innovative learning technologies to develop an immersive virtual experience, specifically a virtual laboratory, designed to recognize and manage the human-occupational causes of RA and consequently create participatory and immersive multimedia paths for the information and training of workers.

## II. LITERATURE REVIEW

Occupational accidents, including work-related road ones, remain a global concern, with traditional safety training methods often failing to engage learners/workers or ensure long-term retention.

The interaction possibilities offered by virtual and augmented reality provide a valuable opportunity to make learning and training more fascinating, engaging, and stimulating [10]. Immersive experiences support a high degree of personalization in the training process. Indeed, the cognitive processes involved allow learners/workers to acquire information about their environment and process it at the level of knowledge functional to behaviour through attention, perception, memory, learning, thought, language, and emotions. Virtual reality can therefore bring significant benefits to learning and training because it fully engages the perceptual systems, resulting in complete sensory immersion [11]. This engagement can encourage people to solve problems through creative and decision-making processes, which are influenced by interactions within a group and/or online [12].

Digital learning should therefore be understood as an original process oriented towards new learning and assessment paradigms, which are non-formal and informal, centred on the practical experience of learner/worker, hands-on learning and on peer learning. Through this approach, individuals learn to share their ideas with others, respecting and exchanging them within a community [13].

Our literature search strategy on this topic consisted of several consequential steps: a preliminary analysis of the causes of occupational injuries and RA was conducted using global, European, and Italian datasets [1–6] combined with person-related determinants, as outlined in the Italian National Prevention Plan 2022–2025, including age, gender, health status, drug and psychoactive substance intake, and distraction [14].

The objective of the review was to identify innovative informational and educational models in the field of road safety to compare them with traditional methodologies. To this end, controlled vocabulary (MeSH/IEEE taxonomy where applicable) as free text synonyms were employed to build search strings as follows: Virtual Reality: “VR”, “immersive simulation”, “3D simulation”. Training: “education”, “instruction”, “learning”. Work-related Road Accidents: “occupational traffic accidents”, “work-related crashes”, “road safety at work”. These findings were then combined with Boolean logic: (“virtual reality” OR “VR” OR “immersive simulation”) AND (“training” OR “education”) AND (“work-related road accidents” OR “occupational traffic accidents” OR “work-related crashes”). Then add proximity operators in Scopus/WoS (e.g., VR W/3 training) and truncation (train\*).

Databases and sources were selected based on their features as follows: Multidisciplinary: Scopus, Web of Science; Health/OSH: PubMed; Engineering/Technology: IEEE Xplore; Grey/Additional: Google Scholar; EU OSHA/OSHA guidance; Screen conference proceedings for OSH + XR. Filters and limits were applied as follows: Years: last 5 years, to capture modern HMDs adoption. Language: English (plus relevant languages if needed).

Type: Peer-reviewed articles, systematic reviews, meta-analyses; Population filter: workers/professional drivers or training for road safety context (excluding health VR experiences purely). To further enhance road safety culture and education using digital technologies, an examination of best practices in the areas of road safety awareness and communication was conducted to explore innovative training and communication tools [15].

The main and most relevant results, i.e., scientific articles and publications obtained from this research have been classified into three categories:

- (1) Systematic reviews and meta-analyses: most categorized studies by Kirkpatrick levels evaluate Learning/Reaction, few Behaviour/Results; useful for mapping measures [16]; meta-analyses show VR outperforms traditional training for knowledge acquisition and retention; highlights need for long term retention data [17]; Bibliometric review: VR superior to traditional methods; discusses constraints (HMD access, evaluation techniques [18]. Finding immersive VR yields the best outcomes; it synthesizes experiential learning benefits and integration [19].
- (2) Guidelines, standards and policy: European Union information agency for occupational safety and health (EU-OSHA) discussion on worker exposure to Extended Reality (XR); notes cybersickness, eye strain, and psychosocial considerations; recommend risk assessment when integrating VR [20]; OSHA interpretation letter (VR as training medium): acceptability hinges on whether training is adequate/effective, advised to pair VR with competency checks [21].
- (3) Road safety/driving focused evidence and related trials: Driving simulators and hazard perception programs (e.g., RAC Foundation 360° VR hazard tests): report improved performance in controlled settings; limited real world accident reduction due to small samples/short follow up; recommend supplementary use; Emergency response in traffic accident contexts (e.g., VR for multi casualty triage): better on scene assessment/triage decisions vs. conventional training; outcomes relate to response quality, not prevention; Industry 4.0 OSH VR training (quasi experimental): indicates ~30% safety awareness increase, improved risk perception/self-efficacy (large cohort, non-driver workforce) [22].

As part of our bibliography research, please find below some findings and related recommendations regarding future directions that need to be pursued by research:

- (1) Constant gains: VR improves knowledge, hazard recognition, engagement, and short-term behavioural metrics relative to traditional training [18].
- (2) Transfer gap: Fewer studies demonstrate reductions in real world work-related crashes; driving literature often reports controlled setting improvements without long longitudinal follow up. It would be desirable to move from “learning” to real-world results with a primary endpoint: accident/crash rates (per vehicle kilometre), near misses, claim severity, and violations, measured via telematics, EDRs, and insurance data.

Reviews show an evidence gap at Level 4 (results) [18], and other objectives include fatigue & impairment integration, which is to embed modules on sleep health/OSA (Obstructive Sleep Apnoea Syndrome), drugs, and alcohol (leveraging internal immersive labs and games) and test behavioural change and incident outcomes [11, 23] and cost-effectiveness and implementation science with full economic evaluations (training costs, downtime, crash cost savings, insurance premiums) and hybrid effectiveness implementation trials to quantify adoption, fidelity, equity of access (shift workers, remote depots) [16].

- (3) Best practice: Use VR as a supplement within a blended program; Safety and health considerations: Cybersickness monitoring and mitigation; record exclusion rates (benchmark ~4% in hazard perception work) and psychological safety: realism versus stress; define ethical thresholds for incident replays [22].

### III. METHODS

The “Safe Driving” training program was developed using an interactive Virtual Reality (VR) application that allows users to control a virtual vehicle and exposes them to various simulated risk scenarios commonly encountered during commutes between home and workplace. The primary objective of the system is to enable users to experience firsthand how specific risk factors can impair vigilance and increase the likelihood of road accidents.

The VR laboratory utilizes Oculus Meta Quest 2, an all-in-one head-mounted display designed to provide a smooth and immersive experience, even during dynamic actions. Equipped with a high-performance processor and a high-resolution display, the system delivers enhanced visual fidelity and a superior level of immersion, further supported by positional three-dimensional audio, real-time hand tracking, and high-precision haptic feedback technologies.

The simulation features a simplified driving task where the key user action is braking in response to a sudden obstacle. The virtual vehicle travels along a pseudo-randomly generated straight route that passes through various environments, maintaining a constant speed of 50 km/h in urban areas and 90 km/h in non-urban contexts. In the initial baseline scenario, users experience driving conditions without perceptual or reactive impairments. Through a guided interface, they learn to brake by pressing the index-finger buttons on both controllers, becoming aware of the average reaction time between the intention to brake and the activation of the braking system, as documented in the scientific literature. Once the obstacle appears, users apply the brake; upon completion, a summary infographic displays their response time, physiological delay, and stop distance.

After this initial experience, users may select additional narrative scenarios that introduce specific impairment, allowing them to directly observe how driving performance is affected. The simulated conditions include alcohol consumption, intake of benzodiazepines (commonly used medications for anxiety, insomnia, and

sleep modulation), use of cannabinoids, episodes of microsleep, and distraction due to mobile-phone use. By comparing performance in “normal” versus “impaired” conditions, the training pathway allows users to immediately observe the effects of these states on reaction times, stopping distance, overall safety, and visual and spatiotemporal perception. This approach fosters increased risk awareness and encourages more responsible driving behaviours. The system provides individualized feedback by reporting actual reaction times, the additional delay induced by the impairment, and the resulting implications for road safety.

The virtual reality headset application was developed through a series of iterative phases, each leading to a prototype. The first prototype of the virtual reality application was designed to establish a foundational framework for user interaction and initial testing of key functionalities. The second prototype specifically validated user interaction by directing participants’ attention to a key driving risk: the braking delay caused by impairments. In the alpha version (third phase) various scenarios were developed and tested using data from scientific literature and statistical evidence regarding the main causes of RA also work-related. This version was tested with a small participant group, leading to the decision to proceed with the development and implementation of immersive scenarios in the beta version, focusing solely on the following driving conditions: a) unimpaired driving, b) driving under the influence of alcohol, c) driving after taking medications (benzodiazepines), and d) driving under the influence of drugs (cannabinoids). In the fourth phase, the beta version of the virtual lab was launched, featuring a complete set of interactive panels for user engagement and various narrative content. In the fifth phase, the beta version of the lab was utilized by a convenience sample of workers at an industry-specific national trade fair organized by the Rubes Triva Foundation. The sixth phase entailed implementing the final version in an innovative training program designed to enhance knowledge and awareness of work-related road risk in industrial hygiene companies.

To evaluate the effectiveness of the training program, the immersive lab experience was evaluated using an ad hoc questionnaire with 18 items: a) 5 socio-demographic items (gender, age, educational qualification, nationality, region of residence); b) 1 work item (ATECO sector); c) 3 items about having driving license and using vehicle for commuting (kind of vehicle, kilometres); d) 1 item about road risks perception (11 options); e) 3 items about VR knowledge in training format; f) 1 item about the most favourite type of training (in terms of efficacy) for OSH training (6 options); g) 1 item on the evaluation of the VR lab (evaluation of the clarity of the content, engagement, immersion, usability); h) 1 item assessing satisfaction with expectations (cognitive aspects, attention, learning, and perceived usefulness); i) 1 graphical emoticon item to evaluate the general user satisfaction; l) 1 open question about suggestions. All questions with more options were assigned a value on a Likert scale of agreement between 1 and 5, where 1 corresponds to “not at all” and 5 to

“completely”. The questionnaire was prepared using the Microsoft Forms application and participants completed the online questionnaire after doing the VR experience. The questionnaire data have been collected and stored appropriately, analysed anonymously and in aggregate form, and used exclusively for scientific research purposes. This immersive tool has been implemented within the research project activities of BRIC Inail 2022 ID06 OSH-RO@D, in cooperation with Rubes Triva Foundation and Siena University.

Informed consent was obtained from all individual participants included in the study by signing the following declaration included at the beginning of the evaluation questionnaire and prevents respondents from proceeding with the completion of the questionnaire if the terms are not accepted: *“in accordance with the legislation on the protection of personal data (EU Regulation 2016/679 - General Data Protection Regulation - GDPR - applicable from May 25, 2018), we inform you that the data you provide will be collected and stored appropriately, analysed anonymously and in aggregate form, and will be used exclusively for scientific research purposes. By continuing, you confirm your willingness to participate in our research and express your consent to the processing of the data provided.”*

#### IV. RESULT AND DISCUSSION

Data collection using an anonymous questionnaire was conducted between June and December 2025. The convenience sample includes 114 subjects: 63% women, 36% men, while 1% does not disclose their gender. Participants have an average age of 37 years, with 64% holding a high school diploma, 31% a bachelor's or master's degree, 4% having completed postgraduate studies and only 1% with a middle school diploma. All subjects are of Italian nationality: 75% lives in Central Italy and 25% lives in the North. The primary employment sectors of participants (according to ATECO classification) include water supply, sewerage, and waste management (41%), electricity, gas, steam, and air conditioning (29%), with the remaining 30% in other sectors. All respondents have a driving license and typically use a private car (94%) as a vehicle for commuting between work and home; only a small percentage use a private motorcycle (2%), train (2%), electric scooter (1%), or bicycle (1%). In 51% of cases, the commuting distance between work and home is less than 25 km, while in the remaining cases, it exceeds 51 km.

Regarding perceived risks linked to alcohol consumption, 56.2% of respondents fully agree that even drinking half a glass of wine increases the risk of an accident; 28.9% somewhat agree, while 1.8% completely disagree and 13.2% slightly disagree. A notable finding is that 15% of respondents underestimate the risks associated with alcohol consumption, even in minimal quantities.

Regarding sleep, 72.8% believe that getting less than 5 h of sleep per night raises the risk of a road accident; 22.8% somewhat agree, while 4.4% slightly agree.

Most participants recognize the risks associated with taking painkillers or anti-inflammatory drugs while

driving, with 46.5% completely agreeing and 32.5% strongly agreeing that such use increases the risk of a road traffic accident. A smaller proportion fairly agreed (7%), while 14% underestimated the risk (7.9% slightly agreed; 6.1% strongly disagreed). All respondents recognized the risks associated with mobile phone use while driving, with 84.2% completely agreeing and 15.8% strongly agreeing that such behaviour increases the risk of road traffic accidents.

However, most respondents do not perceive drinking three or more cups of coffee per day as a significant risk factor for driving. Only 8.8% fully agree with this statement and 15.8% fairly agree, while 46.5% slightly agree and 26.3% completely disagree, indicating a low perception of this risk. The data shows a strong awareness among respondents regarding the main risk factors for road safety. Most respondents recognize that increased accident risk is linked to alcohol and substance use, sleep deprivation, and mobile phone use while driving. This finding is consistent with scientific literature studies, which identify these behaviours as the most dangerous for road safety. However, a portion of respondents (15%) underestimate the risks associated with alcohol consumption, even in minimal amounts. Additionally, some respondents fail to fully recognize the dangers of sleep deprivation (4.4%). A critical area of concern arises from underestimating the risks associated with coffee consumption: 72.8% of respondents do not view excessive caffeine intake as a risk factor, despite it has been also highlighted [24] that stimulant abuse can impair alertness and driving performance through anxiety and/or nervousness, sleep disturbances, physical side effects (e.g., tremors and headaches), dependence and withdrawal, and a false sense of alertness. Regarding prevention measures, almost all respondents report that respecting speed limits is useful for reducing the risk of road accidents (75.4% completely agree; 16.7% strongly agree; 7% fairly agree), but still 0.9% is slightly disagrees. About safety measures, 58.8% of the sample completely agree that wearing a helmet while cycling reduces the severity of accidents, with 25.4% strongly agree, and 8.8% fairly agree. However, still 7.1% of the participants underestimate this important protection measure, declaring themselves completely in disagreement (1.8%) and somewhat in agreement (5.3%). Conversely, wearing a helmet while riding a motorcycle, scooter, or moped is considered useful for reducing the severity of road accidents (85.1% fully agree; 10.5% strongly agree; 4.4% fairly agree). Similarly, the use of seat belts is considered useful in reducing the severity of accidents (86% completely agree; 10.5% strongly agree; 2.6% somewhat agree), even if still the 0.9% of the sample disagrees slightly. Overall, compliance with speed limits and the use of safety devices (helmets, seat belts) is high, highlighting a strong culture of prevention and the respect of the road national legislation. However, a small percentage of respondents (7.1%) still express some doubts regarding the effectiveness of certain measures, such as for example wearing a helmet when cycling. This data suggests the need to raise awareness, especially regarding behaviours that, while not mandatory,

are important in reducing injury in the event of accidents. Among those participating in the survey, the majority believe that the increased use of electric scooters and similar vehicles increases the risk of road accidents (39.5% completely agree; 26.3% strongly agree; 24.6% fairly agree, 9.7 slightly and not at all agree) and are aware that road accidents are the leading cause of death in the 5–29 age group worldwide (90.3%).

Regarding the use of virtual reality as a training tool, 50% of respondents declare to have general knowledge, while 49% do not have knowledge at all, and 1% do not remember. Virtual reality is therefore recognized as a useful training tool, especially for its ability to simulate risky situations in a controlled and safe environment. However, the lack of familiarity with this technology, highlighted by almost half of the respondents, indicates that there is room for improvement in digital literacy. In relation to previous experiences with VR technology, 50% state that they have already had such experiences in the past, mainly in work contexts (53%), gaming (26%), training (18%) and study (4%), while 49% have not experienced it. Participants were also asked which OSH training activities they considered most effective. Practical experience is considered the most effective: 59.6% completely agreed, 29.8% strongly agreed, 8.8% fairly agreed, and only 1.8% slightly disagreed. Direct worker testimonials followed: 48.2% completely agreed, 33.3% strongly agreed, 17.5% fairly agreed, and only 0.9% slightly agreed. The presentation of videos and images: 38.6% completely agreed; 35.1% strongly agreed; 24.6% fairly agreed; 1.8% slightly disagreed. Simulations also received positive ratings: 46.5% completely agreed; 31.6% strongly agreed; 18.4% somewhat agreed; 1.8% slightly agreed. 1.8% for nothing. Regarding the effectiveness of frontal lessons, 25.4% of the participants completely agree, 28.9% strongly agree, 36.8% somewhat agree, 7.9% somewhat agree, and 0.9% strongly disagree. Regarding the effectiveness of the presentation of videos and images: 38.6% completely agree; 35.1% strongly agree; 24.6% fairly agree; 1.8% slightly disagree. Concerning the effectiveness of slide presentations, 17.5% completely agree, 21.9% strongly agree, 43.9% fairly agree, 13.2% slightly agree, and 3.5% strongly disagree.

The most valued training experiences, therefore, are practical (direct experiences) and first-hand accounts from workers. These findings confirm the effectiveness of experiential methodologies for learning OSH-related skills. Simulations and multimedia content also received positive reviews, while traditional frontal lessons and slide presentations received less positive feedback. This suggests the importance of diversifying training strategies, integrating practical and interactive methods, to meet the different needs and ways of learning of each participant.

The laboratory experience has been completed by most respondents (57% completely; 22.8% very much; 16.7% fairly), while only 3.6% report difficulty in completing it. The program helps raise awareness of the risks of driving related to drugs, alcohol, and cannabinoids, as well as cell phone use (43% completely agree; 32.5% strongly agree; 19.3% fairly agree), while only a small percentage (2.6%

slightly agree; 2.6% strongly disagree) report no such feedback.

From an engagement perspective, almost all participants (94.7%) found the experience enjoyable, confirming the effectiveness of the training program in terms of active participation. Furthermore, the experience is found to be immersive in most cases: 34.2% consider it completely immersive, 35.1% very immersive, and 27.2% quite immersive. Only 2.6% and 0.9% consider it slightly and not at all immersive, respectively.

Regarding usability, the headsets are considered easy to use by 67.5% of respondents (completely and very easy), while 27.2% consider them less easy to use, and only 3.5% and 1.8% consider them not very easy and not at all easy to use, respectively. These findings confirm that virtual reality experience represents a valid training opportunity for promoting awareness and responsibility regarding driving-related risks and road safety, thanks to better participant engagement and ease of usability. There are still some specific areas to improve among those respondents who do not experience a significant impact.

With respect to their expectations 29.8% of participants are completely satisfied, 36.8% very satisfied, 26.3% quite satisfied and 5.3% satisfied, only 1.8% are not at all satisfied. The VR experience is therefore evaluated positively in terms of meeting expectations and indicates a high degree of consistency between the training objectives and participants' perceptions. Most respondents do not consider the virtual laboratory as a source of distraction from the content: 56.1% completely agreed and 35.1% strongly agreed with this statement. Furthermore, 85.9% of respondents perceive the virtual laboratory as more than just a fun game, a finding further supported by the fact that approximately 99% strongly consider the experience as a concrete and innovative learning opportunity. Virtual reality uses in the training context can therefore be recognized as a tool capable of stimulating workers' curiosity and active participation, engaging them in acquiring OSH information, and overcoming the distinction between game enjoyment and learning. (Fig. 1).

As part of the laboratory experience, several critical issues related to the use of headsets were also investigated. The analysis of the responses focuses primarily on two aspects: nausea and dizziness. Data indicates that most participants did not experience symptoms of nausea (82.4%) or dizziness (76.9%), with only a small proportion reporting such issues. These findings suggest that, despite potential individual susceptibility, the VR experience was generally well tolerated across the sample (Fig. 2).

Regarding the general user satisfaction with the VR training experience, 53.5% of participants are very satisfied, 30.7% completely satisfied, and 13.2% satisfied. No one expressed a completely negative opinion and only 2.6% reported being slightly satisfied. These results confirm the alignment between participants' expectations and the program's training objectives.

To sum up, the findings indicate a generally high level of awareness regarding major road risks and the corresponding prevention measures, alongside a strong acceptance of the usefulness of safety devices such as

helmets and seat belts. However, certain areas of misinformation persist, particularly concerning the effectiveness of wearing bicycle helmets and the proper use of seat belts. These gaps highlight specific topics that

warrant targeted attention to further strengthen a culture of safety and prevention, potentially through innovative approaches such as VR-based interventions.

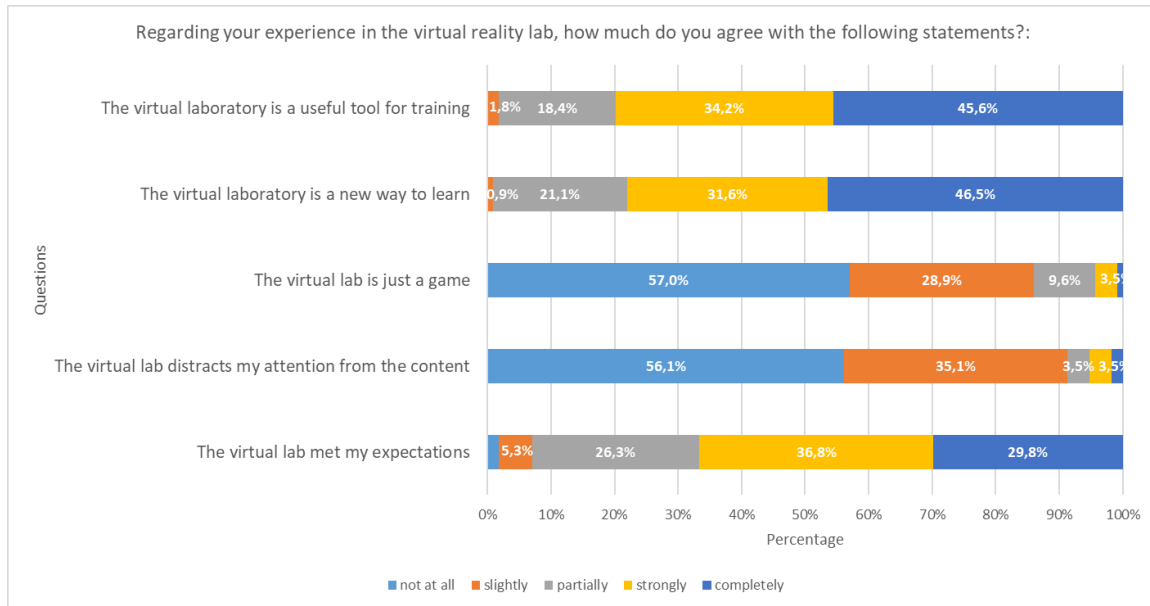


Fig. 1. VR lab experience evaluation.

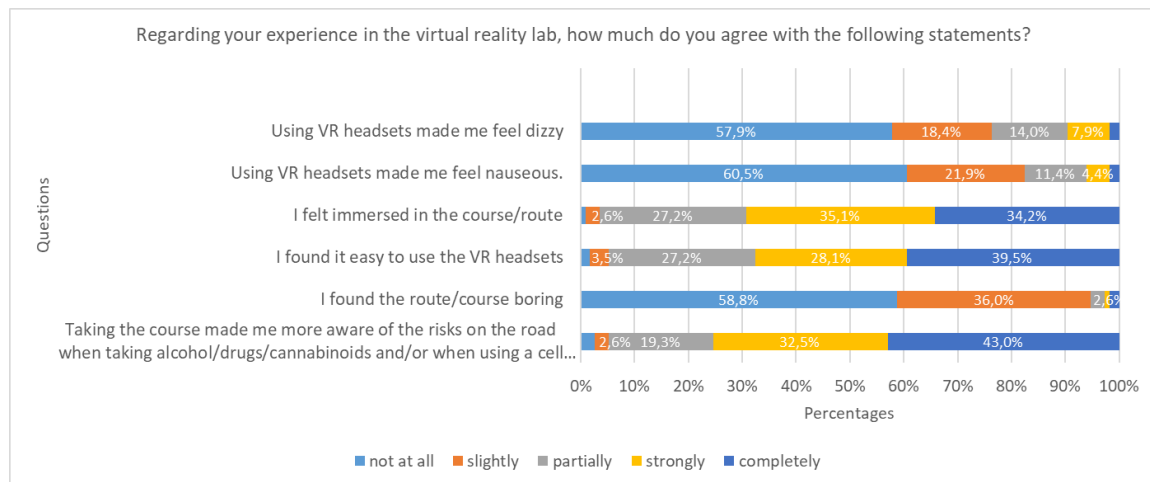


Fig. 2. Cognitive aspects and individual susceptibility.

### V. CONCLUSION

These preliminary findings support the adoption of immersive and interactive methodologies as effective strategies for health and safety training also in the workplace. Consequently, there is potential for the development of tailored VR modules within broader worker information, training, and awareness programs aimed at enhancing risk knowledge and awareness, stimulating correct and preventive behaviours, and promoting health through the understanding and implementation of healthy and thus safe lifestyles. The development of our VR laboratory was carried out considering the main methodologies for learning. Kolb’s experiential learning cycle, which integrates concrete

experience, reflective observation, conceptualization, and active experimentation, is effectively reproduced in virtual simulations; Constructivist theory emphasizes that learning occurs through active interaction with the environment, a principle fully realized in immersive virtual reality experiences, which recreate realistic scenarios to train risk recognition and problem-solving skills. VR further enables complete immersion: participants can “experience” hazardous situations without exposure to real danger, developing cognitive and behavioural memory that supports appropriate responses in real-life contexts. Simultaneously, trainers and safety managers can observe behaviours, errors, and reaction times, provide personalized feedback and enhance the effectiveness of the training intervention.

The gameplay of the presented tool also addresses fundamental psychological needs described by Deci and Ryan's [25] self-determination theory: autonomy (freedom of choice in learning pathways), competence (progressive challenges and recognition), and relatedness (collaboration and peer interaction). Siemens' connectivism theory frames learning as the formation of connections between informational "nodes" within digital networks, analogous to the social and gamified sharing of progress and achievements. Bandura's social learning theory complements these dynamics through cooperative and competitive mechanics that foster virtuous behaviours via observation and imitation within virtual and virtual reality environments.

Finally, constructivist and behaviourist theories posit that participants actively construct knowledge through interaction, including within gamified contexts, principles of reinforcement, such as scores and rewards, to encourage correct reasoning and behaviour. The integrated use of these elements represents an advanced and coherent training strategy aligned to pursue the principles and objectives of Vision Zero (zero fatalities and zero injuries on the road), making prevention more concrete, participatory, and effective, and contributing significantly to the reduction of road-related and occupational accidents.

Nevertheless, challenges persist in risk knowledge, awareness, perception, and risk assessment, and digital literacy, highlighting the need for targeted, personalized interventions. Future studies aiming to develop VR training modules and experiences that integrate participatory and immersive multidisciplinary and multimedia approaches, can significantly contribute to improving workplace safety in worker education and training programs, enhancing both engagement and learning effectiveness.

#### CONFLICT OF INTEREST

The authors declare no conflict of interest

#### AUTHOR CONTRIBUTIONS

E.P., A.M. conducted the research; R.B. analysed the data; D.V., R.B., E.P. and A.M. wrote the original paper; A.M., E.P., R.B., D.V. revised the paper; all authors had approved the final version.

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