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# Influence of different shoulder-elbow configurations on steering precision and steering velocity in automotive context

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ABSTRACT

Ergonomic design requirements are needed to develop optimum vehicle interfaces for the driver. The majority of the current specifications consider only anthropometric conditions and subjective evaluations of comfort. This paper examines specific biomechanical aspects to improve the current ergonomic requirements. Therefore, a research which involved 40 subjects was carried out to obtain more knowledge in the field of steering movement while driving a car. Five different shoulder-elbow joint configurations were analyzed using a driving simulator to find optimum posture for driving in respect of steering precision and steering velocity. Therefore, a 20 s precision test and a test to assess maximum steering velocity over a range of 90° steering motion have been conducted. The results show that driving precision, as well as maximum steering velocity, are significantly increased in mid-positions (elbow angles of 95° and 120°) compared to more flexed (70°) or extended (145° and 160°) postures. We conclude that driver safety can be enhanced by implementing these data in the automotive design process because faster and highly precise steering can be important during evasive actions and in accident situations. In addition, subjective comfort rating, analyzed with questionnaires, confirmed experimental results.

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## 1. Introduction

Every fifth employee in the world commutes more than 90 min per day. 64% of people prefer the car, while in the USA even 85% of people use an automobile to go to work (Schiffner and Kersten-Reichherzer, 2010). The car is also an important means of transportation during leisure time (Zenk et al., 2007). Based on that, research is being done to look for the optimal posture for driving. In the automotive industry the optimum posture was worked out primarily with subjective comfort ratings (Babirat et al., 1998; Bubb, 1992; Hanson et al., 2006; Kyung and Nussbaum, 2009; Lay and Fisher, 1940; Oudenhuijzen et al., 2004; Park et al., 2000, 1999; Porter and Gyi, 1998; Schmidt et al., 2014; Seidl, 1994). Therefore, the main aim of these investigations was to determine the optimum position for comfort. Unfortunately, these results cover a relatively large area of positioning in respect of specific joint angles. The recommendations for elbow flexion and shoulder elevation in the sagittal plane (joint angle definitions according to Wu et al., 2005) for example range from 85° to 167° and 1°–75°, respectively (Hanson et al., 2006; Kyung and Nussbaum, 2009; Park et al., 2000, 1999; Porter and Gyi, 1998; Seidl, 1994) and are shown in Figs. 7 and 8 (elbow 180° refers to fully extended arm, shoulder elevation 0° refers to neutral position, Fig. 1). In addition, it is difficult to compare most of these studies as they vary so considerably in their methodological study design, basic joint angle definition and reference coordinate system (Schmidt et al., 2014). Furthermore, there are restrictions concerning the construction of the car such as the space to get in and out as well as the roof of the car. These facts also influence the results of the subjective comfort studies. Thus, this optimum subjective comfort position is possibly not the optimal one for the driving task. Hence, due to the various subjective research approaches it is hard to filter out precise information and suggestions for constructers as well as users.

By contrast, studies with objective biomechanical methods are rarely found. Existing studies deal with the position of the backrest, seat inclination and lumbar support to find the ideal pressure distribution, intervertebral disc pressure or lowest muscle activation (Andersson et al., 1974; Hosea et al., 1986; Zenk, 2009). The findings

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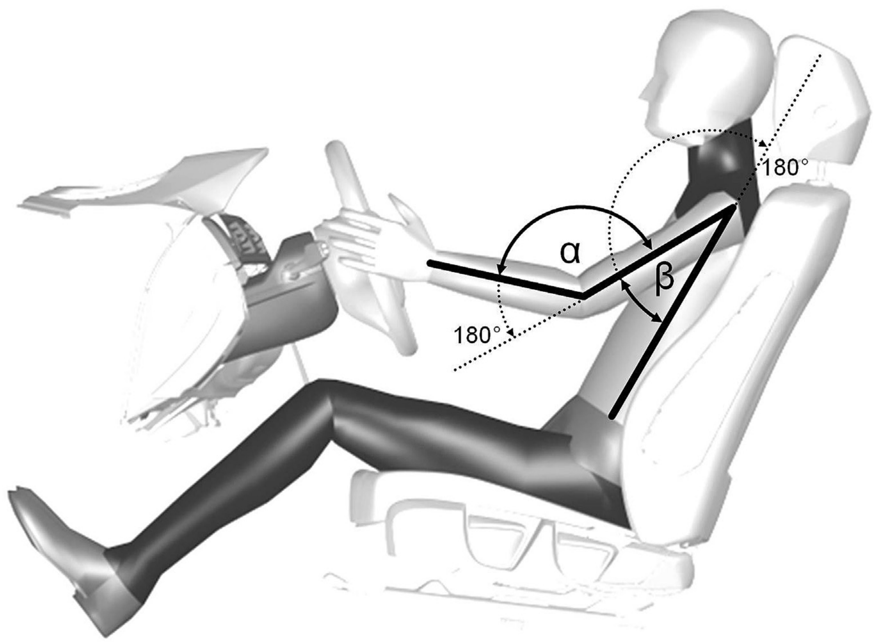


**Fig. 1.** Schematic illustration of subject positioning and definitions of shoulder and elbow angles in sagittal plane (shoulder elevation, elbow flexion).

were primarily discussed in the context of beneficial effects on health. Furthermore, to the authors' knowledge, there is not much research based on biomechanical recommendations for the positioning of the arms or the legs during driving concerning current active safety-related aspects. While "passive safety" might be part of positioning in respect of minimum injury in case of a crash, "active safety" should enhance the drivers' ability to gain maximum control of the vehicle in order to avoid critical situations. Concerning the passive safety it is recommended to bent the arms since in an outstretched position they cannot absorb impact in case of an accident (Gerstl and Schwartz, 2008). At the same time, the distance between shoulder and hand must not be too small. A distance of at least 20–25 cm is needed because otherwise risk of injury exists in the case the airbag deploys (Roccia et al., 1999; Segui-Gomez et al., 1998). Additionally, it is recommended that the shoulder blade and the back must be in contact with the backrest to optimize power transmission, which is thought to be best when steering wheel is pushed and not pulled (Gerstl and Schwartz, 2008). Therefore, support of the backrest is needed to get maximum counter bearing and to increase the stability of the torso.

In the field of sport science the five motor abilities form the basis of scientific analysis of general sport activities and human movements: coordination, endurance, flexibility, speed, and strength (Haibach et al., 2011; Howley and Thompson, 2012). Keeping biomechanical aspects in mind, these motor abilities were also considered to be relevant for an optimum driving posture. At first the optimum position of the arms was sought concerning the steering wheel operation. Because of the technical support (e.g. power assisted steering) strength, endurance, and flexibility seem to be no limiting factors. However, to be able to react to unexpected situations occurring in traffic, coordinative as well as speed abilities of the driver are important.

Therefore, the steering precision and the velocity of the steering movement were suggested to be important for an objective estimation of the posture for safety reasons. The optimum posture would enable the highest steering precision and the fastest steering velocity. This results in an improved safety, for example at evasive maneuvers.

The aim of this study was to provide first reliable experimental data concerning precision and speed of the steering movement in relation to upper body posture, more precisely to shoulder-elbow joint angle configuration. The research question was, if the posture has a measurable influence on these safety aspects in a controlled laboratory environment. Additionally, subjective comfort rating was collected to have the possibility to correlate the measured data with the existing literature.

## 2. Methods

### 2.1. Subjects

A total of 40 volunteers (7 women and 33 men; 35 ± 9 years) without any musculoskeletal disorders participated in this study. They were all required to possess a valid driving license for at least 5 years. In order to standardize the steering joint angle configurations of all subjects, only persons with a certain trunk length (935 mm–945 mm), measured by means of 3 d body scans (Vitus XXL, Human Solutions, Germany), were allowed to take part in this study.

### 2.2. Experimental set-up

The laboratory investigation was carried out by using a mock-up (Fig. 2) which was connected to a driving simulator. The visualization of the steering motion was realized using a measurement steering wheel, a feedback software, and a projector with a screen in front of the participant. The steering motion of the driver was presented as a line on the screen (Fig. 3).

Standardized subject positioning in the mock-up was accomplished by individually adjusting the steering wheel and the driver seat, which represent specific characteristics of a sedan. The seat was adjusted in its basic construction position (seat inclination: 15°, backrest inclination: 25°). The sitting position was defined as a function of elbow flexion at five specific angles (70°, 95°, 120°, 145°, 160°) where 180° refers to full extension (Fig. 1). Hence, a larger distance between the steering wheel and the shoulder results in an

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