How Seat Clearance and Steering Wheel Reach Affect Race Car Driver Performance, Comfort, and Fatigue

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Introduction

Motivation and Problem Statement

In motorsports, races come down to fractions of a second. Teams spend enormous resources optimizing the mechanical side of the car, but the human side matters just as much. A driver's precision, reaction time, and endurance are all tied to how well the cockpit fits their body. A poor seat configuration forces drivers into positions they have to compensate for, and that compensation adds up fast through muscle fatigue, degraded input accuracy, and eventually more errors on track. This is not just a motorsport problem either. The same principles apply to aviation, heavy machinery operation, and even standard vehicle design.

What is interesting is that despite how much cockpit fit clearly matters, there is still a lot we do not understand about how specific fit variables interact. No study has looked at seat clearance and steering wheel reach distance together to see how they jointly affect performance. On their own, both make sense. A seat that is too small puts the driver in a cramped posture and increases strain, while one that is too large forces them to work harder just to stay stable. A steering wheel that is too close or too far throws off arm positioning and makes precise inputs harder. The problem is that no research has looked at what happens when both are wrong at the same time. The combined ergonomic load is most likely worse than either issue alone, but the literature has not yet tested that. That is what this study sets out to do.

Research Question and Goals

This study investigates the following question: “What is the effect of seat clearance and steering wheel reach distance on race car driver performance, comfort, and perceived workload in a controlled simulator environment?” To address this question, a mixed 3x3 factorial design was used, manipulating seat clearance across three levels and steering wheel reach distance across three levels. This yields nine experimental conditions. Both the independent and interaction effects of these variables are examined across four dependent measures: race time, driving error count, NASA-TLX perceived workload scores, and body part discomfort ratings.

There are three primary goals of this study. First, to determine the optimal combination of seat clearance and steering wheel reach distance that minimizes driver workload and discomfort while maximizing race performance. Second, to quantify the individual main effects of each ergonomic variable on objective performance outcomes using race time and driving error count as a measurable outcome. Third, to assess whether a significant interaction effect exists between seat clearance and steering wheel reach distance.

Based on these goals and the supporting literature, three hypotheses were proposed. It was hypothesized that optimal seat clearance would produce significantly better outcomes across all four dependent variables compared to both the undersized and oversized conditions (H1). It was then hypothesized that optimal steering wheel reach distance would produce significantly better outcomes across all four dependent variables compared to both the close and far conditions (H2). Lastly, it was hypothesized that an interaction effect would exist between seat clearance and steering wheel reach distance, with the combination of optimal seat clearance and optimal reach would produce the best outcomes across all dependent variables (H3).

Significance

The findings of this study contribute to the broader understanding of how workspace ergonomic design shapes human performance under high-demand conditions. While the immediate application is motorsports, the implications can extend to aviation, heavy machinery, and consumer automotive designs. No existing study has examined seat clearance and steering wheel reach distance in combination, which results in current cockpit design decisions being made without a quantified understanding of how their interaction affects human output.

Background

Ergonomics in Motorsports

Racing performance is shaped not only by mechanical factors but by how effectively a driver's body interacts with the cockpit. Rosalie and Rosalie (2021) provided direct evidence of this relationship by applying an EMG study to optimize the driving positions of four amateur female drivers. Three of the four drivers improved their lap times by an average of 4.60 seconds after using a custom-molded seat insert. The performance gains were due to reductions in cervical and lumbar angles, which reduced compensatory muscle activation and improved steering precision. These findings show that seat dimensions influence posture, muscle activation patterns, and driver output. This justifies treating seat clearance as an independent variable across three levels in this study.

Mungai (2025) reinforced the significance of this study by performing a systematic review of physiological conditioning in motorsport athletes, analyzing 18 peer-reviewed studies published between 2000 and 2024. The review identified neck, shoulder, and other core muscles as the primary areas of physiological strain during racing, driven by G-force loading that can exceed four to five G-forces during cornering. Core muscle endurance was observed to decline after 30 minutes of G-force exposure, which shows increases in steering error rates, directly supporting this present study’s inclusion of race time and driving error count as dependent variables. The review also cited Pick and Cole (2006) in demonstrating that the driver's position relative to the steering wheel directly determines which muscles are used during steering and how efficiently torque is produced, supporting the decision to manipulate steering wheel reach distance across close, optimal, and far conditions in the present study. Mungai (2025) further mentioned that no existing study had isolated seat fit and steering wheel reach as simultaneous independent variables, identifying this as a gap in the literature that this present study attempts to address.

One of our group members is involved in a racing club here at the University of Florida. This idea stemmed from the fact that the club wanted measurable data to help them understand optimal seat positioning in order to maximize performance among their drivers. As a team we knew we could do the research and provide this club with the information they desired.

Workload and NASA-TLX

Perceived workload is a widely utilized concept in Human Factors research. It combines the mental, physical, and temporal demands placed on an individual and is strongly linked to task performance. Richard G. Marklin et al. (2005) found in a simulated work environment that unnatural postures that require extended or constrained joint positions increased biomechanical effort. This led to slower response times and reduced movement efficiency. In driving contexts, posture is determined by the configuration of the cockpit, which means that seat clearance and steering wheel reach distance directly affect motor performance. However, prior work has focused primarily on extreme postures, with limited studies on how moderate variation in body position impacts performance. This study addresses that gap by evaluating driving performance under small controlled changes in seat clearance and reach distance.

The NASA Task Load Index (NASA-TLX), created by Sandra G. Hart and Lowell E. Staveland (1988), measures subjective workload across six domains to assess cognitive and physical demand. Tse (2019) applied NASA-TLX in a motorsport setting, finding that workload composition shifted with experience. Tse found that physical demand was the dominant contributor to workload at higher performance levels. The study also demonstrated a relationship between workload and lap time as well as track unfamiliarity being a major driver of increased workload, leading to the inclusion of our two-hour familiarization phase. While NASA-TLX has been used previously in driving research, prior studies have not isolated the effects of specific ergonomic variables such as seat clearance and steering wheel reach distance. Together, these studies suggest that posture, workload, and performance are related, but they are rarely examined together within the same controlled ergonomic study. This study extends existing work by evaluating how these ergonomic factors influence perceived workload, physical discomfort, race time, and driving error count.

Anthropometric Measurement

Anthropometric research emphasizes the importance of representative sampling when analyzing variation in human body dimensions. Paquet et al. (2012) stated that anthropometric studies typically require a large number of individuals selected in a manner so that demographic characteristics impacting body size and function are proportionally representative of a user population. Anthropometric design commonly uses extreme percentiles (e.g., 5th and 95th) to ensure that a design can accommodate a wide range of users. This common approach in anthropometric literature is useful for establishing design limits, but it is less suited for evaluating how smaller fit differences affect performance within a more specific user group. In the present study, the goal was not to accommodate the full range of users, but to examine variation among typical individuals near the median. To represent a controlled subset, participants were selected within the 40th-60th percentile range of height and weight. This approach allows us to investigate ergonomic effects and limiting extreme body sizes as potential outliers, making it more appropriate for a controlled experiment, and allows us to potentially translate the data to more anthropometric percentile groups in the future through correlation analysis.

Methods

Study Design

This study used a mixed factorial 3x3 design, with seat clearance as a between-subjects factor and steering wheel reach distance as a within-subjects factor. The first independent variable is seat clearance, which refers to the difference between the width of the seat and the driver's hip breadth. The second independent variable is steering wheel reach distance, which refers to how far the steering wheel is positioned from the driver relative to their optimal reach point. Both variables were evaluated at three levels, resulting in nine experimental conditions, each with ten observations, culminating in a total of 90 race observations across the entire sample. Thirty people took part because each person ran three races, and 90 races divided by 3 races per person equals 30.

Two data sources were used. The primary dataset was generated through AI-assisted simulation using Claude (Anthropic, 2025) with Python-based statistical tools, with all parameters grounded in the peer-reviewed literature reviewed in this paper. An online survey was also administered to approximately 67 members of the general public to collect real-world subjective comfort data as a reference point alongside the simulation findings. A mixed factorial ANOVA was used to evaluate the main effects of each independent variable and their interaction across four dependent variables.

Participants

Two participant groups contributed data to this study. The first group consists of 67 public participants who completed an online survey about their comfort preferences related to driving position and vehicle fit.

The second group consists of 30 simulated male participants modeled after the same demographic profile. Only male participants were included to remove gender as a confounding variable, since males and females differ in hip breadth and arm reach, both of which are directly tied to the independent variables in this study. The 20 to 22 age range was chosen to match the profile of young professional F1 drivers and to reflect a realistic recruitment pool.

Participants were modeled within the 40th to 60th percentile for height and weight, roughly 173 to 180 cm and 70 to 84 kg, so that any differences in outcomes could be tied back to the seating configurations rather than differences in body size. Participants were also assumed to have some prior simulator experience, meaning they had used racing simulation software before but had no formal competitive racing background. Before the study began, each participant's hip breadth and optimal steering wheel reach distance were measured individually and used to set up their assigned conditions.

Independent Variables

The two independent variables in this study were seat clearance and steering wheel reach distance.

Seat clearance refers to how well the seat width fits the driver's hip breadth and was tested at three levels based on incremental offsets from each participant's measured hip breadth. The undersized condition set the seat 2 cm narrower than the driver's hip breadth (-2 cm), which pushed the driver into a restricted posture that limits range of motion and makes it harder to operate controls. The optimal condition set the seat 2 cm wider than hip breadth (+2 cm), giving the driver a natural posture with proper lateral support. It was set at +2 cm instead of 0 cm because a seat that perfectly matches hip breadth leaves no room on either side, which ends up being physically uncomfortable and not ergonomically sound. The oversized condition set the seat 6 cm wider than hip breadth (+6 cm), which takes away lateral support and forces the driver to constantly use stabilizing muscles just to stay in position throughout the race.

Steering wheel reach distance refers to how far the wheel is placed from the driver relative to their personally measured optimal reach point and was also tested at three levels. The close condition placed the wheel 4 cm closer than optimal (-4 cm), which cramped the arms and put extra strain on the shoulders and wrists. The moderate condition placed the wheel right at the participant's optimal position (0 cm), which is the point where a natural elbow angle of about 120 degrees is achieved with hands on the wheel. The far condition placed the wheel 4 cm further than optimal (+4 cm), requiring a slight forward lean and putting more demand on the upper limbs over time. Neither the close nor far condition is extreme or impossible to drive in — both are realistic fit variations that fall within the range documented in McFadden et al. (2000).

Both variables affect how much physical effort the driver has to put in just to stay in control of the car. Anytime you deviate from the optimal level in either direction, workload goes up, precision goes down, and race times get slower.

Dependent Variables

Four dependent variables were measured across the simulated dataset. Race time was recorded in seconds over 66 laps at Circuit de Barcelona-Catalunya and served as the primary measure of driver performance. This metric was chosen because it provides the most direct and measure of how seat orientation affects overall driving output, and is the most realistic driving performance metric used in the real world.

Driving error count captured the number of track limit violations per race, defined as instances in which all four wheels of the car crossed outside the white boundary lines of the circuit. This definition is consistent with the official standard used in F1 racing and was automatically logged by the simulator.

NASA-TLX scores measured perceived workload across six subscales using the standard weighted procedure and were collected immediately after each race. This instrument was selected because it captures both the mental and physical demand placed on the driver, which are both expected to increase under non-optimal ergonomic conditions.

Average Body Part Discomfort ratings captured physical discomfort across five body regions including lower back, hips and buttocks, shoulders, arms and wrists, and neck, using a 1 to 10 scale administered after each session. This measure was included to provide insight into which specific areas of the body are most affected by each seating configuration.

In addition to the simulated dataset we collected data from a survey where 67 participants answered questions like severity of discomfort or tiredness on a scale of 1-10 after a 2 hour drive. This supplemental information, while purely qualitative, gives good insight into how people perceive workload, in relation to car seat preference, like accessibility of controls rated from 1-10 or seat stability (support) rated 1-10. While there is no real quantitative backing, through trial and error people tend to mess around with seat orientation until they find the right positioning for them, so while this information has little researchable backing, they aren't totally random responses.

Apparatus and Procedure

Apparatus

The simulator itself was a racing rig with an adjustable seat and steering column. It had a steering wheel, gas and brake pedals, and a seat on a fixed frame. That's what drivers physically interact with each session. All races were completed on F1 24 using the Circuit de Barcelona-Catalunya — a 4.675 km, 16 corner track that is basically the gold standard for testing in motorsport.

We actually considered doing this study on a real track. The original idea was to throw participants in our UF race car and record their times in person. The problem is that approach opens the door to way too many things we can't account for. Weather changes, road conditions, how rested someone is, prior driving experience, body size differences between participants — all of that could shift results for reasons that have nothing to do with seat or reach. A simulator removes all of it. What happens on track stays tied to the two things we actually care about.

For every session, the same settings were used across the board. F1 2024 car spec, medium compound tires, full fuel every race. Clear dry weather at 22 degrees. Cockpit view for everyone. Steering and force feedback locked in software. Same track, time trial mode, no traffic. Nothing changed between participants except seat clearance and reach distance — that was the whole point.

Procedure

The study ran over four weeks per participant, consisting of one pre-study session followed by three weekly data collection sessions.

In the pre-study session, participants completed a screening questionnaire and had their hip breadth and optimal reach distance measured. They then completed a two-hour familiarization race on the Circuit de Barcelona-Catalunya with no data collected. This session was included to eliminate the effect of track learning before data collection began. Because all participants completed the same track four total times across the study, it was important that gains from track familiarity had already plateaued before the first recorded race, so that differences in race time reflected ergonomic fit rather than track knowledge.

In each of the three data collection sessions, the simulator was set up to match the participant's assigned seat clearance and reach distance condition before they arrived. The seat width and steering wheel position were adjusted and checked against each participant's measurements before every session. Participants then completed a full 66 lap race. Immediately after each race, participants completed the NASA-TLX followed by the Body Part Discomfort scale, rating discomfort from 1 to 10 across five body regions. Race time and driving error count were automatically logged by the simulator. Each session was separated by seven days to allow for physical recovery and to prevent fatigue from carrying over into the next session.

Counterbalancing

To handle order effects across the three reach conditions, we used a Latin Square counterbalancing setup. Every participant was locked into one seat level for the whole study, with ten people per seat group. Inside each group, there were six possible ways to order the three reach conditions, and five participants were assigned to each ordering as shown in Table 1. This way every level ended up as Race 1, Race 2, and Race 3 exactly ten times each across the whole sample. Any performance trends that carried over from one session to the next got spread out evenly so no single reach condition had an edge over the others.

Table 1. Latin Square Counterbalancing Scheme — Seat Level and Reach Condition Order by Group

Group	Seat Level	Participants	Race 1 Reach	Race 2 Reach	Race 3 Reach
1	Undersized	1–5	Close	Optimal	Far
2	Undersized	6–10	Close	Far	Optimal
3	Optimal	11–15	Optimal	Close	Far
4	Optimal	16–20	Optimal	Far	Close
5	Oversized	21–25	Far	Close	Optimal
6	Oversized	26–30	Far	Optimal	Close

Design Evolution and Rationale

A few things changed as we developed this study and we want to be upfront about why.

The original plan was fully within-subjects, meaning every participant would go through all nine conditions across nine separate sessions. That got changed for two reasons. Nine two-hour sessions is 18 hours of commitment per person, which just wasn't realistic to ask of anyone. On top of that, having someone sit in all three seat configurations over time would likely cause them to adjust their driving style as they went, which would mess with the validity of our results. Jacko et al. (2012) point out that between-subjects assignment is the right call when repeated exposure creates learning or adaptation effects you can't control for. So we landed on assigning each participant to one seat level for the whole study, with all three reach levels tested within that across three weekly races. Ten people per seat group, Latin Square counterbalancing applied within each group to spread the reach order evenly. Every condition ended up covered exactly ten times, the dataset was fully balanced, and each participant only had to commit six hours total over three weeks.

We also originally planned to use fixed anthropometric values from population databases for seat clearance, with conditions set at the 5th, 50th, and 95th percentile hip breadth. That didn't work either. A seat built for the 5th percentile would actually be narrower than the hips of anyone in our 40th to 60th percentile participant pool, making the undersized condition literally impossible to sit in for two hours. And testing extreme percentiles on average-sized participants would just produce obvious discomfort rather than anything useful or meaningful. We switched to participant-relative offsets instead, which is explained in the Independent Variables section. The same logic carried over to steering wheel reach, with increments chosen to match the seat offsets and keep both variables on equal methodological footing, in line with McFadden et al. (2000).

Reaction time was on the list as a fifth dependent variable at one point. We cut it because getting accurate reaction time data would have needed a custom stimulus-response task programmed into the simulator, which was outside the scope of this study and would have added its own measurement problems. The four variables we kept cover performance, workload, and physical discomfort without needing any custom modifications to the software.

Results

Descriptive Statistics

Tables 2, 3, and 4 show the descriptive statistics for all four dependent variables broken down by seat clearance level, reach level, and all nine conditions respectively. Looking across all four measures, the optimal seat clearance condition had the lowest mean every time, while the undersized condition came in the highest. The same trend held for reach distance, where the optimal reach condition came out on top compared to both the close and far conditions across the board.

Table 2

Descriptive Statistics for All Four Dependent Variables by Seat Clearance Level

Seat Level	DV	Mean	SD	n
Undersized (−2 cm)	Race Time (sec)	6803.80	71.57	30
Undersized (−2 cm)	Error Count	19.73	3.29	30
Undersized (−2 cm)	NASA-TLX	74.40	9.95	30
Undersized (−2 cm)	Avg BPD	6.19	0.73	30
Optimal (+2 cm)	Race Time (sec)	6664.93	75.76	30
Optimal (+2 cm)	Error Count	12.57	4.07	30
Optimal (+2 cm)	NASA-TLX	62.34	10.81	30
Optimal (+2 cm)	Avg BPD	4.33	0.75	30
Oversized (+6 cm)	Race Time (sec)	6728.10	66.91	30
Oversized (+6 cm)	Error Count	16.47	4.15	30
Oversized (+6 cm)	NASA-TLX	69.61	11.76	30
Oversized (+6 cm)	Avg BPD	5.28	0.85	30

Table 3

Descriptive Statistics for All Four Dependent Variables by Steering Wheel Reach Level

Reach Level	DV	Mean	SD	n
Close (−4 cm)	Race Time (sec)	6794.97	63.97	30
Close (−4 cm)	Error Count	19.30	3.78	30
Close (−4 cm)	NASA-TLX	76.11	10.82	30
Close (−4 cm)	Avg BPD	6.10	0.82	30
Optimal (0 cm)	Race Time (sec)	6663.20	70.28	30
Optimal (0 cm)	Error Count	13.30	4.12	30
Optimal (0 cm)	NASA-TLX	61.22	10.58	30
Optimal (0 cm)	Avg BPD	4.49	0.88	30
Far (+4 cm)	Race Time (sec)	6738.67	85.24	30
Far (+4 cm)	Error Count	16.17	4.62	30

Table 4

Descriptive Statistics for All Four Dependent Variables Across All Nine Seat Clearance by Steering Wheel Reach Conditions

Seat	Reach	Race Time M (SD)	Error Count M (SD)	NASA-TLX M (SD)	Avg BPD M (SD)
Undersized	Close	6854.80 (42.74)	21.80 (2.10)	81.32 (3.72)	**6.95 (0.17)**
Undersized	Optimal	6727.60 (44.65)	17.00 (1.89)	67.77 (10.49)	5.47 (0.38)
Undersized	Far	6829.00 (51.36)	20.40 (3.66)	74.11 (9.63)	6.15 (0.55)
Optimal	Close	6738.30 (45.04)	16.00 (3.59)	70.10 (11.19)	5.12 (0.37)
Optimal	Optimal	**6598.20 (50.16)**	**9.60 (2.37)**	**54.52 (9.24)**	**3.60 (0.39)**
Optimal	Far	6658.30 (54.51)	12.10 (3.41)	62.39 (5.60)	4.26 (0.46)
Oversized	Close	6791.80 (42.09)	20.10 (3.00)	76.91 (12.93)	6.22 (0.34)
Oversized	Optimal	6663.80 (45.83)	13.30 (3.89)	61.38 (8.22)	4.40 (0.49)
Oversized	Far	6728.70 (38.08)	16.00 (2.31)	70.53 (8.69)	5.21 (0.37)

Figure 1 displays the mean race time across all nine conditions grouped by seat clearance level. The optimal seat and optimal (moderate) reach combination produced the fastest mean race time with M = 6,619.5 sec, while the undersized seat and close reach combination produced the slowest with M = 6,844 sec, that is a difference of 224.5 seconds. Figure 2 displays mean NASA-TLX perceived workload scores across the same nine conditions. The optimal seat and optimal (moderate) reach combination produced the lowest mean workload score with M = 52.4, while the undersized seat and close reach combination produced the highest with M = 81.5.

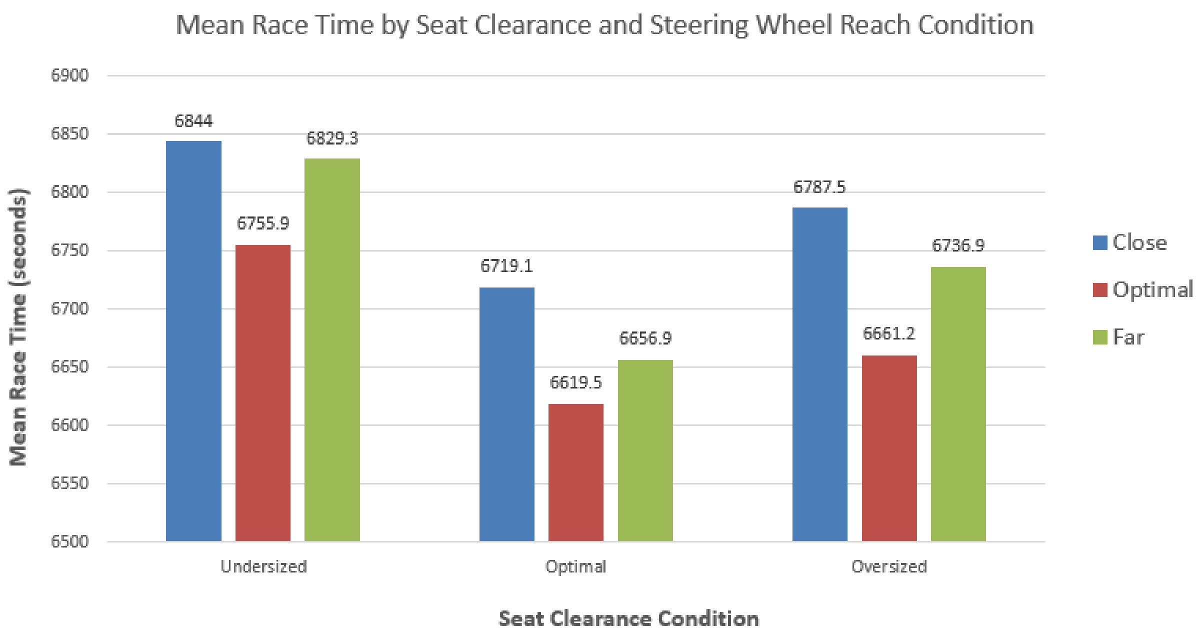

Figure 1. Mean race time (seconds) across all nine experimental conditions grouped by seat clearance level. Bars represent the close, optimal, and far steering wheel reach conditions within each seat clearance group. Error bars represent one standard deviation. The optimal seat and optimal (moderate) reach combination produced the fastest mean race time (M = 6,619.5 sec), while the undersized seat and close reach combination produced the slowest (M = 6,844 sec).

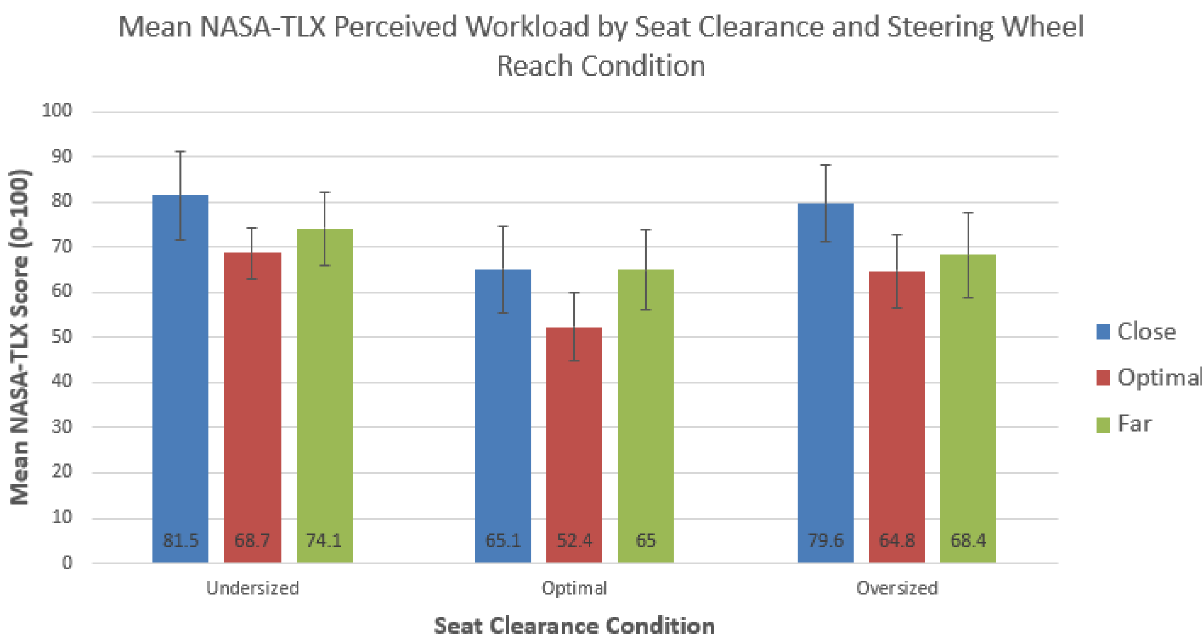

Figure 2. Mean NASA-TLX perceived workload scores across all nine experimental conditions grouped by seat clearance level. Bars represent the close, optimal, and far steering wheel reach conditions within each seat clearance group. Error bars represent one standard deviation. The optimal seat and optimal (moderate) reach combination produced the lowest mean workload score (M = 52.4), while the undersized seat and close reach combination produced the highest (M = 81.5).

Main Effects and Interaction Effect

Table 5

Mixed Factorial ANOVA Results for All Four Dependent Variables

Dependent Variable	Source of Variation	F (df)	p-value	η^2p	Effect Size
Race Time (sec)	Seat Clearance	F(2, 27) = 99.78	< .001	.881	✓ Large
Race Time (sec)	Reach Distance	F(2, 54) = 73.21	< .001	.731	✓ Large
Race Time (sec)	Seat × Reach	F(4, 54) = 0.35	.841	.025	✗ ns
Error Count	Seat Clearance	F(2, 27) = 74.67	< .001	.847	✓ Large
Error Count	Reach Distance	F(2, 54) = 28.56	< .001	.514	✓ Large
Error Count	Seat × Reach	F(4, 54) = 1.29	.286	.087	✗ ns
NASA-TLX	Seat Clearance	F(2, 27) = 31.59	< .001	.701	✓ Large
NASA-TLX	Reach Distance	F(2, 54) = 29.21	< .001	.520	✓ Large
NASA-TLX	Seat × Reach	F(4, 54) = 0.47	.760	.033	✗ ns
Avg BPD	Seat Clearance	F(2, 27) = 166.66	< .001	.925	✓ Large
Avg BPD	Reach Distance	F(2, 54) = 79.17	< .001	.746	✓ Large
Avg BPD	Seat × Reach	F(4, 54) = 0.69	.601	.049	✗ ns

Between-subjects error term df = 27 (seat clearance). Within-subjects error term df = 54 (reach distance, interaction). η^2p benchmarks: small ≥ .01, medium ≥ .06, large ≥ .14 (Cohen, 1988). Green = significant. Yellow = not significant.

The results of the mixed factorial ANOVA for all four dependent variables are presented in Table 5. To evaluate the effects of seat clearance and steering wheel reach distance on all four dependent variables: race time, driving error count, NASA-TLX score, and average body part discomfort, a mixed factorial ANOVA was conducted. Both main effects were statistically significant across all four dependent variables with $p < .001$. Large effect sizes were observed in each case. Seat clearance accounted for up to 92.5% of the variance in body part discomfort ($\eta^2p = .925$), while reach distance accounted for up to 74.6% ($\eta^2p = .746$), which indicates there is a strong influence on driver performance and comfort from the effect of both factors independently.

Optimal seat clearance (+2cm) produced the best outcomes across all dependent variables, while the oversized condition (+6cm) performed second, and the undersized condition

(-2cm) performed worst. This was similarly observed for reach distance, with the moderate condition (0cm offset) performing better than close (-4cm) and far (+4cm) conditions.

However, there was not a statistically significant interaction effect between seat clearance and reach distance for any dependent variable (all $p > .05$), meaning the effects of the two independent variables are additive, not interdependent. Improvements in seat clearance and reach distance have an independent contribution to improved performance and reduced workload without having a compounding interaction effect across conditions.

Post-hoc tests were run to figure out exactly which conditions were driving the differences we saw. For seat clearance, Tukey HSD showed that all three seat levels were significantly different from each other across race time, error count, and body part discomfort. The one exception was optimal versus oversized on NASA-TLX — that comparison didn't hit significance. For reach distance, paired t-tests with Bonferroni correction showed that all three reach levels were significantly different from each other across all four dependent variables, no exceptions. Bottom line — optimal beat both non-optimal levels on every single measure.

Survey Data

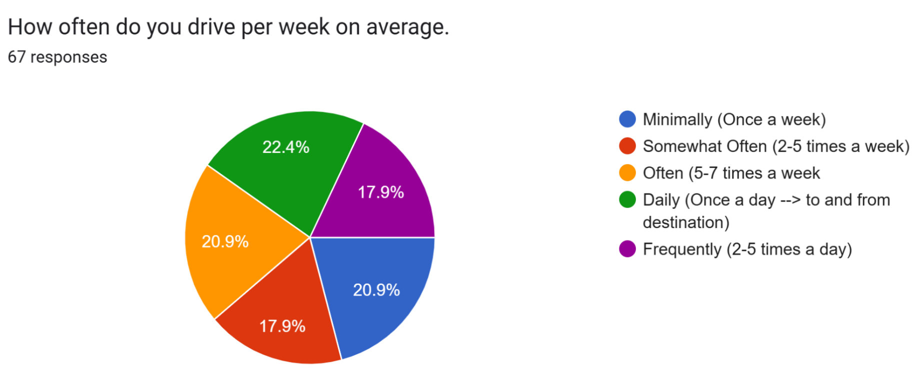

Figure 3. Distribution of driving activity from 67 total responders. The pie chart spans across 5 categories displaying how often the participant drives ranging from minimally (Once a week) to

frequently (2-5 times a day). The data distribution is relatively evenly split, with the maximum percentage of 22.4% of responders being daily drivers, and the minimum percentage of 17.9% for both frequent drivers (2-5 times a day), and somewhat often drivers (2-5 times a week). The maximum difference is 4.5%, which gives us a tight and well-spread data set. Additionally, the median age of responses was 21 y/o, with 26 responses, and 62 of the 67 responses were within the age range of 18-25 y/o, meaning the data set participants are a similar age group to our other simulated data.

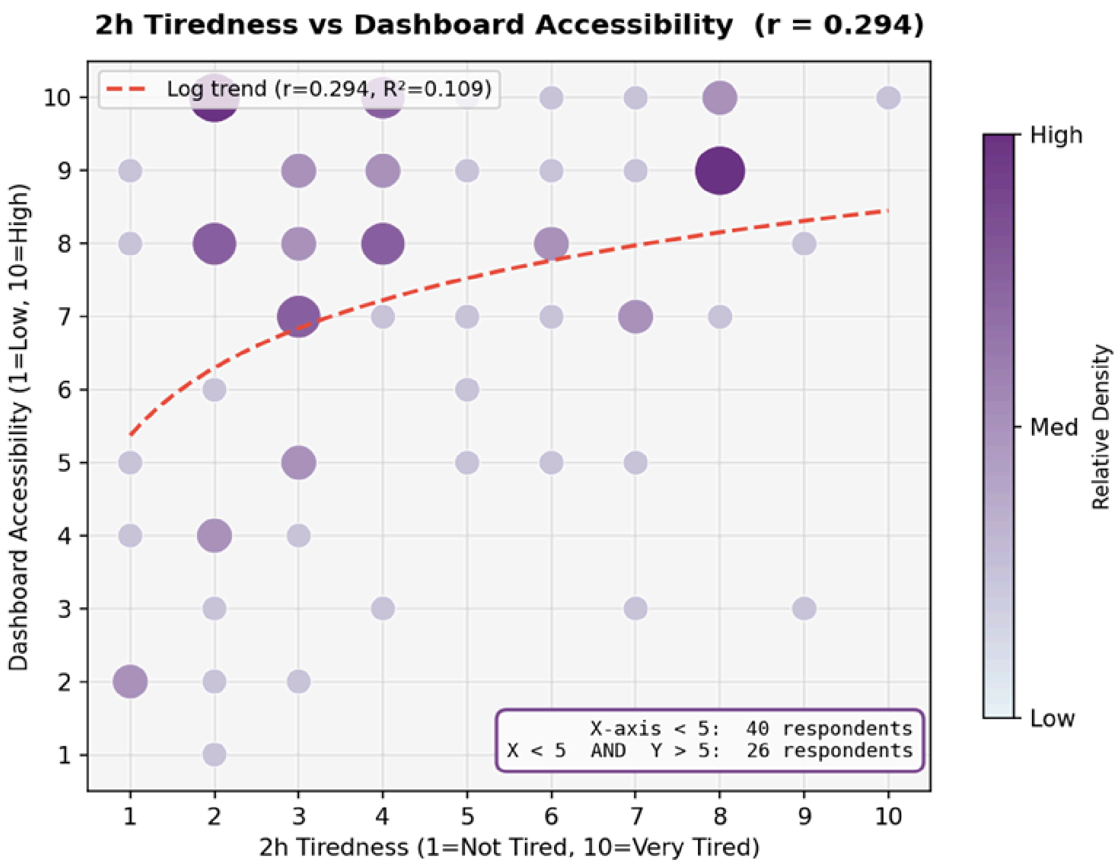

Figure 4. Tiredness vs. Dashboard Accessibility. This bubble chart tracks the correlation between the responses of the participants' expected tiredness (opinionated) after a 2-hour drive, and their accessibility to their controls, such as gear shifts, dashboard, and steering wheel. The darker and larger the bubble is, the more frequent that response is. The heaviest population is in

the top left corner of the graph. The total percent of participants that recorded below the level of 5 tiredness was 59.70% (40/67) of the data set, and 65% of this number (26/40) had above a 5 level of accessibility, meaning 38.81% (26/67) of the participants recorded both.

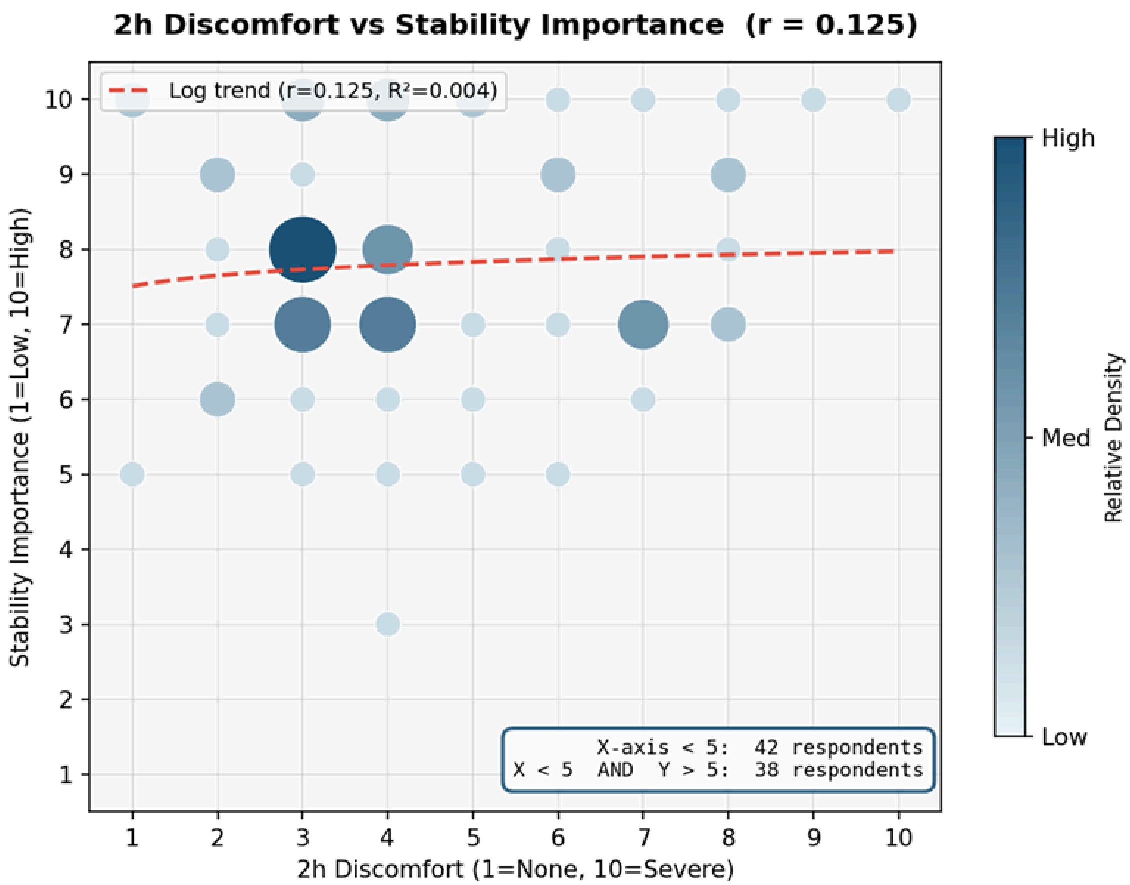

Figure 5. Discomfort vs. Dashboard Accessibility. This bubble chart tracks the correlation between projected discomfort after a 2-hour drive and this person's preferred seat stability. Seat stability was described as support for the driver. The darker and larger the bubble is, the more frequent that response is. The heaviest population, again, is in the top left corner of the graph. The total percent of participants that recorded below the level of 5 discomfort was 62.69% (42/67) of the data set, and 90.48% of this number (38/42) also had above a 5 level of seat stability, totaling to 56.72% (38/67) of participants.

Discussion

Key Findings and Implications

The findings of this study demonstrate a significant and measurable impact of ergonomic fit within the cockpit on driver performance, perceived workload, and physical discomfort. The optimal seat clearance and moderate reach distance conditions produced the best outcomes across all dependent variables. Non-optimal configurations alternatively resulted in degraded performance and increased workload.

Under optimal conditions of seat clearance and reach distance, the drivers achieved fastest race times, lowest error counts, lowest NASA-TLX scores, and lowest body part discomfort ratings. The worst outcomes across all measures were observed in the undersized seat and close reach condition, which indicates that restricted posture and constrained limb positioning introduce significant performance penalties. This was consistent with our findings from our survey, where a majority of people who had minimal tiredness levels from a 2-hour driving session had easy access to their dashboard and controls.

These results can be explained by considering biomechanical efficiency and motor control principles. When drivers are in non-optimal seating configurations, they require more engagement in compensatory muscle activation to keep their posture and operate the control inputs. This not only increases physical demand but also reduces coordination efficiency between upper and lower body movements, which results in slower response execution and decreased precision. Again, with our supplemental survey data, there is a high correlation between low levels of discomfort over a 2-hour drive and high levels of seat stability.

Without having a statistically significant interaction effect, there is evidence to suggest that seat clearance and reach distance have an independent influence on performance. When considering design principles, the results suggest that optimizing either lower-body positioning (seat clearance) or upper-body positioning (reach distance) can improve outcomes. When both are optimized, the highest level of performance is achieved.

These findings directly imply that optimizing cockpit and workstation design in high-demand environments will lead to positive results. Ergonomic fit should be treated as an essential performance factor instead of a secondary comfort consideration, due to small deviations in positioning ($\pm$ 2-4 cm) producing statistically significant differences in performance outcomes.

Limitations

There are several limitations to be considered when interpreting the results of this study. The first limitation is that the dataset used for analysis was simulated rather than collected from real participants. Even though the simulated data was constructed to reflect realistic performance trends, they do not fully capture the variability and unpredictability of human behavior.

Another limitation is that the study sample was restricted to male participants within the 40th-60th percentiles of height and weight. This was done to control body size as a confounding variable, but it limits the generalizability of the findings when applied to broader populations, such as female drivers or other individuals outside this range.

A mixed factorial design was implemented to balance experimental control with practical feasibility. Seat clearance was assigned between-subjects to prevent adaptation across seat configurations, while reach distance was tested within-subjects across three sessions. Individual differences in baseline driving skill and motor coordination may still have introduced variability that was not fully controlled.

Reaction time was initially considered as a dependent variable, but was not directly measured due to technical constraints. In response to this, performance outcomes like race time and error count were indirect indicators of response efficiency but may not fully isolate the specific effects of posture on motor response speed.

Lastly, using a controlled simulator environment eliminates real-world factors such as competitive pressure, environment variability, and dynamic vehicle conditions, which may have an influence on driver performance in an actual race.

Within the public survey, there are many different limitations to be aware of. While the data is good for supplemental understanding, the survey is less relevant to actual race car drivers, since there is no implication on track times. Also, 67 participants are a relatively small population to draw significant results from the trackable data. It is also important to understand that this data set is completely qualitative, so there are no calculations involved to verify these discomfort or fatigue levels.

Conclusion

Summary

This study demonstrates a significant influence of seat clearance and steering wheel reach distance on race car driving performance, perceived workload, and physical discomfort. Both independent variables exhibited strong main effects across all dependent measures. The optimal configurations consistently produced the best outcomes.

The results of the study show the importance of considering both upper and lower body posture in ergonomic design. By deviating from the optimal position even by small increments, biomechanical inefficiencies are introduced that increase physical demand, reduce control precision, and degrade overall performance.

Without there being a significant interaction effect between seat clearance and reach distance suggests they contribute independently to performance outcomes. This highlights the importance of optimizing each dimension individually even though the best results occur when both are aligned.

Overall, this study adds to the understanding of ergonomic design's influence on human performance in high-demand environments. These findings emphasize the importance of optimizing human-system interaction, not only for comfort but also for maximizing performance and safety in applications such as motorsport, aviation, and other complex control systems.

Future Work

There is plenty of room for future research to extend the findings of these results. Future work could incorporate direct measurement of reaction time to more precisely quantify the effects of posture on motor response speed. To achieve this, researchers can integrate controlled stimulus-response tasks within the simulator environment to allow for the separation of cognitive processing time and motor execution delays.

The participant sample should be expanded to include a wider range of anthropometric profiles and both genders to improve the generalizability of the findings and allow for analysis of body size as an additional independent variable.

The survey could still be used in further studies, but there needs to be a larger population, in a more controlled environment, such as only one age range of race car drivers, and potentially a better way of tracking this data quantitatively. An idea would have drivers do the survey after a race, and be able to compare the results to their race times.

Further studies could also use physiological measures such as EMG to quantify muscle activation patterns in different seating conditions. This would provide a deeper insight into the biomechanical mechanisms that cause differences in performance.

Lastly, future work could lean towards adaptive or adjustable cockpit systems that dynamically respond to driver posture and fatigue over time. This could maintain optimal ergonomic conditions through extended driving sessions where fatigue becomes a factor.

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