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# Evaluating Serious Games Effectiveness: Case Of Road Tunnel Safety

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**Abstract**

While the construction of road tunnels is on the increase in the world today, there seems to be a noticeable delay on the part of the authorities in adequately training drivers on how to behave when driving through road tunnels. Research suggests that only a fraction of drivers is aware of the specific protocols for safe tunnel driving, and even fewer are actually committed to following them. This is due to a general lack of awareness among drivers of the potential risks in tunnels and a noticeable lack of training mechanisms to prepare them for such scenarios. Although the number of accidents in tunnels is usually lower than on open roads, their greater severity potential underlines the urgency of innovative training methods. Serious gaming, for example, could be a viable approach. This paper presents the results of a survey in Greece, where a questionnaire was used to assess drivers' tunnel navigation habits and their willingness to adopt safer practices following serious gaming training. The study involved 55 participants who completed a questionnaire about driving in tunnels. This initial assessment measured their familiarity with safety equipment and emergency procedures when driving in tunnels. Participants then engaged in an interactive serious game that simulated tunnel driving scenarios. After navigating through these virtual situations, participants revisited the same questionnaire to determine any increase in knowledge. Results indicated that the serious game approach was effective in enhancing participants' understanding of tunnel-specific driving behaviours. In essence, this research highlights the potential effectiveness of using serious gaming tools for educational purposes beyond tunnel driving to other critical areas.

*Keywords*: serious games, road, tunnels, safety, education

## 1. Introduction

Tunnels are considered to be vital infrastructures that improve a country's road network by reducing travel times, especially in rugged areas. Although, usually, fewer accidents occur in tunnels compared to open roads, their consequences are often more severe due to the enclosed environment of the tunnel (Bassan, 2016). A major contributor to these tunnel mishaps, which result in loss of life, is the limited awareness of drivers regarding the safety specificities when driving through road tunnels (Kirytopoulos et al., 2017). Unfortunately, drivers currently receive inadequate guidance in this area, as in most countries, neither the traffic regulations nor any authoritative body prioritizes this education. This study attempts to fill this knowledge gap by using serious gaming techniques to increase tunnel safety awareness. The rest of this paper is structured as follows: Chapter 2 reviews the existing literature, Chapter 3 details the research approach, Chapter 4 presents the findings, and Chapter 5 concludes the paper.

## 2. Literature review

### 2.1. Driver's knowledge and perceptions

Numerous studies have been conducted to ascertain the knowledge, perceptions, and reactions of drivers on the safety of driving in tunnels. Among those studies, Zeeri et al. (2019) investigate what Greek drivers know and what they plan to do when they go through road tunnels. Significant gaps were found in drivers' understanding of safety issues and appropriate behaviour in tunnels, highlighting the need for better teaching methods and communication efforts. The study shows that conditions, safety measures, training, and people's knowledge need to be improved in Greek road tunnels. It proposes that driving schools should teach students how to handle problems in tunnels, and that serious games should be used to teach drivers about safety and make them smarter and better at what they do. Another study (Kirytopoulos et al., 2020) looks at what drivers know and what they plan to do when they are going through road tunnels. The study shows that drivers are not fully aware on what needs to be done in case of an incident and aren't familiar with the safety equipment in tunnels. The study reveals a lot about how drivers act and how safety-aware they are. More specifically the study reveals that drivers need better information and better ways to learn about tunnels to understand them and behave better in them. Drivers don't always follow the rules when they're passing through tunnels. Significant gaps in knowledge have also been seen, especially when it comes to keeping the minimum distances from vehicles ahead of them. Even though stricter safety rules are needed in road tunnels, most of the people who answered said they weren't keeping the right distance between vehicles. Another problem was found with how the drivers planned to act in the event of a fire accident. It was highlighted that people were likely to attempt U-turns, drive in reverse, and try to pass cars that were on fire. The study also suggests that driving schools should include training in what to do in case of an emergency in a road tunnel and that serious games should be explored in teaching safety. The goal of all these steps is to help drivers understand how to be safer on the road and improve how they drive in likely emergency situations. These efforts are important for lawmakers, tunnel operators, and driving schools that want to make roads safer and help drivers understand and behave better in road tunnels.

From a similar point of view, Lee et al. (2022) look at the cognitive, behavioural, and psychological factors that affect what Chinese drivers know, how they act, what they plan to do, and how they feel while they are driving through road tunnels. The authors use an online poll to get information from 841 drivers who drove through Chinese tunnels before. What the researchers found is that drivers don't really understand tunnel safety and equipment, and they often do and say things that aren't right when they're in tunnels. The study, additionally, explores the things that make users act and think differently about danger in situations like being in front of traffic lights, in a fire emergency, or having car break-downs. It provides authorities and tunnel operators with vital information they can use to make safety rules and campaigns that raise knowledge that will make tunnels safer.

Additionally, Schmidt-Polończyk et al. (2021) look at what people in Poland who might use road tunnels know and how they act. According to the paper, potential road tunnel users' level of knowledge and behaviour were first evaluated, and knowledge gaps and misunderstandings were pointed out, including those related to picking the escape route, using tunnel safety devices, and getting personal items during the escape. The authors also compare the survey results with what they saw during real-life evacuation tests in two road tunnels which reveals how theoretical knowledge of tunnel safety is different from how it is used in real life. Findings like these are discussed in terms of creating safety-focused education and information programs for people who use road tunnels. The researchers propose conducting additional evacuation tests to verify if individuals respond in real emergency (or not) scenarios as they indicated in the survey. The analysis of those experimental outcomes should be conducted by examining videos obtained from monitoring systems in control centres, in addition to conducting interviews with the participants.

The aforementioned papers showcase how important drivers' education regarding road tunnels are and also highlight that the level of education of drivers regarding tunnels is still less than we would like it to be. This knowledge gap can be tackled by many strategic interventions and specific tools, one of which serious games.

### 2.2. Serious games as educational tools

Serious games are computer programs that use game elements to make real-life settings that are meant to teach or train. Although a lot of research has been done on how well serious games work in many areas, such as teaching science, healthcare, travel, and driving, it's still not very common for studies to look at how gaming and serious games affect driving behaviour and performance when traffic rules change. Alyamani et al. (2023) made and tested a serious game that used input as a game-like element. This study used a driving simulator to create a

real-life driving environment and count the number of times people made mistakes like going the wrong way on the light and driving against the flow of traffic. Researchers found that using a serious game with feedback made people much less likely to make mistakes while driving compared to when feedback wasn't present. Their study adds to the body of knowledge since it helps us learn more about how serious games and gamification can help drivers adjust their skills and behaviour when they are in a traffic environment they are not used to.

It has already been said that serious games are made with the specific goal of teaching things that go beyond just being fun. On the other hand, making serious games that work is hard because you must find a good balance between the teaching and motivational parts of learning. Westera (2019) focuses on the main educational ideas and rules that are important in making serious games. These include learning through experience, motivation, and evaluation. The author points out some problems and mistakes in the current ways that serious games are made and suggests a set of rules that will make serious games more useful for learning. Serious games should deal with problems like providing teaching help, encouraging students to learn on their own, and keeping track of their progress. The author also says that assessment and analysis should be the first step in the process of making important games instead of being an afterthought. Westera's paper adds to what is known about serious games by looking at the teaching principles and problems that come up when making serious games in a thorough and critical way.

Kirytopoulos et al. (2023) made a virtual reality app that uses serious games to teach and inform people who want to drive through tunnels about the rules and proper behaviour that should lead their safe driving in tunnels. The application has a simulated world that exactly replicates what it's like to drive through a tunnel from the driver's point of view. It has several different scenarios that show the different problems and events that could happen in tunnels. The authors give a thorough explanation of how the tool was made and how it was used. The paper makes the field of road tunnel safety better by providing a new and interesting tool that can be used along with the current pamphlets to teach people more and make them more aware. The researchers conclude that virtual reality and serious games have a lot of potential to be very useful training tools in a wide range of fields and themes.

Vera et al. (2018) talks about a complex game that uses augmented reality (AR) and 3D virtual features to make people more aware of how to drive safely. A board game called "Game of the Goose" inspired this game. In that game, players have to answer questions about driving safety when they land on certain spots. The questions can be put into two groups: two-dimensional (2D) and three-dimensional (3D). The third group involves simulating dangerous driving situations and giving immediate input. The authors go into great detail about how the game was made and how it was played. They also include an original evaluation that included 285 people who took part in a driving safety demonstration. The results show that the game is interesting, fun, and effective at making people more aware of driving safety, especially younger players. The study adds a lot to the field of serious games by offering a mix of virtual and augmented games that use different ways of interacting and visualizing information to help people learn and remember things better. In the paper there are also discussions about the teaching and technological aspects of making such a game.

Danišovič et al. (2018) in their research talk about how a serious game called “Tunnel Manager” was made and how it was put into use. “Tunnel Manager” mimics different situations that can happen when running and maintaining a road tunnel. The goal of the game is to improve the skills and knowledge of tunnel operators, managers, and engineers, as well as to make tunnel users more aware of safety problems. The paper talks about the parts of the game, the learning goals, the ways the game was evaluated, and the participants' comments. Additionally, this study adds to the body of research by showing how serious games can be used as a new, safe, and useful way to teach people how to operate road tunnels, presenting the pros and cons of this method.

Finally, there seems to be a complete and organized way to make road infrastructure, especially road tunnels, safer and better in Chatzistelios et al.'s (2023) work, which considers what road users and operators want and need. This study come up with a framework that utilises the management system cycle of "Plan-Do-Check-Act" and proposes many tools, like a serious game, to help educate drivers. The researchers believe that the main goal should be to make tunnels much safer, and that ‘how drivers act’ is one of the most important parts of this. The paper demonstrates how the suggested method and tools were used and evaluated in a major safety drill that took place in a road tunnel in Greece.

## 3. Method

### 3.1. Research instrument

The core research instrument is a serious game that puts participants in the role of a driver navigating a vehicle through a virtual road tunnel. This immersive experience challenges the users with scenarios ranging from traffic jams to emergency situations. The game's design meticulously reflects the conditions of Greek road tunnels, capturing potential situations both inside and outside the tunnel. Elements such as dynamic and static signs, speed limits, radio frequencies and other specific details are faithfully reproduced from Greek motorways. In this simulation, participants are instructed to navigate through the tunnel while responding to various prompts. These include starting the engine, accelerating, slowing down, turning, adjusting sunglasses, activating the car's ventilation, tuning in to the appropriate radio frequency, activating the emergency lights, lowering the windows and even preparing to exit. Taken together, these actions represent a comprehensive set of responses that a driver might take in a variety of tunnel-related incidents or emergencies. The game serves as a comprehensive tool for both training and evaluating participants' knowledge and potential responses through a series of scenarios. The training scenarios guide participants on the optimal actions to take, while the evaluating scenarios allow participants to make decisions autonomously. For this research, the focus has been on the training scenarios only, based on previous findings suggesting that many drivers may not be fully aware of correct tunnel driving behaviour. To measure the effectiveness of training through the serious game, each research subject (user) is presented with the same questionnaire twice: once before playing the serious game and once after. The initial questionnaire aims to validate the assumption regarding poor initial knowledge of the users. The training scenarios are divided into three categories. The first category, designed as a 'basic tutorial', introduces participants to the mechanics of the game and covers simple situations such as basic drive through, low fuel situations and lane closures. However, these basic scenarios were excluded from the scope of the current paper. This decision was made to streamline the duration of the experiment and because the subsequent categories provide important information that participants would gain from these basic scenarios, such as emphasizing the criticality of maintaining adequate fuel levels for safe tunnel navigation. The 'Events' category, the second segment, consists of six different scenarios: congestion in a tunnel, encountering red lights in a tunnel, encountering red lights just before entering a tunnel, dealing with a flat tyre in a tunnel and navigating around pedestrians in a tunnel lane. From this critical set, scenarios related to traffic jams, in-tunnel red lights and accidents have been selected. Participation in these scenarios is expected to provide participants with knowledge about congestion and red lights in tunnels. Obeying reduced speed limits during congestion, staying informed of tunnel conditions via radio updates, maintaining a safe distance from preceding vehicles, closing windows while activating air circulation, using hazard lights, and switching off the vehicle engine when stationary for more than one minute, are some of the information that you can get regarding congestion. On the other hand, when encountering red traffic lights inside a tunnel, drivers should stop their vehicles and wait for further instructions by radio or other means of communication available in the tunnel. The researcher, during the experiment, emphasizes that this procedure remains the same if similar red lights are observed at the entrance portal of the tunnel, that is, drivers should stop and wait for instructions.

The third section, entitled "Fire Hazards", includes scenarios such as light smoke from the car engine, heavy smoke from the engine and two different fire situations involving a small and a large vehicle fire. For this study, the scenarios chosen were light smoke and a significant vehicle-fire. Participants learn the following from these scenarios. In the event of light smoke coming from the vehicle's engine, if possible, the users need to continue to drive cautiously until exiting the tunnel to mitigate any potential fire risk inside the tunnel. On the other hand, in the event of a fire in a preceding vehicle, drivers should pull over to the right side of the tunnel, leave the keys on the ignition and move quickly towards the nearest fire exit, making sure to move away from the direction of the fire.

The choice of a significant vehicle-fire scenario, over a small fire, was deliberate to discourage participants from attempting risky manoeuvres such as overtaking the burning vehicle in the tunnel, which could compromise their safety. At this stage, the researcher instructs the participants that if they encounter dense smoke coming from the car's engine, they should follow the guidelines established for fire situations: stop the car at the side of the tunnel, immediately abandon their vehicle and make their way to the nearest fire exit to safely evacuate the tunnel.

### 3.2. Experiment description

To conduct the survey, the subject was asked to complete the same questionnaire twice: once before and once after using the serious game. In total, the questionnaire used in the part of the research presented in this paper consists of 23 questions divided into 4 categories. The first category includes sociodemographic questions (5 in total) providing information such as gender, years of driving experience, number of times the subject has driven through road tunnels in the last year, participation in relevant National Technical University of Athens surveys and frequency of driving. The second category includes questions on knowledge of tunnel safety (7 in total in the set) providing information on drivers' knowledge of congestion in tunnels, safety equipment, ways of being informed about safety issues, reversing and backing up in tunnels, reasons why the subject might immobilise the vehicle in a tunnel, familiarity with safety rules for road tunnels. The third category includes questions on driving habits in tunnels (5 in total), which provide information on driving habits such as switching on car headlights, removing sunglasses, checking fuel level, observing speed limits, keeping distance from the vehicle in front in case of congestion in a tunnel. The fourth and last category includes behavioural intention questions (6 in total), which provide information about the behaviour the subject would adopt in the event of a red traffic light in or at the start of the tunnel, a burning vehicle obstructing visibility, smoke coming from the engine of the car, a warning to leave the tunnel, vehicle damage making it impossible to drive.

### 3.3. Participants selection

In selecting participants for the experiment, individuals of all genders and ages were considered eligible, with the deliberate exclusion of the older group. Specifically, this group included people aged 60 and over. The rationale for this exclusion is that many in this age group are thought to be unfamiliar with computer use, particularly gaming. Such unfamiliarity could compromise the conduct of the experiment and the authenticity of its results. The concern is that, given the potential technological unfamiliarity, participants may be more focused on navigating the computer interface rather than properly engaging with the game's scenarios. The researchers' observations supported this concern, highlighting potential challenges even among middle-aged individuals with limited computer literacy. This issue can arise across different age groups, but becomes more pronounced with older participants. In addition, another factor taken into account when selecting drivers was their level of experience, both in general driving - where longer driving experience is supposed to indicate greater expertise - and specifically in driving through road tunnels. The aim was to include participants with different levels of experience, with an emphasis on those who frequently drive through road tunnels.

### 3.4. Participants profile

Of the 55 participants in the survey, 36 (or 65%) were male drivers and 19 (or 35%) were female drivers. Male respondent's percentage is higher but still expected, since such gender bias is common in surveys (Kirytopoulos et al., 2017; Smith, 2008). Notably, none of these participants had previously taken part in a National Technical University of Athens' survey on tunnel driving. A significant 69% reported driving either daily or several times a month as shown in Figure 1.

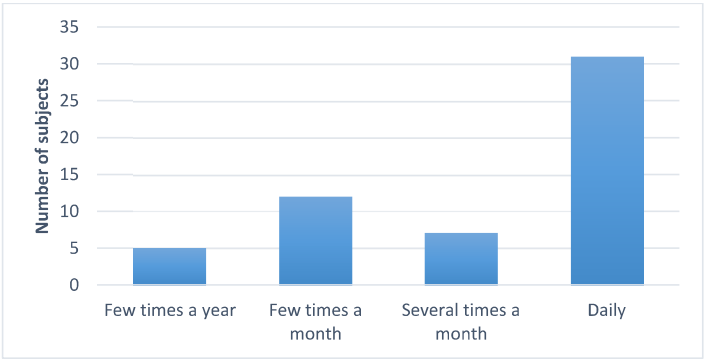


Fig. 1. How often subjects drive.

In addition, 58% reported frequent use of road tunnels, with more than 10 passages per year as shown in Figure 2.

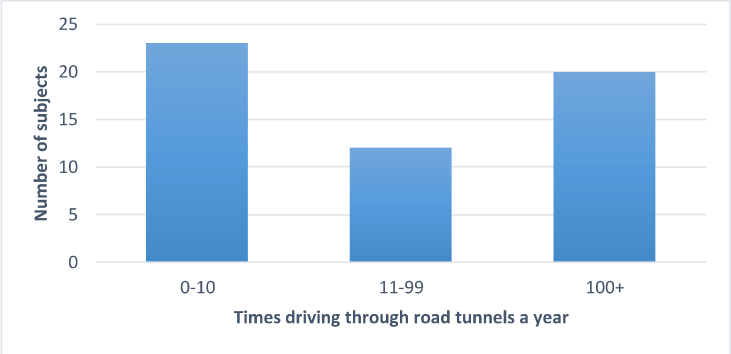


Fig. 2. Times each subject drove through a road tunnel during the last year.

Furthermore, the majority of respondents, 64%, are experienced drivers, having held their licence for more than four years as shown in Figure 3.

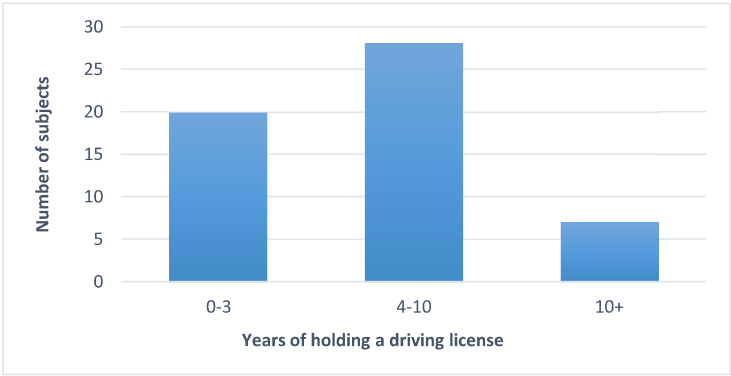


Fig. 3. Years that subjects have been holding a driving license.

### 3.5. Data analysis

In order to assess the effectiveness of the serious game explored in this research, it was essential to evaluate the responses to the questionnaire using a scoring system. This approach aimed to generate a cumulative score for each participant based on the accuracy of their responses. The scoring method took into account the number of correct answers per question (some of the multiple-choice questions including more than one correct answers) and assessed whether any answers contained partially correct information. Here are some illustrative examples given at the following tables:

Table 1. Scoring method-one and only correct answer.

| If there is a traffic jam in the tunnel, vehicles may have to stop for a short time. In this case, the distance to the vehicle in front is: | Points |
|---|---|
| I would slow down and continue driving carefully | 0 |
| I would stop and wait in my vehicle | 5 |
| I would continue driving normally but be prepared to stop if I felt there was a reason to do so | 0 |
| I would stop and leave my vehicle | 0 |

Table 2. Scoring method-one correct-one less wrong answer.

| Just before you enter the tunnel, all the lanes are illuminated with red lights, as in the photo opposite, but you cannot see anything dangerous ahead. How would you react? | Points |
|---|---|
| Less than 2 meters | 0 |
| Between 2 and 5 meters (does not fit or fits at most one car) | 2 |
| More than 5 meters (definitely fits one or more cars) | 5 |

Once the process of scoring each question is complete, the final scores of each research subject in the experiment before and after playing the serious game are obtained. The set of answers constitute the “pre-game score” and “post-game score” variables. During data analysis the normality of the two variables’ distributions was tested using the Kolmogorov-Smirnov normality test in the SPSS tool. It occurred that participants' pre-game scores variable was not statistically significantly deviating from a normal distribution ($p > 0.05$), however, the post-game scores variable did not follow this normal distribution pattern $p < 0.001$. Therefore, we chose to use the Wilcoxon test to determine whether the differences in scores between pre and post-game were statistically significant. In addition, we assessed the change in participants' familiarity before and after interacting with the serious game. For this evaluation, we again used the univariate Wilcoxon signed rank test, as the “familiarity post-game scores” did not follow a normal distribution, as indicated by the Kolmogorov-Smirnov test.

## 4. Results

### 4.1. Descriptive statistics

Figure 4 illustrates each participant's score improvement before and after engaging with the serious game (Graph score = post-game score - pre-game score). Remarkably, all 55 participants showed an increase in their scores, with many experiencing an increase of over 20 points. Specifically, the average score before engagement with the game was 44.5, whereas the average score after engagement with the game increased to 68.4.

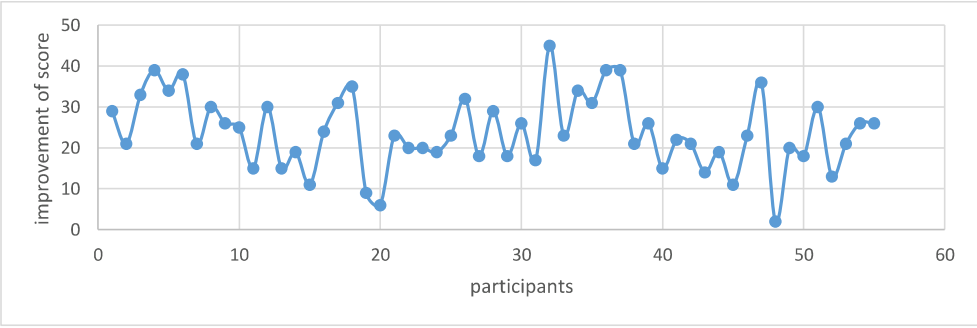


Fig. 4. The improvement of each participants scores after using the serious game

The results of the primary sections of the questionnaire provide valuable insights. In the section on "Drivers' knowledge of tunnel safety", only 47% of respondents would correctly decide to stay in their vehicle and switch off the engine in a traffic jam. In addition, only 5% are aware of the specific radio frequency for tunnel emergency messages. Worryingly, a significant proportion, 55% and 51% respectively, are unaware that reversing or making a U-turn during a tunnel fire emergency would jeopardize their safety. Turning to the second key section, "Driving habits in tunnels", the data shows that an overwhelming majority, over 90%, follow recommended practices such as obeying speed limits, using headlights and removing sunglasses. However, when it comes to keeping safe distances in tunnel congestion, only a quarter (25%) declares that they adhere to the recommended 5 meter distance from the preceding vehicle. Finally, in the 'Behavioural Intentions' section of the questionnaire, a worrying 22% of respondents said they would stop their vehicle and wait for further instructions when encountering red lights in a tunnel. It is further revealed that in the case of a burning vehicle, only 56% of the subjects in the experiment make the correct choice to abandon both the vehicle and the tunnel, while only 9% of the drivers would leave the car keys on the ignition.

### 4.2. Inferential Statistics

SPSS software was used to evaluate the claim that participants in the study showed a significant improvement in their questionnaire scores after playing the serious game (Mean score: 68.4) compared to their pre-game scores (Mean score: 44.5). Using Wilcoxon's univariate test, the results indicated a significant statistical difference between the two sets of scores, with $z = -6.454$ and $p < 0.001$. Specifically, each of the 55 participants showed an improved score on the post-game questionnaire.

Furthermore, the Wilcoxon univariate test was used to assess the hypothesis that participants felt more familiar with tunnel safety rules after the game. The results showed a significant difference, $z = -5.603$ with $p < 0.001$. To elaborate, 40 of the 55 participants felt an increased sense of familiarity, whereas the remaining 15 felt their familiarity remained unchanged.

The researchers also examined whether there was a pre-existing difference in familiarity between men and women with the rules for driving in road tunnels. A t-test analysis showed that there was no statistically significant difference between the pre-test scores of men and women for the 5% level, but it showed that there was a statistically significant difference for the 10% level since $t = 1.69$, $df = 53$ and $p = 0.096$. For the purpose of reporting the results of this research we will not regard this as a significant finding but this result could be a path for further research.

Other tests included exploration of whether there was any correlation between a) knowledge of tunnel safety and frequency of driving through tunnels b) improvement of knowledge after the serious game and frequency of driving through tunnels c) knowledge of tunnel safety and years of holding a driving license d) improvement of knowledge after the serious game and years of holding a driving license. However, the Spearman's tests used to find any correlations showed no significant correlations (a) knowledge of tunnel safety and frequency of driving through tunnels $r = 0.17$ and a $p = 0.227$ b) improvement of knowledge after the serious game and frequency of driving through tunnels $r = 0.18$ and a $p = 0.192$ c) knowledge of tunnel safety and years of holding a driving license $r = 0.03$ and a $p = 0.845$ d) improvement of knowledge after the serious game and years of holding a driving license $r = 0.02$ and a $p = 0.911$)

### 4.3. Discussion of findings

The results of the analysis confirm the assumption that a significant number of respondents have limited knowledge of driving in road tunnels. Several areas highlight a lack of basic understanding, particularly in scenarios such as a vehicle fire, which could pose significant risks to driver safety if encountered in real-life situations. Specifically, only 56% of respondents said they would exit both the vehicle and the tunnel if faced with such a scenario. In addition, only 9% recognised the need to leave the car keys in the ignition when evacuating the tunnel. Surprisingly, more than half were unaware that reversing or making a U-turn is not advisable in such situations. Nevertheless, the serious game led to an improvement in all participants' scores, suggesting a tendency to adopt safer behaviour (mean score before = 44.5, mean score after = 68.4). Moreover, the majority of participants expressed increased confidence in their knowledge of tunnel safety rules after the game compared to their knowledge before the game. In conclusion, the introduction of a more user-friendly serious game could be a valuable initiative by the relevant authorities to improve road tunnel safety. Such a game would educate users about the potential hazards during emergencies and equip them with the skills to respond appropriately.

## 5. Conclusions

In essence, this study aimed to assess the effectiveness of a serious game as a means of improving road tunnel safety. Participants completed a questionnaire both before and after playing the serious game. Initial results from the first questionnaire revealed significant gaps in Greek drivers' understanding of road tunnel safety. Given that Greece has a significant number of road tunnels longer than 500 metres (Hoek et al., 2006), such gaps could potentially lead to serious accidents in the future. Specifically, when faced with scenarios such as a burning vehicle, almost half of the participants were unsure of the correct protocols to ensure their safety and the safety of others in the tunnel. However, after interacting with the serious game, which presented various tunnel-related scenarios and appropriate responses, participants were better informed about the necessary actions to take. When the questionnaire was administered again, there was a marked improvement in the responses of all 55 participants. Each individual showed an increase in their questionnaire score, with the average score rising from 44.5 to 68.4. This suggests a significant improvement in the participants' understanding. In addition, the majority reported that they felt more familiar with road tunnel safety rules after playing the game. There were,

however, some limitations to the research, mainly related to the selection of participants. Participants needed to be computer literate, especially as the experiment involved gaming aspects. The experimental setup lasted approximately 40 minutes per participant and it was not possible to run the experiment with more than one person at a time, which affected the sample size. In addition, the current iteration of the serious game required researcher's supervision during its execution. The researcher guides the participants through the actions as instructed by the game, even translating instructions from English when necessary. However, with some improvements, the authorities could potentially release the game for public use, removing the need for guidance and providing insights into road tunnel driving. All in all, the experiment conducted shows that serious games can be effectively used for the education of drivers on the specificities that need to be taken into account, as well as the behaviour that should be adopted in critical situations, when driving through road tunnels.

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