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A personalized driving simulator for the assessment of adolescents with attention deficit hyperactivity disorder

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***Abstract* — Attention-Deficit Hyperactivity Disorder (ADHD) is a prevalent neuropsychiatric disorder associated with significant impairment and distress throughout the lifespan. Adolescents with ADHD are twice as likely as neurotypical teen drivers to be involved in road accidents. Here, we describe the framework of ADRIS 2.1, an open-source, accessible, realistic virtual reality urban driving simulator that we customized for adolescents with ADHD. It presents 12 scenarios designed to estimate executive functions such as inhibition, working memory, planning, and attentional flexibility. Moreover, it evaluates attentional orientation and alertness levels during unexpected events, including congruent, incongruent and neutral stimuli. The simulator provides measures associated with driving performance, such as observation of the speed limit, the safety distance, and the maintenance of the correct lane. The new version, ADRIS 2.1, is provided with a driving navigator giving the user directions to reduce distraction while driving. Additionally, we used a stereo camera to film the driver during the session and three accelerometers underneath the pedals to monitor hyperactivity and motor correlates of attention e.g. heading. EMG heart signal was also collected as an indicator of emotional self-regulation. Pilot tests were conducted on two adolescents without ADHD to ensure the proper functionality of the system. Despite the need for further investigation into the efficacy of ADRIS 2.1, preliminary results suggest that this system is ready to be tested as a tool for assessing the driving abilities and behaviour of individuals with ADHD.**

I. INTRODUCTION

Driving is an essential everyday activity that promotes independence and facilitates mobility for many teenagers and young adults. Driving is a challenging endeavor that necessitates the coordination of cognitive and motor skills to continuously react to environmental changes, even though driving components become automatic over time [1]. Moreover, adolescence is a stage of life marked by significant changes in the development of the physical, cognitive, and emotional systems [2], and executive functioning skills continue to develop during this time [3]. Thereby, teenagers with deficits in attention, inhibitory control, or executive functions run a higher risk of jeopardizing their safety when driving [4]. According to research [5], [1], [6], drivers with ADHD are also less likely to be able to focus for extended periods when driving, which leads to increased distraction, less monitoring of changing road and traffic conditions, and more glancing away from the road. Specifically, results from advanced driving simulator studies show that drivers with ADHD, both adults and adolescents, exhibit less defensive driving, more abrupt acceleration and deceleration, more lane departures, and increased speeding [7], [8], [9]. Given that driving safety is a rising concern not only for adults and adolescents with ADHD, and their families, but also for all road users, it may be possible to increase the safety of these drivers by better understanding the relationship between dangerous driving and the behavioral and cognitive symptoms of ADHD. Recent investigations have delved into the connection between ADHD and driving outcomes, revealing that distractibility significantly impacts driving performance [5]. The influence of secondary tasks has also been examined, finding heightened susceptibility to distraction in individuals with ADHD during low-stimulus conditions like highway driving situation [12]. Positive bias has been identified in teens with ADHD, leading to overestimations in driving abilities [13]. Moreover, driving performance are characterized by elevated speeds and brake pressures in those with ADHD [14].

Learned helplessness stands as fundamental characteristics of ADHD. Consequently, any intervention targeting ADHD should prioritize enjoyment and modern technologies. In fact, there is preliminary evidence supporting the potential use of serious video games in ADHD treatment [11]. In this context, driving simulators can be an interesting tool for evaluating and training driving skills. Salander et al. [12] aimed to enhance fitness-to-drive assessments by emphasizing the importance of simulator tests for subjects with ADHD. An evaluation of skills-training programs has revealed reduced extended glances and improved real-world driving outcomes for teens with ADHD [15]. Lastly, the relationship between executive functioning and risky driving behaviours has been explored, uncovering correlations between executive functions, and driving metrics associated with crash risk [16]. This study aims to combine an adolescent-centric approach, tailored scenarios, multimodal data collection - behavioral and physiological measures - into a single instrument for the training and evaluation of adolescents with ADHD. The technological objective was to develop an updated version of the Accessible

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DRIving Simulator ADRIS, named ADRIS 2.1, making it highly personalized and easy to use not only by people with sensorimotor diseases, but also with executive functioning deficits, in particular adolescents with attention deficit hyperactivity disorder. This type of evaluation could provide a more comprehensive understanding of the driving challenges and potential intervention strategies for adolescents with ADHD.

II. SIMULATOR DEVELOPMENT

A. *Hardware*

The simulator consists of three main parts: a PC, a driving console (*i.e.*, gaming steering wheel and pedals) and a computer screen. This new version of ADRIS, ADRIS 2.1, has been customized to monitor the motor hyperactivity of adolescents with ADHD by adding:

1. a depth camera (Zed2 stereocamera, Stereolabs sample frequency 30 frame/seconds) positioned behind the monitor and connected to the PC of the simulator. The camera allows monitor the trunk, shoulder, and head motion. We also estimate the heading that provides an indication related to where the user is looking.
2. pedal acceleration sensors, with the x and y axis aligned along the plane of the pedal.
3. heart rate monitoring.

For measuring the pedal acceleration and the heart rate we used MINI WAVE wireless EMG/accelerometers system (Cometa systems, Milan, Italy – sample frequency 2 kHz) due to its compatibility with the trigger box, which generates synchronization signals for the sensor readings.

B. *Software: scenarios specifically designed to detect and assess ADHD*

The software architecture of ADRIS is based on Unreal Engine. The Blueprint Visual Scripting system in Unreal Engine is a complete gameplay scripting system based on using a node-based interface to create gameplay elements within Unreal Editor. It includes an easy-to-use graphic interface for generating personalized scenarios and artificial intelligence (AI) tools managing the simulations (*i.e.*, vehicle traffic volumes, and sounds). Starting from an existing version of ADRIS, developed for the assessment and training of people with sensorimotor disabilities [17], [18], [19], we modified the software to adapt the system for ADHD end-users following the requirements highlighted by the clinical team of the Gaslini Hospital expert on ADHD disorders. The existing version of ADRIS included scenarios with obstacles, both static (such as a garbage bin in the middle of the road) and dynamic (such as a pedestrian crossing the road), to test the driver's attention. These can be defined as neutral and congruent events, respectively and to properly assess people with ADHD it is fundamental to add also incongruent events, i.e. distracting elements followed by an obstacle. The distractor does not pose a real danger to the driver, but it is merely intended to attract his/her attention. This situation is referred to as an incongruent event [20], [21], [22]. To present the different events, we implemented six scenarios, three training and three testing scenarios, that are based on the presentation of neutral, congruent, and incongruent stimuli, designed to explore an individual's ability to manage attention, suppress automated responses, and adapt to complex situations (for more details see Table I and Fig.1). Other six scenarios have been implemented similarly, because in the future the simulator might be used to test whether and how pharmacological treatments affect driving performance.

TABLE I. NUMBER, TYPE AND DESCRIPTION OF OBSTACLES THAT ARE PLACED IN EACH SCENARIO.

Scenario	***Number of events***	***Type of event***	***Event***
01	1	neutral	Object in the street (garbage bin)
02	1	congruent	Doubtful car at a stop
03	1	incongruent	A pedestrian who seems intent to cross the road, followed by a car that cut the driver off
04	2	neutral	A shopping cart and a damaged car in the street
05	2	congruent	A car that suddenly stops and activates the four turn signals and a pedestrian crossing the street
06	2	incongruent	Lots of people queuing for multicolour food truck followed by a police car speeding away. Red Coca Cola sign followed by a jaywalking girl.

Figure 1. Examples of neutral (top), congruent (middle), and incongruent (bottom) events. The neutral scenario depicts a construction site on the right side of the road. In the congruent situation, a pedestrian is crossing the road, while the incongruent one involves a car and a motorbike having an accident on the left, followed by a car abruptly emerging from a garage on the right.

C. *Navigation system*

Another important feature that was developed in ADRIS 2.1 was the navigation system. With the final goal of using this simulator with ADHD children, the voice used to give driving instructions has to be carefully selected. Indeed, the navigation system implemented in the simulator provides directions through a neutral and pre-recorded mechanical voice, minimizing the risk of capturing the driver's attention and causing distraction. We recorded the directional instructions read by Google Translate and for each instruction a trigger box (actor that is used to cause an event to occur when it is interacted with by some other object in the level) was created and placed in the scenario, activating the sound when crossed by the user car. For our application, the users must follow the predetermined route, as they must encounter obstacles placed along the path within the specified time. If the driver makes a mistake, a voice warns him/her that he/she has taken the wrong route and that he/she will be returned to the correct one. The speed of the User Car is then set to zero, and the car is returned to the last given direction, which is repeated.

Other additional new features were added to ADRIS 2.1:

- *Crossing lane infraction*. Two trigger boxes, placed on the right and left sides of the centreline, manage the infraction of the travel direction. Importantly, to determine a crossing lane infraction, the user car must cross the centreline twice (i.e. it crosses over into the oncoming lane and comes back).
- *Speed limit infraction*. At each frame, the velocity of the User Car is compared to the speed limit. If the current speed exceeds the limit, a counter is incremented, and a buzzer sound is played to alert the driver.
- *Safety distance infraction*. A collision component is positioned at the centre of the User Car, and, at each frame, it is translated by an amount corresponding to the safety distance. In case the collision component overlaps with another car, it means that the driver has not maintained an adequate distance from the preceding car, and consequently, a violation is counted (Fig. 2).

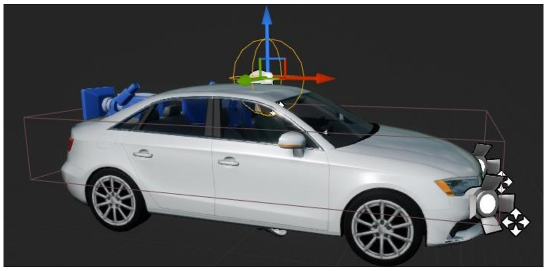

Figure 3. Collision component (in yellow) of the User Car moving an amount equal to the safety distance.

III. PRELIMINARY TESTS

A. Participants

Two 18-year-old participants with no history of neurological, motor, and cognitive deficits participated in the study. The study was approved by the Institutional Review Board of the Department of Informatics, Bioengineering, Robotics and Systems Engineering (DIBRIS), University of Genoa, Genoa, Italy (code CE DIBRIS protocol - 009/2020 approved on 18/05/2020) and it is conformed to the ethical standards of the 1964 Declaration of Helsinki. Each person involved provided written informed consent to participate in the study and to publish individual data.

B. Protocol

The experiment can be divided into different parts, as shown in Fig. 3 and it has an overall duration of 45 minutes. Before participants start driving, they are required to fill out a demographic questionnaire to collect various information such as whether they have a driving license, how often they drive and use video games. The participants complete then a simulation sickness questionnaire to understand whether they had any discomfort related to sickness before starting the simulation [23]. The participants are also administered an ADHD screening questionnaire of 10 questions to evaluate the ability to initiate and sustain mental productivity and to self-monitor and regulate responses in the visual-spatial domain [24]. They are then asked to carefully read brief driving instructions for using ADRIS that included information about traffic rules, as having a driver's license was not an inclusion criterion, and to complete a quiz to assess their level of understanding of the concepts provided. Before starting to use the simulator and become familiar with it, the participants are equipped with EMG sensor to measure the heart rate. Then, the driving session begins. Participants completed three familiarization scenarios in which they were guided in the map by the navigator. Each scenario was placed on the same map, but the driver had to drive through different routes. Each scenario ended when reaching a specific location, or after 2 minutes of driving, whatever occurred first. The map of the training scenarios was composed by an urban road characterised by 4 lanes (two for each direction), a residential 2 lanes road, various traffic lights with big junctions and roundabouts, and a 4 lanes tunnel. In this map, the driver could easily learn how to use the simulator. The experimental session continued with three test scenarios that occurred on a different map that make use of an urban road characterised by a mix of urban 2-lane roads and external 8-lane super expressway. The presence of the highway represents an additional level of difficulty because, when driving in low stimulus, drivers with ADHD seem to be especially prone to distraction [25]. The level of complexity also increases due to the number of events that occur for each scenario, rising from 1 (in the training scenarios) to 2. At the end of the experiment, participants filled out three questionnaires to establish whether any discomfort occurred [23], as well as to assess the workload [26] and the sense of presence experienced in a virtual environment [27].

C. Data Analysis

To analyze the performance while driving, the following parameters were extracted from the data of the simulation: number of infractions (*i.e.*, lane crossing, speeding, safety distance), number of collisions with neutral, congruent and

Figure 2. Study Protocol

incongruent obstacles, maximum speed, mean speed, and variability of the mean speed. The accelerations of the pedals, acquired at 2 kHz, were filtered using a fourth order Butterworth low-pass filter (cutoff frequency: 1 Hz). The accelerations measured along the x (a_x), y (a_y) and z axis (a_z) were used to calculate the pedal inclination angle (θ) using the arctangent function (1).

$$\theta = tan^{-1}\left(\frac{a_z}{\sqrt{a_x^2 + a_y^2}}\right) \qquad (1)$$

By selecting a threshold corresponding to 30% of the maximum value reached, we obtained the percentage of time during which the accelerator, brake, and clutch were pressed in each scenario. The heart signal was filtered with a fourth order Butterworth low-pass filter (cutoff frequency: 40 Hz) and we identified peaks with a minimum amplitude of 100 microVolts and a distance between peaks of at least 500 ms. We chose to extract heart rate (HR) and heart rate variability (HRV) because they are physiological measures used to assess driving performance [28]. HR was calculated as the number of peaks per minute while HRV was expressed as the mean and standard deviation of the time intervals between successive R-peaks. All analyses were performed using custom-developed software written in Matlab (Mathworks Massachusetts, USA; version 2023b).

The stereo camera allows to acquire two high-resolution (2 x (1920 x 1080pixels) at 30 frames per second) videos simultaneously, along with a depth map for depth estimation. Of particular interest can be the extraction of trunk movements in both the frontal and sagittal planes of individuals with ADHD during driving to assess hyperactivity. In addition, the code developed by Cantarini *et al.* [29] introduces a method for estimating head pose in single images, utilizing a concise set of 5 head keypoints. This tool can be utilized to evaluate the head direction, an indirect measure of attention during driving.

IV. RESULTS

First, we focused on the mean, standard deviation and maximum speed reached, and on the infractions committed by each participant on the different maps. Mean and maximum speed were strictly dependent on the scenario. For instance, scenario 6, in which there were two incongruent obstacles, is characterized by a lower mean speed and a lower maximum speed (see Table II).

TABLE II. MAXIMUM AND MEAN SPEED FOR EACH PARTICIPANT (ID1, ID2) AND FOR EACH SCENARIO.

Scenario	*Maximum speed (km/h)*		*Mean speed (km/h)*	
	ID1	ID2	ID1	ID2
01	71	50	17	25
02	61	63	24	23
03	62	66	28	34
04	58	88	30	33
05	63	87	25	31
06	52	54	16	15

TABLE III. NUMBER OF INFRACTIONS COMMITTED BY PARTICIPANTS (ID1, ID2) FOR EACH SCENARIO.

Scenario	*Wrong direction*		*Speed limit*		*Safety distance*	
	ID1	ID2	ID1	ID2	ID1	ID2
01	3	3	2	2	0	0
02	5	0	5	3	0	0
03	1	1	2	6	1	1
04	1	1	2	1	0	0
05	1	0	5	2	0	0
06	0	0	3	2	2	1

The participants demonstrated excellent proficiency in following the instructions provided by the navigation system, thereby avoiding path errors. Table III presents the number of infractions. The incidence of collisions with obstacles was low and they occurred exclusively in scenarios 03 and 06, where incongruent events were present. Safety distance violations seem to have occurred only during these collisions. Compared to other infractions, violations of speed limits were numerous, despite the auditory feedback provided to the driver. The infraction related to the invasion of the opposite lane, on the other hand, was modest. Considering pedal accelerations, Fig. 4 shows, for each scenario, the percentages of time the accelerator and brake were pressed. It can be observed that the second participant applied less pressure to the pedals, especially the brake, compared to the first participant. During the experiment, the clutch pedal was never pressed by either participant; we would expect different results when testing participants with ADHD because of their hyperactivity.

Although HR and HRV are physiological indicators of individual workload, these values did not change within the scenarios. Currently, the scenarios are quite simple as they have been tailored for individuals with ADHD. However,

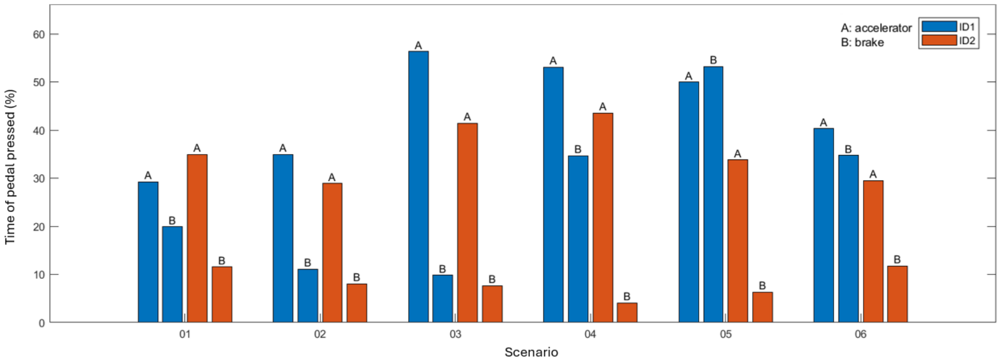

Figure 4. Percentage of breaking (B) and acceleration (A) time for each scenario and for each participant (ID1, ID2).

future analyses will delve into more specific aspects, such as observing HR and HRV variations in response to events.

The frames extracted from the camera recordings were used for head direction estimation during driving, which varies depending on the situation occurring in the scenario at that moment. Further analysis is required to evaluate body movements in the frontal and sagittal planes.

V. CONCLUSION

The implemented modifications were designed to create a novel version of the pre-existing simulator, thereby positioning ADRIS as an instrument applicable not only to sensorimotor disabilities but also to neurodevelopmental disorders. Preliminary tests performed on adolescents without ADHD suggest that ADRIS could detect various driving behaviors, thanks to the definition of personalized scenarios, the computation of performance indices, and the combination of acquisition systems (e.g., EMG, camera). However, to assess the efficacy of ADRIS 2.1, future studies will (i) validate the simulator on a bigger sample of adolescents with and without ADHD; (ii) assess the driving abilities of people with ADHD; (iii) evaluate the impact of pharmaceutical interventions on driving skills.

REFERENCES

[1] A. B. M. Fuermaier *et al.*, “Driving and attention deficit hyperactivity disorder,” *Journal of Neural Transmission*, vol. 124, no. S1, pp. 55–67, Sep. 2015.

[2] L. Steinberg, “Cognitive and affective development in adolescence,” *Trends in Cognitive Sciences*, vol. 9, no. 2, pp. 69–74, Feb. 2005.

[3] R. A. Barkley, “Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD.,” *Psychological Bulletin*, vol. 121, no. 1, pp. 65–94, Jan. 1997, doi: https://doi.org/10.1037/0033-2909.121.1.65.

[4] R. A. Barkley, K. R. Murphy, and D. Kwasnik, “Motor vehicle driving competencies and risks in teens and young adults with attention deficit hyperactivity disorder,” *Pediatrics*, vol. 98, no. 6 Pt 1, pp. 1089–1095, Dec. 1996, Accessed: Dec. 01, 2023. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/8951258/#:~:text=Results%3A%20ADHD%20young%20adults%20were

[5] J. Biederman *et al.*, “A laboratory driving simulation for assessment of driving behavior in adults with ADHD: a controlled study,” *Annals of General Psychiatry*, vol. 6, no. 1, Jan. 2007, doi: https://doi.org/10.1186/1744-859x-6-4.

[6] K. M. Kingery, M. Narad, A. A. Garner, T. N. Antonini, L. Tamm, and J. N. Epstein, “Extended Visual Glances Away from the Roadway are Associated with ADHD- and Texting-Related Driving Performance Deficits in Adolescents,” *Journal of Abnormal Child Psychology*, vol. 43, no. 6, pp. 1175–1186, Nov. 2014, doi: https://doi.org/10.1007/s10802-014-9954-x.

[7] R. Fried *et al.*, “Characterizing Impaired Driving in Adults With Attention-Deficit/Hyperactivity Disorder,” *The Journal of Clinical Psychiatry*, vol. 67, no. 04, pp. 567–574, Apr. 2006, doi: https://doi.org/10.4088/jcp.v67n0407.

[8] R. L. Merkel *et al.*, “Comparison of On-Road Driving Between Young Adults With and Without ADHD,” *Journal of Attention Disorders*, vol. 20, no. 3, pp. 260–269, Feb. 2013, doi: https://doi.org/10.1177/1087054712473832.

[9] M. J. Groom, E. van Loon, D. Daley, P. Chapman, and C. Hollis, “Driving behaviour in adults with attention deficit/hyperactivity disorder,” *BMC Psychiatry*, vol. 15, no. 1, Jul. 2015, doi: https://doi.org/10.1186/s12888-015-0566-y.

[10] K. Mechler, T. Banaschewski, S. Hohmann, and A. Häge, “Evidence-based pharmacological treatment options for ADHD in children and adolescents,” *Pharmacology & Therapeutics*, vol. 230, no. 230, p. 107940, Jun. 2021, doi: https://doi.org/10.1016/j.pharmthera.2021.107940.

[11] A. Sújar *et al.*, “Developing Serious Video Games to Treat Attention Deficit Hyperactivity Disorder: Tutorial Guide,” *JMIR Serious Games*, vol. 10, no. 3, p. e33884, Aug. 2022, doi: https://doi.org/10.2196/33884.

[12] H. Selander, N. Strand, M. Almberg, and Björn Lidestam, “Ready for a Learner’s Permit? Clinical Neuropsychological Off-road Tests and Driving Behaviors in a Simulator among Adolescents with ADHD and ASD,” vol. 24, no. 4, pp. 256–265, Jan. 2021, doi: https://doi.org/10.1080/17518423.2020.1869339.

[13] G. A. Fabiano *et al.*, “Positive Bias in Teenage Drivers With ADHD Within a Simulated Driving Task,” *Journal of Attention Disorders*, vol. 22, no. 12, pp. 1150–1157, Dec. 2015, doi: https://doi.org/10.1177/1087054715616186.

[14] J. Bernstein, S. Roye, M. Calamia, and A. De Vito, “Utility of a novel simulator paradigm in the assessment of driving ability in individuals with and without attention-deficit hyperactivity disorder,” *ADHD Attention Deficit and Hyperactivity Disorders*, vol. 11, no. 4, pp. 403–411, Apr. 2019, doi: https://doi.org/10.1007/s12402-019-00303-w.

[15] J. N. Epstein *et al.*, “Trial of Training to Reduce Driver Inattention in Teens with ADHD,” *New England Journal of Medicine*, vol. 387, no. 22, pp. 2056–2066, Dec. 2022, doi: https://doi.org/10.1056/nejmoa2204783.

[16] J. D. Lynch *et al.*, “Executive Functioning as a Predictor of Adverse Driving Outcomes in Teen Drivers With ADHD,” *Journal of Attention Disorders*, Sep. 2023, doi: https://doi.org/10.1177/10870547231197210.

[17] S. Ricci ***et al*.**, “Adris: the new open-source accessible driving simulator for training and evaluation of driving abilities”, *Computer methods and programs in biomedicine*, 221:106857, 2022

[18] P. Romani, “An immersive open-source simulator for assessment and personalised training of driving skills,” *Master’s Thesis*, Università degli Studi di Genova, 2022.

[19] N. Traverso, “A new hardware platform for training driving skills of people with motor impairment,” *Master’s Thesis*, Università degli Studi di Genova, 2022.

[20] M. I. Posner, “Orienting of attention,” Quarterly Journal of Experimental Psychology, vol. 32, no. 1, pp. 3–25, Feb. 1980, doi: https://doi.org/10.1080/00335558008248231.

[21] J. R. Stroop, “Studies on interference in serial verbal reactions,” Journal of experimental psychology, 1933.

[22] C. W. Eriksen and D. W. Schultz, “Information processing in visual search: A continuous flow conception and experimental results,” Perception & Psychophysics, vol. 25, no. 4, pp. 249–263, Jul. 1979, doi: https://doi.org/10.3758/bf03198804.

[23] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal, “Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness,” *https://doi.org/10.1207/s15327108ijap0303_3*, vol. 3, no. 3, pp. 203–220, 2009, doi: 10.1207/S15327108IJAP0303_3.

[24] R. Cattelani, F. Dal Sasso, D. Corsini, and L. Posteraro, “The Modified Five-Point Test: normative data for a sample of Italian healthy adults aged 16–60,” *Neurological Sciences*, vol. 32, no. 4, pp. 595–601, Feb. 2011, doi: https://doi.org/10.1007/s10072-011-0489-4.

[25] B. Reimer, B. Mehler, L. A. D’Ambrosio, and R. Fried, “The impact of distractions on young adult drivers with attention deficit hyperactivity disorder (ADHD),” *Accident Analysis & Prevention*, vol. 42, no. 3, pp. 842–851, May 2010, doi: https://doi.org/10.1016/j.aap.2009.06.021.

[26] S. G. Hart and L. E. Staveland, “Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research,” *ScienceDirect*, Jan. 01, 1988. https://www.sciencedirect.com/science/article/abs/pii/S0166411508623869

[27] T. W. Schubert, F. Friedmann, and Holger Regenbrecht, “Embodied Presence in Virtual Environments,” *Visual representations and interpretations,* pp. 269–278, Jan. 1999, doi: https://doi.org/10.1007/978-1-4471-0563-3_30.

[28] F. R. Ismail, N. K. Khamis, M. Z. Nuawi, D. Schramm, and B. Hesse, “Measurement of heart rate to determine car drivers’ performance impairment in simulated driving: An overview,” *Jurnal Teknologi*, vol. 78, no. 6–9, Jun. 2016, doi: https://doi.org/10.11113/jt.v78.9142.

[29] G. Cantarini, F. F. Tomenotti, N. Noceti, and F. Odone, “HHP-Net: A light Heteroscedastic neural network for Head Pose estimation with uncertainty,” *arXiv.org*, Nov. 03, 2021. https://arxiv.org/abs/2111.01440.