Designing and Evaluating Meaningful Tactile Displays to Assist Takeover in Automated Vehicles

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Background

Semi-autonomous vehicles still require human drivers to take over when the automated systems reach their limitations and can no longer perform the driving task themselves. Therefore, a reliable human-machine interface may be necessary to help drivers during the sudden and complex takeover process.

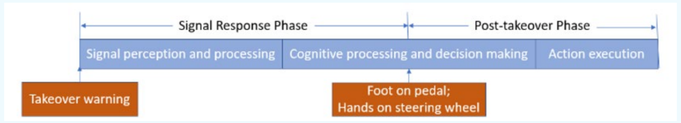


Figure 1: The Takeover Model (Huang & Pitts, 2022); adapted from (Petermeijer et al., 2016).

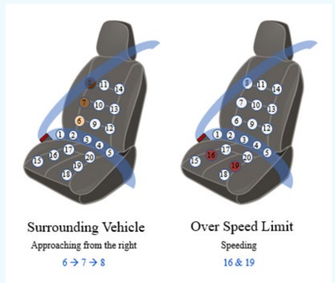
Research Goal: The goal of this study was to design and test the effects of six meaningful tactile signal types, representing six driving scenarios (i.e., navigation, speed, surrounding vehicles, over the speed limit, headway reductions, and pedestrian status) respectively, and two pattern durations (lower and higher urgencies), on drivers' perception and performance during automated driving.

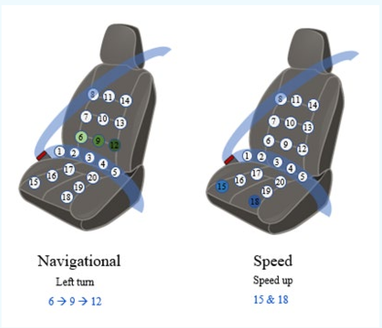
Methodology

Step 1: Driving Simulator & Tactile Display

Figure 2: MiniSim Driving Simulator and Tactile Seat and Seat Belt

Legend
Navigation (N)
Speed (S)
Surrounding Vehicle (SV)
Over Speed Limit (OSL)
Headway Reduction (HR)
Pedestrian Status (PS)





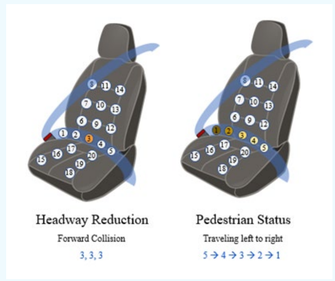


Figure 3: Example pattern descriptions for all six warning signal types

Step 2: Experimental Methods

Participants:

Sixteen SJSU students; Average age = 19.9 years; Average years of driving experience = 2.9 years.

Procedure:

1. Participants were asked to study the vehicle "manual," which listed all the driving scenarios and their associated vibrotactile signals/patterns (Table 1).
2. Participants were asked to keep their hands at their sides and feet off the pedals as the vehicle was simulating an SAE Level 3 drive.
3. At random, tactile patterns would play on the driver's seat (back or pan) and seat belt.
4. Participants were asked to execute a response (e.g., pressing a button) as quickly as they could, but only after they had an answer for the actual meaning the tactile signal was representing, to state their interpretation of the signal, and then to rate their confidence in their answer and intuitiveness of the tactile signals.

Table 1: A summary of tactile signals and patterns used in the study.

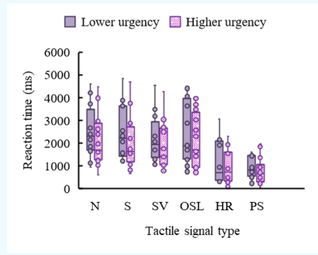
Tactor Sequence	Display Location	Warning Signal	Pattern: Low Urgency	Pattern: High Urgency
Instructional (5)				
Navigational Warning Signals (3)				
2 > 3 > 4	Belt	Left Turn	(3x 215ms ON)	(3x 107.5ms ON)
6 > 9 > 12	Back	Left Turn	(3x 215ms ON)	(3x 107.5ms ON)
4 > 3 > 2	Belt	Right Turn	(3x 215ms ON)	(3x 107.5ms ON)
12 > 9 > 6	Back	Right Turn	(3x 215ms ON)	(3x 107.5ms ON)
3 > 4 > 12	Belt	U-Turn	(3x 215ms ON)	(3x 107.5ms ON)
15 > 18 > 19	Pan	U-Turn	(3x 215ms ON)	(3x 107.5ms ON)
Speed Warning Signals (2)				
2 & 4	Belt	Speed Up	(3x 215ms ON, 215ms OFF)	(3x 107.5ms ON, 107.5ms OFF)
15 &18	Pan	Speed Up	(3x 215ms ON, 215ms OFF)	(3x 107.5ms ON, 107.5ms OFF)
6 & 12	Back	Slow Down	(3x 215ms ON, 215ms OFF)	(3x 107.5ms ON, 107.5ms OFF)
17 & 20	Pan	Slow Down	(3x 215ms ON, 215ms OFF)	(3x 107.5ms ON, 107.5ms OFF)
Informative (5)				
Surrounding Vehicles Warning Signals (2)				
12 > 13 > 14	Back (left)	Back Left	(3x 215ms ON)	(3x 107.5ms ON)
9 > 10 > 11	Back (center)	Back	(3x 215ms ON)	(3x 107.5ms ON)
6 > 7 > 8	Back (right)	Back Right	(3x 215ms ON)	(3x 107.5ms ON)
20 > 19 > 18	Pan (left)	Pan, left side, back-to-front	(3x 215ms ON)	(3x 107.5ms ON)
17 > 16 > 15	Pan (right)	Pan, right side, back-to-front	(3x 215ms ON)	(3x 107.5ms ON)
Over Speed Limit Warning Signals (1)				
7 & 13	Back	Speeding	(3x 215ms ON, 215ms OFF)	(3x 107.5ms ON, 107.5ms OFF)
16 & 19	Pan	Speeding	(3x 215ms ON, 215ms OFF)	(3x 107.5ms ON, 107.5ms OFF)
Headway Reduction Warning Signal (1)				
3, 3, 3	Belt	Forward Collision	(215ms ON, 4800ms OFF, 215ms ON, 3440ms OFF, 215ms ON, 1200ms OFF) + 1800ms OFF delay	(107.5ms ON, 2400ms OFF, 107.5ms ON, 1720ms OFF, 107.5ms ON, 600ms OFF) + 1800ms OFF delay
Pedestrian Status Warning Signals (1)				
1 > 2 > 3 > 4 > 5	Belt	Pedestrian traveling right to left	(5x 215ms ON, 2500ms OFF)	(5x 107.5ms ON, 1250ms OFF)
5 > 4 > 3 > 2 > 1	Belt	Pedestrian traveling left to right	(5x 215ms ON, 2500ms OFF)	(5x 107.5ms ON, 1250ms OFF)

Step 3: Evaluation

Dependent Measures (6 signal type x 2 pattern full factorial design)

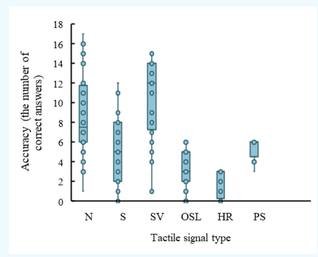
1. Reaction times (ms): time between the onset of the tactile signal and the moment the participant pressed the button on the dashboard.
2. Interpretation accuracy: measured the number of correct answers in each of the 12 conditions (6 signal types × 2 patterns).
3. Subjective satisfaction ratings: participants' ratings based on the confidence in their answers and intuitiveness of the tactile signals, both on a 5-point rating scale (1 low – 5 high).

Results



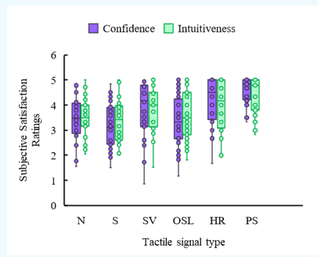
Reaction Time

Boxplot of reaction time, as a function of tactile signal type and pattern.



Accuracy

Boxplot of interpretation accuracy as a function of tactile signal type.



Subjective Satisfaction Ratings

Boxplot of subjective satisfaction ratings (i.e., confidence and intuitiveness) as a function of signal type.

Findings

1. Shorter RTs and higher intuitive ratings for higher urgency patterns than lower urgency patterns.
2. Pedestrian status and headway reduction signals were associated with shorter RTs and increased confidence ratings, compared to other tactile signal types.
3. Lastly, among six tactile signals, surrounding vehicle and navigation signal types had the highest interpretation accuracy.

Future Research

1. Investigate the effects of meaningful tactile displays on automated vehicle takeover performance in complex situations (e.g., urban areas).
2. Explore ways to create an adaptive multimodal display to better fit and guide the individual driving

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Imagine the Future.