

1 **HUDAD: Improving Human Vehicle Interaction With Heads-up Display Assisted**
2 **Driving**
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4 MASON STENCIL* and LIAM HARTMAN*, Colorado State University, USA
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9

10 **1 INTRODUCTION**
11

12 In a continual effort to improve the safety and ease of operating an automobile, the advancement of technology and
13 its integration in the driving environment has become paramount. Head-Up Displays (HUDs) in cars have emerged
14 in recent years and have become a pivotal innovation that can help to make driving safer and more straightforward
15 such as this prototype from Suzuki. Several car companies have begun implementing these within their cars' designs,
16
17



37 hoping to make their vehicles more secure and easier to drive. The ergonomic optimization of driver infotainment
38 systems, a cornerstone of our research, focuses on aligning various HUD designs with human interaction factors to
39 minimize visual and cognitive distractions. Recent studies stated how the use of HUDs can enable drivers to respond
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41

*Both authors contributed equally to this research.

43 Authors' address: Mason Stencil, mstencil9@gmail.com; Liam Hartman, lhartman2014@gmail.com, Colorado State University, W Laurel St, Fort Collins,
44 Colorado, USA, 80521.

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53 faster to unanticipated road events under both low and high driving loads. [2] This demonstrates the usefulness of
54 HUDs, as the ability to respond to cautious road events is greatly improved by providing additional information in a
55 more user-friendly way.

56 Building upon the established benefits of HUD technology in enhancing driver safety and responsiveness, the specific
57 focus of our study explores an additional dimension of driving efficiency—gear shifting. The proper timing of gear shifts,
58 particularly in vehicles with manual or semi-automatic transmissions, is crucial for maximizing a vehicle's acceleration
59 and overall performance. This becomes especially significant in scenarios requiring rapid acceleration, such as merging
60 onto highways or navigating through fast-changing traffic conditions.

61 Integrating HUD technology to assist with gear shifting not only aims to improve driving performance but also
62 to reduce the cognitive load on drivers. By providing clear, timely cues for optimal shift points, HUDs can help
63 drivers maintain their attention on the road, thus minimizing the distraction typically associated with looking down at
64 traditional gear shift indicators or tachometers. Research indicates that these integrations can lead to a more intuitive
65 driving experience, where drivers can react more instinctively rather than splitting their focus between multiple sources
66 of information [5].

67 Moreover, the adaptation of HUDs for this purpose aligns with broader automotive safety goals. By optimizing the
68 information presentation directly within the driver's line of sight, HUDs can significantly decrease the likelihood of
69 reaction-time delays that are common when drivers shift their gaze between the road and instrument clusters [3]. The
70 implications for traffic safety are substantial, offering potential reductions in accidents due to delayed driver responses.

71 The significance of HUDs extends beyond mere safety enhancements. As automotive technologies evolve, the
72 integration of advanced data displays like HUDs can contribute to higher standards of vehicle efficiency and environ-
73 mental considerations. Efficient gear shifting not only improves vehicle performance but also helps in reducing fuel
74 consumption and emissions. Studies have shown that optimal gear shifting can lead to a smoother driving style, which
75 is less taxing on the vehicle's engine and can extend the life span of its components [4].

76 This holistic approach to improving both the mechanical and interactive aspects of driving through HUDs is what our
77 study aims to quantify. By focusing on the dual aspects of safety and efficiency, the research provides a comprehensive
78 look at how modern technology can transform driving into a more secure and enjoyable experience by enhancing
79 both driver efficiency and skill.

80 The HUD prototype we developed utilizes a Raspberry Pi 4 B as its core, interfacing with a 7-inch LCD monitor to
81 display real-time vehicle data crucial for both performance and safety. This data is sourced directly from the vehicle's
82 Engine Control Unit (ECU) via an ELM 327 chip, which connects with bluetooth through the On-Board Diagnostics
83 II (OBD2) port, ensuring seamless communication and data accuracy. Key metrics displayed include engine speed
84 (RPM), oil temperature, oil pressure, and coolant temperature. These are critical parameters that influence not just
85 the vehicle's health but also its performance, particularly during high-demand driving situations where optimal gear
86 shifting is essential. The Raspberry Pi's computational capabilities are leveraged to not only display these metrics
87 but also analyze them to provide actionable insights. This includes identifying the optimal RPM for shifting gears to
88 maximize acceleration and efficiency—a feature particularly beneficial during rapid acceleration phases such as 0 to 60
89 mph tests.

90 Head-Up Displays, or HUDs, put important info right in front of drivers so they can stay safe on the road. A lot of
91 cars are starting to have these screens, and our goal is to make them even better. This targeted focus on enhancing
92 gear shifting through HUD technology not only augments driving performance but also contributes to safer and more
93 efficient driving practices. As we continue to refine our system, we aim to integrate more advanced features such as

adaptive recommendations for different driving styles and conditions, further personalizing the driving experience and optimizing vehicle operation in real-time. Plus, these screens can work with other parts of the car, like the radio or maps, so everything feels like it's part of the same system. People are starting to expect these high-tech features in their cars. Studies show that drivers want cars that help them stay safe. [8] So, we're not just making something cool – we're making something people are looking for. Our research looks at how HUDs can make driving better. With our findings, we hope to make driving a safer and more enjoyable experience.

2 RELATED WORKS

Recent advancements in head-up display (HUD) technology have significantly influenced driving performance and safety. Research indicates that HUDs enhance situational awareness and facilitate quicker decision-making, crucial in high-stress driving environments [1][2]. Furthermore, studies have demonstrated that drivers using HUDs show improved performance in reaction-based tasks compared to those relying on traditional dashboard displays [2].

Despite the benefits, the integration of HUDs in automotive environments raises concerns about potential distractions. Research highlights the risk of information overload, which could detract from the essential visual and cognitive tasks required for safe driving [3]. However, other studies support the use of HUDs in maintaining situational awareness in complex traffic scenarios, suggesting that these technologies can assist in decision-making processes without overwhelming the driver [4].

Further exploration into the impact of HUD design on user experience focuses on how layout, color schemes, and hierarchical display of information affect attention and interaction in simulated environments [5]. These findings underscore the importance of design considerations in developing HUD interfaces that enhance usability and contribute to vehicular safety.

The literature review underscores the dual aspects of HUD technology—enhancing driver performance and potentially introducing distractions. While several studies validate the efficacy of HUDs in improving reaction times and situational awareness [1][2], concerns about cognitive overload necessitate a balanced approach in HUD implementation that maximizes benefits while minimizing risks [3][4]. Insights from recent research provide direction on optimizing HUD designs to improve user interaction and safety outcomes [5]. Collectively, these studies form a comprehensive foundation for our project, aiming to innovate HUD technology by integrating empirical evidence into the design and functional aspects of our development. [13]

Innovations in HUD technology also focus on enhancing the visual and interactive aspects of these systems. Recent advancements include the development of augmented reality (AR) HUDs that project dynamic, depth-variable information onto the windshield, providing drivers with real-time data tailored to the driving context [7][10]. These technologies not only aim to enhance the user interface but also strive to minimize cognitive load by integrating seamlessly into the driver's line of sight.

The design of HUD interfaces has evolved to include more intuitive and user-friendly elements, which are critical for ensuring that drivers can understand and utilize the information presented without distraction. Studies on new holographic and AR HUDs show potential for further reducing the intrusion of the interface while providing clearer, more context-sensitive information [14][15][16]. Such features are designed to improve the overall safety and efficiency of driving by enhancing the driver's perception and interpretation of critical data.

Further research has explored the application of HUDs in specialized scenarios, such as emergency vehicle operations, where the speed of response and accuracy of navigation are paramount.[9] Innovations in this area have leveraged AR and artificial intelligence to enhance the capabilities of HUDs, providing emergency responders with vital navigational

157 and situational awareness tools that adapt to the unique demands of high-speed driving and critical decision-making
158 [9].
159

160 As HUD technology continues to develop, the potential to incorporate features such as gesture recognition and
161 LiDAR-derived holography offers exciting prospects. These technologies can further reduce the effort and distraction
162 involved in operating conventional interfaces, potentially leading to safer and more intuitive user interactions [12][16].

163 Furthermore, emerging research on large and 3D windshield displays explores the boundaries of HUD technology,
164 seeking to create more immersive and informative user experiences. These displays aim to offer a broader field of view
165 and more detailed visual information, which could revolutionize how drivers interact with the myriad of driving-related
166 data and infotainment systems [20].

167 Collectively, these studies form a robust foundation for ongoing HUD research and development. They highlight the
168 importance of a balanced approach to HUD implementation—one that maximizes the benefits of enhanced situational
169 awareness and response time while minimizing potential distractions and cognitive overload [18][19]. This body of
170 work informs our project’s direction, aiming to integrate these insights into the design and functional improvements of
171 HUD systems for both everyday and high-stakes driving scenarios.
172

173 3 METHODOLOGY

174 The advancement of automotive technology has led to the integration of various assistive features designed to enhance
175 driving safety, efficiency, and comfort. Among these innovations, Head-Up Displays (HUDs) have emerged as a promising
176 tool to aid drivers by projecting essential information directly into their line of sight, thus minimizing distractions and
177 improving focus on the road. This experiment is motivated by the potential benefits of HUDs in optimizing vehicle
178 control during critical driving tasks, specifically shifting points during acceleration in manual and semi automatic
179 transmission vehicles. Acceleration efficiency, particularly the timing of gear shifts, significantly impacts a vehicle’s
180 performance and the driver’s ability to react to dynamic driving scenarios. By providing real-time, visually accessible
181 cues for optimal shifting, HUDs may not only enhance vehicular performance but also promote safer driving practices.
182 The study aims to empirically assess the impact of HUD technology on improving 0 to 60 mph acceleration times,
183 comparing the performances of experienced drivers and those less familiar with intricate driving techniques with the
184 use of a HUD compared to no use of a HUD. This research seeks to provide insights into how different driver groups
185 adapt to and benefit from advanced driving aids, contributing to the broader understanding of adaptive automotive
186 technologies’ effectiveness.
187

188 *Research Questions* This study is structured around several key research questions that aim to dissect the functional
189 impact of HUD technology on driving performance and learning:
190

- 191 (1) How does the use of a HUD affect the acceleration performance of drivers during controlled tests from 0 to 60
192 mph?
- 193 (2) Does the HUD provide a measurable benefit in shifting efficiency and timing compared to traditional driving
194 without a HUD?
- 195 (3) Are there significant differences in the benefits provided by the HUD between experienced drivers and novices?
- 196 (4) How do drivers perceive the usability and effectiveness of HUD technology in real-time driving situations?

197 These questions guide the experiment’s design and focus, seeking to clarify the role of HUDs in enhancing both
198 driver performance and cognitive engagement with vehicle operation.
199



Fig. 1. Example of a Participant in the Study

Participants For this experiment, we recruited 10 participants, divided into two distinct categories to assess the impact of Head-Up Display (HUD) technology on driving performance with a focus on shifting points during acceleration. The first group consisted of five "experienced" drivers who frequently engage in driving and use simulation racing games (sim racers), suggesting a higher proficiency and interest in vehicle control and performance. The second group comprised five "novice" drivers, individuals who drive regularly but do not engage deeply with the mechanics of driving or simulation racing, representing typical drivers without specialized driving skills.

Equipment Setup The study employed one vehicle using a semi-automatic transmission. This was chosen due to the simplicity of shifting, helping eliminate any potential errors in performing the gear change, allowing our data to focus on the specific results of the time of shifting with and without our HUD. The vehicle was fitted with our HUD system that provided real-time data on optimal shifting points to maximize acceleration efficiency. The other portion used the same vehicle but without the HUD and served as the control setup. Both vehicles were equipped with standardized telemetry devices to accurately measure acceleration times from 0 to 60 mph and to record shifting patterns. Dashcams were installed to visually document each participant's interaction with the vehicle controls and the HUD.

Procedure Overview Participants attended a preliminary session where they were introduced to the study's objectives, the technology being tested, and the experimental protocol. They were also familiarized with the vehicle to ensure comfort and safety during the driving tests.

The experiment was conducted in a private area to ensure a controlled environment and the safety of all participants. Each participant drove the vehicle in both the HUD-equipped and standard setup in a randomized order to mitigate any order effects. For each setup, participants performed three timed trials to ensure consistent and reliable data collection. In the HUD-equipped setup, drivers were instructed to utilize the HUD cues for optimal shifting points, while in the standard setup, drivers relied solely on their judgment and experience.

Data Collection and Analysis The primary quantitative measure for this study was the acceleration time from 0 to 60 mph for each trial, recorded using the onboard telemetry units. This data was complemented by qualitative assessments derived from video recordings, which provided insights into how participants interacted with the HUD and their shifting strategies.

261 Post-experiment, participants were asked to complete a structured questionnaire designed to capture their subjective
262 experiences, perceived ease of use, and perceived effectiveness of the HUD in assisting with gear shifts. Additionally,
263 semi-structured interviews were conducted to gather more detailed feedback on their preferences between driving with
264 and without the HUD.

265 *Statistical Analysis* The data analysis involved using a graph and averages to compare the acceleration times between
266 two setups—driving with the HUD and without it—across two groups of participants: experienced and novice drivers.
267 This approach helped in determining the significance of the differences observed. Further analysis explored whether
268 the level of driving experience influenced the effectiveness of the HUD, providing insights into how the technology
269 impacts drivers with varying levels of skill and familiarity with gear shifting.

270 This detailed methodology ensures a comprehensive evaluation of how HUD technology impacts driving performance,
271 particularly in optimizing gear shifting during critical acceleration phases, across different driver expertise levels.

272 4 FINDINGS

273 *Quantitative Findings* The central quantitative analysis of this study revolved around the acceleration times from 0 to
274 60 mph across two different conditions: driving with the HUD and without the HUD. This evaluation was segmented
275 further into two distinct driver groups—experienced drivers, often engaged with sim racers, and typical drivers not
276 regularly focused on manual gear shifting.

277 We collected data by retrieving an average time for both acceleration with the HUD and without the HUD for
278 each participant. We performed 30 trials total, with each participant performing three trials using the HUD and three
279 trials without the HUD. These trials were then divided into the two participant categories, the novice drivers and
280 the experienced drivers. We then graphed the data using Matplotlib to help better understand the correlation. For
281 novice drivers, the average acceleration time without the HUD assistance was approximately 11.7 seconds. However,
282 with the HUD indicating optimal shifting points, this average decreased to 10.8 seconds, demonstrating a noticeable
283 improvement in acceleration efficiency. Experienced drivers showed a similar trend, where the average time without
284 HUD assistance was around 10.2 seconds, and with HUD, it was reduced to 9.6 seconds. These results suggest that the
285 HUD system effectively aids drivers in achieving faster acceleration by optimizing shift timings, irrespective of their
286 prior driving experience.

287 The graph and the data collectively highlight a significant correlation between HUD assistance and improved
288 acceleration performance across both novice and experienced drivers. Notably, the improvement in acceleration times
289 was more pronounced among novice drivers, indicating a higher relative benefit from HUD guidance. This suggests that
290 while experienced drivers already possess more efficient shifting habits, possibly due to their familiarity with manual
291 gear shifting or racing simulations, the HUD system still offers a measurable enhancement in their performance.

292 Experienced drivers, accustomed to reacting to dynamic driving conditions, were able to incorporate the real-time
293 data from the HUD seamlessly into their driving strategy, resulting in a smaller yet significant improvement in their
294 acceleration times. This efficiency gain underscores the HUD's potential not only as a training tool for less experienced
295 drivers but also as an enhancement for skilled drivers to fine-tune their performance.

296 Conversely, the larger improvement seen in novice drivers emphasizes the HUD's role as a critical support system
297 that can significantly augment a driver's ability to make optimal decisions in real-time. For these drivers, the HUD acts
298 almost as an on-the-fly training module, demonstrating the ideal times to shift gears which they might not otherwise
299 recognize or execute without the augmented display.

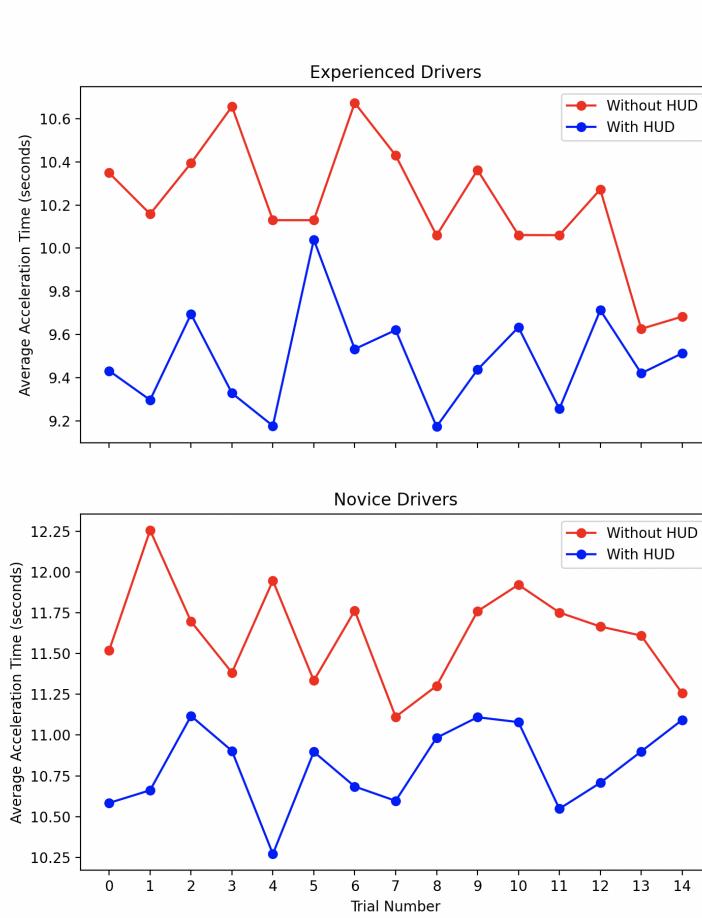


Fig. 2. HUD Data

These findings suggest a dual utility of the HUD technology—serving both as an educational tool for novices to improve their basic driving skills and as a performance enhancement tool for experienced drivers to maximize their driving efficiency. This dual benefit underscores the potential widespread applicability of HUD technology in improving road safety and driving performance across various levels of driving expertise.

Qualitative Findings In addition to the measurable performance improvements, qualitative data derived from post-experiment interviews and questionnaires provided deeper insights into the participants' experiences and perceptions. Both groups reported that the HUD significantly enhanced their driving experience by providing clear, timely, and useful cues for gear shifting. Many participants noted that the HUD not only helped in reducing the cognitive load but also made the driving process more engaging and less stressful, particularly during the intense focus required for optimal acceleration.

365 Experienced drivers expressed a high appreciation for the HUD's precision and reliability, stating that it closely
366 matched their intuitive shift points, thereby enhancing their natural driving style. On the other hand, novice drivers
367 appreciated the educational aspect of the HUD, which helped them understand better vehicle dynamics and the
368 mechanics of efficient gear shifting.
369

370 The feedback also highlighted some areas for improvement, such as the desire for customizable HUD interfaces that
371 could adapt to individual preferences and driving conditions. Some participants suggested that additional real-time data,
372 such as temperature gauges, could be integrated into the HUD to further support decision-making processes during
373 different driving scenarios.
374

378 5 DISCUSSION

379

380 The findings from this study indicate that HUDs can significantly enhance vehicle performance by optimizing gear
381 shifting times during acceleration phases. The improvement in acceleration times across both novice and experienced
382 drivers confirms the HUD's role in enhancing situational awareness and driving efficiency. Moreover, the positive
383 qualitative feedback underscores the potential of HUD technology to make driving a more intuitive and enjoyable
384 experience. These insights could be pivotal in guiding future developments in automotive HUD technology, focusing
385 on customizable and adaptive interfaces to cater to a broader range of driving styles and preferences.
386

387 The research questions posed at the beginning of this study sought to explore the multifaceted impact of HUD
388 technology on driving performance, particularly through the lens of acceleration efficiency, user experience, and
389 adaptability between different driver skill levels. Our findings provide compelling evidence that HUDs significantly
390 enhance vehicle performance by optimizing gear shifting times, thereby improving acceleration times from 0 to 60 mph
391 for both novice and experienced drivers. This underscores the technology's capacity to enhance situational awareness
392 and improve driving mechanics, effectively answering our primary research questions.
393

394 Furthermore, the differential benefits observed between novice and experienced drivers begin to address the inquiry
395 into whether HUD technology disproportionately benefits one group over the other. While both groups saw
396 improvements, novice drivers displayed a more pronounced enhancement in their driving performance, suggesting that
397 HUDs may serve a dual role: as an educational tool for less experienced drivers and as a performance enhancer for the
398 more seasoned. This finding is critical as it suggests that HUD technology can be tailored to varying levels of driving
399 experience, enhancing its utility across a broad spectrum of users.
400

401 Additionally, the qualitative feedback collected highlights the user's perception of HUD effectiveness and usability.
402 Drivers reported that the HUD not only reduced cognitive load but also made the driving process more engaging
403 and less stressful, particularly during intense driving sessions. This suggests that HUDs do more than merely display
404 information; they integrate into the driving experience, making it more intuitive and enjoyable. This feedback begins to
405 answer the final research question regarding driver perceptions, indicating that the usability and integration of HUD
406 technology are well-received by users, pointing towards a strong potential for broader adoption in future automotive
407 designs.
408

409 These insights collectively provide a robust framework for understanding the various dimensions in which HUDs
410 impact driving, guiding future technological enhancements and ensuring that such innovations are responsive to the
411 needs and experiences of all drivers.
412

417 6 CONCLUSION

418 This study has demonstrated the significant potential of Head-Up Display (HUD) technology to enhance vehicle
419 performance and driving safety through optimized gear shifting. The empirical data gathered from both experienced
420 and novice drivers indicate that the use of HUDs can effectively reduce acceleration times by providing timely and
421 accurate shifting cues. For experienced drivers, the HUD reinforced their skilled practices, while for novice drivers, it
422 served as an invaluable learning tool, enhancing their understanding and execution of efficient driving techniques.
423

424 The positive reception of the HUD system, as reflected in the qualitative feedback, highlights its utility in reducing
425 cognitive load and enhancing the driving experience. This acceptance across different driver groups underscores the
426 adaptability and broad appeal of HUD technology. Moreover, the suggestion for customizable HUD interfaces suggests
427 a direction for future enhancements that could cater more specifically to individual driver preferences and conditions.
428

429 HUDs have become a revolutionary technology for improving both driving efficiency and safety, and are something
430 that are becoming more and more prevalent for the future. Developing and experimenting with this technology has
431 provided us with extensive knowledge on how these programs work, allowing us to create our own customized system
432 that has proved to be effective in aiding driving skills and safety. With this knowledge, we look forward to what is to
433 come from future HUD technologies, as well as further expanding our project to include more customizable features.
434

435 7 FUTURE WORK

436 Future research should focus on refining the HUD technology to offer more personalized driving aids. One promising
437 avenue is the integration of machine learning algorithms to dynamically adjust the information displayed based on the
438 driver's habits and the driving context. This could involve more sophisticated metrics that predict and advise on not
439 just gear shifting but also fuel efficiency and predictive vehicle maintenance.

440 Additionally, expanding the study to include a larger and more diverse sample of drivers could provide further
441 insights into the universal applicability of HUD technology. Studies could also explore the long-term effects of using
442 HUDs on driving skills development and accident rates, which would provide more substantial evidence of their impact
443 on road safety.

444 Experimentation with advanced display technologies, such as OLED or flexible displays, could enhance visibility and
445 integration into different vehicle designs, making HUDs more accessible and appealing to a wider market. Moreover,
446 the exploration of augmented reality (AR) in HUDs to project navigational and hazard detection directly onto the
447 windshield could revolutionize driver awareness and interaction with the vehicle environment.

448 In conclusion, the research conducted provides a strong foundation for the future development of HUD technologies
449 in automotive applications. It is clear that with continued innovation and user-centered design, HUDs have the potential
450 to significantly enhance the safety and efficiency of driving, making them a critical component of modern automotive
451 technology.

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456 of HUDs on driving behaviors.
457

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