ERGONOMIC FIT

IN THE COCKPIT

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

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Problem Statement

Problem Statement: Despite the critical role of cockpit fit in driver performance, no existing study has isolated the combined effects of seat clearance and steering wheel reach distance on driver outcomes.

Why it matters — Driver performance depends on precision, reaction time, and endurance

The Problem — Poor cockpit fit increases fatigue, reduces control, and causes errors

Research Gap — No study isolates seat clearance and reach distance together

What the Research Tells Us

Existing Work

- Seat fit directly affects posture, muscle activation, and lap time (Rosalie & Rosalie, 2021)
- G-forces create high physical strain, increasing error rates and fatigue over time (Mungai, 2025)
- Non-neutral postures increase biomechanical effort, slowing reaction time (Marklin et al., 2005)
- NASA-TLX captures workload; physical demand dominates at high performance levels (Tse, 2019)

Research Gaps

- Limited research on moderate ergonomic variation (not just extreme postures)
- No studies isolating seat clearance and reach distance together
- Lack of integration between workload, posture, and performance metrics

Extending Prior Work

- Tests seat clearance + reach distance simultaneously
- Focuses on typical users (40th–60th percentiles) instead of extremes
- Links ergonomics → workload (NASA-TLX) → performance outcomes

Research Question and Hypothesis

Research Question:	How do seat clearance and steering wheel reach distance affect race car driver performance, comfort, and perceived workload in a controlled simulator environment?

H1 (Seat Fit)	Optimal seat clearance (+2 cm) will significantly outperform undersized and oversized conditions across all four dependent variables.
H2 (Wheel Reach)	Moderate reach distance (0 cm offset) will significantly outperform close and far conditions across all four dependent variables.
H3 (Interaction)	A significant interaction effect will exist, where the combination of optimal seat and moderate reach will produce the best outcomes overall.

Independent Variables

IV1 — Seat Clearance

The difference between the participant's hip breadth and the width of the seat

Undersized −2 cm

Compressed posture, restricted ROM

Optimal +2 cm

Natural posture, proper lateral support

Oversized +6 cm

Excess space, compensatory stabilization

IV2 — Steering Wheel Reach

The horizontal distance from the driver's seat back to the steering wheel, adjusted relative to the participant's functional arm reach

Close −4 cm

Cramped arms, shoulder & wrist strain

Moderate 0 cm

Natural 120° elbow angle — optimal position

Far +4 cm

Forward lean, upper limb fatigue

Dependent Variables & Controls

What We Measured

- **Race Time:** Seconds over 66 laps — primary performance measure
- **Error Count:** Track limit violations — auto-logged by simulator
- **NASA-TLX:** Perceived workload, 6 subscales, post-race
- **Body Part Discomfort:** 1–10 scale, 5 body regions, post-race

1. Lower back
2. Hips and buttocks
3. Shoulders
4. Arms and wrists
5. Neck

To eliminate outside noise, we ran everything on an F1 24 simulator — same track, same car, same weather, every single time.

- F1 2024 spec car — identical every session
- Medium tires, full fuel load
- Clear, dry, 22°C weather (fixed in software)
- Cockpit camera — fixed for all participants
- Time trial mode — no opponents
- Same track every session (Barcelona)
- Fixed steering sensitivity & force feedback

Experimental Setup

Circuit de Barcelona-Catalunya

F1 24 Simulator — Cockpit View

4.675 km
Circuit length

16 corners
Technical layout

66 laps
Per race session

Time Trial
No opponents — full control

METHODS

Study Design & Setup

Design	Mixed-subjects 3×3 factorial — 9 conditions Each participant tested across 3 reach conditions, assigned to 1 seat level
Participants	30 simulated males, ages 20–22 (UF student profile)
Anthropometrics	40th–60th percentile, 173–180 cm, 70–84 kg
Data Sources	AI simulation (Claude, Anthropic 2025) + survey (~67 UF students)

9 conditions

90 total races

30 participants

10 obs per condition

Procedure

Pre-Study	Week 1	Week 2	Week 3	Week 4
Screening	2-hr race on Barcelona	Data Collection	Data Collection	Data Collection
Questionnaire	No data collected	66 laps — full race	66 laps — full race	66 laps — full race
Hip breadth measured	Eliminates track learning effect	NASA-TLX after	NASA-TLX after	NASA-TLX after
Arm reach measured		Body part discomfort after	Body part discomfort after	Body part discomfort after
Condition assigned				

Counterbalancing : 6 orderings × 5 participants · every condition appeared equally as Race 1, 2, and 3 · all 9 conditions covered exactly 10 times

What We Found

Mixed Factorial ANOVA | Seat Clearance: Between-Subjects × Reach Distance: Within-Subjects | N = 30 | α = .05

BEST CONDITION
6,598 sec
Optimal seat × Moderate reach — fastest race time

WORST CONDITION
6,855 sec
Undersized seat × Close reach — slowest race time

PERFORMANCE GAP
257 sec
Race time difference: best vs. worst condition

HIGHEST WORKLOAD
81.3 TLX
Undersized × Close — highest NASA-TLX score

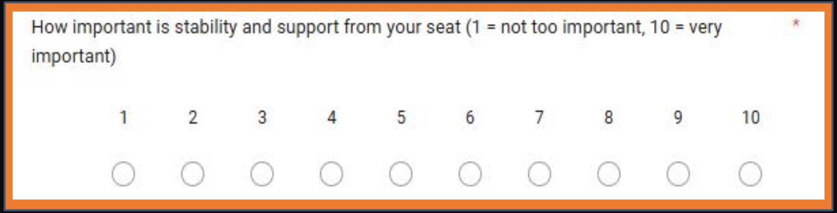
Source	Race Time	Error Count	NASA-TLX	Avg BPD
Seat Clearance	$F(2,27)=99.78$ $p<.001$, $\eta^2=.881$	$F(2,27)=74.67$ $p<.001$, $\eta^2=.847$	$F(2,27)=31.59$ $p<.001$, $\eta^2=.701$	$F(2,27)=166.66$ $p<.001$, $\eta^2=.925$
Reach Distance	$F(2,54)=73.21$ $p<.001$, $\eta^2=.731$	$F(2,54)=28.56$ $p<.001$, $\eta^2=.514$	$F(2,54)=29.21$ $p<.001$, $\eta^2=.520$	$F(2,54)=79.17$ $p<.001$, $\eta^2=.746$
Seat × Reach (Interaction)	$F(4,54)=0.35$ $p=.841$ ns	$F(4,54)=1.29$ $p=.286$ ns	$F(4,54)=0.47$ $p=.760$ ns	$F(4,54)=0.69$ $p=.601$ ns

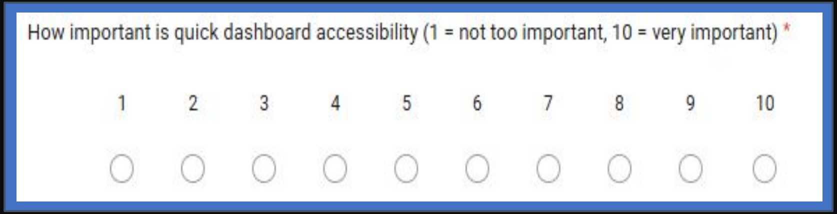
✓ H1 Supported | ✓ H2 Supported | ✗ H3 Not Supported — IVs act independently (no interaction effect)

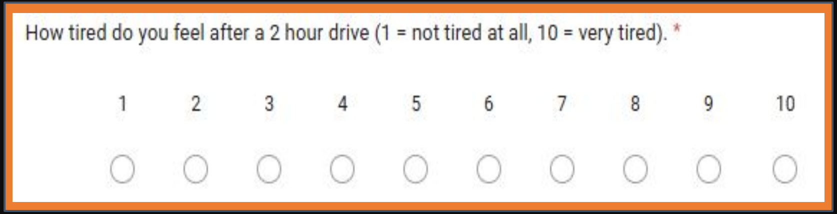
RESULTS

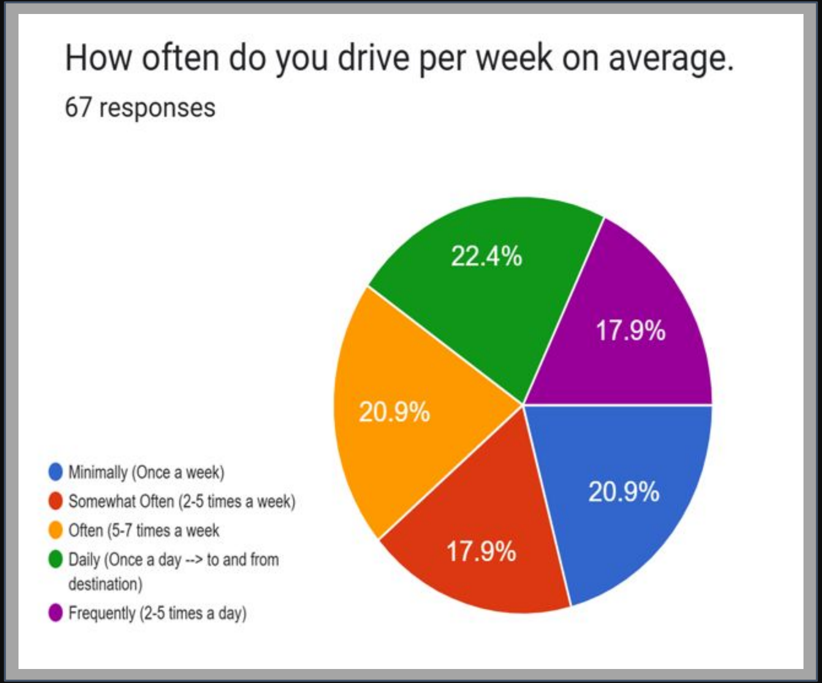
Survey – Qualitative Analysis

67 participants, 62 of which were in the range of ages 18-25 (median 21). Users were asked a series of questions to help supplement out data and add to our understanding of our experiment.



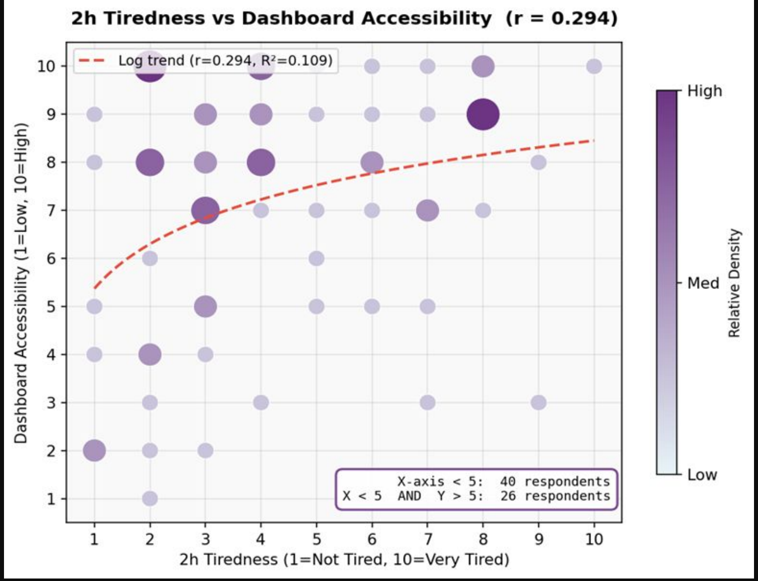


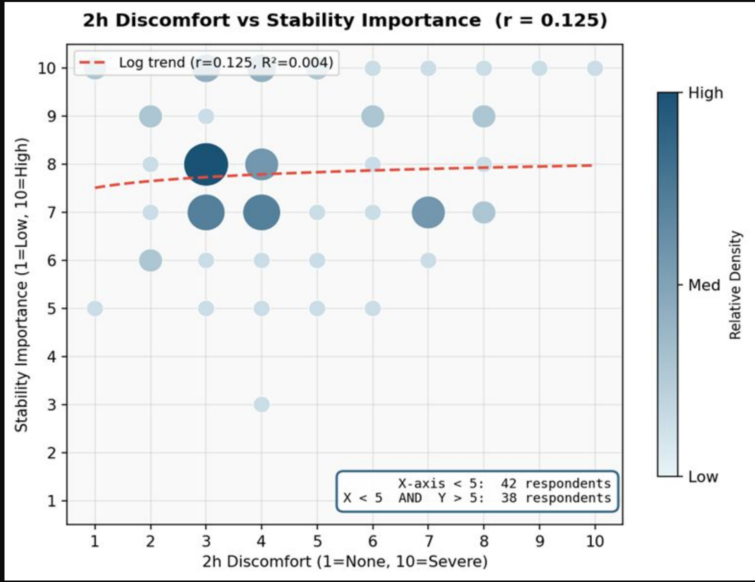




RESULTS

Survey Results — Real World Data





Tiredness vs. Control Accessibility

38.8%

- 59.70% (40/67), < 5 Tiredness
- 65% (26/40), also > 5 Accessibility

Discomfort vs. Seat Stability

56.7%

- 62.69% (42/67), < 5 Discomfort
- 90.48% (38/42), also > 5 Stability

What the Data Tells Us

Optimal Configuration Wins Across All Metrics

- Best seat + reach = fastest times, fewest errors, lowest workload, least discomfort
- Worst outcomes: undersized seat + close reach condition

Small Deviations, Big Consequences

- Just 2-4 cm shifts caused significant performance drops
- Forces compensatory muscle activation ⟶ slower, less coordinated responses

Independent but Additive Effects

- Seat clearance and reach distance each improve performance on their own
- Optimizing both together = highest performance outcomes

Limitations

Narrow Sample Reduces Generalizability

- Male only, 40th–60th percentile
- Excludes female drivers and broader body types

Qualitative Survey Lacks Objective Discomfort Measurement

- Self-reported only, no physiological or biomechanical validation
- Perceived discomfort may not reflect actual physical strain

Simulated Conditions and Unverified Survey Data

- Simulator removes real-world pressure and vehicle variability
- 67-person survey is qualitative only, no statistical verification

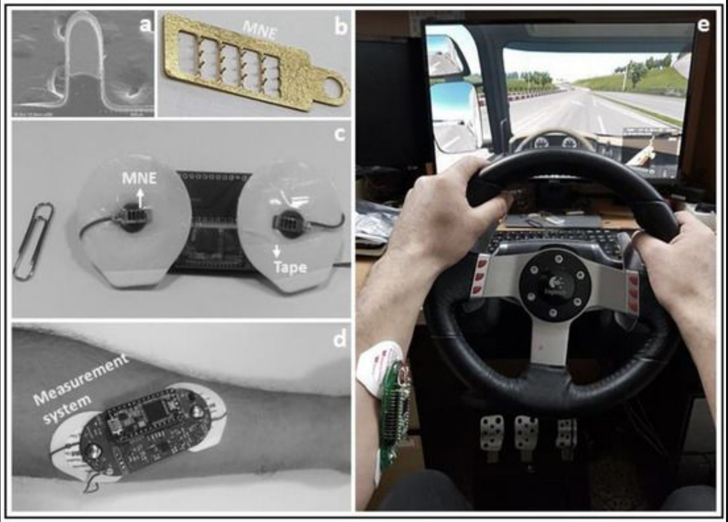
Between-Subjects Seat Factor Design Introduces Individual Variability

- Baseline driving skill and motor coordination not fully controlled
- May have introduced unexplained variability in results

Future Work

Future Work

- Validate findings using real drivers in controlled testing
- Include female drivers and broader anthropometric range
- Add EMG to quantify muscle activation patterns
- Test larger ergonomic deviations (5th/95th percentile)
- Expand survey: larger sample, controlled settings, quantitative data
- Explore adaptive cockpit systems responding to driver fatigue



Ergonomic fit is not a comfort preference — it is a measurable driver performance variable.

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Appendix A - AI Data Simulation Prompt

The following prompt was provided to Claude (Anthropic, 2025) to generate the simulated dataset used in this study:

"I need you to simulate a dataset for a mixed-subjects 3x3 factorial Human Factors study examining the effect of seat clearance and steering wheel reach distance on race car driver performance, comfort, and perceived workload in an F1 simulator environment.
Study parameters:

30 male participants, ages 20–22, modeled within the 40th–60th percentile anthropometric range (173–180 cm, 70–84 kg)
IV1 — Seat Clearance: 3 levels (Undersized: −2 cm, Optimal: +2 cm, Oversized: +6 cm from each participant's measured hip breadth)
IV2 — Steering Wheel Reach: 3 levels (Close: −4 cm, Moderate: 0 cm, Far: +4 cm from each participant's optimal reach position)
9 conditions total, 10 observations per condition, 90 total race observations
Each participant completes 3 races — one per reach level — assigned to one seat level for the full study
Latin Square counterbalancing across 6 reach condition orderings, 5 participants per ordering

Dependent variables to simulate for each observation:

Race Time in seconds over 66 laps at Circuit de Barcelona-Catalunya. Baseline optimal ~6,600 sec. Penalties: Undersized +150 sec, Oversized +80 sec, Close reach +120 sec, Far reach +60 sec. Noise SD ±45 sec.
Driving Error Count (track limit violations). Baseline optimal ~10 errors. Penalties: Undersized +7, Oversized +4, Close +6, Far +3. Noise SD ±3.
NASA-TLX Score (0–100, weighted). Baseline optimal ~55. Penalties: Undersized +15, Oversized +8, Close +14, Far +7. Noise SD ±8.
Average Body Part Discomfort (1–10 scale, 5 regions: lower back, hips/buttocks, shoulders, arms/wrists, neck). Baseline optimal ~3.5. Penalties: Undersized +2.2, Oversized +1.2, Close +2.0, Far +1.0. Noise SD ±1.0. Apply regional weighting so seat clearance most affects lower back and hips, reach distance most affects shoulders and arms.

Use Python with numpy and a fixed random seed of 42 for reproducibility. Output the dataset as an organized Excel file with the following sheets: Raw Data (one row per race observation), Summary Statistics (means and SDs by condition), ANOVA-Ready data, and Participant Profiles. All simulation parameters should be grounded in the ranges reported in vehicle ergonomics literature."