Figure 1: Participant is driving in a closed circuit while experiencing the breathing exercise; and breathing waveform before and during the haptic guidance breathing intervention (bottom).

On-road Guided Slow Breathing Interventions for Car Commuters

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ABSTRACT

This is the first on-road study testing the efficacy and safety of guided slow breathing interventions in a car. This paper presents design and experimental implications when evolving from prior simulator to on-road scenarios. We ran a controlled study (*N*=40) testing a haptic guided breathing system in a closed circuit under stress and not-stressed driving conditions. Preliminary results validate prior findings about the efficacy and safety of the intervention. Initial qualitative analysis shows an overall positive acceptance, and no safety-critical incidents (e.g., hard brakes or severe lane departures) – all participants graded the intervention as safe for real traffic applications. Going further, additional analysis is needed before exposing commuters to the intervention on public roads.

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CCS CONCEPTS

• **Human-centered computing** → **Haptic devices**; *Ubiquitous and mobile computing systems and tools*; • **Applied computing** → **Consumer health**; *Psychology*; • **Computer systems organization** → **Sensors and actuators**.

KEYWORDS

Slow breathing; Deep breathing; Stress management; Just in time intervention; Health; Mental health; Commute; On the road; Road safety.

A successful in-car breathing intervention is **effective** in reducing breathing rate and physiological arousal, while not affecting driving **safety** nor inducing critical changes in driving behavior, e.g., major reduction in speed. We call those **subtle** in-car interventions.

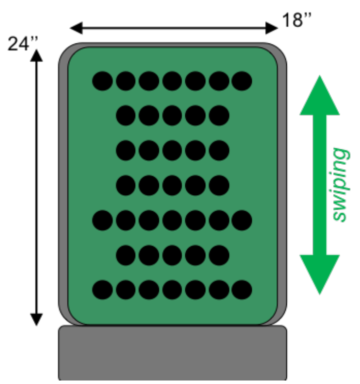

Figure 2: Seat mat configuration covering a back space of 12x18 inch, able to produce a variety of haptic stimulation patterns. In this experiment, the system delivered a swiping (up and down) sensation to guide participants' breathing rhythm. For a more precise description of spatio-temporal guidance patterns, we refer to our prior work [8].

MOTIVATION

Prior studies have shown the efficacy of guidance systems to reduce breathing rate and physiological arousal in a simulator setting [1, 8]. Evaluating a similar system under an ecologically valid setup allows us to observe if the risk of harm could lead to a shift in focus away from a secondary task (e.g., phone dialing) and towards the actual driving task [9]. Our embodied interaction [5] aims at regulating physiology during a task that requires high attention, leading to a potentially perceived risky situation, which could affect the value of the breathing intervention. Additionally, on-road driving induces vibrations and driving forces that could affect the guidance stimulus, potentially lowering engagement and efficacy.

In this work we explore the following research questions: ***RQ1:*** *Is the in-car on-road breathing guidance system effective in lowering driver's breathing rate and arousal levels?* ***RQ2:*** *Are in-car on-road guided breathing interventions safe?* ***RQ3:*** *Are there any additional changes in driving performance?*

The contribution of this paper is two-fold:

(1) Early qualitative findings that demonstrate the feasibility of in-car on-road guided slow breathing interventions with respect to both efficacy and safety.
(2) Design and methodology considerations for intervention systems in a risky environment.

No statistical analysis was performed to determine the viability to use this intervention on public roads.

SYSTEM AND METHODOLOGY

Our experiment design choices aimed at replicating the daily *commuting*. First, we invited a gender-balanced group of frequent commuters with an average age similar to the population of American commuters (M = 42.4, SD = 14.4 years) [6]. Second, we setup the apparatus to carry a single passenger because the majority of US commuters drives alone (76.4 % in 2013) [6]. Third, participants drove in a closed circuit in the same direction to resemble familiarity and tediousness of a commute route. IRB

Driving Course. To provide a safe test environment, we conducted the experiment in an empty underground parking garage, with structural pillars separated 24 feet. A 0.65 miles long driving course included four left and four right turns. We placed four stop signs to resemble city/neighborhood driving. Arrow-signs guided the way. We marked lanes with white duct tape at a distance of 12 feet, which falls within the range of a typical city road configuration [12].

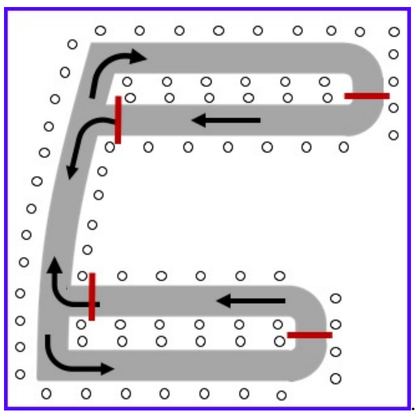

Figure 3: Experimental driving course in the garage. Red lines show positions of stop sings, and circles represent structural pillars.

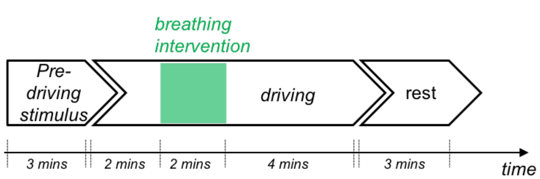

Figure 4: Experimental task procedure.

approved our study, and our institution provided insurance against accidents upon approval of a valid drivers license.

Participants. We recruited a total of forty commuters (N = 40, 20 females). Average age was M = 41.0 years (SD = 12.9, with min = 20 and max = 69 years), and reported years of driver's license possession was M = 21.8 years (SD = 13.8). Daily commute time ranged from 30 minutes to 2 hours. Twenty-five percent of participants reported to practise deep breathing on a regular basis, whereas one-fourth reported to have no prior experience with breathing exercises. We instructed all participants to not eat, drink caffeinated or energizing beverages, do heavy exercises, sleep, or take hot showers one hour before the experiment.

Apparatus. We used an Infinity Q50 equipped with cameras to record participants' frontal and side angles, along with a frontal view of the road (Figure 1). We designed a seat mat haptic breathe guidance system inspired by a prior system integrated in a car seat described in [1, 7, 8]. The system consisted of forty-one 2–3.6 V linear resonant actuator vibration motors, arranged as shown in Figure 2. We covered vibrators with a 0.2 inch foam layer to cushion the actuators. We kept a simple swiping guidance pattern [7, 8]. If applicable, the experimenter (E1) requested participants to take off thick jackets to allow sensitivity in the back.

Procedure and Experimental Tasks. We randomly assigned participants into an intervention and a control group. The intervention group was exposed to the breathing guidance for at least 30 seconds, until participants felt comfortable with the intervention. All participants experienced two different counterbalanced modes of pre-driving activities while being seated in the parked car (engine running): (1) stress-inducing and (2) neutral pre-condition.

The stressful pre-driving condition was a variation of the Trier Social Math Task [4]: for three minutes, participants had to perform recursive subtractions from 1521 in steps of 13. In case of a wrong answer or if people took more than four seconds, the experimenter prompted the participants to start over again. In the neutral pre-driving condition (three minutes long), participants waited, while E1 pretended that a battery had to be exchanged in the trunk. After each pre-condition, participants drove in the one-directional circuit for eight minutes. The intervention group experienced the intervention after two minutes of driving for a duration of two minutes for both pre-driving conditions (Figure 4) with a three minute wash out period in between. Experimental tasks were preceded by a baseline task that included watching a soothing video of a beach setting in the parked car (engine running) as well as a familiarization with the driving course during ten laps (average duration M = 13 min 49 sec with SD = 1 min 47 sec). We counterbalanced baseline and familiarization tasks across participants.

Quantitative Measures. To assess the (1) efficacy, (2) safety, and (3) potential changes in driving performance, we collected a variety of physiological, subjective, and car-related measures. *Psychophysiological*: We captured breathing waveform (18 Hz) and electrocardiogram (ECG) (250 Hz) with a Zephyr BioModule device worn around the torso. We captured Electro-dermal Activity (EDA) (4Hz)

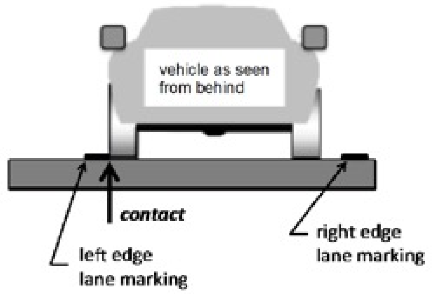

Figure 5: Derived from the SAE Standards for Operational Definitions of Driving Performance Measures [11]. Lane departures (option B) occur once a tire touches the inside of a lane marking. Lane departures become "severe" once the center of the vehicle crosses a lane marking. While mild lane departures might be less risky on empty roads, severe lane departures are considered to violate driving safety, especially since our driving circuit is surrounded by structural pillars.

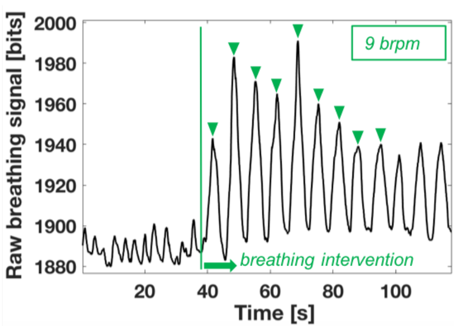

Figure 6: Raw breathing waveform before and during the breathing intervention.

with an Empathica E4 bracelet worn around participants' non-dominant arm wrist. *Self-report*: After each sub-task (baseline, familiarization, 2 x pre-stimulus, 2 x driving, and rest), we measured subjective stress responses via a simplified version of the Perceived Stress Scale (PSS) [10]: *"How stressed do you feel right now?"* with a 10-point scale from 1 = *"low"* to 10 = *"high"*.

Driving: We collected speed (50 Hz, mph), steering angle (100 Hz, degrees), and acceleration pedal position (50 Hz, degrees) from the CAN bus data stream. Further, we positioned two cameras on the frontal fenders of the car, to capture spacing between tires and lane markings on each side. Because driving safety is highly context-dependent and often defined in correspondence to other driving parties or incidents, e.g., time to collision measures [11], we define the following safety violations suited to a closed circuit that is free of additional traffic: number of hard brakes in response to a sudden driving incident [3]) and number of severe lane departures (Figure 5). For driving performance we will calculate the following SAE recommendations [11]: number and rate of steering reversals, standard deviation of lane position, average speed, and acceleration.

Subjective Measures. We surveyed perceived efficacy, safety, and changes in driving behavior, by means of a post-experimental questionnaire.

PRELIMINARY FINDINGS

A first visual inspection of the raw breathing waveform validated that most participants lowered their breathing, e.g., one participant lowered his rate from 14 breathes per minute (brpm) to 9 brpm (Figure 6). Two experimenters inspected lane capturing videos, finding no lane departures. Early analysis of subjective user feedback indicates that most participants experienced the intervention as helpful to reduce breathing pace, and that this reduction led to a decrease in perceived stress. All participants reported that the system would be safe for real traffic applications, but two participants noted their concerns regarding applying the intervention to drowsy drivers, as it would further "add calming effects".

FUTURE ANALYSIS AND FOLLOW-UP STUDY

Analysis will comprise cleaning psycho-physiological data, and extraction of secondary measurements, such as breathing rate (BR), heart rate (HR), and RMSSD (ms) as measure of short-term heart rate variability [8]. From CAN bus data, we will derive occurrence of hard brakes (measured as one standard deviation of maximum deceleration), number and rate of steering reversals, and changes in speed (mph) and acceleration (m/s^2) [11]. We will use computer vision to calculate the number, duration, and severeness of lane departures, as well as mean, and standard deviation of lane centering (Figure 7). With additional analysis we aim to test following hypotheses: ***H1:*** *BR and arousal levels will be lower during the intervention compared to pre-intervention*; ***H2:*** *The decrease in BR and arousal is higher compared to the control group*. We will also aim at answering RQ2 and RQ3, and analyze open text subjective results using thematic analysis [2] to distill main conclusions from the user feedback. If quantitative results validate that our closed-circuit experiment is safe, we will move our guided slow breathing intervention to common traffic. For safety reasons, we will give participants time to familiarize themselves with the slow breathing system in an empty parking lot before entering public roads. Commuters will drive on a 12.3 mile GPS-guided route comprised of urban, mountain, and highway roads. We will conduct the experiment during evening commute hours (3.30 to 8.00 pm). Every six minutes we will administer two minute breathing interventions to evaluate potential sustaining effects. We will further evaluate perceived impacts on efficacy, focus, safety, and opinions on beneficial or inappropriate driving scenarios. To reduce risk, we will instruct participants to always prioritize safe driving.

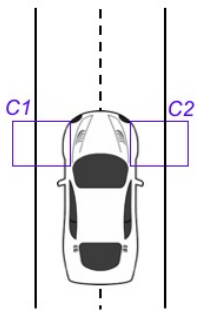

Figure 7: Image processing of video streams C1 and C2 (60 frames per second), will allow us to automatically derive driving safety and behavior measures such as amount and duration of severe and mild lane departures, and standard deviation from center line.

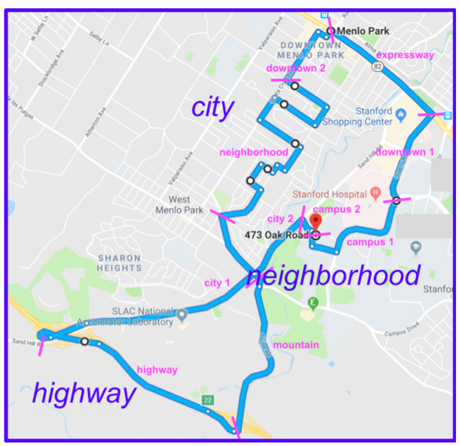

Figure 8: Driving course for follow-up study.

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