Space Utilisation and Comfort in Automated Vehicles: A Shift in Interior Car Design?

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ABSTRACT

Autonomous vehicles will provide an opportunity for a paradigm shift in interior car design in the next decade. For over 100 years the evolutionary development of cars with a focus on driving has created vehicle architectures unfit for the opportunities afforded by autonomy. Highly autonomous cars (L4) will allow occupants to engage in non-driving related tasks (NDRTs), such as working, reading, social media and watching films, which could potentially increase the value of time spent in the vehicle. This research concerns interior space requirements, design, comfort, and wellbeing for highly autonomous vehicles using a novel simulator-based methodology. The holistic approach taken provides an insight into how occupants choose to use space in the vehicle, what activities they might do and how comfortable they might be when engaging in NDRTs.

Sixteen participants (8 males, 8 females) aged between 20 and 47 (M = 31.8, SD = 8.14) took part in the study, which involved three 45-minute simulated drives to determine relative comfort and wellbeing across three different conditions. A bespoke simulator buck was designed and built, and a 270-degree simulated environment was used. Occupants were given freedom to position themselves in the vehicle within the physical restrictions of each condition (including seat rotation, recline and seat height adjustment). Condition 1 involved a current vehicle layout with a fixed passenger seat, centre console, steering wheel, and pedals; Condition 2 presented a customisable vehicle layout with a moveable centre console, steering wheel and pedals; and Condition 3 was a co-designed layout where additional features were added based on participant feedback. A questionnaire was used to assess comfort and wellbeing at two points during each trial (after 10 minutes, and after 35 minutes). Data were also captured on posture and the chosen NDRTs.

The seat was reported to be comfortable and supportive in all three user trials, but when comparing between sessions, Condition 3 represented a significant improvement over Condition 1 and 2 for backrest and headrest comfort. Overall wellbeing scored highly across all three conditions and no significant difference was found between sessions for this metric. In Condition 2, some actively looked for flat surfaces to carry out their tasks (e.g., using the dashboard, or using the arm rest). This led to several personalised features for the co-designed layout, such as lap tables, fixed tables, and door ledges. There were some interesting effects of the new layouts for example, some participants experienced feelings of claustrophobia due to the addition of such features decreasing their reported wellbeing; others reported feeling less vulnerable as they were able to move themselves further towards the centre of the car.

KEYWORDS

Vehicle Design, Comfort, Autonomy, Ergonomics, NDRTs

Introduction

Automotive comfort has traditionally encompassed air quality, sound and noise, temperature, and vibrations (da Silva 2002) as well as postural comfort through the seat design. Automotive seat design has also been driven primarily by the task of driving. With future ACES cars (Autonomous, Connected, Electric and Shared) the definition of automotive comfort could be broadened to include naturality, disturbances, apparent safety, and motion sickness (Elbanhawi et al. 2015). With autonomy allowing more cognitively and physically engaging Non-Driving Related Tasks (NDRTs), the need to design a suitable interior increases. One benefit of autonomy is the freedom given to occupants to re-adjust their posture that could reduce the levels of discomfort (Large et al. 2017) which will require an interior design that allows for movement.

Large et al. (2017) ran a study on conditionally automated vehicles in a simulated environment. Most participants used a smartphone (80%) followed by reading a book, magazine, or printed paper (25%). Participants in this study used a current production vehicle and so were not afforded the potential freedoms of autonomy. In an Australian survey of 5,089 participants Cunningham et al. (2019) found watching the road, interacting with passengers, and eating and drinking to be the most frequent activities. Still, 53.3% would use a personal device, and 37.2% would read. Activities such as reading and using a smart phone require a change in posture (compared to driving) and as such, ensuring the interior space is designed for these activities should be of importance. This study presents postural comfort and wellbeing results and qualitative feedback from a three-condition simulator study investigating NDRT and space requirements for highly autonomous vehicles.

Simulator and Vehicle Buck Setup

A bespoke interior buck was built to the internal dimensions of a current production vehicle. The occupant driving position was maintained, including the pedals, steering wheel and seat height with all adjustability operatable by study participants (seat height, recline, lumbar adjustment, steering wheel height). A central display was used to display a timeline of the journey showing key points and providing audio-visual prompts. A modular centre console was designed that could be fixed in place, moved around the cabin or optionally removed depending on the condition. The participants' seat was mounted to a frame that held four ball-transfer units in each corner giving them the freedom to position themselves in the cabin by pushing themselves with their feet and hands. The roof height was set to 870mm (SAE H61-1) and the H-point height was 316mm from the floor, which was flat, level and carpeted. The interior width was 1444mm, and the centre of the steering wheel and the H-point "Y" position was 369mm from the centre line of the buck. The aim was to provide more rearward space than would be needed with a dashboard to the back wall of the buck measuring 2480mm.

The buck was placed inside a 3-screen driving simulator providing a 270-degree field of view for the occupant. A front wide-angle camera was placed to capture the occupant activities and postures. The simulated environment (built with SCANeR Studio 1.9) showed a typical two-lane motorway with simulated traffic which was used to increase immersion and add a feeling of motion.

Method

Participants were recruited using a convenience sampling strategy and were staff and students at the university. All participants held a driver's licence and were screened for motion sickness susceptibility due to the possibility of motion sickness in the simulator. Each participant (N=16) took part in three 45-minute simulated drives during a three-week period (each user trial was roughly one week apart). Participants were reminded that they would be simulating a morning or evening autonomous commute before each session and were instructed to bring things to do with them during the user trial. In all three conditions the participant was free to move within the limitations of the condition. The differences between the three conditions are as outlined below.

- ***Condition 1 – Baseline:*** The front passenger seat and centre console (which contains a cup holder and an arm rest) are both fixed in place.
- ***Condition 2 – Customise:*** The front passenger seat is removed, and the participant can freely move the centre console to create more space or to use it as a surface or a footrest.
- ***Condition 3 – Co-design:*** Participants are given the same freedom as Condition 2. However more features have been added based on the feedback from the first two sessions. These features include lap tables, armrests and the ability to use the central display for their own tasks.

Figure 2: Photographs of the layout for Condition 1 (left), Condition 2 (middle), Condition 3 (right)

Participants were asked to complete both a comfort and wellbeing survey after 10 minutes, and again after 35 minutes. The comfort survey was adapted from Corlett and Bishop, (1976), and included eight areas of the body and a six-point Likert scale (from “not uncomfortable” to “extremely uncomfortable”). The wellbeing survey was adapted from Ahmadpour, Robert and Lindgaard, (2016) and included questions relating to feeling confined, feeling refreshed and feeling stiff using a five-point Likert scale (from “strongly agree” to “strongly disagree”).

Participants postures were recorded using a posture reference guide (Table 1) adapted from Kamp, Kilincsoy and Vink, (2011). Postures were noted every time the participants settled on a new posture for more than 30 seconds. The observations were time-stamped so posture duration could be calculated, and the data correlated with other data sources. A short interview with the participants after each user trial was also conducted in the buck to gain some further understanding on their decisions.

Table 1: Posture reference guide

Head		**Trunk**	
Free of Support	1	Fully Supported	1
Against Headrest	2	Reclined	2
Looking Down	3	Upper Back Detached/Twisted	3
Legs		Slouching	4
Stretched	1	**Arms**	
Neutral	2	On Lap or Resting on Body	1
Close	3	Raised and Unsupported	2
Raised	R	Raised and Supported	3
Crossed	C	Extended/Stretched	E

To analyse the survey results, Wilcoxon signed-rank tests were performed for within condition analysis, and a repeated measures ANOVA was used for the between condition analysis. Chi-squared test with post-hoc analysis (Bonferroni correction) was used to analyse the posture data.

Results

Sixteen participants (8 males, 8 females) aged between 20 and 47 (M = 31.8, SD = 8.14) took part in the study and in total their where 48 simulator sessions. Eight of the participants were in full time work, six were doctoral researchers and two were undergraduate students. Table 2 presents the key measurements of the participants.

Table 2: Key measurements of the participants

	Total (n=16) (M ± SD)	**Male (n=8) (M ± SD)**	**Female (n=8) (M ± SD)**
Age (years)	31.8 ± 8.3	34 ± 11.2	29.6 ± 3.6
Stature (mm)	1706 ± 112	1785 ± 75	1628 ± 84
Sitting Height (mm)	889 ± 90	947 ± 43	830 ± 87
Buttock – sole of foot (mm)	1060 ± 78	1110 ± 59	1009 ± 60
Bi-deltoid (mm)	439 ± 35	463 ± 28	416 ± 24
Forward grip reach (mm)	650 ± 47	678 ± 38	623 ± 41

Figure 3: Images showing participants performing activities in different conditions.

For much of the total time (i.e., all participants) spent in autonomous mode, participants were using a device (73.6% of total time spent) split between using a laptop, mobile phone or tablet. Mobile phone use was highest in Condition 1 (34% of time spent) with laptop use the second most frequent activity (20% of time spent). In Condition 3 however, laptop use was the most frequent activity (46% of time spent) compared to mobile phone use (22% of time spent). In total, 22 unique primary activities were recorded throughout the user trial.

A common behaviour observed during the trial involved participants searching for flat surfaces during Condition 1 and Condition 2. This is most clearly shown in Figure 3 (Image B & C) where the participant rotated their seat to use the fixed-in-place armrest as a mouse rest. Other participants felt safer seated in the centre of the buck (Image A), and most participant carried out multiple activities at once as shown in image D (sketching & making a video call).

Discomfort and Wellbeing

Overall, the seats used were found to score low on the discomfort scales. Despite this, some statistically significant differences were still observed within and between conditions. Significant differences between conditions were found in the backrest and head contact area (p=0.012) (Figure 4). A significant increase in discomfort was also observed when analysing within condition 1 for the upper back (p=0.015) and condition 2 for the head/neck (p=0.008), upper back (p=0.006) and lower back (p=0.004). There was no significant increase in discomfort for other areas of the body within conditions or between conditions. Analysis of the wellbeing questionnaire found a significant difference for the "I am not feeling stiff" measure in condition 1 (p=0.046) and condition 2 (p=0.015). No other significant differences were found within conditions or between conditions.

Chosen Postures During Autonomy

The number of unique postures recorded increased from Condition 1 (43), Condition 2 (49) and in Condition 3 (53). In total 98 unique postures were recorded throughout all three conditions. Figure 4 shows the most observed postures during the user trial. Posture '3113' (head looking down, trunk against the backrest, arms resting on the body and legs close to the seat) was observed most with 12% of the total time spent across all three conditions. Posture '3112' (same as 3113 with legs in a neutral position) was the second most frequent posture with 7% of the time spent. Posture '1122' (head neutral, trunk against the backrest, arms raised and unsupported and legs in a neutral position).

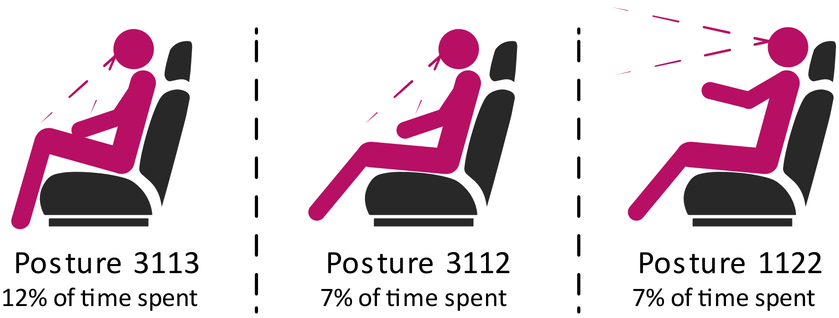

Figure 4: Illustration showing the top three chosen postures.

In Condition 1, 45% of session time was spent in neck flexion where a posture was held for longer than 10 minutes. This is significantly more than Condition 2 (36%, $p = 0.04$) and Condition 3 (27%, $p < .001$). There is also a significant difference between Condition 2 and 3 ($p = .007$).

Comparing results from the chi-squared tests, some chosen postures are significant when coupled with activities. Neck flexion is significantly more likely to occur with mobile phone use compared to laptop use ($p < .001$). There are also differences in leg position with laptop use more coupled with legs close to the seat (leg position 3) ($p < .001$) as well as raised and extended (leg position 1R) ($p < .001$). Extended legs (leg position 1) as well as extended, raised, and crossed (leg position 1RC) are significantly associated with mobile phone use (both $p < .001$).

Conclusions

This research has attempted to understand the journey comfort experience of highly autonomous vehicles by providing a simulated and adaptable environment for participants to use. From this research, several conclusions can be made:

- Using electronic devices such as laptops, mobile phones and tablets were found to be the most frequent activity carried out during the simulated journeys.
- Condition 3 (Co-designed interior space) resulted in less discomfort compared to Conditions 1 and 2. This could be because the added features and freedom of space provided the opportunity for participants to adopt a more comfortable posture.
- Time spent in neck flexion significantly reduced when features such as surfaces, armrests and footrests were added to the interior.

It has been believed that autonomous vehicles will improve the journey experience. However, autonomy could be a contributing factor for postural discomfort if no supporting features cabin, such as raised surfaces and arm rests are designed into the cabin. This research has shown that although providing more space, and hence freedom to adopt a more comfortable posture is desirable, there is still a possibility of postural discomfort.

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