Evaluation of Powered Wheelchair Driving Performance in Simulator Compared to Driving in Real-life Situations. the SIMADAPT (Simulator ADAPT) project: a pilot study

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Abstract

Objective

The objective of this study was to evaluate users tolerance and driving performance of an electric wheelchair driving simulator in comparison to a test on a real circuit in the context of the SIMADAPT project.

Methods

Three real circuits intended to assess the driving performance with power wheelchair (PWC) in an indoor traffic situation were defined. These circuits were then modelled in 3D to create three test scenarios in virtual reality. These three sessions corresponded to the three levels of driving difficulty. Users tested the three circuits in virtual reality (VR) on a simulator and on a real circuit (R) during three different sessions. In each session, users tested the two conditions. Number of collisions, time of completion, cognitive load and driving performances were assessed. Cyber sickness, users satisfaction and sense of presence were measured in VR. The order of passage between R and VR was randomized.

Results

Twenty-nine participants who were expert drivers with neurological disorders were included in the study. Number of collision between R and VR were identical for circuits 1 and 2 but higher for circuit 3 in VR (p = 0.006 and 0.008), the RV completion times were longer in C1 and C2 (p = < 0.001, 0.01), however it tended to decreased for C3 (difference were not significant for second run). The mental load was higher in VR than R (p = 0.001; 0.01;0.03). The sense of presence was good and the cybersickness remained low on the three circuits.

Conclusions

Simulator is valid technological solution for expert drivers. The performances were equivalent between R and VR and there was a quick adaptation to the virtual application, without any noticeable unexpected effects. Future researches are needed to assess the quality of skill transfer for novice drivers from the simulator to the real world.

Introduction

Powered wheelchairs (PWC) may be the only solution to maintain moving autonomy. Several studies have underlined the benefits of using a wheelchair by improving mobility and participation, and reducing caregiver burden [1]. For people with traumatic brain injury (TBI), independence in mobility is identified as one of the main barriers to maintain societal participation in activities such as employment [2]. A study carried out by the Breizh Cerebral Palsy Network has shown the negative impact of limitations in moving around on the quality of life [3]. PWC driving confidence is therefore extremely important to guarantee the autonomy of these users. 25% of wheelchair accidents are linked to the use of PWC [4]. Up to 40% of people with TBI who use PWC regularly have problems with steering and 5–9% cannot steer at all in a clinical setting [2]. Driving learning is therefore an important time to limit the risk of accidents. Researchers have developed and tested simulators dedicated to wheelchair driving training which can help users adapt their driving strategies to different environment [5, 6, 7, 8, 9]. Virtual reality-based simulators may be a promising tool for wheelchair driving assessment allowing more immersive driving situation but needs a good sense of presence i.e. a subjective experience of driving in the environment with the PWC of good quality [10, 11]. A high level of presence results in perceiving the environment as a more engaging reality than the surrounding real word, and thus ensures better learning. Motion sickness is also often experienced during simulator or other virtual reality exposure and must be taking into account in the use of driving...
simulator. It seems to be negatively related with sense of presence, which underlines the importance of the level of immersion, to ensure a good level of sense of presence and thus a good quality of learning. Another problem is the cognitive load induced by immersive VR simulation training. Patients with cognitive disorders are good candidates for the use of a simulator, because they can be in difficulty for driving but a high cognitive load may be a barrier.

In this context, the Assistive Devices for empowering disabled People through robotic Technologies (ADAPT) project is developing new technologies to facilitate the training of powered wheelchairs driving. The final aim is to allow a maximum number of users to use a PWC in safety in daily life. For this purpose we have developed a simulator combining visual virtual reality and proprioceptive feedback. The simulator Adapt project (SIMADAPT1) aims to evaluate the reliability of the simulator compared to the performance on real circuit and of the tolerance of the use of the simulator, including sense of presence, cyber sickness and cognitive load. So we proposed to regular PWC users with neurological disorders to test this prototype of simulator after having modeled in 3D the real standardized circuits.

**Materials And Methods**

**Study Design**

This is a prospective, monocentric, controlled pilot study. The trial was conducted in January 2020 at the rehabilitation center Pole St Helier in Rennes, France.

**Participants**

Participants were recruited during medical consultations by a physiotherapist 10 days before entering the study. The investigator presented the objectives and modalities of participation according to the protocol and delivered an information paper to the participant. The consent form was signed by voluntary participants after 10 days of reflection.

The study was approved by the People Protection Committee: ethical approval n°2019-A001306-51

The inclusion criteria were being over 18 years old, having freely consented to participate in the study, using a PWC as the main mode of locomotion for more than three months because of a stabilized medical problem.

The exclusion criteria were having difficulties to understand and follow instructions, motor disorders of the upper limb requiring additional driving technical assistance, being pregnant and unable to express consent.

**Intervention**

**Process**

Each participant performed three sessions spaced one week apart. These three sessions corresponded to three growing levels of driving difficulty.

In each session, users tested two conditions: real circuits (condition 1) or virtual circuits on simulator (condition 2). Order of passage in these conditions was random with software Randomizer (simple randomization).

Three real circuits intended to assess the driving performance with PWC in an indoor traffic situation have been defined according to data from the literature and recommendations for evaluation.

The first circuit composed of several easy tasks such as driving forward (10m) and backwards (2m), turning in place and while moving forwards (90°). Second circuit included slightly more difficult tasks such as getting through a hinged door, ascending and descending 5° access ramp, rolls on soft surface (2m) and crossing a threshold and driving through narrow
corridors. The third and last circuit was the most difficult with tasks such as avoiding moving obstacles, ascending and descending 10° access ramp. These circuits were modelled in 3D by Unity engine to create three test scenarios in virtual reality. Proprioceptive feedbacks were generated by a mechanical platform for entertainment and simulation D-BOX - Gen II Actuators 1.5.

Reals circuits were made of plastic walls, carpet, boxes and inclines. The virtual scenarios of the modelled circuits and the proprioceptive feedback were developed to reproduce the characteristics of driving a Quickie salsa M2 wheelchair identical to the real wheelchair used in the control condition. Different skills were required in each circuit (Table 1).

<table>
<thead>
<tr>
<th>Individual Skill Names</th>
<th>Circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Move controller/ tiller away and back</td>
<td>In C1, C2, C3</td>
</tr>
<tr>
<td>Turn power on and off</td>
<td></td>
</tr>
<tr>
<td>Roll forward (10m)</td>
<td></td>
</tr>
<tr>
<td>Roll backward (2m)</td>
<td></td>
</tr>
<tr>
<td>Turn in place (180°)</td>
<td></td>
</tr>
<tr>
<td>Turn while moving forwards (90°)</td>
<td></td>
</tr>
<tr>
<td>Get through hinged door</td>
<td>In C2 and C3</td>
</tr>
<tr>
<td>Ascend 5° incline</td>
<td></td>
</tr>
<tr>
<td>Descend 5° incline</td>
<td></td>
</tr>
<tr>
<td>Roll on soft surface (2m)</td>
<td></td>
</tr>
<tr>
<td>Cross threshold</td>
<td></td>
</tr>
<tr>
<td>Avoid moving obstacles</td>
<td>Only in C3</td>
</tr>
<tr>
<td>Ascend 10° incline</td>
<td></td>
</tr>
<tr>
<td>Descend 10° incline</td>
<td></td>
</tr>
</tbody>
</table>

A phase of handling of the PWC and recognition of the circuits was organized before each test session, in both real and virtual conditions.

Equipment and materials used

The driving simulator was developed by computer science researchers from the INSA Rennes [21]. This PWC simulator is composed of three connected parts: the platform moving at four degrees of freedom (pitch, roll, yaw, and heave), the joystick to drive the wheelchair in the virtual environment and the virtual reality helmet.

The head mounted display (HTC Vive Pro Full kit, certifications: CE 2200, ROHS) complies with the European R & TTE directives.

Standard WPC QUICKIE Salsa M2 from Sunrise Medical (Class I Medical Device CE marked) is used by participants to carry out the three real circuits. Before running these courses, they disposed of 5 minutes to get familiar with the PWC.
Outcomes and measures

Primary outcomes

The primary judgment criterion was the number of collisions on the three standardized circuits, in real condition versus virtual condition. A collision was defined as a contact with real or virtual walls of the circuits. Two evaluators identified the collision live during the trial (on a screen for the virtual circuit). An agreement between the two evaluators was necessary to validate a collision.

Secondary outcomes

The driving speed was measured by the completion time in real versus virtual conditions, with two measures on each circuit.

We used the Wheelchair Skill Test 4.2.3 items corresponding to the different courses in real and virtual conditions. Each skill was scored from 0–2 (0 = fail, 1 = pass with difficulty or assistance, 2 = pass). The three circuits were of increasing difficulty and integrated different items of the Wheelchair Skill Test for each one (Table 1)

The cognitive load of tests under both conditions was measured by the NASA-Task Load Index [22, 23] NASA-TLX is in the form of six scales which must be scored from 0 to 100, a high score indicate a growing level of intensity. Three dimensions are related to the demands imposed on the subject (mental, physical and temporal) and three to the interaction of the subject with the task (effort, frustration and performance). A mean score from the six scales is calculated to interpret it and the total obtainable score is between 0 and 100.

The satisfaction of the use of the PWC under the conditions was evaluated by the Ease of Use Questionnaire (EUQ) [24]. The questionnaire includes 30-item survey scored on a seven-point Likert rating scales, with 4 dimensions. Users were asked to rate agreement with the statements, ranging from strongly disagree (1) to strongly agree (7).

The sense of presence in virtual environment was evaluated by the Igroup Presence Questionnaire (IPQ) [25, 26]. The IPQ consists of 13 questions and defines the user's general sense of presence, involvement, spatial presence, and realism. It is composed of three subscales and one additional general item. The general item assessed the general "sense of being there". The Spatial Presence sub-scale is related to the sense of being physically inside the virtual environment. The involvement subscale aim to evaluate the attention devoted to the virtual environment. The experienced realism sub-scale evaluate the sense of reality attributed to the virtual environment.

Each question takes the form of 7-points scale.

Simulator Sickness Quantifying (SSQ) measured the feeling of motion sickness and was performed after each VR circuit. The discomfort and motion sickness during VR circuit were also assessed using the Graybiel score [27]. This questionnaire quantified the intensity of different symptoms during motion sickness.

Data analysis


Quantitative analysis of data was expressed as mean and standard deviation and median and inter-quartile range (Md+/IQR). The real and virtual conditions were compared using the nonparametric Wilcoxon test. Pearson's correlation coefficient was used for measuring the statistical relationship between data.

The significance level was P < 0.05
Results

Participants (Table 2)
<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex</th>
<th>Age</th>
<th>Diagnosis</th>
<th>Use of the wheelchair since</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>M</td>
<td>67</td>
<td>cerebral palsy</td>
<td>2018</td>
</tr>
<tr>
<td>02</td>
<td>F</td>
<td>46</td>
<td>spinal cord injury</td>
<td>2019</td>
</tr>
<tr>
<td>03</td>
<td>M</td>
<td>54</td>
<td>spinal cord injury</td>
<td>2006</td>
</tr>
<tr>
<td>04</td>
<td>F</td>
<td>46</td>
<td>multiple sclerosis</td>
<td>2018</td>
</tr>
<tr>
<td>05</td>
<td>F</td>
<td>66</td>
<td>stroke</td>
<td>2014</td>
</tr>
<tr>
<td>06</td>
<td>F</td>
<td>54</td>
<td>cerebral palsy</td>
<td>2011</td>
</tr>
<tr>
<td>07</td>
<td>M</td>
<td>61</td>
<td>spinal cord injury</td>
<td>2019</td>
</tr>
<tr>
<td>08</td>
<td>F</td>
<td>49</td>
<td>neuro muscular disease</td>
<td>2013</td>
</tr>
<tr>
<td>09</td>
<td>M</td>
<td>45</td>
<td>Guillain Barre SD</td>
<td>2018</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>27</td>
<td>cerebral palsy</td>
<td>2017</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>65</td>
<td>multiple sclerosis</td>
<td>2018</td>
</tr>
<tr>
<td>12</td>
<td>F</td>
<td>42</td>
<td>neuro muscular disease</td>
<td>2018</td>
</tr>
<tr>
<td>14</td>
<td>M</td>
<td>56</td>
<td>spinal cord injury</td>
<td>2019</td>
</tr>
<tr>
<td>15</td>
<td>M</td>
<td>35</td>
<td>cerebral palsy</td>
<td>2018</td>
</tr>
<tr>
<td>16</td>
<td>M</td>
<td>41</td>
<td>spinal cord injury</td>
<td>2019</td>
</tr>
<tr>
<td>17</td>
<td>F</td>
<td>33</td>
<td>cerebral palsy</td>
<td>2015</td>
</tr>
<tr>
<td>18</td>
<td>F</td>
<td>41</td>
<td>cerebral palsy</td>
<td>2013</td>
</tr>
<tr>
<td>19</td>
<td>F</td>
<td>42</td>
<td>neuro muscular disease</td>
<td>2007</td>
</tr>
<tr>
<td>20</td>
<td>F</td>
<td>64</td>
<td>multiple sclerosis</td>
<td>2014</td>
</tr>
<tr>
<td>21</td>
<td>F</td>
<td>38</td>
<td>cerebral palsy</td>
<td>2011</td>
</tr>
<tr>
<td>22</td>
<td>M</td>
<td>33</td>
<td>cerebral palsy</td>
<td>2017</td>
</tr>
<tr>
<td>23</td>
<td>M</td>
<td>82</td>
<td>stroke</td>
<td>2017</td>
</tr>
<tr>
<td>24</td>
<td>F</td>
<td>41</td>
<td>cerebral palsy</td>
<td>2018</td>
</tr>
<tr>
<td>25</td>
<td>M</td>
<td>34</td>
<td>spinal cord injury</td>
<td>2019</td>
</tr>
<tr>
<td>26</td>
<td>F</td>
<td>41</td>
<td>stroke</td>
<td>2018</td>
</tr>
<tr>
<td>27</td>
<td>M</td>
<td>58</td>
<td>Guillain Barre SD</td>
<td>2017</td>
</tr>
<tr>
<td>28</td>
<td>M</td>
<td>42</td>
<td>spinal cord injury</td>
<td>2019</td>
</tr>
<tr>
<td>29</td>
<td>M</td>
<td>67</td>
<td>spinal cord injury</td>
<td>2017</td>
</tr>
<tr>
<td>30</td>
<td>M</td>
<td>44</td>
<td>multiple sclerosis</td>
<td>2012</td>
</tr>
<tr>
<td>31</td>
<td>F</td>
<td>63</td>
<td>spinal cord injury</td>
<td>2017</td>
</tr>
<tr>
<td>32</td>
<td>M</td>
<td>62</td>
<td>multiple sclerosis</td>
<td>2018</td>
</tr>
</tbody>
</table>
32 users were contacted and 31 included: 15 men and 16 women with a mean age of 49.6 +/- 13.1. They were all confirmed wheelchair drivers. One user could not perform circuit 2 and 2 circuit 3.

Comparison of driving performance between real and virtual environment

Results are presented in Table 3. There was no significant difference for the number of collisions between the two conditions in the circuit 1 and 2. However, in circuit 3, a significant difference (p < 0.01) can be observed regarding the two runs for the number of collisions: the simulator experience generated more collisions than the real condition in the more difficult circuit. Time of completion was also always longer in the virtual condition except for the second run in the two last circuits. They were no difference between the real and virtual conditions for the three circuits in terms of driving capacity with high scores on the WST.

<table>
<thead>
<tr>
<th>CIRCUIT 1</th>
<th>CIRCUIT 2</th>
<th>CIRCUIT 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COLLISIONS</strong></td>
<td><strong>TIME (s)</strong></td>
<td><strong>WST</strong></td>
</tr>
<tr>
<td><strong>CIRCUIT 1</strong></td>
<td><strong>CIRCUIT 2</strong></td>
<td><strong>CIRCUIT 3</strong></td>
</tr>
<tr>
<td>Real Median (IQR)</td>
<td>Virtual Median (IQR)</td>
<td>difference</td>
</tr>
<tr>
<td><strong>COLLISIONS</strong></td>
<td><strong>TIME (s)</strong></td>
<td><strong>WST</strong></td>
</tr>
<tr>
<td>- T1</td>
<td>0.00 (0.00)</td>
<td>0.00 (0.00)</td>
</tr>
<tr>
<td>- T2</td>
<td>0.00 (0.00)</td>
<td>0.00 (0.00)</td>
</tr>
<tr>
<td><strong>TIME (s)</strong></td>
<td><strong>WST</strong></td>
<td><strong>USE</strong></td>
</tr>
<tr>
<td>- T1</td>
<td>84.00 (10.00)</td>
<td>102.00 (15.75)</td>
</tr>
<tr>
<td>- T2</td>
<td>84 (8.00)</td>
<td>99.00 (12.00)</td>
</tr>
<tr>
<td><strong>WST</strong></td>
<td>12.00 (0.00)</td>
<td>12.00 (0.00)</td>
</tr>
<tr>
<td><strong>USE</strong></td>
<td><strong>NASA TLX</strong></td>
<td></td>
</tr>
<tr>
<td>1- Utility</td>
<td>5.75 (2.75)</td>
<td>4.00 (2.5)</td>
</tr>
<tr>
<td>2-Ease of use</td>
<td>6.4 (0.80)</td>
<td>6.00 (1.5)</td>
</tr>
<tr>
<td>3-Ease of learning</td>
<td>7.00 (0.25)</td>
<td>7.00 (1.00)</td>
</tr>
<tr>
<td>4- Satisfaction</td>
<td>6.33 (1.17)</td>
<td>5.5 (1.84)</td>
</tr>
<tr>
<td>NASA TLX</td>
<td>5.00 (10.83)</td>
<td>18.33 (21.67)</td>
</tr>
</tbody>
</table>
The satisfaction of the use on the Ease of Use Questionnaire was high in the two conditions, but significantly higher for the real circuit. The most important difference appears for the utility score of the virtual circuit, whose score was always below 5.

Cognitive load

The required cognitive load is higher when the simulator is used compared to the PWC on all three circuits (p < 0.002). In the virtual condition, cognitive load remains high but without influence of the complexity of the circuits. No correlation was noticed between cognitive load and number of collisions or time of completion.

Motion sickness (Table 4)

<table>
<thead>
<tr>
<th>CIRCUITS</th>
<th>C1 Mean (SD)</th>
<th>C2 Mean (SD)</th>
<th>C3 Mean (SD)</th>
<th>C1 VS C2</th>
<th>C1 VS C3</th>
<th>C2 VS C3</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRAYBIEL</td>
<td>1.83 (2.26)</td>
<td>0.83 (0.80)</td>
<td>2.07 (2.79)</td>
<td>0.014</td>
<td>0.48</td>
<td>0.018</td>
</tr>
<tr>
<td>SSQ</td>
<td>4.25 (4.16)</td>
<td>3.43 (4.29)</td>
<td>4.72 (6.19)</td>
<td>0.15</td>
<td>0.70</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Results between the three circuits appear in this table

Participants rated their cyber sickness to be relatively low (Mean SSQ 4.25, 3.43 and 4.72). Sensation of feeling sickness was higher in the most difficult circuit (C3). There was a significant decrease on the second circuit on the score of the Graybiel but not for SSQ while the score on the third circuit returned to a level similar of the first circuit (p = 0.48).

Presence

IPQ showed a correct general and spatial presence with the virtual environment that lacked a bit of realism with a tendency to a lower involvement score (Fig. 2)

Discussion

The results of our study show on the one hand the good performance of the simulator in terms of driving and on the other hand a good tolerance with little motion sickness.

Cooper [28] and Archambault [29] have already highlighted that the performance was identical in virtual environment then in real environment. Collisions are the main assessment criteria during a driving test on standardized circuit in literature and were then used in this study [20, 30, 31]. The collision scores were low both in real life and virtual reality probably due to the expertise of the participants. No significant difference was found between the two test modalities in the two first two circuits, but for the third circuit the number of collisions was significantly higher in virtual conditions. The third circuit was the most difficult and that may explain a part of the difference. Furthermore, we can hypothesize that virtual reality supports risk-taking since the collisions are not risky, however, the speed of completion remains significantly lower for all circuits and is not sufficient to explain the observed difference.

The more important cognitive load in virtual condition may contribute to the increase of collisions on a more challenging circuit. Winter found that cognitive load was significantly higher in immersive condition compared with treadmill training.
without virtual reality [32]

Frederiksen have also noticed this point and postulated that it could be the consequence to a possible perceived higher number of elements to interact with [15]. This may be improved by enhancing the quality of the virtual environment. Although the realism of the virtual environment still needs to be improved, the sense of presence in our study was acceptable and leads to a good immersion in virtual environment. Sense of presence depends on the type of display, freedom of orientation of the visual field and visualization of the avatar [1]. We can then hypothesize that an improvement of the virtual environment could decrease the cognitive load. Kamaraj [33] showed the importance of the quality of the virtual environment and the sense of presence in the cognitive load. In this study users have identified a correct general and spatial presence, but the virtual environment appeared insufficient in terms of realism. Improvements are then needed in this field for the future development.

Contrary to previous studies [12, 34], problems of motion sickness remained low. Immersive VR cyber sickness can be technically reduced by controlling angular velocity and visual angle [35] Winter [32] synchronized speed of visual motion in the virtual environment with the physical speed of the treadmill with good results. The addition of computer based and mechanical technologies combining the visual and proprioceptive perception of the wheelchair movement seems to be efficient to reduce the appearance of motion sickness. Moreover it seems also important to gradually and regularly confronting user in immersive situations, each run was of very short time in our experimentation [36].

Perspective

Nevertheless the place of the simulators remains to be determined. While only 10% of wheelchair users use electric models [37, 38] 25% of accidents are linked to their use [4]. In addition, 100,000 accidents involving wheelchair users were recorded in the United States in 2006, double the number of accidents recorded in 1991 [39]. The use of motorized devices for mobility assistance is not without risks and accidents can occur. The most common causes of accidents are related to falls and tips, but with electronic assistive devices collisions are more frequent than falls [40, 41] Moreover Ummat noticed that 7.6% of the affected persons in wheelchair-related accidents were not the user but people hit by them [40]. The risk of an accident is therefore not negligible and may lead to the user being forbidden to use his wheelchair.

this highlights the importance of training to drive a power wheelchair. Currently, real-life assessment remains the Gold Standard. In the present study users appreciated the simulator, but their satisfaction was greater in real situations than in virtual situations on the Ease of Use Questionnaire over all domains, even if score remained high in virtual conditions. Archambault also noticed that participants were neutral in terms of wanting to continue using the simulator particularly when their performance on this one was good [29]. So, simulator may be a promising approach to complement training received in rehabilitation center especially in case of learning difficulties. Different scenarios can be imagined to optimize the control of the driving in total safety. However simulator remains an expensive technology that is not accessible to everyone. In the first instance, the ecological approach should be preferred with the possible use of a circuit.

Strengths and limitations

The simulator is currently only at the prototype stage and our tests have only involved simulations on circuits. The creation of more complex environments is necessary in order to consider simulations of everyday life.

Conclusions

Our results show the efficiency of the simulator in the evaluation of electric wheelchair driving for expert drivers. We noticed equivalent performances and quick adaptation to the VR application with no significant adverse effects. Cognitive load remains high during virtual immersion and raises the question of the use of VR for patients with cognitive disorders. The use of simulator cannot be proposed in first intention, but can be an useful tool in the learning of the driving for
patients unable to drive a PWC in safety to obtain a driving license. Currently the programs remain limited in number but developments are planned to cover different types of situations to train patients in a wide variety of driving conditions: outside, crowded, at night, on the sidewalk,..., to promote their autonomy. However, further studies should be conducted to assess the quality of skill transfer for novice drivers from the simulator to the real world.

**Declarations**

*Ethics approval and consent to participate*

Only participants who consent to participate have been included in this trial. This study received the ethical approval n°2019-A001306-51 from Comité de Protection des Personnes Sud Mediterranée IV. The trial has been registered the 19/11/2019 on ClinicalTrials.gov in ID: NCT04171973-


*Consents for publication*

Authors: contributions, consent to publication and declaration of conflict of interest

*Availability of data and materials*

The datasets used and analysed during the current study are available from the corresponding author on reasonable request

*Competing interests: NA*

*Funding*

This study is founded by INTERREG publics European funds

*Authors’ contributions*

The authors cited have all contribute to this trial. They declare no conflict of interest and consent to this publication.

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*Authors’ information (optional): NA*

**References**


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Figures

Figure 1

Material: INSA simulator and real circuit. Each real circuit was modeled in virtual reality for performance comparison
Figure 2

graphical representation of IgrouP Presence Questionnaire results. The IPQ Questionnaire is composed of three subscales and one additional general item. The general presence item assessed the general "sense of being there". Results were similar for the 3 circuits, with lower scores for experienced realism and involvement.