Resync: Towards Transferring Somnolent Passengers to Consciousness

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The advance of automated driving allows the users to engage in non-driving related activities such as sleeping. However, until full automation is reached, the user may have to interact with the vehicle, for example, in planned take-overs, which requires the user to be awake and conscious. To evaluate auditory and visual awakening concepts (alarm, fading in 5, and fading in 20s), we conducted a between-subject (*N*=45) Virtual Reality study, in which participants dozed/slept for 15min, were then awoken, and then had to complete an ordering, a stroop, and a counting task. We only found a significant difference in the perceived sleep duration, which was highest in the alarm condition.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**.

Additional Key Words and Phrases: Sleep; Autonomous vehicles; Sleep Inertia Countermeasures.

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1 INTRODUCTION

Activities during a (partially) automated journey will change drastically [13]. While the user is needed to be constantly vigilant during SAE Level 3 [16], the user does not have to survey the system at Level 4. Users of such automated vehicles (AVs) are, therefore, expected to engage in a variety of non-driving related tasks (NDRTs) [13]: eating, watching a movie, or even **sleeping**. Nonetheless, the user will most likely have to engage with the AV in some scenarios such as taking over control at the end of the operational driving domain (e.g., driving of a highway). Other scenarios include, for example, selecting an alternative route in case of blocked streets.

Up to 2 hours after awakening, subjective attention and cognitive performance may still be impaired [7, 14]. The length of sleep duration seems to have no effect on this. This is also referred to as the 'dead point after waking up' [14]. Therefore, we propose to include auditory or visual signals to speed up this process and improve cognitive abilities after sleeping/dozing.

We employed Virtual Reality (VR) to explore potentially generalizable sleep inertia counter measures. In a between-subject study (*N*=45), we compared an auditory and two visual stimuli that differed in their duration (5 vs 20 s). For this, we let participants doze/sleep for 15 min and then let them complete the three tasks ordering, stroop, and counting (see Section 3.1). We only found a significant difference in perceived sleep duration, however, none in cognitive load, affective state, perceived ease of transition, as well as no significant differences in the employed tasks.

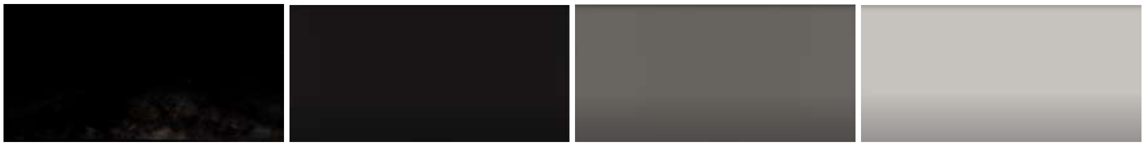

(a) Sleeping scene. (b) Start of fade. (c) Half of fading (2.5 or 10s). (d) End of fading (5 or 20s).

Fig. 1. Scene during sleeping duration and visual stimuli afterward (filled entire view).

2 RELATED WORK

First, we provide general insights into the sleeping rhythm and present first work that investigates takeovers after sleeping and potential countermeasures.

2.1 Sleep, Sleep Inertia, and Sleep Inertia Counter Measures

Sleep can be defined as a "behavioral state of perceptual disengagement from and unresponsiveness to the environment" [3, p. 15]. Sleep stages are characterized by arousal thresholds [3]: Wakefulness, N1 (light sleep), N2 (stable sleep), N3 (deep sleep), and REM (rapid-eye-movement) sleep. The deeper the sleep is, the stronger the cues need to be to awake and the more time it takes for the person to be fully alert [3]. During prolonged repetitive tasks, sleepiness occurs. Therefore, microsleep can occur during driving [10] which heavily affects driving performance [1].

The state after being awoken from sleep in which the person experiences hypnopompic disorientation, confusion, and performance impairment is called "sleep inertia' [4]. During this phase, human performance is impaired in a variety of tasks such as performance reaction time tasks, visual-perceptual tasks, memory, and cognitive tasks [15]. Sleep inertia duration depends on the operationalization but can occur from at least 1 min after waking up until 4 h later [15]. Generally, the most severe effects are experienced in the first 20 min after waking up [5].

Sleep inertia countermeasures can be divided into proactive and reactive countermeasures [6]. Proactive countermeasures include sleep schedules, strategic naps, or caffeine prior to sleeping. Hilditch et al. [6] found in their literature survey in 2016 that few reactive countermeasures to sleep inertia have been evaluate. While light (pre- and post-wake) and sound seem appropriate for the automotive context, caffeine, self-awakening, temperature, and face-washing are inappropriate either due to the timely manner in which a user has to respond or the missing possibility to perform such actions (i.e., face-washing). Ferrara et al. [5] also state that alerting factors such as physical exercise, light, and sound seem usable as countermeasures. Therefore, we chose to use light and sound as sleep inertia countermeasures. To the best of our knowledge, VR has not yet been used to study sleep-wake contexts. However, VR enables the evaluation of reproducible environments and stimuli and, therefore, is a suitable study tool.

2.2 Sleep in Automated Driving

Sleep is mentioned as one of the likely activities humans will engage when using automated vehicles [13]. However, only when full automation is reached can the vehicle operate under all circumstances. Therefore, takeovers both in scheduled and non-scheduled situations were investigated [9]. Recently, this research started to include sleeping drivers. Wörle et al. showed in two studies that 60 s showed be a sufficient time for a takeover after sleep [21], that reaction times were impaired by about 3s [21] and that with a takeover time of 15s, driving performance is significantly impaired [20]. Wörle et al. also proposed a sleep inertia counter-procedure. In their experiment, they evaluated a non-invasive "gaming application on a tablet similar to a classical choice-reaction" [19, p. 6] which was subjectively assessed as assisting. While they report to have varied the wake-up procedures (loud and sharp sound and flashing lights **or** soft music and a warm yellow light), the authors do not report any results.

3 EXPERIMENT

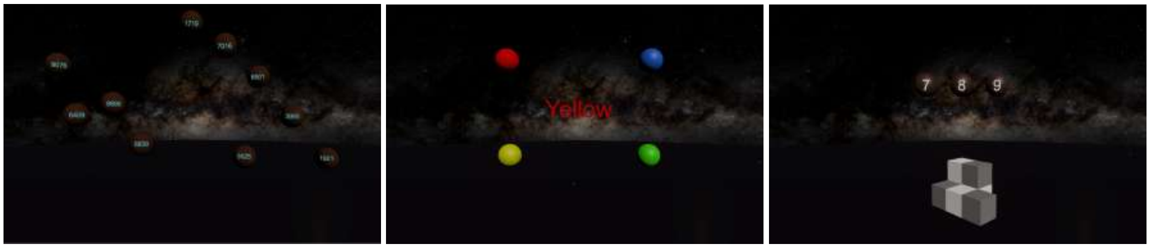
To evaluate the effects of auditory and visual stimuli on transferring somnolent people to consciousness, we designed and conducted a between-subjects study (*N*=45). The study was designed as a three conditional between-subject design. The three conditions were an auditory signal (resembling a Chevrolet Pontiac chime), and a fading of light in in two durations (5 and 20s; see Figure 1).

3.1 Materials

(a) Possible seat settings. (b) A participant on the seat.

Fig. 2. Seat arrangements. For the lying position, there is a footrest to compensate for the center of mass.

We implemented a VR space scene in Unity [17] (see Figure 3). We played spherical and calm music continuously [11]. We compared two stimuli differentiated by their duration to brighten (see Figure 1) and an auditory signal which had to be stopped. To measure the effects of awakening strategies, we implemented three tasks: a sorting, a stroop, and a counting task (see Figure 3). In the sorting task, participants had to sort non-normally distributed numbers. In the stroop task, participants had to select the textual described color. In the counting task, the correct number of cubics had to be selected. These tasks were chosen as they require different mental properties: the ordering task requires numerical, the counting task spacial, and the stroop task requires interference resilience in the presence of conflicting multidimensional stimuli [8].



(a) Ordering task. (b) Stroop task. (c) Counting task.

Fig. 3. The tasks "Ordering", "Stroop", and "Counting". The background (without task) was shown during the sleeping phase.

3.2 Measurements

Objective Measurement: We logged head movements with 4 Hz. Additionally, the performance (duration and correctness) regarding the three tasks were measured.

Subjective Measurements: We measured affective state using the Self Assessment Manikin (SAM) [2] before and after the exposure to the VR scene. Cognitive load was measured using the Rating Scale Mental Effort (RSME) [18]. These measurements were taken within the VR scene to minimize effects of taking off the VR headset and moving to a laptop. Afterwards, participants were asked whether they were tired prior to and after the experiment. Additionally, the agreement regarding statements on comfort ("I felt comfortable trying to sleep with a VR head-mounted display." and the inverted "I didn't feel that comfortable trying to sleep with a VR head-mounted display.") and the transition ("The transition from sleeping/resting to solving tasks was easy for me." and the inverted "The transition from sleeping/resting to solving tasks was hard for me.") were asked on 7-point Liker scales (1="Strongly agree" to 7="Strongly Disagree"). Finally, participants indicated their agreement to using sleep masks ("I usually sleep with a sleep mask on."), to using VR headsets permanently ("I can imagine wearing a head-mounted display permanently, if they become tiny and comfortable."), being woken up in a vehicle like this ("I can imagine being woken up like in the experiment to prepare for dangerous situations (e.g. take the control of a car)."), and meditation experience ("I have experience with meditation.") on the same 7-point Likert scale.

3.3 Procedure

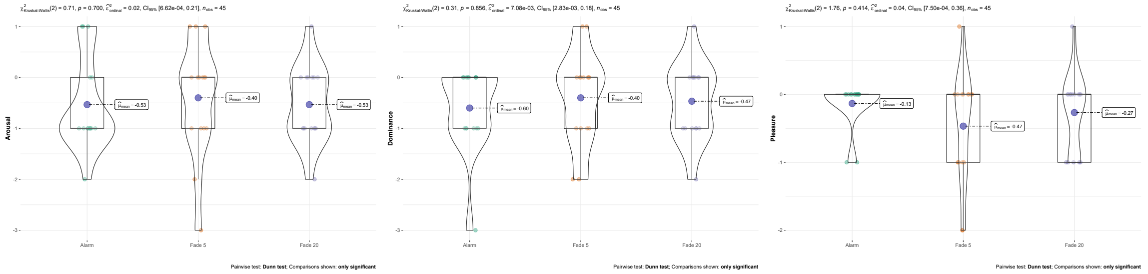
First, participants were introduced to the study procedure and the VR scene. They then signed informed consent and could adjust the seat (see Figure 2). In the next 15 min, participants remained in the VR scene to calm down and become sleepy. After this, participants were, based on the condition, awoken with one of the three stimuli. Participants then solved the study tasks (see Figure 3). Finally, participants answered questionnaires. The study took approximately 30 min, participants were compensated with €5.

3.4 Participants

12 female and 33 male people participated. The median of participants' age was *Mdn*=23 (range: 19 to 30; *M*=23.04, *SD*=2.53). Participants employed, on average, a tilt of 38.6°. Participants that were awakened with audio had a button to switch it off. This timing was measured. The range for this was 3.91s to 10.84s (*M*=6.60, *SD*=2.18). A Kruskal-Wallis test showed no significant differences for the wearing of masks for sleeping (χ^2 (2)=3.82, *p*=.15; range: *M*=1.00 (Fade 20) to

M=1.33 (Fade 5)) and experience with meditation (χ^2 (2)=4.57, *p*=.10; range: *M*=3.07 (alarm) to *M*=4.40 (Fade 20)). A Kruskal-Wallis test also showed no significant differences for comfort sleeping with a VR headset ("I didn't feel that comfortable trying to sleep with a VR head-mounted display."; χ^2 (2)=0.28, *p*=.87; range: *M*=3.20 (Fade 5) to *M*=3.40 (Alarm)). 14 participants fell asleep in the "sleeping" phase, 5 in the Fade 20, 3 in the Fade 5, and 6 in the alarm condition.

4 RESULTS



(a) Arousal. (b) Dominance. (c) Pleasure.

Fig. 4. Pre-Post differences for the SAM [2]

4.1 Data Analysis

We compared the three concepts and also compared the alarm vs. the merged data of the two fading concepts (i.e., auditory vs. visual). Depending on the data's nature, we employed or Kruskal-Wallis tests or Mann-Whitney tests (non-normally distributed data) or Welch one-way ANOVAs and t-tests (normally distributed data).

For post-hoc tests, we used Bonferroni correction. For the figures, we used the R package ggstatsplot [12]. R in version 4.1 and RStudio in version 1.4.1717 was employed. All packages were up to date in June 2021.

4.2 Affective State and Cognitive Load

Kruskal-Wallis tests found no significant differences neither for the difference in arousal, dominance, nor pleasure between the three conditions (see Figure 4). Also, Mann-Whitney tests found no significant differences between the alarm and the merged fading conditions.

A Welch test found no significant differences between the subjective cognitive load (measured by the RSME) for the three conditions. A Mann-Whitney test also found no significant difference in cognitive load between the alarm and the merged fade groups.

4.3 Task Performance

We found no significant differences in any of the tasks' objective performance between the three concepts neither for mistakes nor for the duration needed. We also found no significant differences between the merged groups for the objective performance in the ordering, stroop, and counting task. In all three conditions, the median number of mistakes for all three tasks was 0.

4.4 Perceived Sleep Duration and Vigilance

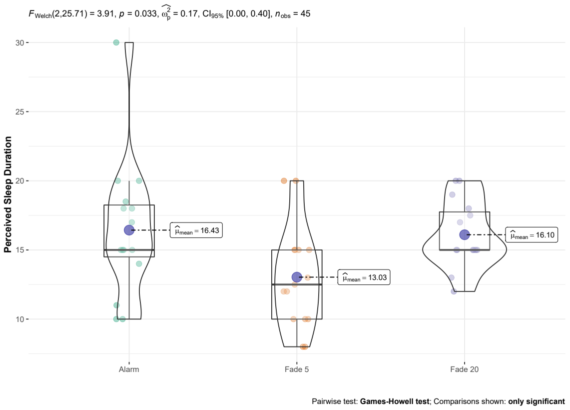
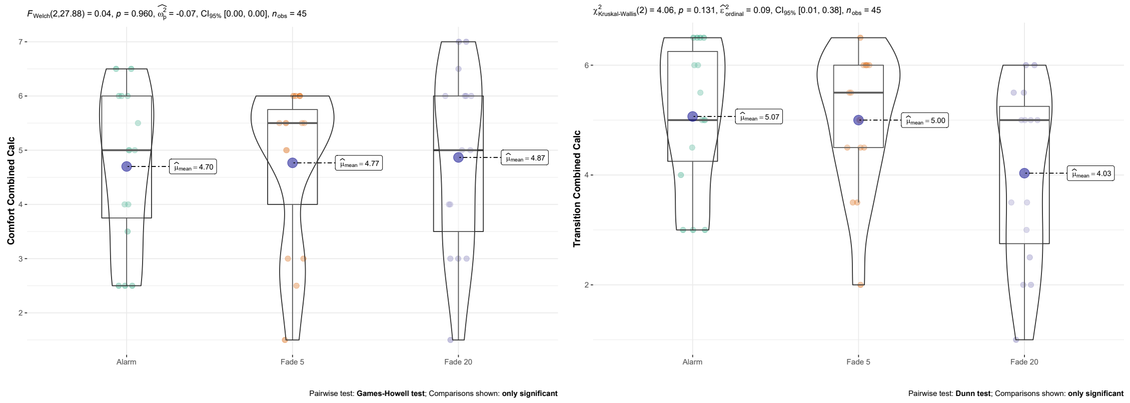


Fig. 5. Perceived sleep duration.

A Welch one-way ANOVA found a significant difference in perceived sleep duration ($F(2,\ 25.71) = 3.91$, p=.03; see Figure 5). However, post-hoc tests showed no significant differences. Nonetheless, sleep was perceived as longest in the alarm condition (see Figure 5).

A Kruskal-Wallis test showed no significant differences for the perceived vigilance of the subjects after the tasks between the three conditions (χ^2 (2)=1.18, p=.55; medians: 6 in alarm, and 5 in both fading groups). A Welch t-test also found no significant differences between the alarm and the merged fading groups ($t(28.18) = 0.58$, p=.56).

4.5 Transition, Comfort, and Waking Up



(a) Comfort score.

(b) Transition score.

Fig. 6. Comfort and transition scores.

We calculated a transition ("The transition from sleeping/resting to solving tasks was easy for me." and the inverted "The transition from sleeping/resting to solving tasks was hard for me.") and a comfort ("I felt comfortable trying to sleep with a VR head-mounted display." and the inverted "I didn't feel that comfortable trying to sleep with a VR head-mounted display.") score (less is better).

We found no significant differences neither for the three conditions (see Figure 6) nor between the alarm and the merged fade groups (Mann-Whitney tests for Transition: $\chi^2(1) = 5.43$, p=.94 and Comfort: $\chi^2(1) = 5.46$, p=.81).

A Kruskal-Wallis test showed no significant differences for the agreement on being woken up for dangerous situations of the subjects (χ^2 (2)=0.91, p=.64; median in all conditions 4.00). A Mann-Whitney test also found no significant difference for the comparison between the alarm and the merged fade groups $\chi^2(1) = 5.34$, p=.68; medians again 4.00).

4.6 Head Movements

We limited our analysis to the movement of the head (rotation and distance) and neglected the controller. In particular, we were interested in whether some users look around more often before making a decision (rotation).

A Kruskal-Wallis test showed no significant differences for the subjects' rotation between the three conditions (χ^2 (2)=2.93, p=.23). A Mann-Whitney test also found no significant differences between the alarm and the merged fade groups (p=.11).

5 DISCUSSION & REFLECTIONS ON STUDY DESIGN AND LIMITATIONS

This is, to the best of our knowledge, the first study that investigated the effects of awakening support in a VR simulation. The results are relevant for a wide range of (future) applications: (1) automated vehicles in which passengers may sleep, (2) (future) VR headsets that are worn permanently, and (3) other scenarios in which there is full control of the surrounding or the wake-up mechanism, e.g., automated hotels.

While a combination of auditory and visual stimuli is likely the most promising and there is significant work to be done for the design of this concept, our aim was to find main effects of these stimuli before combining them. We found surprisingly few significant differences between the three concepts as well as between the alarm and the merged fade groups. It is, however, unclear whether this stems from no relevant differences between the stimuli or the general setup of the study and, potentially, low sleepiness of participants.

Regarding the study design, a baseline was not feasible for the study as any kind of signal is necessary to signal the participant the start of the task. Wörle et al. [19] varied the time of day for their trials and participants had to be sleep-deprived in the morning (under 4h of sleep). This would most likely increase the number of participants that fell asleep (14/45 or 31.11%). We opted for generic tasks that include different cognitive properties, however, are not focused on a specific task such as, for example, taking over control from an automated vehicle. Therefore, we believed the findings to be more generalizable.

Limitations are the unfamiliarity of the study setup for participants which could have led to lower relaxation. Some of the participants also reported the music to be disturbing. Also, the group size per condition was rather small (n=15). Additionally, 73.33% of the participants were male. Finally, the low error rates could indicate that our measurements were not sensitive enough to find differences between the conditions.

6 CONCLUSION

Overall, this work presents three concepts for awakening sleepy or sleeping participants in VR: an auditory alarm, fading in 5, and fading in 20s. In a between-subjects study (N=45), we evaluated the concepts with regard to perceived ease of transition, cognitive load, affective state, and performance in an ordering, the stroop, and a counting task. However, we found almost no significant differences.

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