Learning on Navigation Information Presentation for Motorcycle Head-Up Displays

Joana Manso Arezes
joana.arezes@tecnico.ulisboa.pt

Instituto Superior Técnico, Lisboa, Portugal

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Abstract

Motorcycle riders have difficulty getting navigation information. Head-down displays force them to look away from the road and head-up displays made for motorcycles and their riders are only just now surfacing, but there seems to be a lot of options on how to present navigation information, such as placement, quantity, formats and color. This dissertation investigates different layout parameters in turn-by-turn navigation, namely arrow formats with different context information quantity, colors and two different versions of information stabilization, that change how the user perceives it: helmet-stabilized and world-stabilized information. Because of all the risks and difficulties in testing an Augmented Reality interface for motorcycles in a road, this work uses Virtual Reality to simulate the real world for all testing phases. A total of 15 users tested each parameter, except for the stabilization evaluation, where two independent groups of users tested each possible stabilization version. Analysis of the results showed that users preferred formats more complete in information about the referent intersection and the color green for the world-stabilized presentation. The opinions were tied on the color for the helmet-stabilized presentation. The world-stabilized information presentation had slightly better performance outcomes, namely in the number of collisions with the surroundings. On this basis, the world-stabilized presentation shows the potential of being safer and providing a better driving experience for the user. Further research on different environments and transition into the real world need to be done to verify and generalize these results.
Keywords: motorcycle, navigation, virtual reality, head-up display, driving assistance

1. Introduction

People use GPS navigation systems every day to go from one place to another, to find places of interest, like gas stations or restaurants, to find the best available route to get somewhere or to follow pre-made tracks. If a person is driving a vehicle, this can become distracting - they will easily have to shift their eyes and attention from the road to the navigation system to check directions or other information.

With motorcycles it is more difficult to have the navigation system installed close to the rider's FOV, when they are focusing on the road, which makes the distance the eyes have to travel to look at the navigation system bigger. This contributes the driver's distraction level, which in a motorcycle can quickly become a lot more fatal than in a car. The risk of death is 26 times higher for motorcyclists involved in a crash compared to a car passenger [1].

A solution for this problem that has been attracting attention is the use of Augmented Reality (AR) - a see-through screen or projection that, in the case of driving, can display different types of information relevant to the driver without requiring them to divert their attention from their usual focus - the road. Several studies have been done on this subject for cars, but a unification on how to provide a good AR experience for motorcycle drivers does not seem to exist.

Some startup companies filled bankruptcy somewhere in the past, for their first heads-up displays (HUD) prototypes failed, but were picked up again and now have a functional product for sale. Moreover, not only startup companies on crowdfunding but big companies well known in the automobile industry have also announced a conceptual motorcycle HUD helmet, such as BMW at CES2016. With many companies trying to realize and start mass production of a motorcycle HUD, it can be described as some proof of indication that there are high demands of a information presentation system that is less distracting by motorcycle riders.

1.1. Goals

This work aims to explore different formats and designs to present navigation information to a motorcycle rider, using a HUD, test their performance and compare the user feedback on each design, with the goal of enhancing the driver's navigation experience, whilst reducing the amount of distractions.

During the development process, there will be several phases of evaluation with user testing. Because the interface needs to be displayed in front of the rider, covering their field of view partially, a virtual environment will be used to simulate the real world and AR interface in all test phases in order to assure the subject's safety.

2. Related Work

Most of the research and developments on navigation systems have been focused on cars, likely because it's the most common transportation vehicle[2]. The vehicle difference between cars and motorcycles makes it difficult to simply transfer navigation systems from the first to the later. Motorcycles have very little space for adding extra devices, which also need to be water and dust proof, to prevent malfunctions, and the display needs to be legible under various sunlight conditions, since they would be a lot more exposed to weather conditions than in cars.

Compared to driving a car, driving a motorcycle is even more complex task that requires great motor skills and coordination [3]. Motorcycle riders also tend to pay a lot of attention to the road surface to escape hazards like rocks or trash on the road surface. For example, riders tend to avoid manhole covers placed in the traffic lanes, specially if the road is wet [4]. This leads to a critical difference in the viewpoint movements between motorcycle and car drivers. The car driver's viewpoint movement is mostly horizontal and the motorcycle rider's is mostly vertical [5].

Due to this difference, it is important to study the best way to present information to the rider, specifically if the idea is to introduce that information in the rider's field of view, which is the case of using a HUD.

2.1. State of the Art

Head-Up Down (HDD) solutions, such as smartphones and dedicated GPS devices which are mounted on the motorcycle's handlebar have the major problem of being outside the rider's FOV, causing distractions in the user from the driving task, to obtain navigation information. Since motorcyclists tend to pay high attention to the road surface, the time they have to deviate their attention from the road to the HDD to obtain information is considered very short and is considered a distraction from the driving task [6].

Head-Up Displays (HUD) can provide information close to where drivers keep their visual attention while they are driving. With this concept, it should be possible to provide information more efficiently and in a more useful way, compared to placing a HDD somewhere in the vehicle, since, theoretically, drivers will always keep their focus on the road ahead, thus contributing for a safer driving experience.

It has been proven that HUDs can decrease driving workload and raise situational awareness by a factor of 0.2 seconds, in comparison to HDDs [7]. Although this number might seem small, it has a big impact in drivers' attention level and may be decisive in critical situations. Another study comparing HUDs with smartphones, concluded that the same tasks, such as navigating a route indicated by the devices, seem to be safer with and HUD than with a smartphone while driving[8].

There are two main placement possibilities for a HUD in a motorcycle, presented in Figure 1. In (1), the HUD is equipped on the helmet or is equipped as a wearable HUD, like Google Glass. In this case, it moves according to the movement of the head, so the virtual image is always present in the rider's FOV, no matter where they're looking, meaning the image displayed is helmet-stabilized from the rider's POV.

In (2), the HUD is equipped on the motorcycle body. Seeing that it is in a fixed position in relation to the motorcycle and the rider's FOV is dynamic, since they move their head around, this position loses in relation to example (1), because the rider will not be able to always see the image. This position makes the image vehicle-stabilized, similar to car HUDs. Moreover, the HUD is placed at a greater distance from the rider's eyes than in example (1), so it will need to be bigger, in order to cover the same area of the rider's FOV, when the rider is looking ahead. This option would be more practical for motorcycles that already have a tall windshield.

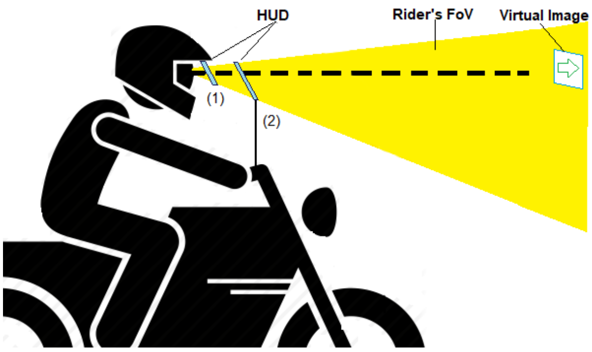

Figure 1: HUD placements in a motorcycle. (1) HUD placed in the helmet. (2) HUD placed in the motorcycle.

Recent attempts to develop a motorcycle HUD have adopted the strategy of applying it on the helmet [9]. This approach can also be called as Head-Mount Display (HMD). Currently in 2019, some HUD/HMD solutions for motorcycles have been announced or even launched in the market by various start-up companies. Some notable examples are:

- **Nuviz[10]** consists of an HUD which can be attached to any full-face or modular helmet, putting the display below the right eye; features include a navigation system (turn-by-turn and minimap), communication, music and photo/video capture; its interface uses mostly the color white, with some bright color annotations, like blue, orange and purple.
- **Skully[11]** Fenix AR helmet has an incorporated HUD, as a screen located in the lower right corner next to the helmet's visor; features include turn-by-turn navigation assistance, blind-spot rear-view camera that displays directly into the HUD and smart-phone integration; its interface uses mostly white and blue for navigation purposes.
- **BikeHUD**[1] consists of a monocle placed on the helmet (non see-throuh) bellow the left eye; features include basic information display such as user speed, time or virtual gear position, and a very simply designed navigation system; its interface uses mostly white and blue colors to show information.
- **Livemap[12, 13]** based on projection technology, it is a small reflective display on the center of the rider's FOV, that allows the control of the focal distance of the virtual image, giving the visual perception that the image is being projected on the road ahead, at a distance of approximately 20 meters, so the rider does not need to re-focus to look at the image projected on the HUD; their navigation information presentation is in between a minimap and a simple direction arrow, it shows a graphic representation of the structure of the intersection, and the direction to be followed highlighted interface uses white color as base, with a light fluorescent green/yellow on the outline, and orange for highlights.

Other studies and experiments also explored HUD options for motorcycles. Mendes[14] displayed navigation and weather information on a self-made HMD which was based on a Recon Snow 2 display unit integrated into skiing glasses and a helmet. A user study with 7 participants showed that the helmet-mounted display was found to be overall useful. The participants did not like that the display was non-see-through and that they had to glance away from the road.

Häuslschmid, Fritzsche and Butz[15] compared the performance between a self-made HUD and a HDD showing the same pieces of information: speed, speed limit and curve characteristics. Their results indicated that for users who usually exceed the speed limits, there was a significantly reduced speed for the HMD compared to the HDD. As for the workload, the results showed a lower workload in general for the HMD, except for the tactile workload, which the authors justified with the higher weight of the helmet. The visual, attention and interference workloads were significantly lower, meaning the rider could focus more on the road scene.

In contrast to the helmet-mounted approaches, Ito[5] reflected a car-like HUD in the motorcycle's windshield. This leads to a bike-stabilized instead of a head-stabilized placement. He concluded that the bottom corners of the rider's FOV were the fastest placements to show information to the user and that symbols and Hiragana characters were the fastest format to deliver the information. They also concluded that the distance from the intersection the users felt most comfortable with for showing the direction to take was between 40 and 55 meters.

These last two studies used Virtual Reality(VR) to simulate the real world and test their HUDs in a safe and controlled environment, which has been studied to be valid, for systems that are too dangerous or complicated to test in the real world[16].

To conclude, non-see through HUDs have the major problem of blocking part of the driver's FOV completely and as for the see-through displays, there seems to be two main positions adopted: (1) the corner of the rider's FOV, bellow one of the eyes - which still implies the rider to move their eyes away from the road and refocus; (2) right in the center of the rider's FOV - which might obstruct what shoud be the rider's main focus, the road, too much. Besides this, there does not seem to be an unification on how to design an interface for a motorcycle HUD, in quantity of information to be shown at the same time, the format in which navigation information is shown or even the colors to use.

All but one of the examples above are helmet-stabilized (meaning the information is fixed on the rider's FOV), but there haven't been experiments with world-stabilized information HUDs for motorcycles. This means there is untested ground to cover, as to if world-stabilized navigation information, such as having indications "projected" on the road, would be more useful and less error-inducing

[1] http://www.bike-hud.com/

than having such information fixed on a display.

3. Methodology

Based on the knowledge acquired on the previous section, this dissertation focused on exploring different approaches and parameters to present navigation information to the user. As most existing motorcycle HUDs, this work will only explore turn-by-turn navigation solutions.

Due to the sensitivity of testing an interface which might block the rider's FOV on the real world with external factors, such as weather and traffic, and also the difficulties in creating a functional prototype that would allow an interface to be shown in the user's FOV, a virtual environment was used for development and tests, which was shown to the user through a non-transparent HMD, an HTC Vive set[2].

3.1. Parameters and Tasks

The main goal for this work is to test for performance differences between two distinct possibilities to present navigation information to a motorcycle driver through a HUD, which are helmet-stabilized information presentation and world-stabilized information presentation. With helmet-stabilization, the information is fixed on the rider's FOV, independently of the rider's head movements, meaning the information is always displayed in the same place of the helmet visor. With world-stabilization, the information adapts to the world, meaning the rider will see it fixed in the same position in the world.

Before comparing both types of stabilization, there are a few parameters were found interesting to test, such as color, which was tested in both presentation types, and arrow format (with different amounts of information), which was tested in the helmet-stabilized version.

To test these parameters, the user needed to safely drive the motorcycle through the designed routes, executing actions like accelerate, brake, drive straight, turn left, turn right, while interpreting the various directions presented on the HUD. Taking this into account, the virtual environment and interaction were designed and programmed accordingly.

3.2. Virtual Environment and Interaction

All the modelling, environment setup and scripts were developed using Unity3D[3].

First thing to be designed was the virtual environment that consisted of a roadmap, traffic signs and houses to avoid the user getting an immediate perspective of most of the map. A relatively simple urban style was opted for, as HUDs were seen to perform better in low complexity scenes as background[17].

The road map was the first thing to be designed, as a simple map with nine 9 roads, 5 horizontal, 4 vertical, with different lengths and all perpendicular intersections at different distances from each other.

A simple collection of traffic signs were added, including *Stop*, *Curve* and *Crossroad Warning* signs, and distributed according to the *Instituto da Mobilidade e dos Transportes, IP* criteria for placing vertical road signs[18]. All signals were placed 2.20 meters above the ground, since they were all placed either next to crossroads or on sidewalks. Warning signals were placed 100 meters away from the point of danger, when possible[19]. In the case of some intersections that were too close to each other, the warning sign was placed as soon as possible (40 meters in the shortest case)

Figure 2: Road close up with *Stop* sign.

The models used also had to be simple and textured using the UV mapping technique[20] that only requires one texture file. Models that did not use this technique and needed several texture files for different polygons ended up being too complex for the computer to render while the environment was running, freezing some of the frames with the VR glasses.

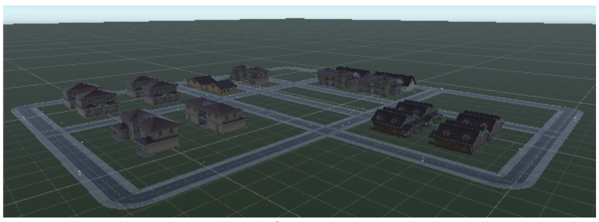

Figure 3: City perspective.

The interaction with the environment (motorcycle driving) was made through the Gemini MS1 Controllers, that resemble the handlebar of a scooter, meaning the virtual motorcycle will have automatic

[2]https://www.vive.com/us/product/vive-virtual-reality-system
[3]https:
www.unity.com

transmission, leaving only the handle, throttle and brake operations to the rider.

The motorcycle 3D model used was similar to the controls. The camera was set above the motorcycle seat, so when the user is wearing the VR glasses, it looks like they are seating on the motorcycle. A UI was added to the dashboard position to simulate the display that presents the motorcycle current speed to the rider, in kilometers per hour.

The leaning motion of motorcycle physics - which enables the motorcycle to turn at medium-to-high speeds - was left out of the simulation because preliminary tests concluded that it would aggravate motion sickness symptoms. This was due to the inability the simulator available had to create the physical sensation of lateral rotation, meaning the user would perceive a movement that their body was not feeling, which is proved to lead to an increased probability of motion sickness [21]. Taking this into account, the virtual motorcycle is driven and turned as it is in lower speeds - through the turn of the handlebar.

3.3. Navigation System

The navigation system designed was a rather simple script which worked turn-by-turn, meaning it would only show the direction to follow for the next intersection and kept updating every time the user made the turn and/or got near the next one.

The script read a route from a text file (.txt) and would show the directions to the user as they went through it. In every route, the rider starts in the same place. After processing the information about the route, it shows the first direction the rider should take. When they leave the intersection object, the direction disappears, the HUD is clear of any information (as to not unnecessarily clutter the FOV) and the script waits for the rider to come close to the next intersection.

The distance from the motorcycle to the intersection chosen to show the information for the next turn was based on Ito's experiment[5], that concluded that the distance the users were most comfortable with showing the direction to take for the intersection was 40 meters. So as soon as the motorcycle enters the 40 meters radius within the next intersection, the direction they are supposed to follow appears on the HUD.

When the route is over, a message is presented to the rider in the HUD saying "Ended Route. Press-Left Brake- to Continue.". This message makes the user aware of what is happening and gives them time and control to process and choose when to reset the environment, to start the next route. When the system is restarted, the motorcycle position is set for the starting point, and its speed is set to zero.

For the helmet-stabilized navigation, the approach was similar to NUVIZ's[10] and Skully's[11] HUDs, in which the information was shown in the right bottom corners of the rider's FOV, with a transparent background.

The models used also had to be simple and textured using the UV mapping technique[20] that only requires one texture file. Models that did not use this technique and needed several texture files for different polygons ended up being too complex for the computer to render while the environment was running, freezing some of the frames with the VR glasses.

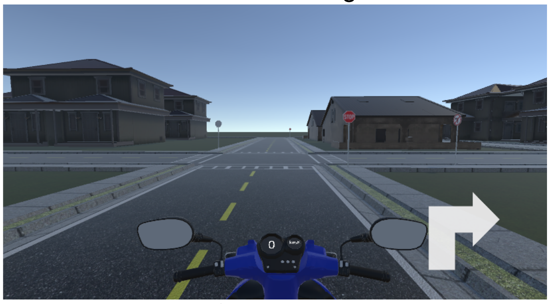

Figure 4: Example of the helmet-stabilized navigation.

A small animation was implemented, which made the direction appear from the bottom of the FOV and stop in it's final place, in a quick shift, as to not induce the user in error when close intersections had the same turn (*left* $>$ *left*) and give them visual feedback of the direction updating.

In the world-stabilized navigation, the rider would see the directions in form of a path displayed on the road. As the rider approaches the next intersection on the route they are following, the path appears as an animated line, that ends in an arrow head, starting from the point where the motorcycle is, to the pivot point in the intersection and following the direction the rider is supposed to take. Besides aesthetic reasons, the animation was created so the user could better tell which way in the line portrayed in front of them they are supposed to follow and so a considerable area of their FOV would not just suddenly become obstructed. As the motorcycle moves closer to the intersection, the portion of the line that would be after the motorcycle, disappears behind it, so if the rider looks back to their previous position, they will not see it.

This is the presentation that resembles a true Augmented Reality interface the most, instead of just being a see-through display, with information that does not adapt to the world. The point of this approach was to compare if a world-stabilized information presentation, that would only clutter that specific section of the "real world", would have a better performance and provide a better experience to the user than the helmet-stabilized presentation, that always covers the same portion of the

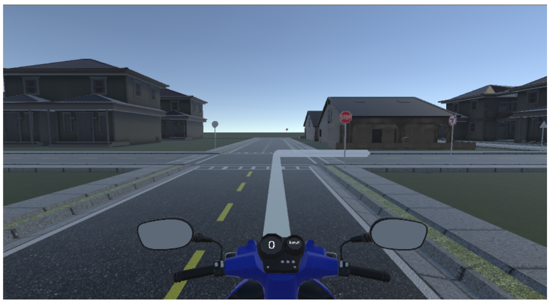

Figure 5: Example of the world-stabilized navigation.

user's FOV, which is the most common approach motorcycle HUDs have been taking.

4. Evaluation and Results

The testing model was similar between the different phases. Due to the low availability of users with a motorcycle driving licence, users with a car driving licence and any type of experience with a motorcycle were accepted to participate in the tests. All the tests were conducted in a calm laboratory, with the same hardware.

Figure 6: Setup for the user tests.

In the beginning of each user test, the project and goal of that specific test phase were presented verbally to the user. Even in the absence of traffic, the users were asked to follow the road code. The users were also warned about the possible risks of simulator sickness, when interacting with Virtual Environments with non-transparent HMDs. After getting all this information, the users were introduced to the VR equipment and motorcycle controls and all adjustments were made. They were given a 2-4 minute period of adjustment, both to the VR glasses and the motorcycle controls.

Each user had to complete six similar routes, which were designed to the same amount and type of directions, having exactly seven directions in which five are turns - *left* or *right* - and two are *forward*. The routes were used in a random order for each user, as to not bias any of the parameters under evaluation. The parameter under test would change automatically between routes. The total time for the test per user was around 10-12 minutes and a total of 15 users for each test.

Several data was collected throughout the tests, to allow for a performance comparison of each parameter under evaluation: (1) time per route; (2) amount of errors per route; (3) amount of collisions (with sidewalks or road signs) per route; (4) coordinates and controls' input at a certain time (4 times every per second). In the end, the users were also required to fill out a questionnaire with some demographic data, namely age and gender, their experience with Virtual Reality, a simulator-sickness set of questions[22] and their preferred parameter and why (optional).

4.1. Helmet-stabilized Format Evaluation

The first testing phase focused on testing different types of formats for the helmet-stabilized version of the navigation system. The aim was to find out the quantity of information about an intersection that would be the best performance wise, without cluttering the rider's FOV too much or confuse them, in the position chosen.

Figure 7: Formats chosen to test.

Each user drove two routes with each format, so the formats were switched every two routes and the routes order was always chosen at random, so this would not bias the data. Besides that, two different permutations were used for the order that the formats were tested: half of the users tested with (1, 2, 3); the other half tested with (3, 2, 1). These permutations counteract the user's learning curve, that is if the same order was used for all the tests, the formats that would be tested last would get better results, as the user gets more used to the whole system.

For this test, each user drove three routes with each color. The route order was also chosen at random and there was a permutation between the colors as well: half of the users tested with (white, green); the other half tested with (green, white).

Figure 8: Different intersection represented with Format 3.

These permutations existed for the same reason as they existed in the formats test, to counteract the user's learning curve. This test phase was conducted individually for both helmet and world-stabilized navigation presentations.

The results showed no evidence of statistical differences between the performances of the three formats. However, there was a noticeable difference on the user preference, that showed a big advantage for two formats that showed more information, with written feedback saying that in more complex intersections, users would prefer the most complete format, that shows the intersection structure and which turn to take.

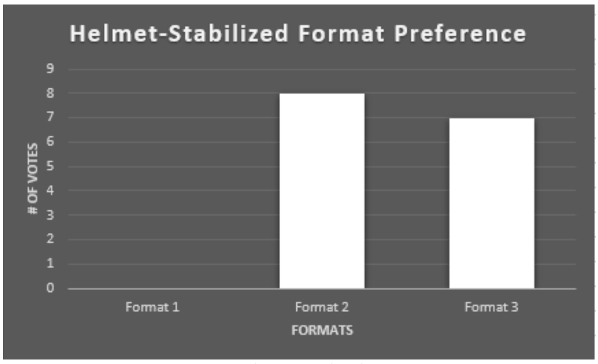

Figure 9: User preference for format evaluation.

Even though the difference between the performances of the three formats were not significant, it is possible to conclude based on user feedback that in more complex urban contexts, such as non-perpendicular intersections and intersections that involve more than two roads, Format 3 would represent the best compromise between being informative enough, whilst not being too distractive.

4.2. Color

The second testing phase focused on testing different colors for both helmet and world-stabilized navigation. The goal of this phase was to understand if there was a difference in performance between colors and what colors did the users prefer, found more appealing and/or visible, in a urban-type background. The colors chosen for this test were *white* and *green*, RGB(255,255,255) and RGB(0, 255, 0) in their respective RGB model codes[23].

For the **helmet-stabilized** navigation, there were no statistical differences between the performances of both colors and user preference was tied up as well. Users that chose the color *white* said that it was more neutral and less distracting, being "easier on the eye" and smoother.

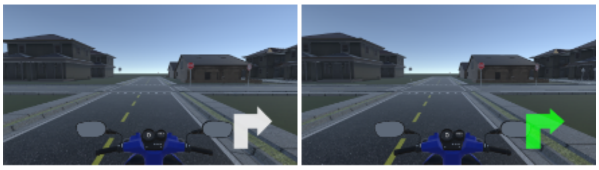

Figure 10: Different colors on helmet-stabilized navigation.

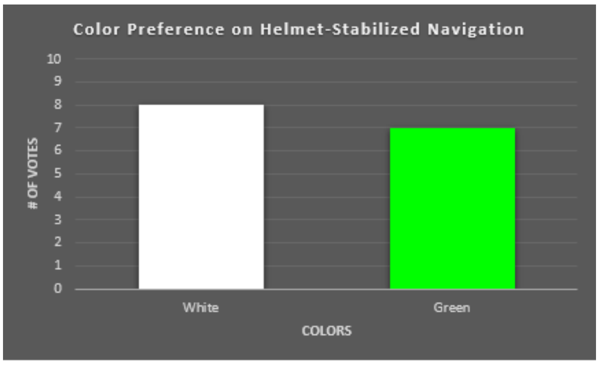

Figure 11: User preference for helmet-stabilized color evaluation.

Users that chose the color *green* said it was more easier to see, had higher contrast, not blending as much with the background and one user also said that it was the color they naturally associated with GPS devices and changing directions.

In the **world-stabilized** navigation, there was no statistical difference between both colors performances, but there was a notable difference in user preference.

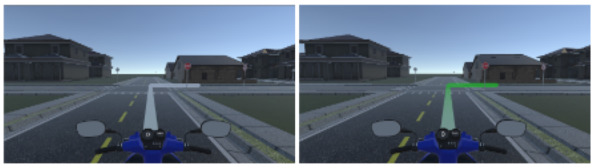

Figure 12: Different colors on world-stabilized navigation.

Users that chose the color white said that it was more pleasant, opposite to the green, that they found too strong and intrusive. Users that chose the color green said it was more intuitive, more noticeable and perceptible than the white, because it blended less with the road and road marks and, again, that green was more familiar in navigation contexts. This to show that even with an inconclusive data analysis of the performance results, there was evidence of an enhanced user experience, which could ultimately translate in a better driving experience in the real world.

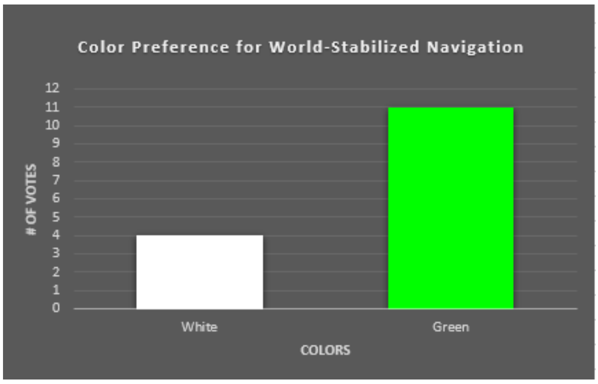

Figure 13: User preference for the world-stabilization color evaluation.

4.3. Helmet-Stabilized vs World-Stabilized

The goal for this test phase was to explore if the different types of navigation information presentation - helmet and world-stabilized - would have different outcomes and consequences in terms of user experience and performance.

This test phase was not an independent phase per se, meaning that it is was just an independent analysis of all the data collected in the color test phase. For this analysis, the color variable was ignored, since the same colors were tested on both formats, therefore only the navigation version variable was considered.

The results for this data analysis showed that there was a significant difference between both navigation versions in the variables *time* and *collisions*. The helmet-stabilized information presentation had a smaller time per route than the world-stabilized one, but also had a higher collision number per route. Although time is a variable which should be minimized, collisions are related to the safety of the driver, because they can put the motorcycle balance at risk.

Taking this into account and considering that the time for the helmet-stabilized version was only $\pm 7\%$ smaller then the world-stabilize, opposite to the collision means, in which the world-stabilized version is $\pm 59\%$ smaller than the helmet-stabilized version, it can be concluded that the world-stabilized information presentation is a better compromise between safety (collisions) and efficiency (time).

The Simulator Sickness Questionnaires did not show significant differences in any of the symptoms but three people withdrawned while doing the test while using the helmet-stabilized information presentation, thus showing the most extreme consequence of motion sickness - physical impairment. Combined with the performance analysis of both presentation versions, this proves that the world-stabilized information presentation would translate into a more pleasant and safe navigation experience.

5. Conclusions & Future Work

There is a need and demand from motorcycle riders for navigation solutions for their vehicles. Motorcyclists are the road users who are exposed to the highest risks, so every system designed for a motorcycle needs to be well tested to ensure that it causes the minimum number of distractions possible and does not put the rider's safety at risk.

From related work, it was concluded that there was a lack of unification on how to design an interface for a motorcycle HUD. Different HUDs in the market and studies use different amounts of information presented at the same time, different color pallets and different formats for the navigation information as well. Both helmet-stabilized HUDs and one vehicle-stabilized HUD were analyzed, but no work was found about world-stabilized information presentation in motorcycle HUDs - the true AR experience. So this work focused on comparing helmet-stabilization with world-stabilization performance.

The results showed that under the circumstances of the environment developed and what should only be an initial testing phase, the world-stabilized information presentation was safer to present navigation instructions, both for the reduced number of collisions, as well as the motion sickness symptoms, that were aggravated when testing the helmet-stabilized version.

Even though it was not an intensive and extensive evaluation, it opens up the possibility for world-stabilized information presentation being more relevant to develop and investigate to apply on motorcycle HUDs, than simply having a see-through display in the corner of the rider's FOV, that shows non-dynamic information that the user needs to translate into the real world.

It is still necessary to do further tests, with different contexts and more complexity, as well as in an improved simulator, that allows the user to feel the full extent of motorcycle physics or/and in controlled real world environments. Per example, traffic will affect the way the world-stabilized presentation is viewed by the user and vice-versa, because they're both projected on the road.

Regarding the different layouts, there are several ways in which both can be improved and put to test against one another again, by adding more relevant information as the distance to the intersection, or making the layouts more adaptable to different types of intersections. In the case of the world-stabilized version, it could eventually project the adequate trajectory for a curve, taking into con-

Type	Time (mean)	σ	Errors (median)	Coll. (median)	React. Time (mean)	σ
HS	48.657	8.834	0	1	0.990	1.196
WS	52.716	8.938	0	0	1.079	1.222

Table 1: Descriptive statistics of helmet vs world-navigation evaluation dataset.

sideration the motorcycle speed and it could even change color if the user was approaching the curve too fast.

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