Driver seat comfort for level 3-4 autonomous vehicles

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Abstract Autonomous vehicles can classified on a scale from 0 to 5, where level 0 corresponds to vehicles that have no automation to level 5 where the vehicle is fully autonomous and it is not possible for the human occupant to take control. At level 2, the driver needs to retain attention as they are in control of at least some systems. Level 3-4 vehicles are capable of full control but the human occupant might be required to, or desire to, intervene in some circumstances. This means that there could be extended periods of time where the driver is relaxed, but other periods of time when they need to drive. The seat must therefore be designed to be comfortable in at least two different types of use case. This driving simulator study compares the comfort experienced in a seat from a production hybrid vehicle whilst being used in a manual driving mode and in autonomous mode for a range of postures. It highlights how discomfort is worse for cases where the posture is non-optimal for the task. It also investigates the design of head and neckrests to mitigate neck discomfort, and shows that a well-designed neckrest is beneficial for drivers in autonomous mode.

This study was supported by Bridgestone Corporation Japan.

Keywords: Autonomous vehicles, seating, simulator study, backrest, comfort.

1 Introduction

For the past century car seats have been developed primarily for drivers but with little emphasis on passengers or occupants in the rear seats. The classical driving posture involved the driver interacting with pedals and a steering wheel, and with the eyes continually looking at the road ahead or scanning mirrors, controls and displays. Seating postures are well defined and several standards have been produced such as SAE J287 [1] that gives guidance on driver hand control reach.

Technical innovation means that some level of automated control is becoming a standard feature in road cars. This could be a simple as anti-lock brakes, that are now mandated, or intelligent speed assistance, that will be a requirement in Europe from 2022. Autonomous vehicles are classified using six levels of autonomy as defined by SAE [2] (Table 1). From Level 3 autonomy and above the human ‘driver’ may move attention from the driving task. As appropriate for the technology and context, potentially the driver could release the steering wheel, desire to undertake another task (e.g. working, watching entertainment, sleeping), and sit in a different posture (Figure 1). Therefore the requirements for packaging the driver will be very different. Paddan et al. [3] showed that a reclined backrest at 157.5 degrees (i.e. almost reclined was the most comfortable when exposed to vertical whole-body vibration.

At Level 3 autonomy, the vehicle could request human intervention. Therefore the driver might be required to drive in a posture that is optimal for relaxing in the car, but not optimal for driving. At Level 2, drivers will be required to keep close attention on the road ahead forcing a posture that is able to maintain visual vigilance but is still relaxed.

Table 1. Levels of Autonomy as defined by the Society of Automotive Engineers [2].

Level	*Description*
Level 0 No automation:	No direct vehicle control, but warning systems may be present (e.g. parking sensors).
Level 1 Driver assistance:	Automated speed (cruise) control, lateral (lane keeping) control, and parking assistance.
Level 2 Partial automation:	System can take full control of vehicle (e.g. Tesla autopilot), but human supervisor is necessary to re-take control at any time.
Level 3 Conditional automation:	The driver can move their attention from the driving task in well-controlled environments (e.g. highways), but is needed to manually drive the car in complex scenarios. The car can take decisions on whether to overtake and can request a rapid return to human control.
Level 4 High automation:	The car can drive itself in almost all circumstances. Human control may be needed if systems fail (e.g. in poor weather) but the car can safely proceed if the driver is unable to take control. Human control may be possible at the human's request.
Level 5 Full automation:	There is no possibility for the human operator to physically drive the car. The human occupant is effectively a passenger.

Fig. 1. Manual driving assumes hand, feet and head position in a standard posture. In autonomous mode, these assumptions may no longer hold.

This paper reports two studies. The first considered the effect of autonomous and manual driving on comfort in two postures that could be used at Level 3-4 autonomy; the second considered the effect of providing a neckrest.

2 Methods

A driving rig was developed for the study. The rig took overall dimensions from a production saloon car (Toyota Prius) and was custom built from aluminium extruded parts. Steering and seat position were adjustable such that they could be configured for any car model. A seat from a Toyota Prius was used in the driving rig. The visual display comprised four computer monitors each with a width of 630mm. One was placed directly in front of the driver and one placed at an angle of 55° on either side of the front screen providing a nominally continuous field of view of 166° interrupted by the two bezels. The vertical field of view from the primary screens was 21°. The driver sat at approximately 600mm from the central screen, but this was affected by seat fore-aft adjustment. The fourth screen was positioned below the central screen and displayed the instrument panel from the vehicle.

Two sets of driving scenarios were programmed. Set 1 (‘manual driving’) comprised a journey in Great Britain that lasted 30 minutes and was guided using a software ‘satnav’ built into the simulation platform. Drivers needed to manually drive the simulation in this set. Set 2 (‘autonomous mode’) comprised a similar journey to that in Set 1 but the simulation ran in an autonomous mode such that the driver did not need to engage with the steering wheel or pedals in order for the journey to be completed.

Three different seating setups were used in the simulation. In the ‘upright’ position the seat backrest was set to 105° representing a standard driving posture. In the ‘reclined’ posture the seat backrest was set to 127° representing an extreme reclined driving posture, but similar to that used by passengers when relaxing, or in some racing cars and some military vehicles (Figure 2). In the ‘reclined neckrest’ posture drivers were provided with a neckrest designed to support the neck and head, optimised using FEA and piloted. The neckrest (Figure 3) was only used in conjunction with the reclined posture.

Fig. 2. Lab setup showing manual and autonomous modes in the two driving positions.

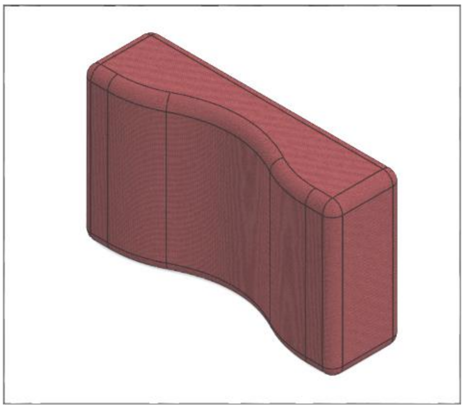

Fig. 3. CAD model of neckrest used in the reclined driving positions in Study 2.

2.1 Study 1 – Backrest angle and driving mode

In Study 1, 7 male and 7 female participants were recruited from the staff and student population of Nottingham Trent University. Each participant visited the laboratory three times. The first visit to the laboratory was a familiarization and preparation session where participants were given instruction, training and information about the study. Participants were given an opportunity to learn how to drive the simulator and ask questions. During the other two visits participants completed four driving scenarios (two per lab visit), presented in a balanced random order. Between each scenario participants left the simulator and completed a 10 minute walk, which has previously been shown to be sufficient to give discomfort recovery [4].

The four driving scenarios comprised:

1. Autonomous mode in the upright posture
2. Autonomous mode in the reclined posture
3. Manual driving in the upright posture
4. Manual driving in the reclined posture

Participants were required to report their discomfort using the two-stage discomfort assessment protocol as previously used by Sammonds et al. [5]. Stage 1 of the protocol comprises a body part discomfort questionnaire where participants were asked to rate their discomfort on a 6 point scale adapted from ISO2631-1 [6]. Seven body regions were considered: lower back, upper back, neck, ankle, sitting bones, buttock area and edge of seat contact. Perceived workload was measured using NASA-TLX [7].

2.1 Study 2 – Effectiveness of neckrest at mitigating discomfort

Study 2 also used 7 male and 7 female participants, but they were different individuals than used in Study 1. The protocol was similar to Study 1 except that five driving scenarios were used:

1. Manual driving in the upright posture
2. Manual driving in the reclined posture
3. Manual driving in the reclined posture with neckrest
4. Autonomous mode in the reclined posture
5. Autonomous mode in the reclined posture with neckrest

3 Results

There were no significant differences between discomfort scores for males and females for any of the conditions in either study. Therefore data were combined for further analysis.

2.1 Study 1 – Backrest angle and driving mode

As expected discomfort increased with time for all conditions studied in Study 1 (Fig 4). In the autonomous mode only small differences were observed between the discomfort ratings in the upright and reclined postures. However, in the manual mode, discomfort was significantly greater for the reclined posture. These discomfort scores were elevated from a mean score in the 'moderate' discomfort range to 'high' discomfort for the manual, reclined.

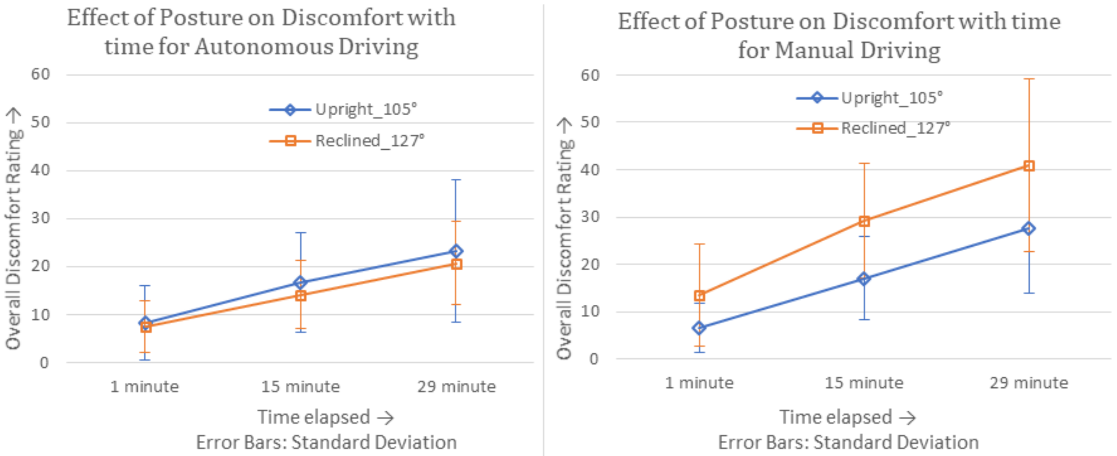

Fig. 4. Mean overall discomfort ratings for Study 1.

Individual body part discomfort scores were low for areas in contact with the seat pan cushion (Fig 5). Scores were highest in the neck region for the manual driving mode in the reclined posture. Increased discomfort was also apparent in the upper back. Verbatim comments also confirmed that the highest levels of discomfort occurred in the neck and upper back and this was attributed to the effort of holding the head in a position allowing for the driver to see the road ahead. Therefore, it was hypothesized that provision of a neckrest optimized for a reclined posture would mitigate the neck pain and improve the overall discomfort scores.

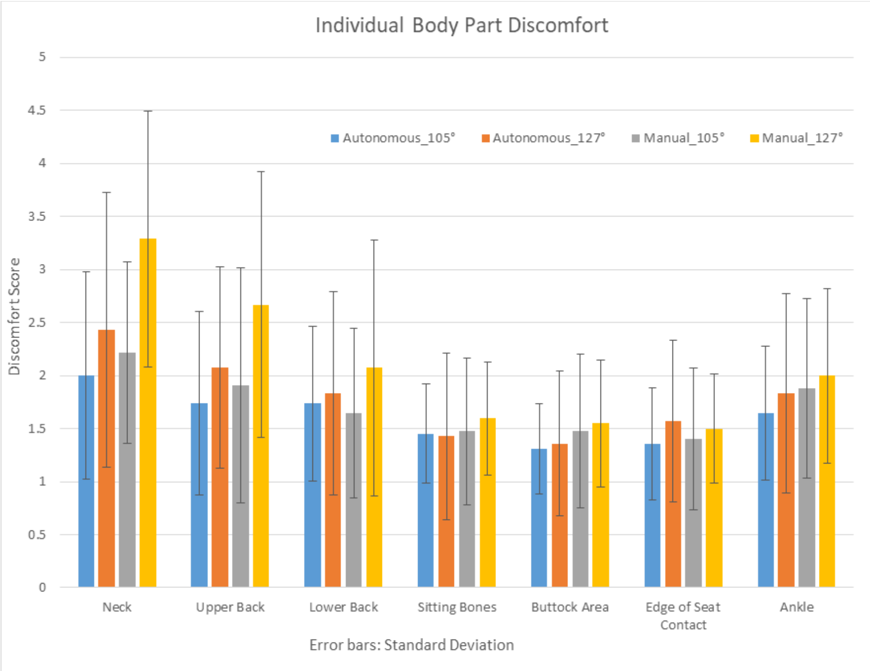

Fig. 5. Individual body part discomfort for Study 1 measured at 29 minutes.

2.1 Study 2 – Effectiveness of neckrest at mitigating discomfort

In Study 2 the overall discomfort scores were not as great as those observed in Study 1. For those conditions that repeated those from Study 1, similar trends were observed with manual reclined being the most uncomfortable posture, and showing significantly more discomfort (Fig 6). In the reclined postures, when the neckrest was used, there was significant improvement in the discomfort scores for both manual and autonomous modes (Fig 7). Individual body part discomfort scores showed that there was no adverse effect on neck discomfort when in the reclined posture when a neckrest was used.

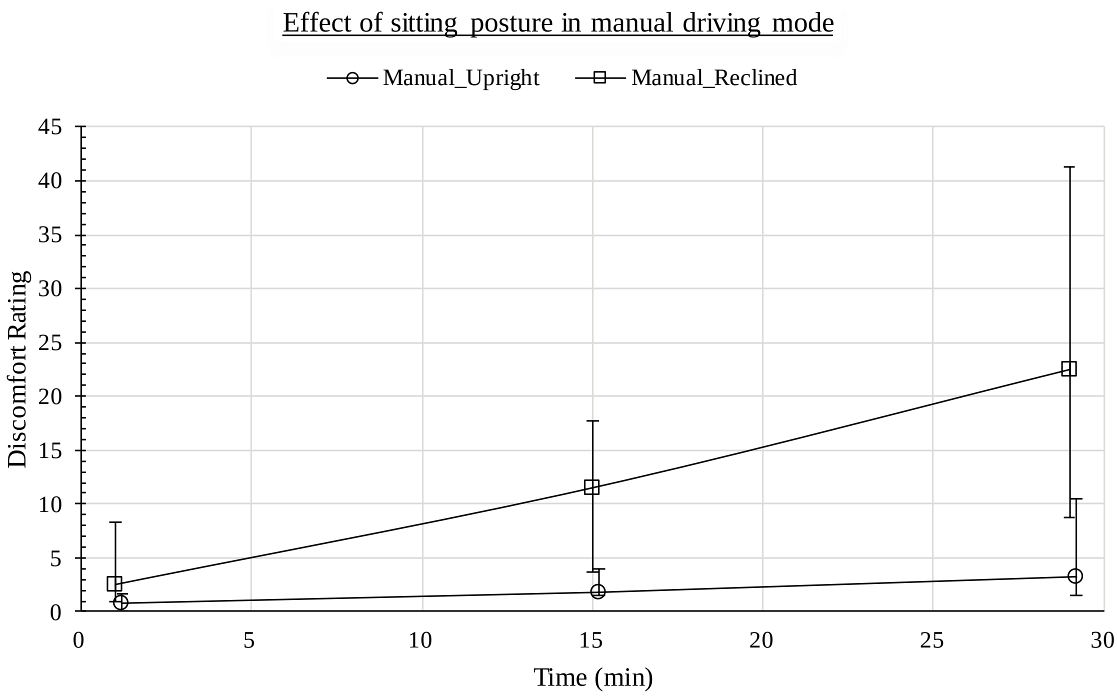

Fig. 6. Overall discomfort measured for manual driving with no intervention in Study 2.

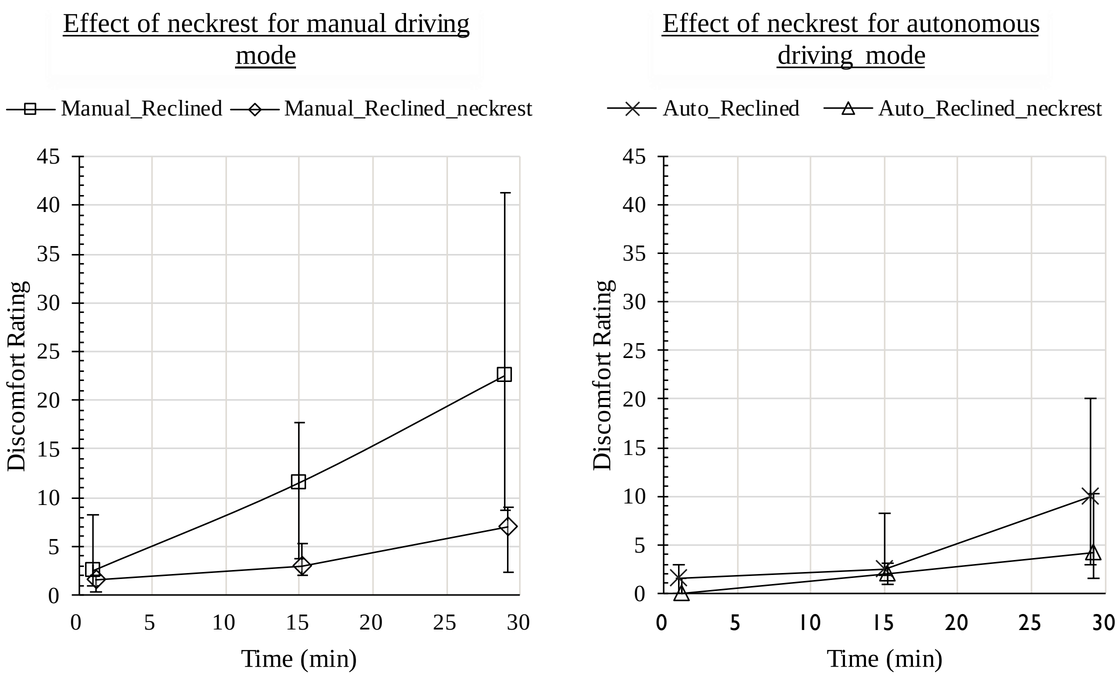

Fig. 7. Overall discomfort measured for manual and autonomous driving with and without neckrest in Study 2.

4 Discussion

The studies in this paper show that reclined postures can induce neck discomfort in both manual and autonomous modes. This might appear to contradict the results of Paddan et al. [3], but the previously published work used a flat seat, and importantly, this seat included a padded headrest. The studies reported here demonstrate how a neckrest can be used to support the head to ensure that the experience of the user is optimized. The neckrest used in this study was a first iteration after initial design using anthropometry and finite element analysis to inform the contouring. Additional improvements are likely to be possible with further optimization of the seat design, the neckrest position and the backrest angle.

Acknowledgments The research work reported here was made possible by the support of Bridgestone Corporation, Japan.

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