TempSeat: Investigating the Suitability of a Heated Car Seat for Feedback Purposes

Patrizia Di Campli San Vito
Stephen Brewster
Patrizia.DiCampliSanVito@glasgow.ac.uk
Stephen.Brewster@glasgow.ac.uk
School of Computing Science, University of Glasgow
Glasgow, United Kingdom

ABSTRACT

Thermal cues in the car can be used as an alternative to audio and vibration feedback to lessen the burden on the often overloaded visual channel. This paper presents an investigation of a heated car seat to evaluate the effectiveness of the heating for feedback purposes. The temperature changes of a heated car seat were measured without and with seated passengers to assess the heating capabilities in general and to understand the temperature interaction with a seated person. A user study (N=12) investigated the recognition times during a simulated driving task. Temperature changes during driving simulation were detected on average in under 1min, with an average increase of around 0.33℃ on the backrest (0.36℃ on seat). These initial results can be used as basis and inspiration for further investigations to lessen the visual channel with thermal cues.

CCS CONCEPTS

• **Human-centered computing → Haptic devices**.

KEYWORDS

Thermal; haptic; in-car

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1 INTRODUCTION

Drivers nowadays are presented with a plethora of information, both driving and non-driving related, and the latter is expected to increase in automated vehicles, in which entertainment or work related activities are expected to increase. Multimodal feedback has been frequently explored as a way to lessen the load on the visual channel of drivers, engaging audio and vibrotactile cues to reduce reaction times and increase driving performance [11, 18, 20]. However, these modalities have disadvantages: audio feedback can disrupt conversations, is unsuitable for deaf drivers and its performance can drop in noisy environments [15]. Vibration can be hard to detect as it can be masked by vibration from the road [12]. In fully automated vehicles, driving will be handed over to the car and non-driving related activities will be increasingly important. Modalities are needed that can effectively work alongside in-vehicle tasks without disrupting the passenger experience during movie watching, reading or working.

Thermal feedback can be recognised effectively in noisy and bumpy environments [12] and thermal feedback can have affective associations [2, 21], add emotional layers to media [1, 9] and increase social presence in communication [10, 13], which could enhance the experience of in-vehicle activities. Future entertainment use of mixed reality within the car [14] could benefit from the increase of immersion enabled by thermal feedback [8, 16].
Research on the use of thermal feedback within the car has been focused on manual driving, mostly by presenting thermal cues on Peltier devices attached to the steering wheel for directional [4, 5, 7] and informational cues [3, 6]. To enable the effective use of thermal feedback during automated driving, where the user's hands may not be on the wheel, other locations and devices need to be tested. Vibrotactile feedback has been tested on the car seat [17, 19] and found to be a suitable location, but an investigation of thermal feedback on the seat is still missing. Different kinds of tactile feedback on the seat expand the design possibilities and could present feedback for different use cases. Many cars already have heated seats so could provide thermal feedback without any additional hardware, but little is known about their ability to do this effectively. This paper, therefore, presents an investigation of a heated car seat and its warming capabilities to evaluate its usefulness for feedback purposes. We present measurements of the heating of an empty seat, capturing the scope and speed of the heating hardware. Then a pilot test with a seated person was performed, investigating changes in the temperature of the seat over time as a consequence of the passenger occupying the seat. A user study was conducted to collect detection times and the extent of temperature change needed for detection.
Results showed that the seat warmed faster at the beginning and that the passive cooling takes considerably longer with a seated passenger. Passive warming of the seat, meaning the adaptation of the seat temperature by the seated body alone without any active heating, can have a similar temperature change as the active heating of the adapted seat. In the user study, participants detected the temperature change on average after warming of around 0.36℃ and 0.33℃ on the seat and backrest, respectively, within around 53s.

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(a) Car Seat setup with thermal sensors on seat and backrest.

(b) Thermometer and measuring points on the seat.

Figure 1: Car seat with attached thermal sensors and temperature measurement with an infrared thermometer.

2 APPARATUS

The car seat used, see Figure 1(a), was taken from a JLR Range Rover Sport and prepared for out of car use by Fleet Automotive Scotland [1]. It was a standard seat with a built-in heating mat with three levels of heating intensity. The heating mat could only heat, cooling was only achieved passively after turning off the mat. The mat and the seat adjustment electronics were powered with an attached car battery. All measurements were taken for the highest heating intensity. The temperature of the empty seat was measured with a Precision GOLD N85FR Infrared Thermometer pointed at the seat pad and the backrest, see Figure 1(b). This method was very reliable in collecting the surface temperature of the seat, but could not be used with a seated passenger., Therefore, the temperatures with a seated passenger were collected with two K Type Thermocouple Temperature Sensors M6 connected to an Arduino Uno board with MAX6675 modules, collecting data in the same locations (see Figure 1(a)). These temperature readings captured the temperature between the passenger and car seat. The passenger used a Logitech G920 steering wheel to drive a car in a driving simulator environment implemented with OpenDS[2], presented on a screen in front of the user.

3 SEAT MEASUREMENTS

3.1 Methodology

To establish the rate of temperature change of the empty seat, the seat pad and backrest were manually measured every 30s with the infrared thermometer. These readings would capture the seat's overall heating capabilities without any interaction between body heat and the seat. The temperature readings were collected during active warming and then passive cooling, after turning off the seat heating. Warming and cooling phases of a short (5min) and a long time frame (30min) were measured. The longer time period was measured to get a scope of the heating capabilities of the seat, the shorter period would give an indication of how similar the heating and cooling patterns were for different heating times and temperature changes. In addition, we measured heating of 2.5min and the time taken until the seat temperature returned to the start temperature before the heating. We were interested in seeing how long the temperature would take to return to the start temperature after a short time of heating. This took about 8min. The measurements of the empty seat, therefore, where collected for 5min heating, followed by 5min cooling, as well as 30min heating followed by 30min cooling and a short 2.5min of heating followed by 8min of cooling. The room temperature was approximately 21.4℃.

The measurement with a seated passenger were taken while the participant was engaged in a simulated driving task. They manoeuvred a virtual car with a constant speed of 100km/h on a five lane motorway and performed 18 lane changes, visually prompted with arrows appearing on gantries above the lane. The driving task was chosen to occupy the participant with a task associated with a car seat. Each driving block took 10min and the temperature was changed twice within that time. Before starting the driving task, the participant was seated without driving for 5min, to allow passive adjustment of the seat temperature. Within the driving part, the heating was turned on twice at random times and left on until the participant reported feeling the seat actively being warmed, after which the heating was turned off. All three activities were manually logged by the experimenter. The pilot consisted of 3 driving parts, leading to 6 heating phases and recognition times. The room temperature was approximately 13.9℃ and the participant took breaks between the driving parts in which they left the seat. Afterwards, the participant returned to the seat for 30min after a short break: 10min of active warming and 20min of passive cooling after the heating was turned off. This continuous heating and cooling was measured to compare it to readings of the empty seat and observe changes in temperature behaviour that could occur because of interaction with the participant's body heat.

3.2 Results

3.2.1 Heating of Empty Seat. The temperature change over 30min of heating the empty seat led to an increase of temperature of 16.4℃ on the seat pad and 17.6℃ on the backrest. After passive cooling over 30min the temperature returned to the start temperature, see Figure 2. This corresponds to an average heating (and cooling) of 0.55℃/min on the seat pad and 0.59℃/min on the backrest, though the heating and cooling was not linear, as can be observed in Figure 2.

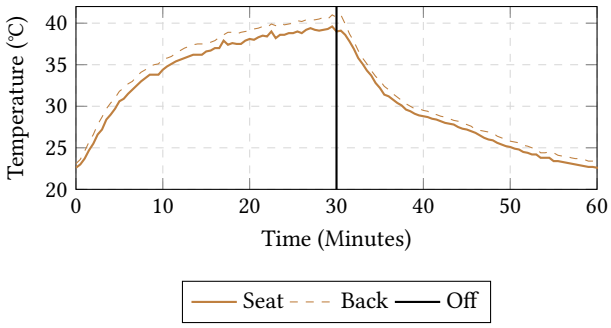

Figure 2: Empty seat warming for 30min and passive cooling until return to start temperature, black line always indicates the moment when heating was turned off.

The heating of the empty seat over 5min can be seen in Figure 3(a).

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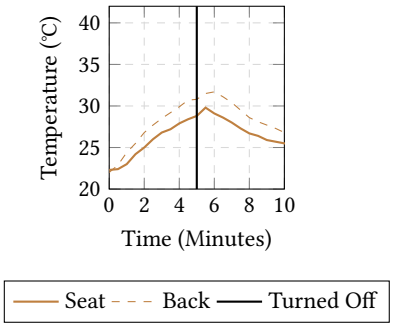
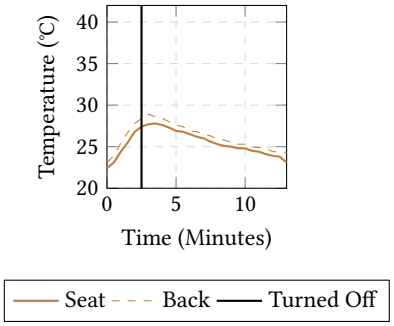
[2] opends.eu



(a) Heating and Cooling of 5min

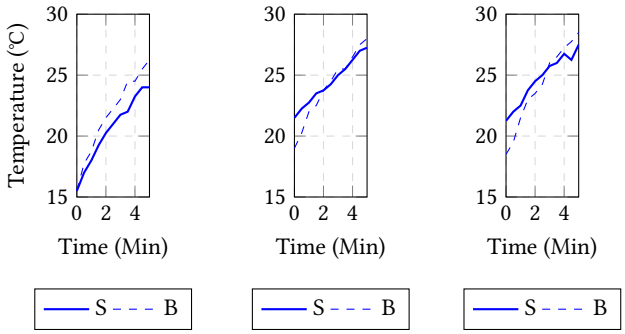


(b) Heating for 2.5min and cooling to start temperature

Figure 3: Empty Seat Warming: 5min of heating and cooling and 2.5min heating and passive cooling until returned to start temperature, the black line indicates the moment the heating was turned off.

The temperature increased 6.5℃ on the seat pad and 8.8℃ on the backrest during that time frame, leading to an average of 1.3℃/min and 1.8℃/min on seat pad and backrest, respectively. During the 5min of passive cooling the temperature changed 4.5℃ on the seat pad and 5.0℃ on the backrest, an average of 0.9℃/min and 1.0℃/min on seat pad and backrest, respectively. The temperature change was not linear and it can be seen that the temperature did not start to decrease directly after turning off the heating, but still increased for up to almost 1min, before decreasing.
The heating of the empty seat for 2.5min led to a temperature change of 5.0℃ on the seat pad and 5.3℃ on the backrest, see Figure 3(b). This corresponds with a rate of change of 2.0℃/min and 2.1℃/min on the seat pad and backrest, respectively. The temperature returned to the starting value after 8min of cooling, leading to a rate of cooling of 0.58℃/min for both locations.

3.2.2 Heating of Seat with Passenger. The female participant sat in the seat for 5min before starting the drive to adapt the seat temperature. The room temperature was 13.9℃, the first adaptation, therefore, started at a cooler temperature than the following. Figure 4 shows all three adaptation phases. On average, the temperatures changed 6.8℃ on the seat pad and 9.9℃ on the backrest, leading to a rate of change of 1.4℃/min and 2.0℃/min, as can be seen in Table 1.



(a) Adaptation 1 **(b) Adaptation 2** **(c) Adaptation 3**

Figure 4: Passive adaptation of seat (S) and backrest (B) due to passenger, 5min time frame.

	Seat	Back	Rate Seat	Rate Back
Adaptation 1	8.5℃	10.8℃	1.7℃/min	2.2℃/min
Adaptation 2	5.8℃	9.0℃	1.2℃/min	1.8℃/min
Adaptation 3	6.3℃	10.0℃	1.3℃/min	2.0℃/min
Mean	6.8℃	9.9℃	1.4℃/min	2.0℃/min

Table 1: Passive Adaptation, 5min time frame.

	Seat HeatOn	Back HeatOn	Seat Felt	Back Felt	Seat Delta	Back Delta	Detect Time
Drive 1	25.8℃ 30.8℃	27.5℃ 31.5℃	27.3℃ 31℃	28.8℃ 32.5℃	1.5℃ 0.3℃	1.3℃ 1.0℃	83.14s 56.23s
Drive 2	28.8℃ 31.0℃	29.5℃ 31.5℃	29.3℃ 31.0℃	30.3℃ 32.0℃	0.5℃ 0.5℃	0.8℃ 1.0℃	77.06s 49.13s
Drive 3	28.8℃ 31.3℃	30.0℃ 32.3℃	29.8℃ 31.8℃	31.0℃ 32.8℃	1.0℃ 0.5℃	1.0℃ 0.5℃	84.05s 38.56s
Mean					0.6℃	0.8℃	64.70s

Table 2: Heating Detection

Information on the temperature change detection during driving can be found in Table 2. The active warming was on average detected around one minute and after a change of only 0.6℃ on the seat pad and 0.8℃ on the backrest.

Figure 5 shows heating over 10min, while the participant was seated and then 20min measurement after the heating was turned off, with the participant still occupying the seat. The temperature changed 12.3℃ on the seat pad and 15.3℃ on the backrest during heating, a rate of change of 1.2℃/min and 1.5℃/min, respectively. The cooling phase, however, showed almost no temperature change over 20min. The temperature increased slightly after the heating was turned off and cooled very little. 20min after heating, the seat was 0.3℃ warmer than when the heating was turned off and the back only cooled down 0.8℃.

3.3 Discussion

Temperature changes of the seat have been collected under differing circumstances. Heating and cooling phases on the empty

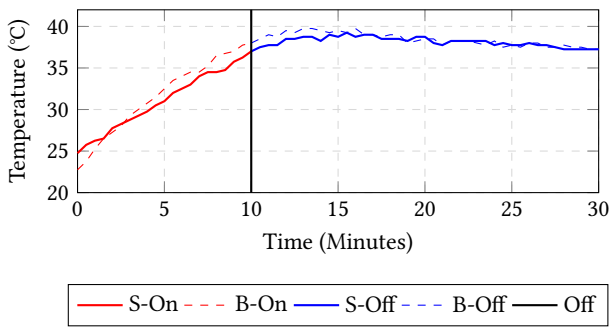


Figure 5: Seat (S) and backrest (B) warming with seated passenger for 10min (S/B-On) and passive cooling for 20min (S/B-Off), black line indicates the moment when heating was turned off.

seat have been monitored, showing a non-linear increase of 16.4℃ and 17.6℃ over 30min on the seat pad and backrest, respectively. Overall, it could be seen that the temperatures on the back of the seat varied more than on the seat pad, both when heating and when cooling after turning the heating off. The rate of temperature change was considerably higher right after turning the heating on and decreased over time. The same could be observed for the cooling phase, with cooling being slower than heating overall due to its passive nature. Heating of 2.5min led to an increase in temperature that took 8min to reverse.

The presence of a passenger occupying the seat had an observable effect on the temperature changes of the seat. The seat temperature increased up to 10℃ in 5min without active heating, due to the body heat of the occupant. This was comparable to the temperature change observed for the first 5min of active heating of the empty and occupied seat, see Figure 6. Further investigations will have

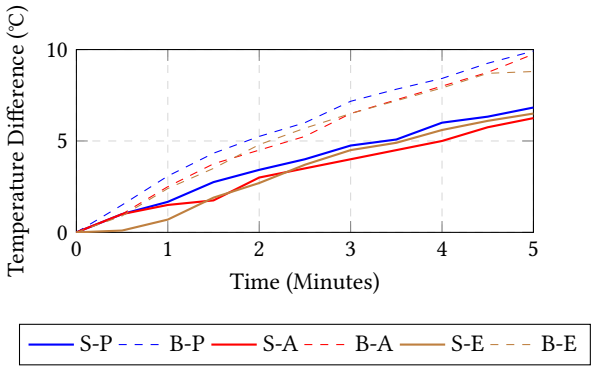


Figure 6: Seat warming difference for 5min: Passive only by passenger sitting in the seat (blue, *P*), active warming with passenger (red, *A*) and active warming without passenger on empty seat (brown, *E*); full line shows the warming of the seat pad *S*), dashed lines the warming of the backrest rest *B*).

to observe the effect of active heating right after occupation of the seat to decide if the difference could be distinguished, as otherwise any feedback given within the natural adaptation phase after newly occupying the seat would take considerably longer to be detected. The active heating during driving was detected within a maximum of 84.05s (64.70s on average) and after only a small increase in temperature, which could be attributed to the large body area in contact with the heated surface. The intensity of thermal feedback can be increased by presenting temperature changes on a larger area, an effect which is called spatial summation. A further user study with more participants was conducted to confirm these values.

Observation of the cooling process of the occupied seat showed that the temperature hardly decreased over 20min after turning off the heating. This could influence the feeling of comfort of the passenger considerably, if heating as feedback was turned on repeatedly and thus increased the temperature to a degree that exceeds the preference of the passenger. This type of feedback would only be useful to inform on events that occur rarely and do not need to be addressed immediately, such as low fuel or oil for driving related feedback or adapting the seat temperature to mirror the setting of a VR scenario to increase immersion as non-driving related use case. These initial observations were further investigated in a user study, to get more diverse data on recognition times and subjective feedback on the experience.

4 USER STUDY

4.1 Methodology and Participants

Detection times and temperature changes with passengers were collected in a user study with 12 participants, who were engaged in the same simulated driving task as used in the measurement with the seated passenger. Before starting the driving task, the participants were already seated in the car seat during the introduction of the driving task and a short test drive of approximately 1.5min without heating, which allowed passive adjustment of the seat temperature to mirror the settings of the measurement. The driving part of the experiment consisted of three 10min drives, in which the heating was turned on three times, leading to 9 heating events for each participant (after the 3rd, 9th and 14th lane change, or at least two lane changes after the last recognition). The seat was heated until the participants reported feeling the seat actively warming, after which the heating was turned off. All three activities were manually logged by the experimenter. The room temperature was collected at the beginning of each driving part and participants left the seat during breaks between the driving parts. At the end, the participants filled in a short questionnaire, capturing the clothes worn and some subjective ratings of how well they could feel the warming, how sure they were when they reported the heating and how much they enjoyed it the warming of the seat as feedback, all on a 5-point Likert scale (with 1 not at all and 5 very much). They were also encouraged to comment on how and if this warming could be used as feedback during driving.

The participants of the user study (7 male, 5 female), between 20 and 51 years old (*Mean*=28.33, *SD*=8.72), had an average driving experience of 8.29 years (*SD*=7.74). The participants wore predominantly shirt or jumper and jeans or shorts, a single layer of clothing on both upper and lower half of their body. Only P09 and P11 reported on a second layer on the upper half of the body. Room temperatures varied between 22.0℃ and 28.7℃ with an average 24.6℃ (*SD*=2.06),

	P01	P02	P03	P04	P05	P06
RecTime	39.33	72.00	44.56	47.22	36.78	23.78
TempSeat	0.31	0.39	0.22	0.22	0.19	0.00
TempBack	0.14	0.44	0.31	0.03	0.03	0.06
AddReport	0	0	2	1	11	15
	P07	P08	P09	P10	P11	P12
RecTime	69.00	76.22	46.44	37.56	66.44	72.67
TempSeat	0.64	0.50	0.36	0.19	0.69	0.53
TempBack	0.69	0.42	0.47	0.08	0.53	0.67
AddReport	1	0	1	5	0	1

Table 3: Participant averages of recognition time in seconds (*RecTime*), temperature change of the seat (*TempSeat*) and the backrest (*TempBack*) and the number of additional reporting of heating (*AddReport*).

however, the influence of room temperature on detection should be minimal as the passenger was in direct contact with the seat and the air around them would not influence this temperature once it was adapted to the body contact.

4.2 Results

4.2.1 Recognition. The time for participants to report the active heating was calculated from the onset of the heating until the participants reported feeling the temperature change and was recognised on average within 52.66s (*SD*=27.01), with a minimum recognition time of 3s and a maximum of 151s. The average temperature change occurring during this time was 0.36℃ on the seat (*SD*=0.46) and 0.33℃ on the backrest (*SD*=0.48). The maximum temperature change was 2℃ on the seat and 1.5℃ on the back over 114s. The performance varied between participants, as did the number of reporting of heating when it did not occur: while several participants only reported heating when it was turned on, one participant reported 15 and another 11 additional occurrences, which would influence the reliability of their recognition time. The two participants (P09, P11) with as second layer of clothing on the upper part of their body had recognition times close to the mean time, with other participants being both faster and slower than them. These additional occurrences of reporting as well as the average recognition time, temperature change on the seat and backrest of each participant can be seen in Table 3.

4.2.2 Subjective Data. The rating of how well they could feel the warming of the seat, how sure they were when they reported the heating and how much they enjoyed the heating as feedback was collected on a five-point Likert scale, where 5 annotated very well/sure/much and 1 not well/sure/much, respectively. How well they could feel the heating was rated with an average of 3.92 (*SD*=0.79, *Median*=4, *Range*=3-5), the reported surety averaged at 3.42 (*SD*=1.24, *Median*=3.5, *Range*=2-5) and the enjoyment at 3.42 (*SD*=1.17, *Median*=4, *Range*=2-5). Participant's thoughts on this modality for feedback purposes ranged between *Yes, it was definitely noticeable even when I wasn't concentrating on the temperature* (P12) over *I think it could work, however I was not sure for whether the seat is actually warming up or it is just my body temperature. Hence, I think it would work only for feedback which can have a long delay as it takes time to notice it.* (P07) to *No. If my car seat was to become warm out of the blue it would be weird. I'd probably think there was some kind of fault.* (P05). Other participants were concerned about heating in warmer climates and a possible loss of comfort (P08) and that it might be too relaxing (P01). However, participants also mentioned that it could help keep drivers to stay alert (P04) or remind them to take breaks after driving for a long period (P10).

4.3 Discussion

The average recognition time over all active heating phases was 53.66s, with average temperature changes of 0.36℃ on the seat and 0.33℃ on the backrest. However, performance varied widely between participants, as did preferences. Participants also had concerns about possible decrease in comfort if the seat would warm up on hot days. The actual temperature change needed for recognition during this experiment was relatively low, however, and this small change in temperature might only have a minimal influence on the comfort of the passenger. In future work we plan to investigate if recognition time was influenced only by the amount of temperature change or also by the overall temperature of the seat. This aspect could have significant influence on the comfort level of this technology for feedback purposes. On the other hand, slightly changing the comfort level during driving could aid the effect of keeping the driver alert or remind them to take breaks, use cases suggested by participants. These measures would be once in a while notifications or reminders, which do not require an immediate reaction, so the comparatively longer recognition time would suit these.

5 CONCLUSIONS

This paper presented an initial investigation of a heated car seat to evaluate its usefulness as feedback modality. Measurements of temperature changes of both the empty and occupied car seat were taken and discussed. The temperature increased and decreased non-linearly, with higher rates of change at the beginning of the heating. After turning off the heating, the temperature did not decrease immediately, especially when the seat was occupied where the temperature changed little over 20min. In addition, detection times during driving where collected in a user study, showing that small temperature changes of around 0.35℃ were detected in under 1min. The results presented in this paper aid in forming the basis for discussion on using a heated car seat for feedback. The passenger will always have to be seated in the car, independent of the activity they are engaged in. Feedback on the seat could, therefore, universally be used for driving related and non-driving related tasks, during both manual and automated driving. It could provide a versatile and useful modality for the in-car environment.

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