Preliminary Evaluation of Variables for Communicating Uncertainties Using a Haptic Seat

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Abstract
Recent findings have indicated that the communication of uncertainties is a promising approach for overcoming human factors challenges associated with overtrust issues. The existing approaches, however, are limited in that they require operators to monitor the instrument cluster to perceive changes. As a consequence, significant changes may be missed and operators are regularly interrupted in the execution of non-driving related tasks even if the system is performing well. To overcome this, unobtrusive interfaces are required that are only interruptive if needed. This paper presents a lab-based study aiming at the preliminary evaluation of haptic variables for communicating automation uncertainties using a haptic vehicle seat. The initial results indicate that particularly increases in amplitude as well as a rhythm consisting of long vibrations separated by short breaks are well suited for communicating the exceedance of specified uncertainty thresholds. The communication of decreases in uncertainty using vibration cannot be recommended.

Author Keywords
Uncertainties; haptic; seat vibration

CCS Concepts
•**Human-centered computing** → **User interface design; Haptic devices;** *HCI theory, concepts and models;*

Introduction

The iterative approach to achieving full driving automation entails significant human factors challenges [4]. In particular, expecting human operators to resume the driving task following automation failures may lead to critical situations, partially due to a lack of situation awareness and overtrust issues [3, 7]. Researchers have suggested to communicate the uncertainties of the automated system in order to calibrate operator trust and prepare users for potentially imminent failures [1, 5]. However, while the existing approaches have indicated benefits in terms of driving safety following takeovers, it seems unlikely that the proposed interface concepts will prove to be valuable in practice. Foremostly, both publications used visual displays to convey uncertainties. This requires users to regularly glance to the instrument cluster in order to perceive changes. Particularly when considering the usage context, which will likely involve visual non-driving related tasks (NDRTs) [8], this impedes the prolonged usage uncertainty displays. Instead, an (for the majority of time) unobtrusive interface is needed that attracts the attention of the user as uncertainties increase and a takeover becomes increasingly likely. One approach of achieving this is to communicate significant changes in uncertainty with haptic feedback. Several publications have explored the use of a haptic seat to communicate information, for instance navigational content [2] or takeovers [9]. Compared with the visual and auditory perceptual channels, the tactile channel is characterised by very fast perception dwell times [12] and is likely not preoccupied with NDRTs.

The study presented in this paper examines a set of fundamental haptic variables in terms of their suitability for communicating changes in uncertainty. Thereby not only the exceedance of thresholds is of interest but also instances in which uncertainties drop below the threshold. As such, this study investigates how clearly different variables communicate increases and decreases in uncertainty.

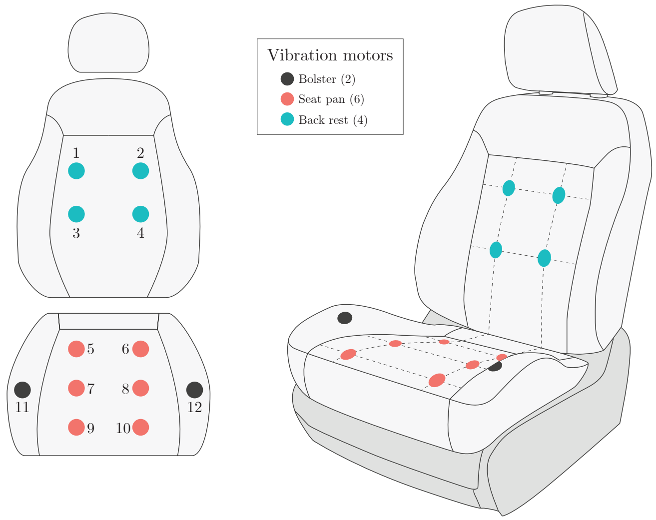

Figure 1: Position of vibration motors in vehicle seat

Preliminary Evaluation of Variables

A comparative study was conducted to address the research question. Similar to prior publications [10, 6], the design variables *amplitude*, *position*, *movement*, and *rhythm* were chosen for examination.

Participants and Design

A total of 25 participants (7 female) with an average age of 32.64 years (SD=10.00) participated in the experiment. The study was conducted with a within-subjects design whereby the sequence of variables was randomised to prevent order effects.

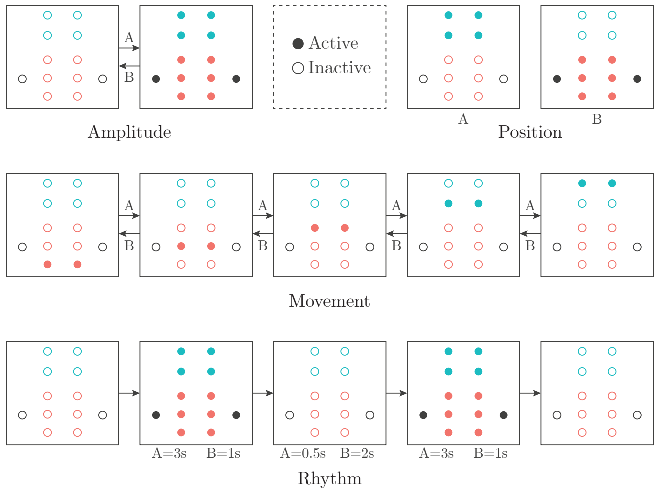

Figure 2: Haptic variables

Table 2: Descriptive statistics for the agreement with each statement regarding increasing/decreasing uncertainty

		Direction			
		Increasing		Decreasing	
Variable	**Pattern**	*Mean*	*SD*	*Mean*	*SD*
Amplitude	A	5.68	1.14	2.20	1.15
	B	4.88	1.90	3.04	1.86
Movement	A	5.08	1.71	2.64	1.63
	B	4.64	1.93	3.24	2.03
Position	A	4.80	1.19	2.64	1.32
	B	4.64	1.52	3.28	1.37
Rhythm	A	5.36	1.44	2.20	1.04
	B	4.08	1.63	3.32	1.57

Feature	**Specification**
Op. voltage	3 V
Op. current	100 mA
N. amplitude	7 G
Body diameter	8.7 mm ± 0.2

Table 1: Values for rated operating voltage and current as well as typical norm. amplitude and body diameter

Apparatus and Procedure

The study was conducted in a laboratory setting and participants were seated in a driving simulator consisting of three projectors and a vehicle cockpit for the duration of the study (approximately 30 minutes). Throughout the experiment, the automated system was engaged and participants were not required to perform the driving task. The position (see Figure 1) and specification (see Table 1) of the eccentric vibration motors is consistent with prior publications [2]. The maximum vibration amplitude for seat pan and back rest was selected based on prior findings [6]. Participants were introduced to the study with a video explaining driving automation and the meaning of uncertainties. Following the introduction, the variables were evaluated in a randomised order. For each variable, two opposing patterns were designed (see Figure 2). The variable *amplitude* characterises an increase (pattern A) or decrease (pattern B) in vibration intensity. *Movement* was implemented through a successive activation of vibration motors up (pattern A) or down the seat (pattern B). *Position* was varied between back rest (pattern A) and seat pan (pattern B). *Rhythm* was varied between long vibrations with short breaks (pattern A) and short vibrations with long breaks (pattern B). Each pattern was presented three consecutive times to each participant, whereby the order of the patterns was randomised. For each pattern, participants had to indicate on a 7-point Likert scale to which degree they agree with the statement that the haptic pattern conveys that the uncertainty of the vehicle is (a) increasing and (b) decreasing. Prior to each pattern and question, the vibration was turned off.

Results, Discussion and Limitations

Table 2 and Figure 3 summarise the results of the study. For all variable patterns, the agreement with the statement

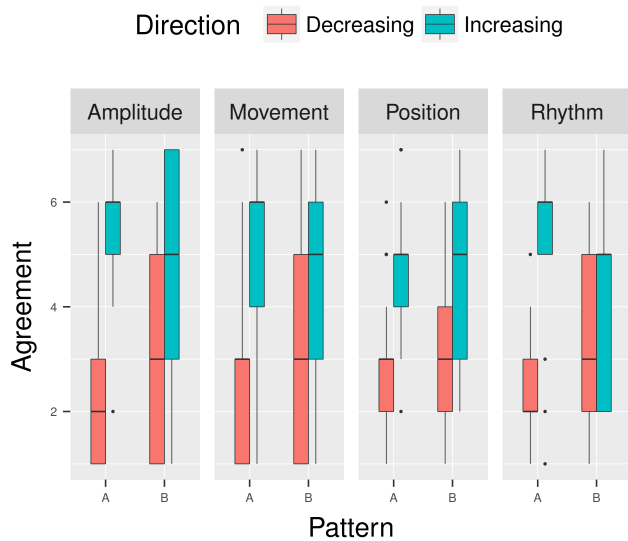

Figure 3: Box plots for the responses regarding each variable pattern

Table 3: Results of paired t-tests between responses regarding direction (increasing/decreasing)

Variable	Pattern	t-test	MD
Amplitude	A	$t(24) = 8.05^{***}$	3.48
	B	$t(24) = 2.56^{*}$	1.84
Movement	A	$t(24) = 3.80^{***}$	2.44
	B	$t(24) = 1.86$	1.40
Position	A	$t(24) = 4.73^{***}$	2.16
	B	$t(24) = 2.54^{*}$	1.36
Rhythm	A	$t(24) = 6.97^{***}$	3.16
	B	$t(24) = 1.28$	0.76

Significance levels: $^{***}p < .001$ $^{**}p < .01$ $^{*}p < .05$

that the uncertainty is increasing was higher than that for the opposing statement. Paired t-tests were conducted to examine the significance of the differences (see Table 3) [11]. Except for pattern B of *movement* and *rhythm*, all t-tests returned significant results, indicating that it is more intuitive to associate haptic feedback with increases in uncertainty rather than decreases. Overall, pattern A of the variables *amplitude* ($M = 5.68, SD = 1.14$) and *rhythm* ($M = 5.36, SD = 1.04$) received the highest scores regarding the communication of an increase in uncertainty. Further, the differences between the opposing directions (increasing/decreasing uncertainty) were highest for these patterns. The results indicate that particularly a pattern that gradually increases the vibration intensity (pattern A, *amplitude*) as well as a rhythm consisting of a long vibration (3s), followed by a short break (0.5s) and another long vibration (pattern A, *rhythm*) clearly communicate an increase in uncertainty. The presented results show the first implications for communicating uncertainties using haptic feedback. However, the findings must be validated in a driving context in order to ensure that participants can quickly interpret the haptic stimuli and respond accordingly. To ensure internal validity, several parameters were not varied, for instance the maximum amplitude. Further, the impact of gender, age, or weight on vibration intensity must be considered when implementing vibration into vehicle seats [6].

Conclusion

The initial results indicate that particularly increases in amplitude as well as a rhythm consisting of long vibrations ($3s$) separated by short breaks ($0.5s$) are well suited for communicating the exceedance of specified uncertainty thresholds. Further, the communication of decreases in uncertainty using vibration cannot be recommended.

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