



Evaluation of Road Safety Education Program with Virtual Reality Eye Tracking

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Abstract

Traffic rules are essential and part of today's road safety education programs at school. However, learning how to properly use attention in complex traffic situations has never before been a focus when teaching pupils. A new road safety education program based on latest findings in Neuro-Education has been developed. In the program, pupil learned three new concepts: risk, orientation and attention. This to stimulate the pupil's reflection about own behavior on school roads, before attended a session at a traffic center, where teachers encouraged pupil's reflection about how to practically use their new knowledge about the three concepts. This new program design was evaluated in a Virtual Reality laboratory. This paper presents the approach for evaluation using VR and eye-tracking, including scenario building, measurement approach, and procedure for measurements in addition to a look at the actual evaluation results. The results showed that pupils managed to cycle in a safer way by putting their attention at the right places after the course compared to student following existing curriculum. As such the selected validation approach utilizing VR gave clear support for the proposed education program.

Keywords Virtual reality · Education · Cycling

Introduction

The Norwegian Council for road safety (Trygg Trafikk), SINTEF and Nord University have developed a new road safety education program, focusing on teaching methods for children's development of attention and risk perception during cycling. Over the past 20 years, an international discipline has developed under the term "Neuroeducation" in which knowledge from psychology, pedagogy and neuroscience was united in the understanding of educational methods and learning processes [1–3].

Traffic rules are essential and part of today's road safety education programs in Norwegian schools. On the other hand, although risk awareness and perception Training (RAPT) is well known methods in driving education of drivers [4, 5], learning how to properly use attention in complex traffic situations has never before been a focus in Norway when teaching children. As such a new real world education program (new teaching approach, new curriculum) was develop using learning methodology design based on Neuroeducation, targeted especially toward children.

This paper summarizes the approach taken to develop the new education program, but have a focus on the design of evaluation of the education program using eye tracking in Virtual Reality. The decision for using Virtual Reality (VR) for the evaluation of the new education program were based on multiple factors. First, using a VR approach enabled construction of tests that was easily repeatable between participants. Secondly, analysis of eye tracking data from real world are labor intensive. In the VR evaluation application this was significantly simplified, as the method used in our implementation gathered eye tracking data for each separate scene object. Third, using VR enables fast definition and testing of potential interesting areas to observe by traffic safety experts. Finally, VR enables one to pack a

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larger amount of interest areas to study compared to what would be natural in a real world setting.

For evaluation of the new learning program, it was hypothesized that measuring eye fixations on selected regions of interest (ROI) in a virtual reality environment mirroring the real world site where education was performed, would show differences in perception of risk, orientation and attention between pupils having been educated using new versus old curricula. The results from this novel application of virtual reality for evaluation using did show that the group having undergone the new curricula managed to cycle in a safer way by directing their attention at the right places.

The remaining work is structured as follows: Sect. “[Previous Work](#)” introduce previous work in context of this work. Section “[Methods](#)” explains the new education program, as well as details on the evaluation; scenario building, hardware and software setup, pretest–posttest design, trial setup and procedures for measurements. Section “[Results](#)” presents the findings and results from the trial, while Sect. “[Discussion and Future Work](#)” presents an in-depth discussion of the results and findings.

Previous Work

In the field of Neuroeducation a range of findings in the last decade from Neurobiology has increased understanding and expanded the toolbox for constructing new education programs and curriculums. In 2014, May-Britt and Edvard I. Moser shared the Nobel Prize in Physiology or Medicine with John O’Keefe of University College London for their discoveries of place cells and grid cells in the hippocampus formation. How to find a known place includes two independent processes, navigation, and episodic memory [6–9]. The brain systems guiding navigation, the hippocampus and entorhinal cortex, are according to Buzsaki and Moser [10] the same that support episodic or declarative memories.

In the hippocampus formation the brain is not only creating a mental map about the physical environment and the surroundings, but also about what happened there and when. It means that when you are moving in an environment you will make a mental map of the location, and at the same time create episodic memories of things you experienced. Many reviews have summarized how brain systems involved in navigation, episodic memory, imagination, and planning of actions strongly interacts [8–11]. Neuroplasticity deals with the brain’s ability to change and is very high in children and adolescents and reduces with increasing age [12, 13].

Several studies indicate that bicycle education and training increases children’s knowledge about traffic safety, for instance the work by Hooshmand et al. [14] and Lachapelle et al. [15]. Children’s inhibition of irrelevant information while cycling was specifically explored in a study at Eberg

traffic center by Roche-Cerasi et al. [16]. The Eberg facility consists of a traffic system in miniature, with roads, intersections, working traffic lights and signs, identical to those in cities. The aim of the study was to provide knowledge and understanding of children’s inhibitory control system while cycling by the use of a Tobii Eye Tracker. More specific the study focused on children’s ability to use their planning and attentional capacity during cycling.

There are clear anatomical connections between the different parts of the brain which communicates by means of many neurotransmitters like dopamine, serotonin, noradrenalin and acetylcholine, as pointed out by Amso and Scerif [17]. During childhood and adolescence there is a dramatic change in the development of these anatomical connections and the biochemical systems. Fjell et al. [18] showed that the maturation of the brain brings about the gradual improvement in self-regulation during childhood that refers to the ability to control behavior, cognition, and emotions. The awareness of the situation and existence (context) is always what the brain is focused on consciously as unconsciously. The main questions are “where am I?”, “why am I here?”, “what am I going to do?” and “what will be the result?” [19]. The anatomical connections of interacting cognitive subsystems underpinning functions like goal-directed behavior, attentiveness and impulsivity are still immature among children aged 8–10, as described by Posner et al. [20].

Thus, children’s ability to make a correct cognitive priority map of a situation is insufficient because the executive attention network is not fully developed yet. Fjell et al. [18] and Ptak et al. [21] showed that this affects their concentration and the ability to suppress (inhibit) stimuli from their surroundings and are easily distracted.

In the Eberg eye-tracking study, the task was to respectively look at and avoid looking at a selection of stimuli in the surroundings in a GO/NO GO test. The children’s basic skills on a bicycle were tested before the attentiveness study. These measurements showed that 40% of the pupils failed the NO-GO test. This means that they did not manage to resist the temptation of focusing on distractions on the roadside.

Based on the understanding of the neural mechanisms described above, including the results from the Eberg eye-tracking study, a didactic cognitive teaching approach was chosen for the new education program, to encourage children to create and construct cognitive maps and to develop children’s attention and the ability to assess risk during cycling [22].

This new read world education program would have to be evaluated and its impact on learning studied. The immersive experience provided by virtual reality (VR) can be used for numerous purposes such as education, training, entertainment and therapy. Using VR in education has often been motivated by the wish for increased students’ intrinsic

motivation, and development has usually been based on factors such as constructivism pedagogy, especially inquiry-based learning for the exploratory stage.

However, the mayor focus of the VR implementation presented here is not toward making a training or an educational VR software, but on utilizing VR in studying and evaluating the proposed new real world education program and its effect.

In the education program the observation ability was of critical importance. Observation ability can be measured through eye-tracking. This enables exploration of the learning outcome, as this data is directly derived and impacted from the learning process. To help evaluate the new education program, a software using eye tracking in a VR cycling simulator was developed. The approach of using VR cycle simulator with eye-tracking for evaluating a educational program, differs with earlier concept of VR cycling simulators that utilizes eye-tracking data. For instance, an eye-tracking based cycling VR simulator feedback system on gaze behavior, was focused on online feedback to a trainer for children with Developmental Coordination Disorder [23].

Validation and evaluation of virtual reality learning software for soft road users, such as ViStreet [24], has been previously done for pedestrians [25–27]. In such validations the focus has mostly been on fidelity between the virtual world and the real world, spanning from visual and interactive fidelity to behavioral and situational fidelity, i.e. the observed behavior in the virtual world at a given situation is the same as in real world, and the situations are perceived as equal to real world situations.

In previous works validation has typically been done using tools such as post-usage questioners, and comparison of orientation, walking paths, walking speed, speed perception and so on. As such, our approach is similar to such existing approaches as we have a high focus on visual and interactive fidelity. However, instead of parameter and behavioral comparison between the real world and the virtual reality education software, we focused in the use of eye tracking in VR. Previously, [28] has shown that the use of eye tracking in VR can be helpful in pure observation of behavior and monitoring relevant skills and abilities (of pedestrians). The work presented here does however show an approach on how to use region of interests to actually measure fixation, and their application in evaluation and analysis of the educational program.

Methods

A virtual world was constructed to evaluate and gather knowledge on the effect of the new learning program, based on the Eberg centre. However, an overview of the new learning program is included before going into details on the VR

application, as the learning method forms the context for the implementation of the VR evaluation software and method.

Learning Program

The innovative and adapted learning methodology was built with voluntary teachers. In the program, pupils learned three concepts: risk, orientation and attention. This was then applied through discussions so that the pupils could reflect on their own behaviour on their school road. This was to trigger learning from the pupil's own experiences, i.e., episodic and semantic memory. Next, the pupils attended a session at Eberg traffic center, where teachers encouraged them to reflect about how to practically use their new knowledge about the three concepts.

As part of the new model, teachers had to be introduced to the new working method. The problem-based teaching model required the teachers to help define the problems in complex traffic situations and control the instructional stimuli to engage the children's reflection and actions. Based on discussion and discoveries, new successive questions were created and answered. A more in-depth discussion on this new methodology can be found in [22].

In the execution of the new curriculum, teachers instruct their own pupils in special attentiveness drills in traffic situations. The execution of the new curriculum, nor the new curriculum in itself was the focus for the VR development presented in this work. There was, however, a need for testing and evaluation in order to ensure specific changes in behaviour after participating in the new proposed curriculum, to further development of the bicycle education and training and for information to teachers and parents.

The new education model has a strong focus on attention, orientation, and risk assessment. The children will develop mental (cognitive) maps by discussion's and walking around in the traffic center. The task given is to identifying risk factors, working together in groups. Afterward, they have to explain to teachers what they have come up with. Finally, the children had to use their cognitive maps when planning for action and navigation at the traffic center while cycling.

Virtual Reality Evaluation Software

For the implementation of the VR software for evaluation, interaction fidelity, visual fidelity and the design for data gathering of eye tracking data was of special importance.

Virtual Reality Interaction Fidelity

To enable interaction fidelity a physical bicycle was placed on a stand, and the brakes was instrumented to measure braking. This enabled limited user control over the speed of a digital representation of the bike in a virtual world. A test

subject could then cycle in the virtual world, seen through an HMD.

To achieve high interaction fidelity, a standard physical child bike was purchased and placed on a bike stand, as seen in Fig. 1, and the brakes were instrumented to measure braking. The bike was recreated in the VR application and the player controlled this model. The HMD was then positioned and oriented to synchronise the position of the virtual bike with the real bike.

To achieve re-createability in measurements, the virtual bike was implemented to follow a predefined path through the virtual world, so all participants had the same viewing distances and angles toward different objects and areas in the world. This did influence the interaction fidelity, as turning the handlebar on the bike did not introduce the expected change of steering angle in the virtual world.

Speed control was also simplified to not take undue focus away from eye usage. The speed model implied that the virtual bike character controller was accelerated to a set maximum speed at a set rate and independent from pedal usage. The maximal speed was adjusted somewhat for downhill and uphill areas. Also, if the participant used the brake handle, the virtual bike decelerated (braking) at a rate consistent with the pressure the participant applied to the brake handle. Usage of a physical brake handle was detected using an in-house developed load sensor attached to the brake wire. The sensor values were measured using an Arduino transmitting the measurements to the unity game engine through threaded asynchronous serial communication inspired by Zucconi [29].

Virtual World Visual Fidelity

Graphic fidelity in virtual environments does not necessarily matter for player experience and engagement in a non-VR setting [30], or even in a VR setting if only an emotional

response is required [31]. Although, if strategy and performance, as well as subjective judgments of presence, engagement, and usability are to be considered, both display and interaction fidelity may significantly affect performance [32].

When considering VR to explore children's awareness and attentiveness in a setting where they have received education and training to develop a cognitive map of the real-world environment, it is therefore paramount that both interaction and display fidelity closely follows this environment. This, as the curriculum and teaching focused on developing self-insight on strategic traffic safety issues.

In this work, it was also important that the results were not influenced by additional cognitive workload or distractions forcing the children to make new plans and actions that is not agreeable with the teaching or by experiencing a virtual environment not easily recognizable from the training session onsite. As such, a high degree of fidelity to the Eberg site was required, while still maintaining a high framerate. A Vive HMD with integrated eye-tracker modified by Tobii [33] was selected for the trial. Low refresh rate and frame rate of a VR headset are mayor factors that can cause motion sickness (cybersickness or simulator sickness), due to multiple reasons, including sensory mismatch and flicker. According to LaViola [34], a refresh rate of 30 Hz is usually good enough to remove perceived flicker from the fovea. However, the human eye is most sensitive to flicker in its peripheral vision, meaning that the periphery requires higher refresh rates. The Vive has a refresh rate of 90 HZ. A refresh rate may include repeated drawing of identical frames, but to limit sensory mismatch a frame rate of 90 Hz was targeted when constructing the 3D model and interaction.

The complete 3D model of Eberg the site was built in Unity based on height map of 10 cm resolution, using a large rang of reference satellite images, photos and movies from the actual site. Some objects were modelled in 3DS Max,

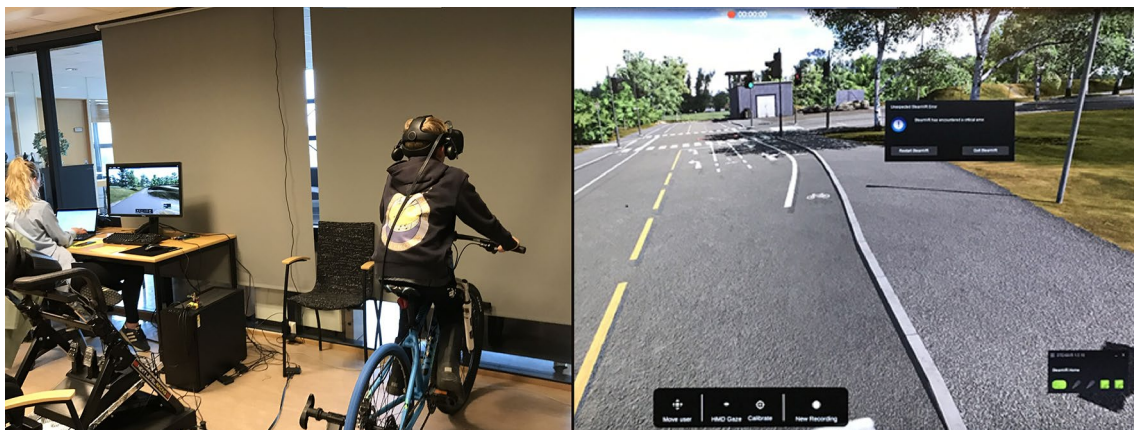


Fig. 1 Laboratory setup (left), operator view of rendered image to HMD (right)

while others were generated or imported from commercially available Unity asset tools and models. A special focus was to get viewing distances and angles correct. For the Eberg site, this meant that trees' foliage and shrubs had to be carefully considered, while constantly weighted against the rendering cost of foliage. The final model, as seen in Fig. 2, was implemented in close cooperation with subcontractor Agility3 [35], that did most of the 3D modelling and the final assembly of the terrain model. Overall, the model could mostly be run at 90 Hz on the available hardware, although in areas with heavy vegetation some frame-rate drops had to be allowed for short periods to ensure fidelity in viewing distances and angles.

Evaluation Software Design

The implementation of the VR eye tracking was based on the (now deprecated) Tobii Pro VR Analytics software development package [36], a Unity engine plugin and code. The supplied software was used to implement a cycle-character controller in unity engine for VR, complete with eye tracking. This unity software package was originally developed to simplify implementation of eye tracker setup, calibration, trial setup and control, data recording and data playback for standing and walking VR experiences. These concepts were reused in our implementation. While recording, the software collects time-stamped data position points of the participant in the 3D world, the gaze position in world space and the gaze orientation in object/local space. From this a view vector can be calculated for each eye.

The VR Analytics software package further works by defining what objects in the unity world should detect 3d intersection between the object itself and the view vectors calculated from the eye measurements of the user (i.e. the user looks at the object). For each such objects the point

on the object for each intersection are gathered, and used to calculate if the user looks at the object long enough to be characterize as a fixation. The software package uses a dispersion filter (ID-T), based on the work by Widdel [37] to define fixations. The dispersion filter group data points into fixations by identifying fixations as spatially dense clusters of gaze positions over a continuous time period. A value of 60 ms was used in this study as suggested by Komogortsev [38]. Metrics for each tracked object was exported for each participant, and included fixation count, total and average fixation duration and time to first fixation.

In the virtual world, the objects configured to record measurements were either invisible planes or visible objects such as a road roller placed around a corner at an intersection as seen in Fig. 3. The invisible planes were created, similar to normal scene objects for data gathering, except that a transparent material was applied. As such they were invisible for the participant but used to gather fixation positions and counts as described above. The position and orientation of the invisible planes was defined to intersect the



Fig. 3 Steam roller configured for eye tracking data gathering placed around a corner

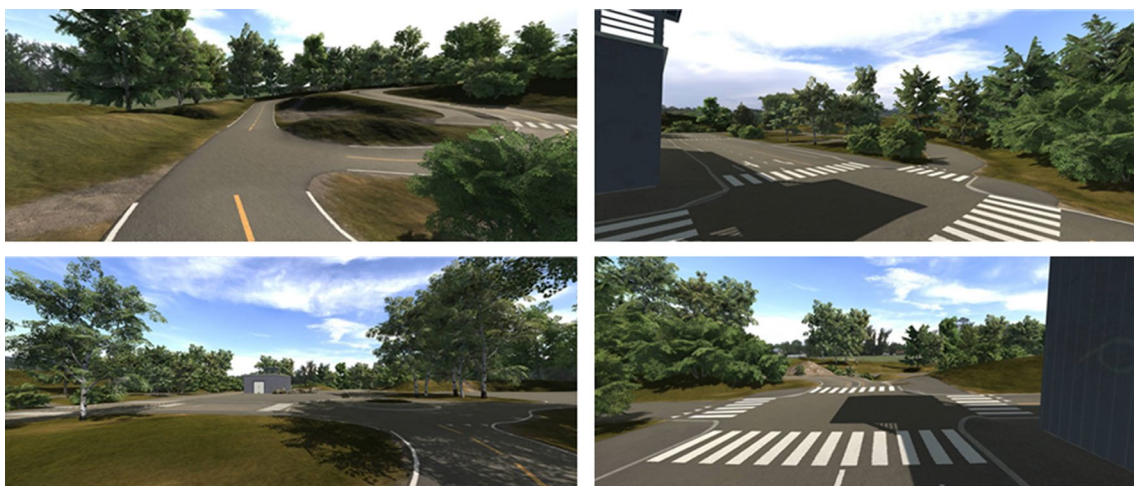


Fig. 2 Scenes from the Eberg traffic centre in VR

view direction between a participant and a Region of Interest (ROI), areas deemed of special importance by traffic safety experts, as seen in Fig. 4. In addition, as the user moved through the virtual world, several of the objects and invisible planes were moved in and out of the scene dynamically. This was to avoid that the user cycled through objects placed in the road (steam roller) where the user would cycle later. Also, this ensured that fixation data was not recorded for any object when the user were not approaching a ROI from a direction of interest, as defined by the safety experts.

The position and orientation of the invisible planes, as well as visible objects, used for data gathering was of high importance to ensure that relevant and correct data was gathered. First, an expert in traffic safety suggested ROI's that should be observed, and defined critical locations/regions these ROI's should be observed from, together with the route for a cycle trip at the Eberg site. This was then refined together with two more experts. Finally, the invisible planes and objects was placed into the virtual world to cover the region between the identified ROI's and the critical viewer locations, so as to gather eye-tracking data for each ROI.

A version of the software for analysis mode was also implemented. When running the software in analysis mode, the observer could move freely in the virtual world, and observe both the position and view vector of each participant included for analysis. Fixation count and position data

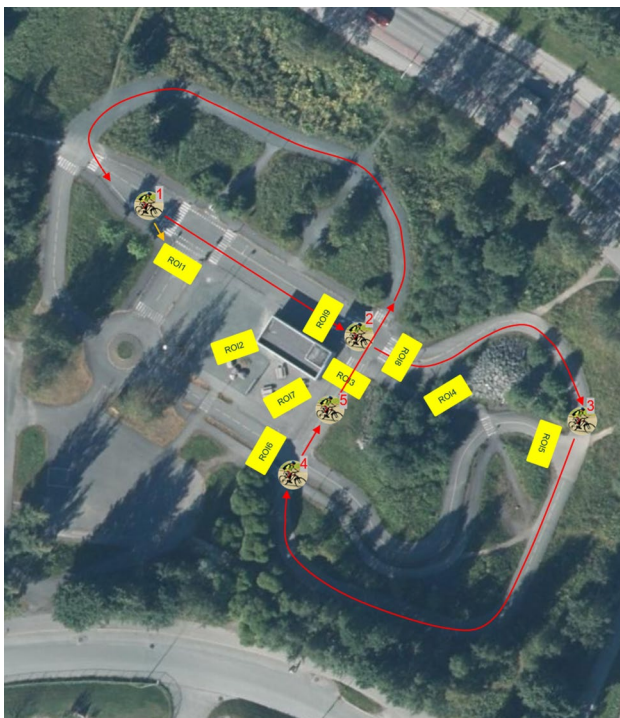


Fig. 4 Region of Interests along cycling path (red line) identified for this study. Location 1: ROI1, ROI2. Location 2: ROI3, ROI4. Location 3: ROI5. Location 4: ROI6, ROI7, Location 5: ROI8, ROI9

gathered for each object during the trials, could then be used in visual analysis post trial. Fixations were rendered as a heatmap and were overlaid on the models for visual study. As such, in an analysis session, the number and position of fixations on any invisible objects were made visible by adjusting the alpha value for any areas of the object with heatmap data, as seen in Fig. 5. This analysis supported any composition of participant and groupings of such, by including or excluding fixation data for the grouping when calculating heatmaps. For each ROI, we analyzed the eye fixations visually in the software's analysis mode for individual users as well as for each group of participants (old or new curriculum), and numerically by exporting the data for further statistical analysis.

Test Setup and Measurement Procedures

To evaluate if the new curriculum had measurable effect, a pretest and posttest were carried out as performing a run through the VR application by pupils in fifth grade; either having received training using the existing curriculum (pretest), or receiving training using the new curriculum (posttest). The defining criteria for the evaluation was defined as a distinct and observable difference in eye usage behaviour between participants in the pretest and posttest groups.

In the early phase of the project, the Norwegian National Research Ethics Committees confirmed that a pre-approval was not required for the planned research. Similarly, the Norwegian Data Protection Authority was contacted to check if preapproval was required for data gathering and data storage given the project's data handling plan. Participant recruitment to the trial was performed by personnel at schools in the local area. A requirement was an informed consent from both the participants and their parents. The parents of potential participants was given an information leaflet, authored by the project members. Signed consent forms from parents were gathered and handled by the school personnel. The identification of the participants was not shared with the project or project members. And consequently, no pre-approval was finally required by the Norwegian Data Protection Authority.

In all 32 schoolchildren in the pretest group and 29 in the posttest group participated in the trial. The schoolchildren were 10–11 years old children from three different schools, located far away from each other in Trondheim. The difference in numbers of children between the two groups is due to children being not present at school the day of the trial. The participants in the pretest had gone through training using the existing curriculum ($n = 32$), while the others in the posttest had received training using the new curriculum ($n = 29$). The experiment group was composed of 62.1% girls and 37.9% of boys, while the pretest group consisted of 46.9% girls and 53.1% boys.



Fig. 5 Example of visual analysis with heatmap (ROI 3). Top image: placement of one ROI data gathering plane (red arrow indicate path direction), bottom left: all eye fixations for posttest group. Bottom right: all eye fixations for pre-test group

Before the trial, a pilot study with 5 children was performed to validate the interaction fidelity, graphic fidelity, measurements, and test procedure. All participants commented positively on the graphic fidelity and did not react negatively to the somewhat limited interaction fidelity.

Before experiencing the virtual reality, each participant got a short introduction to how the HMD and interaction with the cycle work. Each participant cycled the route twice. A complete run took approximately 1.5 min if the participant did not break down.

If at any time a participant felt unwell, she/he had been instructed to immediately inform of this, and the trial was then stopped. If the participant was after a short time reported that she/he was not unwell anymore, she/he got to try one more time.

As part of the study, all participants were asked to fill out a short post-questionnaire with a few simple questions. Although the post-questionnaire was not constructed complete as an in-depth study.

Results

The VR software and method developed in the work presented here, had as focus to evaluate differences in view data between pupils having received training with the proposed new education program, and pupils trained using the existing approach. As such, we present results from both the pupils self-reported reaction to the software. As part of the evaluation, the post-questionnaire had questions to rate the participants VR experience, as measured by users' self-reported perception of realism in the virtual world. This was to acquire an indication on graphic and interaction fidelity.

The answers showed that close to 70% totally or strongly agreed that their experience in the virtual world was like cycling at the actual Eberg site ($N=61$), as seen in Fig. 6. In all, a large share of participants (95.2% when including those who little agreed) agreed that they cycled

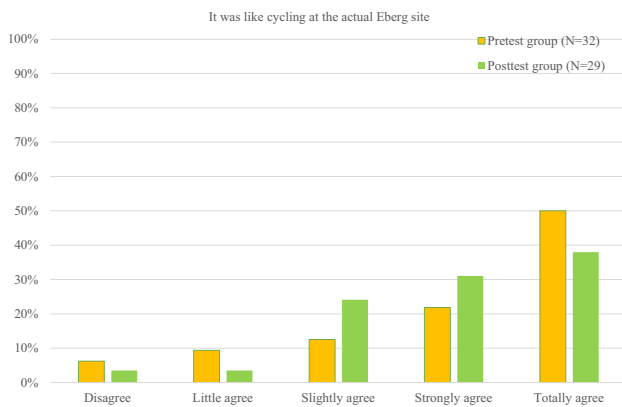


Fig. 6 Answers on fidelity for pretest and posttest group

in VR like they did in the real world. Although the post-trial questioner was limited in scope, this did give a good indication that fidelity was good.

One should note that 10–15% of the participants reported that they felt somewhat or strongly unwell during the first run-through. This could be several factors, such as limited previous exposure to VR or the limited interaction fidelity (turns along a fixed path through the virtual world). It is also likely that the few areas where the framerate dropped below 90 Hz influenced this feeling of unwellness. However, all participants completed the course (after a short brake), and they did not report any feelings of nausea afterwards either immediately or later the same day.

In addition to the children's reaction to the software, we also present the results from the actual trial, to show how the software were used to evaluate the results, which is even further discussed in Sect. 4. In the trial, the children performed two rounds of the virtual cycle track. Data gathered from the trial were exported for statistical analysis. Additional analysis can be found in [22].

The statistical analysis show that there were no significant differences between the rounds 1 and 2, except at ROI2 where the pretest group did not fixate at this AOI during round 2, whereas 21.9% did during round 1. For all further analyses round 1 and 2 was analyzed together.

Next, we analyzed to what extent the participants fixated on the defined ROI's at all. The posttest group fixated on average 6.83 ROIs ($N=29$, Mean 6.82, Std. deviation 1.91), whereas those in the pretest group fixated on average 4.53 ROIs ($N=32$, Mean = 4.53, std. deviation 2.08). There was a statistically significant difference between the post-test and pretest groups (Independent t -test, $t(59) = -4.477$, $p = 0.000$).

This was further analyzed per distinct ROI. Figure 7 shows the proportion of observers of the nine ROIs per test group. There were measured significant differences between the groups for all ROIs, except for ROI 4, 6 and 7 (p -value

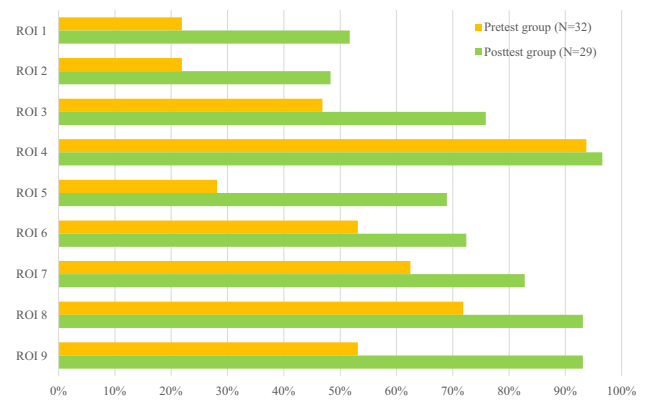


Fig. 7 Percent vice fixations for each participant group per ROI

over 0.05). One should note that the children who fixated a ROI in the first round not necessarily did so the next round. However, in the analysis, the children who fixated during both rounds, were counted only once.

Finally, there was no significant gender difference in either the groups or in the whole sample.

Discussion and Future Work

A main goal of this study was to evaluate the effects of a new road safety teaching model of cycling training based on the development of mental (cognitive) maps to strengthen their attentional skills. This teaching model is based on the MBE concept for reaching the higher cognitive executive functions of the brain, and focused on children's ability to pay attention, orient themselves and assess risk factors. Although a basic description on the teaching model is included for completeness, the main focus and contribution explained in this work is on the practical usage of the virtual reality based approach for the task of evaluation of this model.

To measure and investigate the differences between pupils having been educated using new versus existing curricula for safe cycling, eye tracking fixation data toward region of interests was gathered. A high degree of visual and interaction fidelity was considered as essential to achieve this. The results from the limited post-questionnaire indicated that fidelity was achieved to a degree where the participants reported that the VR experience was close to the real situation. However, the post-questionnaire was limited in scope, and not designed as a full study, and as such can only be used as an indicator.

The new teaching model was shown to be more effective in helping the children to put their attention on the right place, to orientate themselves and to behave in a safer way when cycling. Using the developed VR tool, replay of single participants and visual inspection of heatmaps in analysis

mode, and exported data for statistical analysis, traffic safety experts and experts in teaching and pedagogy could perform in depth analysis of differences between the pretest and posttest groups. Most results showed a significant difference between the groups in eye usage and fixations (p value under 0.05). Of note is the fact that for ROI4, ROI6 and ROI7, where the statistical analysis does not show any difference between the groups. However, the lack of statistical difference in ROI4, ROI6 and ROI7 does not mean that the new curriculum did not improve the pupils' performance for these locations. Traffic safety experts investigated the eye-tracing data for these regions using the implemented VR software, and they argued that the lack of difference could be explained by the position of the ROI: The ROI is located on the route in front of them, they cannot avoid it and they all fixated on it to some extent or the ROI is visible with no object, building, or tree hampering the sight and the school-children did not use long time to fixate it and to evaluate it as not dangerous. By being able to replay tests and view the eye usage data on the heatmaps, the domain experts could visually control the differences in eye usage for participants in the pretest and posttest groups, and provided a confirmation of the suggested explanation.

For this work, it was important that the results were not influenced by cognitive load introduced by having to form new abstracts by introducing an environment not easily recognizable from the onsite training session. The teaching took place at the same real-world location as implemented in the virtual world. As such, this study does not explore to what extent pupils receiving the new education program show improved behaviour when applied outside Eberg. For future work it is planned to examine this further, trying to describe to what extent, having to form such new abstracts from the teaching by using an unknown virtual site, may affect the performance of participants. Such a future work could be to evaluate pupils that undergo the new education program at another site than Eberg, but using the virtual world of Eberg for evaluation, compared to pupils undergoing the whole education program at Eberg.

Both the use of a fixed path through the world, and the simplified speed control scheme impacted the interaction fidelity. The user of the bicycle could turn the handlebar, or trying to control speed using the pedals on the physical bike, and this was not replicated in the virtual world. As such, controlling the virtual bike using the physical bike as an input unit could potentially impact the participants' mental load as the user had to consider the difference in control to how a real bike is controlled. However, we can argue that this did not undue impact the validation of the evaluation as the focus was on eye usage in a given situation, and not on the navigation task through the world. Although it is unclear to what extent any extra cognitive load from a navigation task could have impacted the results, however, as

both pretest and posttest group had to experience the same restriction conditions, the results have to be considered as valid in that context.

Another aspect that could be considered as a weakness is the relative short test duration of 2×1.5 m for each pupil. However, this was selected in close cooperation with traffic safety experts. They defined the regions to observe, and ensured that there was both an adequate number of such regions, as well that they were adequately different. As such, it is argued that the coverage of the regions of interest was to such an extent that the test acquired sufficient data for evaluation, although the short test durations.

Conclusion

In this work, it has been shown how eye tracking in virtual reality can successfully be utilized to evaluate interactive cognitive systems involved in navigation and the planning of actions based on a new educational curriculum in a traffic safety educational setting. There is, however, further need to examine unresolved questions concerning interaction fidelity.

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Declarations

Conflict of interest The authors declare that there is no conflict of interest.

Ethical approval The Norwegian National Research Ethics Committees contacted to see if pre-approval was required. No approval was required.

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