# Effects of Fatigue on Driver Behavior in Urban and Highway Environments Using a Driving Simulator


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# Introduction

- Road traffic crashes cause about 1.2 million deaths every year worldwide.
- Driver fatigue is a major cause, with effects similar to alcohol.
- Fatigue slows reactions, affects decisions and reduces hazard awareness.

- This study investigates how sleep-deprivation fatigue affects driving behavior by comparing performance in urban and highway environments under both low and high traffic conditions.

# Experimental Design

- A FOERST Driving Simulator was used for the experiment recorded 60 data points per second.
- Thirty-five young licensed drivers aged 18 to 30 participated in the study.
- The experiment was conducted in two phases: one when participants were well-rested and one after a night of sleep deprivation.
- Driving scenarios included urban roads with low traffic and highways with both low and high traffic.

# Data collection & Analysis

- Participants completed questionnaires to provide demographic information, driving experience, and fatigue-related behaviors.
- Data collected from the simulator included speed, reaction time, headway distance and acceleration.
- Linear regression models were applied to examine the effects of fatigue on performance indicators.

# Results: Speed & Reaction Time

## Driving Speed:

- Fatigue significantly increased average driving speed by about 20%.
- Drivers who made more daily trips also tended to drive faster.
- The number of hours awake had a measurable impact on speed regulation.

## Reaction Time:

- Fatigue increased reaction time by approximately 0.23 seconds.
- Drivers who had engaged in more physical activity during the day also reacted more slowly.
- Reaction times were also longer on highways and among drivers who took frequent daily trips.

*Average Speed Model Prediction*

| Independent Variables | βi | Std. Error | t Value | p-Value | Sig. | e |
|---|---|---|---|---|---|---|
| (Constant) | 11.962 | 5.406 | 2.213 | 0.028 | * | - |
| Driver fatigue<br>(1: driving with fatigue, 0: driving without fatigue) | 7.074 | 2.881 | 2.456 | 0.015 | * | 0.208 |
| Driving environment<br>(0: urban, 1: highway) | 49.526 | 2.896 | 17.103 | 0.000 | *** | 1.456 |
| Daily trips in urban areas and highways | 2.896 | 0.813 | 3.562 | 0.000 | *** | 0.085 |
| Hours awake | 0.763 | 0.296 | 2.582 | 0.011 | * | 0.000 |
| Self-reported behavioral adaptations under fatigue<br>(1: vehicle immobilization, 2: speed reduction, 3: speed increase, 4: driving near the road edge, 5: phone use or passenger interaction, 6: energy drink consumption, 7: window opening, 8: no behavioral change) | 3.107 | 0.754 | 4.119 | 0.000 | *** | 0.001 |
| $R^2$ = 0.693<br>Adjusted $R^2$ = 0.683 | | | | | | |

*Reaction Time Model Prediction*

| Independent Variables | βi | Std. Error | t Value | p-Value | Sig. | e |
|---|---|---|---|---|---|---|
| (Constant) | 0.939 | 0.143 | 6.586 | 0.000 | *** | - |
| Driver fatigue<br>(1: driving with fatigue, 0: driving without fatigue) | 0.226 | 0.101 | 2.237 | 0.032 | * | 0.168 |
| Driving environment<br>(0: urban, 1: highway) | 0.361 | 0.122 | 2.960 | 0.006 | ** | 0.268 |
| Gender<br>(1: male, 2: female, 3: other) | 0.406 | 0.107 | 3.801 | 0.001 | *** | 0.302 |
| Daily trips in urban areas and highways | 0.116 | 0.038 | 3.040 | 0.005 | ** | 0.086 |
| Intensity level of exercise performed by the driver during the day<br>(1: none, 2: low, 3: moderate, 4: high, 5: very high) | 0.136 | 0.065 | 2.077 | 0.045 | * | 0.101 |
| $R^2$ = 0.519<br>Adjusted $R^2$ = 0.448 | | | | | | |

# Results: Headway Distance & Acceleration

## Headway Distance:

- Fatigued drivers maintained following 15% shorter distances.
- Older drivers kept longer and safer following distances.
- Self-reported fatigue symptoms were associated with shorter headway distances.

## Acceleration:

- Fatigue reduced acceleration by about 34%, reflecting weaker vehicle control.
- Greater driving experience slightly reduced acceleration.
- Drivers who reported more fatigue symptoms displayed riskier adjustments in acceleration behavior.

*Headway Distance Model Prediction*

| Independent Variables | βi | Std. Error | t Value | p-Value | Sig. | e |
|---|---|---|---|---|---|---|
| (Constant) | 91.470 | 25.889 | 3.533 | 0.001 | *** | - |
| Driver fatigue (1: driving with fatigue, 0: driving without fatigue) | -19.785 | 5.148 | -3.843 | 0.000 | *** | -0.155 |
| Driving environment (0: urban, 1: highway) | 57.973 | 6.219 | 9.322 | 0.000 | *** | 0.455 |
| Traffic volume (0: low traffic, 1: high traffic) | -127.456 | 6.832 | -18.657 | 0.000 | *** | -1.000 |
| Driver age | 2.395 | 1.078 | 2.222 | 0.028 | * | 0.000 |
| Self-reported fatigue symptoms (1: tendency to fall asleep, 2: lack of concentration, 3: yawning, 4: eye blinking, 5: no symptoms, 6: other) | -7.756 | 3.220 | -2.409 | 0.017 | * | -0.001 |
| $R^2$ = 0.705 | | | | | | |
| Adjusted $R^2$ = 0.695 | | | | | | |

*Acceleration Model Prediction*

| Independent Variables | βi | Std. Error | t Value | p-Value | Sig. | e |
|---|---|---|---|---|---|---|
| (Constant) | -0.359 | 0.056 | -6.384 | 0.000 | *** | - |
| Driver fatigue (1: driving with fatigue, 0: driving without fatigue) | -0.102 | 0.028 | -3.633 | 0.000 | *** | -0.338 |
| Driving environment (0: urban, 1: highway) | 0.233 | 0.029 | 8.158 | 0.000 | *** | 0.769 |
| Driving experience | -0.019 | 0.006 | -3.292 | 0.001 | ** | -0.001 |
| Self-reported fatigue symptoms (1: tendency to fall asleep, 2: lack of concentration, 3: yawning, 4: eye blinking, 5: no symptoms, 6: other) | 0.047 | 0.017 | 2.757 | 0.007 | ** | 0.002 |
| $R^2$ = 0.367 | | | | | | |
| Adjusted $R^2$ = 0.354 | | | | | | |

# Discussion

- The study confirms that fatigue impairs key aspects of driving behavior.
- Fatigued drivers often adopt risky strategies such as speeding and reducing headway.
- Fatigue effects were stronger in high-traffic conditions, where drivers showed a greater tendency for unsafe behavior.
- Common strategies such as opening windows, or energy drink consumption were ineffective.

# Conclusions

- Fatigue poses a serious risk to road safety and significantly alters driver performance.
- Key findings include higher speeds, slower reaction times, shorter following distances and altered acceleration control under fatigue.
- These results highlight the importance of fatigue monitoring systems and stricter regulations.
- Future research should involve real-world studies to expand on these findings.

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