Evaluation of Traffic Stress Measurement in a VR-Based Micromobility Simulator

Master‘s Thesis of Khushnood Maqsood

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Figure 1: Participant in a CAVE-Based Environment at TUM

Introduction and Objectives

The growing pace of urbanization and population density is reshaping modern cities, creating an urgent need for sustainable transportation systems. Among these, micromobility has emerged as a promising alternative to motorized travel, offering low-carbon and efficient commuting options. As micromobility vehicles increasingly share space with dense and unpredictable urban traffic, safety concerns have become more pronounced and demand systematic investigation.

This thesis explores the physiological dimensions of micromobility users' experience in complex traffic conditions. Focusing on attention patterns and stress responses, it examines how riders adapt to dynamic environments through a VR-based simulation platform, see Figure 1.

To meet these goals, this thesis addresses three research questions:

- How do physiological stress markers correlate with micromobility users’ behavioral responses in a VR-based traffic simulation?
- What are the most effective biometric and behavioral indicators for measuring traffic-induced stress in virtual environments?
- How do different traffic scenarios influence micromobility users’ stress levels and maneuvering strategies in a controlled VR setting?

The findings can be used by urban planners, transport policymakers, and safety researchers, contributing to the development of safer, human-centered micromobility systems.

Aspect	Normal Traffic	High Macro Mobility Traffic	High Micro and Macro Mobility Traffic
Traffic Density (Buses and Cars)	Moderate density of cars and buses	Bus and car density increased by 50% compared to Normal Traffic.	Car and bus density remains the same as in the High Macro Mobility Traffic.
Traffic Density (Bicycles)	Moderate density of bicycles and e-bikes.	No increase in bicycle and e-bike density.	Bicycle and e-bike density increased by 50% compared to the Normal Scenario.

Table 1: Comparison of Traffic Scenarios and Mobility Dynamics

Methodology

This study employed a quantitative-experimental research design, conducted in a controlled laboratory environment using virtual reality (VR) technology to examine stress and behavioral responses, as shown in Figure 1. Seventeen participants aged 20–30 years were selected through purposive sampling based on specific inclusion and exclusion criteria. Each participant provided informed consent and completed pre- and post-experiment questionnaires to record demographic data and subjective responses.

The experiment was conducted in a CAVE-based VR micromobility simulator equipped with a stationary bicycle at the TUM Main Campus, as shown in Figure 1. The simulation environment was developed through the integration of SUMO, Unity 3D, and MathWorks RoadRunner to replicate dynamic urban traffic conditions. Three traffic scenarios were designed: Normal Traffic, High Macro Mobility, and High Micro and Macro Mobility, each differing in vehicle and micromobility density to induce varying stress levels, see Table 1. Physiological and behavioral data were recorded using Empatica EmbracePlus, Firstbeat Bodyguard, and Tobii Pro Glasses. All data streams were time-synchronized for precise temporal alignment. This experimental setup enabled controlled observation of participants’ physiological and cognitive responses to varying urban traffic complexities within an immersive VR environment.

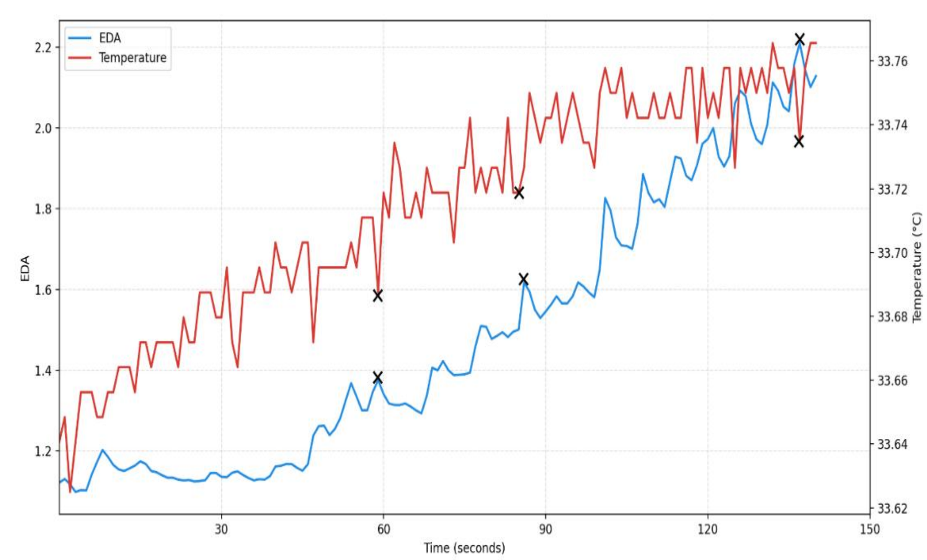

Figure 2: EDA and Temperature Time-Series Plot

Results and Conclusion

This study examined how cyclists respond to traffic-induced stress in a VR-based micromobility simulator, integrating physiological, behavioural, and perceptual measures to provide an overall view of stress dynamics. The findings demonstrate that traffic complexity directly shapes both physiological arousal and attention patterns. As vehicle and cyclist density increased, participants exhibited stronger stress responses. Figure 2 depicts the effect of participants in a High Micro and Macro Mobility Scenario, showing the decrease in temperature and increase in EDA due to more stress in this scenario. These physiological responses closely matched participants’ subjective experiences of anxiety, reduced concentration, and the adoption of defensive behaviors. Eye-tracking data further revealed that stress narrowed visual attention, producing shorter fixations and fragmented scanning patterns concentrated on potential dangers. Scenario-specific results highlighted that High Micro and Macro Mobility traffic caused peak stress responses and strong defensive strategies. These findings show the link between environmental complexity, cyclist perception, and stress, offering important practical insights for designing safer urban environments, and clearly shows that VR-based tools are highly effective for studying cycling safety and behaviour.