
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 between subjects controlled study ($N=40$) testing a haptic guided breathing system in a closed circuit. We contrasted both stress and not-stressed driving conditions. Preliminary results validate prior findings about the efficacy and safety of the simulator studies. Initial qualitative analysis shows an overall positive acceptance ratio, 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, quantitative and statistical analyses need to validate these early findings before exposing commuters to the intervention on public roads.

SIGCHI' 19, May 2019, Glasgow, UK

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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).

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.

ACM Reference Format:

Stephanie Balters, James A. Landay, and Pablo E. Paredes. 2019. On-road guided slow breathing interventions for car commuters. In *Proceedings of ACM CHI Conference (SIGCHI' 19)*. ACM, New York, NY, USA, 6 pages. <https://doi.org/10.1145/nnnnnnn.nnnnnnn>

MOTIVATION

Breathing plays a fundamental role in regulating the autonomic nervous system and reducing autonomic arousal. First HCI studies have shown the efficacy of seat-embedded breathing guidance systems to reduce breathing rate and physiological arousal in a simulator setting [1, 9]. In the next step, we need to evaluate applied systems under ecologically valid circumstances for the following reasons (among others). Firstly, automotive studies show that the realness of potential physical harm in on-road driving, leads to a shift in focus compared to simulator driving – away from a secondary task (e.g., phone dialing) and towards the actual driving task [10]. Hence, people might no longer engage with the intervention. Secondly, our *embodied interaction design* [6] not only requires cognitive processes but aims at inducing actual changes in physiology. Those changes, itself, might induce risk. Hence, interventions might no longer be safe in a real car. Further, compared to the simulator, physical driving induces vibrations, visceral cues, and driving forces that could superimpose the guidance stimuli or impede a driver's physical engagement with the intervention. Hence, the system design might no longer be effective.

The reasons stated above let us formulate the following research questions: **RQ1**: *Is the in-car on-road breathing guidance system effective in lowering driver's breathing rate and, in turn, arousal levels?* **RQ2**: *Are in-car on-road guided breathing interventions safe and, if so, would it be safe to test them on public roads?* **RQ3**: *Are there any resulting changes in driving behavior, e.g., in speed or acceleration?* 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.

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

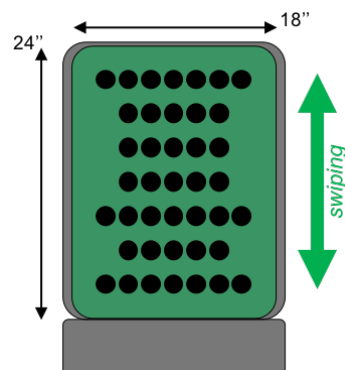


Figure 2: Seat-mat configuration covering a back space of 12x18 inch grid, able to produce a variety of different haptic stimulation patterns. In this experiment, the system delivered a swiping (up and down) sensation to guide participants' breathing rhythm.

Driving Course. To provide a safe test environment, we conducted the experiment in an empty underground parking garage, with no additional traffic. 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 [13]. At an approximate six-foot distance from both lanes, structural pillars bordered the driving course.

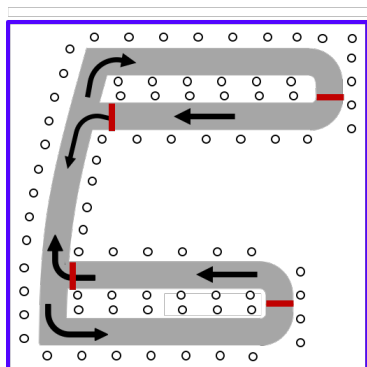


Figure 3: Experimental driving course in the garage. Red lines show positions of stop signs, and circles represent structural pillars.

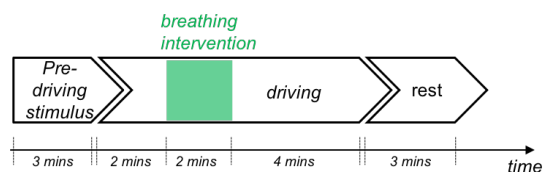


Figure 4: Experimental task procedure.

(2) A series of design and methodology considerations when testing intervention systems in risk-critical environments, e.g., driving.

No part of this paper currently includes quantitative and statistical analysis, which would be required before exposing commuters to the intervention on public roads.

SYSTEM AND METHODOLOGY

Our main objective was to reach high ecological validity with respect to *commuting*. We adapted a series of methodological parameters accordingly. Firstly, we invited only frequent commuters (a few times a week at minimum) to study habituated drivers. We pursued gender balance, and an average age of about $M = 42.4$ years ($SD = 14.4$) to approximate the cohort of American commuters [7]. Secondly, we designed the apparatus setup to carry a participant as single passenger because the majority of US commuters drives alone, e.g., 76.4 % in 2013 [7]. Thirdly, during the entire experiment, participants drove in a closed circuit in the same direction to resemble familiarity and tediousness of a commute route. The Institutional Review Board approved experimental procedures. Participants were 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 ($SD = 12.9$), 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 another 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. As experimental vehicle, we used an Infinity Q50. We equipped the car with cameras to record participants in frontal and side angles, along with a frontal view of the road way (Figure 1). A haptic breathing guidance system integrated in a car seat described in [1, 8, 9] served as a template to design an actuator system blent into a seat-mat. 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 inches thin foam layer to cushion the actuators without lowering the vibrating stimuli. As participants reported that a simple guidance pattern would be most intuitive and helpful to follow slow breathing rhythm [8, 9], we chose to stick to a simple pattern that swiped up and down the user’s back. Lastly, if applicable, experimenter (E1) asked participants to take off thick jackets to allow sensitivity in the back.

Procedure and Experimental Tasks. We alternately divided participants into two groups (each $N = 20$ with gender balance): an intervention and control group. E1 introduced participants of the intervention group to the haptic seat system and asked them to follow the breathing guidance for at least 30 seconds, and until they felt comfortable. The scenario of *commuting home from work*

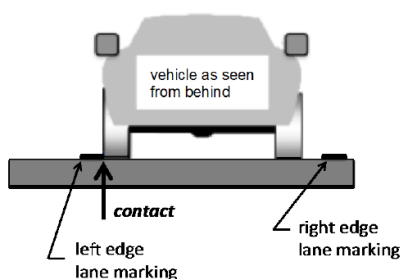


Figure 5: Derived from the SAE Standards for Operational Definitions of Driving Performance Measures [12]. Lane departures (option B) occur once a tire touches the inside of a lane marking. Once the center of the vehicle touches and/or crosses a lane marking, lane departures become “severe”. While mild 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.

guided the design of the experimental tasks. All participants experienced two different modes of pre-driving activities while being seated in the parked car (engine running): (1) stress-inducing and (2) neutral pre-condition. During the stressful pre-driving condition, we administered a variation of the Trier Social Math Task [5]: for a duration of three minutes, participants had to count backwards from 1521 in steps of 13. In case a wrong answer was given or a time limit of four seconds was violated, the experimenter prompted the participants to start over again. During the neutral pre-driving condition (three minutes long), E1 asked the participants to wait in the car pretending a battery had to be exchanged in the trunk. We decided to include the latter “neutral” task to provide a similar experimental length across participants. After each pre-condition, participants drove in the one-directional circuit for eight minutes. The intervention group experienced the guidance after two minutes of driving for a duration of two minutes in both conditions (Figure 4). The control group did not experience any intervention. After the first driving task, a three minutes rest period followed to allow washing out of the prior stimulus. We randomized the order of stress-inducing and neutral conditions across participants to avoid bias. 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 randomized baseline and familiarization tasks across participants. We chose a between subject study design because research indicates that a repeated exposure to a similar arithmetic task reduces stress responses in participants [14].

Quantitative Measures. To assess the (1) efficacy, (2) safety, and (3) potential changes in driving behavior upon on-road breathing interventions, we collected a variety of physiological, subjective, and car-related measures. *Psycho-physiological Measures:* We captured breathing waveform (18 Hz) and electrocardiogram (ECG) (250 Hz) with a Zephyr BioModule device worn around the torso. Electrodermal Activity (EDA) (4Hz) was measured with an Empathica E4 bracelet worn around participants’ non-dominant arm wrist. *Subjective Measure:* 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) [11]: “How stressed do you feel right now?” with a 10-point scale from 1 = “low” to 10 = “high”. *Car-related Measures:* From the CAN bus data stream, we collected speed (50 Hz, mph), steering angle (100 Hz, degrees), and acceleration pedal position (50 Hz, degrees). Further, we positioned two cameras on the front 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 [12], we define the following safety violations suited to a closed circuit that is free of additional traffic: number of hard braking in response to a sudden driving incident [4]) and number of severe lane departures (Figure 5). With respect to changes in driving behavior, we will analyze the following metrics according to the

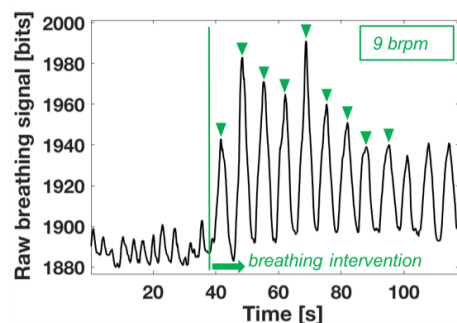


Figure 6: Raw breathing waveform before and during the breathing intervention.

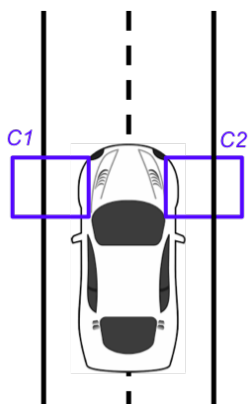


Figure 7: Image processing of video streams C1 and C2 (60 frames per second), will allow us to automatically derive driving safety and behavior measures such as amount and duration of severe and mild lane departures, and standard deviation from center line.

SAE recommendations [12]: number and rate of steering reversals, standard deviation of lane position, as well as average speed, and acceleration.

Qualitative Measures. We surveyed subjective experiences of the intervention, specifically with respect to the 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 validates a breathing rate of nine breaths per minutes (brpm) that was a participant-specific administered system pace during the breathing exercise (Figure 6). Secondly, two experimenters inspected lane capturing videos with respect to safety violations. Specifically they counted the observed number of hard brakes in response to a sudden driving incident, and the number of severe lane departures. No safety violations were observed. Lastly, an early analysis of qualitative user feedback indicates that participants experienced the intervention as helpful to reduce breathing pace, and that this reduction further led to a decrease in perceived stress. Further, all participants of the intervention group (20/20) reported that the system would be safe for real traffic applications. Two participants noted their concerns regarding applying the intervention in a drowsy driver state, as the intervention would further “add calming effects”.

FURTHER ANALYSIS AND FOLLOW-UP STUDY

Further analysis will comprise the processing (including e.g. artefact correction) of psycho-physiological data, including breathing rate (brpm), heart rate (bpm), RMSSD (ms) as measure of short-term heart rate variability [9], EDA (amount of phasic peaks [2]), and self-reported stress. 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) [12]. Via image processing we will calculate the amount, duration, and severeness of lane departures, as well as mean standard deviation of lane positions (Figure 7). We aim to test following hypotheses: **H1:** *Breathing rate and arousal levels will be lower during the intervention compared to before administration;* **H2:** *The decrease in breathing rate and arousal levels during the intervention is higher compared to the control group;* and **H3:** *The intervention is safe to apply while driving; and does not induce major changes in driving behavior.* Additionally, we will analyze qualitative results using thematic analysis [3] to distill main conclusions from the user feedback.

Upon validation, we will assess the guided slow breathing system/apparatus within commute traffic in a follow-up study. 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. A 12.3 miles long driving course will comprise urban, mountain, and highway roads to test the system in different driving contexts. Commuters will follow a provided GPS route. We will conduct the experiment during

