Car Control knob usability: a posture based comfort assessment

Renata CARENZA[1], Domenico DE MARIA[2], Stefano MORDENTE[1], Silvana PIRO[3], Alma Chiara SANTORO[4], Iolanda FIORILLO[1], Rosaria CALIFANO[1], Alessandro NADDEO[1]

[1] University of Salerno – Fisciano (SA), 84084 Italy

[2] Carpediem srl – Mercogliano (AV) 83013 Italy

[3] Ferrari S.P.A. – Maranello (MO), 41053 Italy

[4] Everis Italy – Milano (MI), 20135 Italy

Abstract Today, people spend much more time in the car, especially the ones that drive for job (taxi driver, couriers, truck drivers, etc.); for this reason, several studies have been performed on car interiors in order to improve the driver and passenger comfort experience. The aim of this study was the evaluation of perceived comfort while using the infotainment board system inside a C-segment car MY2012. The Car manufacturer claims to guarantee connectivity to its users, but also to ensure the same "web comfort" of a PC or smartphone even when it is on the go. To prove that, a sample of twenty-three students performed three different tasks in a Mercedes class A180 CDI EXECUTIVE. Postural angles of students had been acquired non-invasively by cameras and processed by KINOVEA® software. A further virtual-postural analysis had been realized with a DHM (Digital Human Modeling) software. Subjective postural comfort has been evaluated through questionnaires by which participants were asked to rate on a 10-point Comfort scale the expected comfort before beginning the test and on a 9-point Likert scale the perceived comfort after using the knob. Objective postural comfort had been gathered through CaMAN® software. Finally, a large multivariate analysis had been done to evaluate the correlations among the data (anthropometric data, subjective and objective postural comfort). Results showed which could be the most comfortable position of the knob and which body-part mostly contributed to global perceived comfort.

Keywords: Postural comfort, Expectation, Car control knob, Car interiors

1 Introduction

Four decades ago, there was not a great technology level for the automobile instrument panel. Indeed, its functionality was reduced into simple operations, thus the number of interaction between the driver and dashboard was very low. Forty years later, the technology improvement was amazing: the dashboard assumed an important role and its design was more complexed. As a matter of fact, the number of required functions has increased, and there were laws requirements (e.g. Law 81\08 in Italy [1]) to respect.

Nowadays, customers expect to have advanced devices inside their cars, which they can use or interact with even while they are driving. Such devices provide useful information, entertainment, and connectivity.

The potential for such technology is great, as web applications, location-based services, and passive and active safety systems become standard in vehicles. These devices provide to drivers and passengers both the capacity for enhanced efficiency and productivity and technologies to prevent potential problems due to distraction and unexpected events. Consequently, there are increasing safety concerns regarding the interaction with devices that may increase visual load and cause the driver to shift his/her gaze from the road [2–5]. As result of a literature analysis of the last ten years, vehicle design and its ergonomics/comfort correlated issues are one of the main topic of both academia and industries researchers.

Manufacturers and suppliers recognize ergonomics as an important aspect of vehicle planning and design, while interior designers focus their attention on comfort analyses. Many studies were published on ergonomics/comfort topics and most of them concerns about seat comfort, controls reachability and understandability, mental load and aesthetics.

In the field of research about the comfort, for example, Reed et al. [6], Kolich [7–9], Fazlollahtabar [10], dealed with the anthropometric measures as one of the most important aspects in vehicle design process; in Naddeo and Memoli [11], and Naddeo et al. [3], driver comfort was studied to assess postural comfort, reachability and usability; in Vergara & Page [12], the sitting comfort was evaluated through the relationship between comfort and back posture and mobility; in Seoke et al. [13], and in Kolich and Tabourn's [14] the evaluation of driver's discomfort and postural change was made using dynamic body pressure distribution; in Reed et al. [6] and in Kolich [7], the seat's geometry, breathability and rigidity were considered the most important indexes of driver comfort.

During the driving experience, the driver needs to interact with a high number of elements (steering wheel, pedals, knobs, etc.).

Dashboard and cockpit's elements concur to make the vehicle cockpit more or less comfortable [5] with their characteristics as shape and dimensions [15], position [3,5,16–18] and orientation [19]. Dauris et al. [20] studied discomfort due to vibrations that can increase the level of irritability, lack of attention and postural overload. In these studies, the authors focused on infotainment system that, nowadays, is often common in vehicles. Currently, almost every new car is equipped with at least an entertainment system and/or a navigation system. Applications during driving are, for example, making a call, manually adapting the driving route to the traffic situation or merely changing the music, receiving and sending messages and e-mails. Nevertheless, even if the use of some infotainment tasks is not allowed when driving, drivers are generally not willing to stop their cars and tend to use these systems in parallel to the driving task instead [21]. Therefore, many of these systems have been especially optimized for this purpose [22]. One of the purposes of this paper was the evaluation of perceived comfort while using the infotainment board system inside a C-segment car (Mercedes-Benz W176). Virtual prototyping and Digital Human Modeling (DHM) were used to perform several simulations to assess the required performance of an in-vehicle "product", i.e. the knob, under the human factors and ergonomics [5,23,24] point of view.

Predictive studies were coupled with broad test sessions, using human subjects to test both hard (physical mockup) and hybrid (virtual/physical mockup) prototypes. In this research, the objective and the subjective comfort were estimated for the use of a specific car part, the use of the knob for the infotainment system, and at the same time, in order to understand the "comfort-zone" inside the car; during the tests, the interaction of the driver with steering wheel and gear shift were also evaluated.

2 Material and methods

2.1 Experimental sample

Twenty-three students of University of Salerno, 17 males and 6 females, took part to the experiment. All students enjoyed good health. **Errore. L'autoriferimento non è valido per un segnalibro.** shows anthropometric data of participants.

Table 1. Demographic data of the participants.

	Age (years)	*Height (mm)*	*Arm (mm)*	*Forearm (mm)*
Mean	*25,7*	*1720,9*	*319,4*	*272,7*
Std. Deviation	*2,2*	*70,4*	*27*	*15,5*
Minimum	*22*	*1540*	*251*	*240*
Maximum	*31*	*1860*	*379*	*300*

2.2 Experimental setup

A camera system to identify and evaluate posture angles for describing the entire body posture was used. Three Nikon D3300 cameras were placed in order to acquire: driver's right (A), driver's left (B), driver's back (C) as shown in Fig. 1:

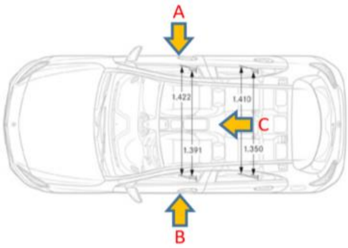

Fig. 1. Camera system.

Each shot was taken using the same camera positions, so even without a reference point, we could superimpose the differences in posture for all subjects. A correction for distortion (fish-eye effect) was applied to each photo image.

2.2 Protocol

In this study, the purpose is to estimate the postural comfort due to the use of knob, steering wheel and the gear shift and, at the same time, to understand the subjective perception of different users. This leds to seek two different comfort indexes: postural comfort (by virtual-objective assessment) and perceived comfort (by a subjective assessment).

The test procedure was the following:

(1) During the experiments, the subjects performed sequentially three main tasks: the subject holds both hands on the steering wheel; the subject reaches the push button on the knob with his right hand and keeps his left hand on the steering wheel; the subject makes the gear changes while holding the left hand on the steering wheel and the right on the gearshift;

(2) After the use of the knob control, subjects were asked to fill the comfort questionnaire;

(3) For each task, the postures of the subjects were acquired via photo acquisition (Fig. 1);

(4) The photos were processed using Kinovea® software to acquire the angles of the joints;

(5) The angles were then used as input into Delmia® to simulate each posture;

(6) The upper limb angles were processed by CaMAN® to objectively rate the upper limbs comfort indices and, the global comfort index, in order to correlate them to the subjective perception and validate the results. In this study, shoulders, neck, hands and elbows behaviours were investigated because the upper limbs are mainly involved in this kind of interaction.

2.3 Evaluation Technique for General Comfort

To acquire the subjective perceived comfort perception while using the infotainment system, a comfort questionnaire was used in which students were asked to rate

- the expected comfort before starting the experiment, on a 10-point scale;
- the perceived comfort for each part of the upper body, involved in the task (neck, back, shoulder, arm, forearm, hand), on a 9-point scale from 1 (Not comfortable) to 9 (Extremely comfortable);
- the overall perceived comfort, on a 10-point scale.

2.4 Technique for Body Angle Measurements

Human-joints' angle measurements were performed using photogrammetric analysis; this analysis, processed by Kinovea® software rel. 0.8.7, allows to acquire data about three-dimensional points' coordinates simply by analyzing photos [1]. In Fig. 2, two examples of the cameras' shooting angle can be observed.

Fig. 2. Angles acquisition during control knob use

Data processing by Kinovea® required the following data to be acquired:

1. Steering wheel: shoulder flexion, elbow flexion, wrist flexion and neck frontal flexion;
2. Gear shift: shoulder flexion, shoulder abduction, elbow flexion, wrist flexion and neck frontal flexion;
4. Knob control: shoulder flexion, shoulder abduction, elbow flexion, wrist flexion and neck frontal flexion.

Some angles such as arm medial rotation, forearm pronation/supination and hand flexion/extension, radio-ulnar deviation were not available through the photographic acquisition and were simulated and calculated through Digital Human Modelling (DHM) in CATIA® V5R16. Car interiors were modelled in CATIA® environment too.

DELMIA® DHM software was used for modelling the virtual twin of each participant thanks to the acquisition of anthropometric measurements [2] [3] [4] [5] [6] [7]. Few small modifications on the angles acquired by Kinovea® were carried out to guarantee the accuracy of the manikin's postures, according to the photographic acquisition.

Acquisition precision has been evaluated in [1] and [8]. Fig. 3 shows an example of the three postures involved in the analysis.

Fig. 3. Simulations carried out in DELMIA®

2.5 Evaluation Technique for Postural Comfort

Comfort evaluations were performed by CaMAN® [9–13] software that takes the angles describing operator posture as input, and which gives an index of postural comfort (CI) whose output value is in the range of 1-10. For each posture and each participant, both body-parts (neck, shoulder, elbow and hand) and entire body postural comfort indexes were obtained.

3 Data analysis

For each participant and for each task, the global postural comfort index, obtained by CaMAN® software, is shown in Fig. 4.

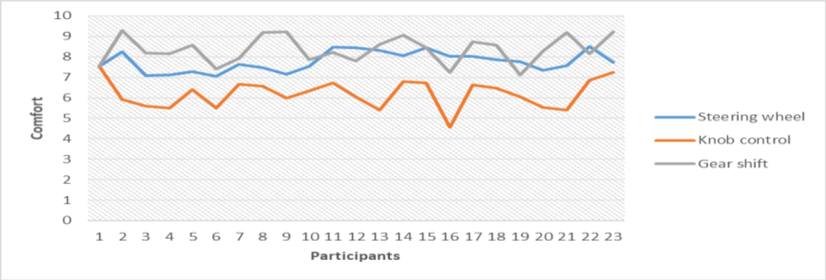

Fig. 4. Global comfort index related to the three tasks involved in the study

In order to assess the contribution of body-parts to the global comfort, the mean values of the objective comfort (by CaMAN®) were taken into account.

Table 2. CaMAN® index

	Neck		Elbow		Shoulder		Wrist	
	Flex/Rot	Lateral	Flex/Ext	Pron/Sup	Flex	Abd	Flex/Ext	Radial Dev.
Gear shift	9,07	9,90	8,29	6,24	9,08	5,14	7,59	6,82
Knob control	6,72	9,90	6,20	6,26	2,18	5,15	6,42	6,66
Steering wheel	9,18	9,90	8,01	8,78	7,18	8,78	8,33	6,96

The data analysis (Fig. 4) shows that, dealing with global comfort, the worst rated task is the knob reaching while the best rated is the steering wheel use.

This result was expected because, in the steering wheel use, arms were extended forward and are supported by the steering wheel itself, the wrists assumed a posture nearly the geometric zero and the rotation of the neck was low to look straight to the road. Contrarily, in the knob task, the subjects showed a reachability issue due to the knob's backward position: right shoulder and elbow had to move backwards and the wrist was far from neutral position (Table 2).

3 Correlations

The knob-reachability task was under investigation though statistical methods.

Data were gathered to evaluate:

1. the impact of the anthropometric measures on the objective/subjective comfort scores, both on the overall comfort and on the comfort of each bodypart;

2. the correlations between the objective comfort indexes (CaMAN®) and the subjective ones (questionnaires).

SPSS rel.13 was used to perform statistical analyses and Pearson index was used to find statistical correlations among investigated parameters.

Errore. L'autoriferimento non è valido per un segnalibro. shows the significant correlations between the subjective comfort indexes obtained by the questionnaires and the subjects' anthropometrics data.

Subject’s height and arm length are positively correlated with shoulder, elbow and wrist comfort. This results were expected because higher subjects were easily able to reach the knob.

Table 3. Correlation between the anthropometric data and comfort perception obtained by the questionnaires

Variables correlated	Pearson Indexes
Height –elbow questionnaire	,435*
Height –wrist questionnaire	,433*
Height –global questionnaire	,507*
Arm – elbow questionnaire	,465*
Arm – shoulder questionnaire	,519*
Arm – wrist questionnaire	,424*
Arm – global questionnaire	,490*

*** The correlation is significant at level 0.01 (2-queues)*

** The correlation is significant at level 0.05 (2-queues)*

Table 4 shows the most significant correlations between the objective comfort indexes obtained by CaMAN® and the subjects' anthropometrics data.

Table 4. Correlation between the anthropometric data and comfort indexes obtained by CaMAN®

Variables correlated	Pearson Indexes
Height – CaMAN® elbow	,533**
Height – CaMAN® shoulder	,506*
Arm – CaMAN® shoulder	,553**

*** The correlation is significant at level 0.01 (2-queues)*

** The correlation is significant at level 0.05 (2-queues)*

The Table 5 shows the most significant correlations between the subjective and objective comfort indexes.

Table 5. Main correlations between comfort index obtained by CaMAN® and those extracted from the questionnaires

Variables correlated	Pearson Indexes
CaMAN® neck – elbow questionnaire	*,543***
CaMAN® neck – shoulder questionnaire	*,459**
CaMAN® neck – wrist questionnaire	*,534***
CaMAN® neck – global questionnaire	*,423**
CaMAN® elbow – elbow questionnaire	*,534***
CaMAN® elbow– shoulder questionnaire	*,421**
CaMAN® elbow – global questionnaire	*,566***
CaMAN® shoulder – neck questionnaire	*,505**
CaMAN® shoulder – shoulder questionnaire	*,454**
CaMAN® global – shoulder questionnaire	*,484**

The results showed an absence of correlation for the wrist, between CaMAN® and questionnaire, during control knob use.

The photographic acquisitions revealed that the posture assumed by the majority of participants was strongly unnatural: the flexion/extension and the radio-ulnar deviation of the wrist were very far from the wrist comfort range of motion [9,10]. This condition had a negative effect both on objective comfort and on subjective comfort of the wrist.

Furthermore, the results showed that the subjective comfort (obtained by questionnaires) was lower than the objective one (obtained by CaMAN®). The absence of correlation was linked to the fact that CaMAN® considered only the posture, instead, the participants evaluated both the posture and the difficulties to carry out the task. During the control knob use, the posture hindered the implementation of the task and this had a damaging effect on the perceived comfort. Furthermore, the use of the knob in this unnatural position caused a fatigue effect on the ulnar-flexors (muscles) that activate the fingers for using the knob, and this added effects further decrease the perceived comfort of the wrist.

4 Conclusions

In this work, both the postural comfort related to the use of a car control knob, steering wheel and the gear shift and the overall subjective perception of different users were investigated.

The method used to analyze the postural comfort was based on photo/video recording and photogrammetry, image processing using Kinovea® software, coupled with the use of DHM commercial software (CATIA® for modelling, DELMIA® for simulation) and comfort rating software developed by the authors for the evaluation of non-subjective comfort (CaMAN®).

A preliminary analysis showed that, dealing with global comfort, the worst rated task was the knob reaching while the best rated was the steering wheel use.

Via a statistical analysis, performed with SPSS-Statistics®, the impact of the anthropometric measures on the objective/subjective comfort scores and the correlations between the objective comfort indexes (CaMAN®) and the subjective ones (questionnaires) was investigated.

The results showed that the height and the arm length were correlated with the comfort indexes related to the shoulder, elbow and wrist; and an absence of correlations, between CaMAN® and questionnaire, of the wrist. The absence of correlation was explained through the limitation of CaMAN® use; CaMAN software is able to take into account only the postural aspect of an interaction while, in the performed tests, the subjects gave answers to the questionnaire considering both their posture and the difficulties to carry out the task (usability) and the difficulties to reach the knob control (reachability). The implementation of the task resulted not only hindered but also caused a local discomfort.

Obtained results can be a useful support during the problem solving and directly suggest, to designers, easy solution to re-place the knob. The analysis showed that a possible solution was to place the knob near the gear shift. The proposed solution takes into account the characteristics of the tasks that the subjects have to carry out and the subject's anthropometrics characteristics.

In order to verify the solution, the method used in this work can be reused for performing a comfort driven re-design session, both in virtual and in physical environment. The acquisition method is very cheap and easy to use. The precision of the acquisition method, as well as the fact that by not using complicated, expensive acquisition methods, gave the possibility to reach a very good level of numerical/experimental correlation, that are important results revealed by this paper.

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