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A literature review on optimum and preferred joint angles in automotive sitting posture

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ABSTRACT

In this study, a survey of the scientific literature in the field of optimum and preferred human joint angles in automotive sitting posture was conducted by referring to thirty different sources published between 1940 and today. The strategy was to use only sources with numerical angle data in combination with keywords. The aim of the research was to detect commonly used joint angles in interior car design. The main analysis was on data measurement, usability and comparability of the different studies. In addition, the focus was on the reasons for the differently described results.

It was found that there is still a lack of information in methodology and description of background. Due to these reasons published data is not always usable to design a modern ergonomic car environment. As a main result of our literature analysis we suggest undertaking further research in the field of biomechanics and ergonomics to work out scientific based and objectively determined "optimum" joint angles in automotive sitting position.

1. Introduction

In today's consumer society the availability and affordability of luxury products grows worldwide (de Looze et al., 2003; Yeoman and McMahon Beattie, 2006). For this reason, ergonomics and comfort design get more attention from industrial designers because designing ergonomically optimized products leads to popular products as seen by Apple's iPhone (Walker et al., 2009). In sales promotion ergonomic design is a growing factor and contentment and comfort is a frequently used phrase. The same development can be noted in the automotive industry (Kolich and Taboun, 2004; Franz et al., 2011). To be ahead of competition in the automotive industry, ergonomics and seating comfort need to be more focused on the car interior designing process (Zenk et al., 2009, 2012). The main reasons are the suburbanization of the cities, the increase of traffic jams, growing business and leisure travel. As such, people are spending more time in their cars (Hasselbacher and Schwaighofer, 2001; Frank et al., 2004; Lyons and Urry, 2005; Zenk et al., 2009). To avoid discomfort and fatigue it is necessary to investigate an optimum seating posture which can be adapted to the car (Andersson et al., 1974; Hanson et al., 2006).

To analyze seating posture and components needed for driving (e.g. steering wheel, pedals, gear selection lever, navigation systems or displays) manufacturers use 2D and 3D tools, especially CAD and digital human models (DHM). Most of DHM can be used to investigate vision, comfort, reachability, clearance and the driving posture in general. Although there are lots of studies, theoretical and laboratory/fieldtests (e.g. Hosea et al., 1986; Harrison et al., 2000; Oudenhuijzen et al., 2004), customers often complain of postural discomfort especially in the neck and shoulders, as well as of low back pain, which is an increasing disease in modern society (Magnusson and Pope, 1998; Andersson, 1999; Ebe and Griffin, 2001).

In order to achieve correct ergonomic design and comfort it is necessary to work with joint angles in DHM which have to be deduced from scientific studies in literature. On this topic Kyung and Nussbaum (2009) related to Reed et al. (2002), Hanson et al. (2006) and Chaffin (2007) claimed that: "With expanding use of digital human models (DHMs) for proactive as well as retrospective ergonomic analysis of automotive interior design, there is a concomitant need for accurately predicting and specifying driving posture" (p. 939). To obtain knowledge of sitting posture a few

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studies have been undertaken with biomechanical methods, e.g. EMG, spine disc pressure investigations and shearing load in hu man joints in the field of sitting on office chairs (Andersson and Oertengren, 1974; Goossens and Snijders, 1995; Hasegawa and Kumashiro, 1998; Harrison et al., 1999). Research on the driver's workspace during car designing processes, and on optimum sitting posture with a focus on joint angles is mostly done with values of subjective comfort (e.g. Hanson et al., 2006), while studies using biomechanical methods like Andersson et al. (1974), Zenk (2009), Franz (2010) or Hosea et al. (1986) are rarely found. In addition, published material shows a large variance concerning optimum and comfort joint angles. Because of these differences described in literature it is necessary to decide on one source as discussed by Vogt et al. (2005).

The main aim of this work is to show which recommendations exist on optimum and preferred sitting posture and scientific evidence.

Nowadays, factors like human strength do not play an important role in cars anymore. Therefore, it is questionable whether opti mum driving posture should be defined on objective or on sub jective comfort and discomfort values.

Articles found in literature with available joint angles were discussed and compared in order to obtain a general overview. It was no matter whether the sitting angles were defined based on studies with biomechanical or physiological facts, or on the sub jective preferred posture.

Moreover, quite often a mixture of the expressions optimum and preferred joint angle is found in literature. Therefore we created a clear predefinition for these two expressions which we followed throughout the paper to make it easier for the reader.

In order to make clear statements we defined 'optimum joint angles' and 'optimum joint posture' to be dependent on biome chanical and physiological factors that, for example, lead to less muscular fatigue which in turn results in greater safety. 'Preferred joint angles' as well as 'comfortable joint angles' are indicated by subjective impressions and defined by the drivers' preferences.

However the preferred posture is only one part which in fluences the comfort and discomfort of the driver (Kyung et al., 2008).

In general there is a need for additional research for the opti mization of DHM with biomechanical methods. Precise joint angles for comfortable driving positions will improve ergonomic design when these factors are implemented in digital human models (Kyung and Nussbaum, 2009).

Therefore, this study focused on the investigation of similarities and discrepancies in methods, results and recommendations of scientific papers dealing with optimum and preferred joint angles in automotive sitting posture.

2. Methods

In order to identify the published papers in this field a literature research was carried out up to and including June 2012. To cover as much information as possible, four international databases (Science direct, Pubmed, Google Scholar, Medline), as well as three tradi tional libraries were analyzed: the library of the technical Univer sity of Munich, the library of the University of Applied Sciences of Munich and the Bavarian State Library. The following keywords were chosen: driver workspace, optimum driving posture, preferred driving posture, automotive driver posture and comfort angle. Additionally, the reference lists of the retrieved articles and books were inspected and the publication lists of the authors were checked. The results comprise scientific reviewed journals as well as standard literature such as traditional books on biomechanics, transport, cars, anatomy and ergonomics. The books were considered because several authors took them as a reference in their own investigations and since the textbook is currently in use. Articles were first screened by the researchers and checked on their relevancy based on their abstract or their title. Final selection of articles was done using following criteria: (1) the article had to be published in English, French or German and (2) the article had to show results reporting joint angles and optimum or preferred driving posture in concrete numerical data. Based on these criteria, a total of 30 articles were judged to be relevant for further exam ination. Table 1 shows the selected articles.

Thereupon the full papers were accessed and read by the au thors. The angles of several joints were compared with each other on their numerical outcome including standard deviation (SD). Further, study design and the methods used to obtain joint angles have been examined and compared. The original sources were separated into three groups: Articles with 1) theoretical deriva tions, no precise information about the origin of their data and literature reviews, 2) a 2D experimental design, 3) a 3D experi mental design.

The theoretical articles and the reviews were analyzed regarding the methods, strategies and the derivation and justifi cation of the results. Studies with an experimental design were investigated according to the methods (e.g. measurement method, laboratory or field test) and the number of participants. This was done in order to get an overview regarding the comparability of literature data. Further analysis has been undertaken on the topic of subjective or objective measurement and rating of the data. That means whether the subjects choose their position by their own preferred posture or the recommendation regarding the posture was given by medical, physiological or biomechanical aspects as defined above.

To get a good overview of the research method a concept model is included (see Fig. 1).

In order to get a comparable database several criteria were defined in a second selection round. In the section discussion a selection of the most relevant studies, based on following criteria is presented: given data origin, 3D measurement and experimental design data with more than 30 participants to find out the current state of comparable literature.

3. Results

According to the inclusion criteria of this examination, 30 ref erences in total, published between 1940 and 2009, which focused on optimum or preferred joint angles of the driver, were studied. Seven of them include an experimental test design with 2D data (e.g. Bubb, 1992), nine include an experimental design with 3D data (e.g. Andreoni et al., 2002) and 14 papers don't have an experi mental design. Five of these 14 describe results derived from theoretical considerations (e.g. Grandjean, 1980), four studies are literature reviews (e.g. Vogt et al., 2005) and the remaining five articles give no precise information about the origin of their data (e.g. Kahlmeier and Marek, 2000).

The number of investigated joints varies between one (Oudenhuijzen et al., 2004) and 16 (Kyung and Nussbaum, 2009), where all large human joints (neck, shoulder, elbow, wrist, torso, hip, knee, ankle), which are necessary for defining the human posture, and two angles of the vertebra were integrated. A huge range could be found concerning the number of subjects. It differs between four (Keegan, 1964; Andersson et al., 1974) and 250 (Lay and Fisher, 1940). Although several authors mentioned distribu tion of gender in the methods section of their papers, only a few of them presented gender specific results (Park et al., 2000).

28 studies investigated only one side of the human body, just Kyung and Nussbaum (2009) and Hanson et al. (2006) conducted

Table 1
An overview of studies in the field of preferred and optimum human joint angles in automotive sitting posture. The table is structured according to the applicability of the data and the number of recommendations. The following informations are in the column Methods: 1) type of article, 2) location of the study, type of car/mock-up, 3) adjustability of the setup, 4) experimental methods, 5) implementation and analysis of the study. The abbreviation n.s. is standing for not specified, MV for mean value, L for left and R for right.

	Applicable to	Reference	Methods	Subjects	Objective	Ankle joint	Knee joint	Hip joint	Shoulder joint	Elbow joint	Wrist joint	Neck flexion	Gender difference	Additional
Theoretical derivations, literature reviews and not specified data	The results in the table are mostly based on good theoretical knowledge. But they should be used with care because the recommendations are not based on scientific experimental research.	Rebiffe (1969)	1) Theoretical derivation		Human body	90° 110°	95° 135°	95° 120°	10° 45° (arm-vertical)	80° 120°	170° 190°	20° 30°	n.s.	Backrest inclination: 20° 30°
		DIN 33408 (1987)	n.s., the basis is the "Kieler Puppe"		Human body	90°	125°	Hip: 95° Lumbar spine: 175°	38°	120°	170°	170° (head-trunk)	n.s.	
		Wallentowitz (1995)	n.s.	n.s.	Human body	90°	110° 130°	100° 105°	28°	105° 115°	4°	20° 30°	n.s.	
		Kahlmeier and Marek (2000)	n.s.	n.s.	Human body	85° 95°	95° 120°	85° 110°	15° 35°	85° 110°	4°	15° 25°	n.s.	
		Babbs (1979)	n.s, angular comfort ranges for body joints are a part of the developed systematic		Human body	85° 95°	95° 120°	95° 115°	15°-35° (arm-vertical)	80°-110°	170° 190°		n.s.	Backrest inclination: 15° 25°
		Picard and Wiesner (1961)	n.s.	n.s.	Human body	85° 95°	100° 120°	85° 100°	5° 15°	80° 90°			n.s.	Backrest inclination: 10° 20°
		Grandjean (1980)	1) Theoretical derivation		Human body	90° 110°	110° 130°	100° 120°	20° 40° (arm-vertical)			20° 25°	n.s.	Seat inclination: 10° 22°
		Tilley and Dreyfuss (2002)	1) Theoretical derivation/ literature review		Human body	90° 100°	110° 120°	95° 100°	0° 35°	80° 165°			n.s.	
		Preuschen and Dupuis (1969)	1) Theoretical derivation		Human body	85° 105°	110° 120°	105° 115°		100°		<20°	n.s.	Backrest inclination: <20°
		Schmidtke (1989)	1) Theoretical derivation		Human body	100°	145°	110°	50°	120°	"normal position"		n.s.	
		Diffrient et al. (1974)	n.s.		Seat			93° 95° (seat backrest)			11° 25° (steering wheel-vertical)		n.s.	
		McFarland and Stoudt (1956)	1) Theoretical derivation		Seat			105° (seat backrest)					n.s.	Seat inclination: 7°
		Fubini (1997)	1) Theoretical derivation		Seat			93° 106° (seat backrest)					n.s.	Seat inclination: 10° 17° Backrest inclination: 20° 26°
		Harrison et al. (2000)	1) Theoretical derivation		Seat			95° (seat backrest)					n.s.	Backrest inclination: 100° to horizontal seat inclination: 5°

	Applicable to		Reference	Methods	Subjects	Objective	Ankle joint	Knee joint	Hip joint	Shoulder joint	Elbow joint	Wrist joint	Neck flexion	Gender difference	Additional
Experimental design with results including 2D data	2D: The data can be accepted under reserve for DHM.	n.s.	Bubb (1992)	1) Study, 2D 2) Laboratory, mock-up 3) 17 degrees of freedom 4) Camera 5) Overlay the pictures of the individual posture (individual comfort	Almost 100, different gender	Human body	84° ±19%	147° ±5%	107°±6% clutch pressed: 119°±5%	39° ±30%	146° ±12%	31° (wrist-vertical)	6° (neck-vertical)	n.s.	LWS/BWS: 173°±2% Backrest inclination: 29.7°

(continued on next page)

Table 1 (*continued*)

Applicable to	Reference	Methods	Subjects	Objective	Ankle joint	Knee joint	Hip joint	Shoulder joint	Elbow joint	Wrist joint	Neck flexion	Gender difference	Additional
		angles) with body template (e.g. Kieler Puppe DIN 33408)											
Military seat	Dupuis (1983)	1) a) Theoretical derivation and b) study, 2D 2) Laboratory, driving seat (military seat) vibration simulator (vertical vibrations) 3) Stochastic signal (vibrations records from cross-country course) and sinusoidal load, adjustable backrest and seat inclination 4) EMG m. trapezius, accelerometer, subjective evaluation	b) 7 -10	Human body		a) 110° 120° b) 120°	a) 105° 115° b) 102°	b) 25°	b) 120°		148° (head-trunk)	n.s.	Seat inclination: 20° Backrest inclination: 32°
n.s.	Jones (1969)	1) Summary of studies; study, 2D 2) Laboratory 5 a) First study: fitting trials 5 b) Second study: seat discomfort index	a) 42 b) a small number	Seat			111° (seat backrest)			30° (steering wheel-vertical)		n.s.	Seat inclination: 7° Backrest inclination: 18° Footrest-horizontal: 37.5°
n.s.	Keegan (1964)	1) Study, 2D 2) Laboratory 4) Xray 5) Analysis of different sitting and standing positions	4	Human body		115°	115°					n.s.	Results: application to automobile seats
Sedan	Hosea et al. (1986)	1) Study, 2D 2) Field test, car: 1982 midsized sedan 3) Adjustable backrest inclination, seat inclination, lumbar support 4) Electromyography of 12 paraspinal muscles, goniometer 5) Static test and dynamic test on a 7 mile testround at 55 mph	12 ♂: 12	Seat			101.5° 106.5° (seat backrest)					n.s.	Lumbar support: 5 cm Seat inclination: 13.5° 18.5° Back rest inclination: 120°
n.s.	Lay and Fisher (1940)	1) Study, 2D 2) Laboratory, universal test seat 3) Adjustable frame, seat cushion, seat back, floor and the toe-board unit (up and down, forward and backward), seat cushion contains 49 calibrated cylindrial coil springs 4) cameras	250	Seat			104° 107° (seat backrest)					n.s.	Seat inclination: 6° 7° Toe-board angle: 36°-40°
Sedan	Andersson et al. (1974)	1) Study, 2D 2) Laboratory, mock-up: standard Volvo driver's	4, ♂: 1 ♀: 3	Seat			120° (Seat-backrest)					n.s.	Lumbar support: 5 cm

	Applicable to		Reference	Methods	Subjects	Objective	Ankle joint	Knee joint	Hip joint	Shoulder joint	Elbow joint	Wrist joint	Neck flexion	Gender difference	Additional
				compartment, clutch pedal could be depressed 3) Variation of the backrest inclination, lumbar support and seat inclination 4) Measure disc pressure (L3-L4) with a needle and myoelectric activity with 11 electrodes 5) Investigation of all combinations of the three parameters and two driving manoeuvres (viz. shift of gear, depression of clutch pedal)											seat inclination: 14°
Experimental design with results including 3D data	3D: Applicable to DHM.	Sedan and SUV	Kyung and Nussbaum (2009)	1) Study, 3D 2) Field test: SUV, sedan, two seats Laboratory: SUV, sedan, two seats, driving simulator 3) Adjustable seat and steering wheel 4) Comfort and discomfort scales, surface markers and joint centers (FARO System) 5) Determing comfortable joint angles after filtering the data with the Maximal Comfort and Minimal Discomfort (MCMD) method	38 ♂: 18 ♀: 20	Human body	Sedan: Gr.1L: 82° 88° Gr.1R: 77° 91° Gr.2L: 92° 123° Gr.2R: 108° 112° SUV: Gr.1L: 94° 130° Gr.1R: 80° 86° Gr.2R: 108° 116°	Sedan: Gr.1L: 84° 91° Gr.1R: 93° 110° Gr.2L: 118° 129° Gr.2R: 123° 142° SUV: Gr.1L: 95° 105° Gr.1R: 97° 111° Gr.2L: 135° 138° Gr.2R: 136° 139°	Sedan: Gr.1L: 79° 87° Gr.1R: 83° 92° Gr.2L: 107° 118° Gr.2R: 112° 123° SUV: Gr.1L: 84° 87° Gr.1R: 85° 91° Gr.2L: 119° 126° Gr.2R: 120° 130°	Sedan: Gr.1L: 1° 29° Gr.1R: 3° 26° Gr.2L: 32° 58° Gr.2R: 35° 59° SUV: Gr.1L: 2° 11° Gr.1R: 4° 11° Gr.2L: 38° 59° Gr.2R: 37° 63°	Sedan: Gr.1L: 85° 120° Gr.1R: 85° 108° Gr.2L: 146° 165° Gr.2R: 133° 167° SUV: Gr.1L: 84° 116° Gr.1R: 84° 109° Gr.2L: 121° 160° Gr.2R: 117° 157°	Sedan: Gr.1L: 129° 170° Gr.1R: 128° 154° Gr.2L: 173° 191° Gr.2R: 173° 195° SUV: Gr.1L: 130° 166° Gr.1R: 128° 189° Gr.2L: 172° 188°	Sedan: Gr.1: 1° 27° SUV: Gr.1: 30° to -1° Gr.2: 0° 27°	Yes	Torso-vertical: Sedan: Gr.1: 18° 26° Gr.2: 32° 43° SUV: Gr.1: 18° 23 ° Gr.2: 35° 42°
		n.s.	Porter and Gyi (1998)	1) Study, 3D 2) Mock-up, driving simulator, pedals, gearbox and steering wheel all incorporated some realistic force to allow subjects to mimic the movements of driving, seven different seats with different foam densitiy 3) Adjustable: steering wheel, pedals, seat (tilt, backrest angle and lumbar support). 4) Goniometer (right side of the subjects) 5) 2,5 hour (60 mile) test route	55 ♂: 28 ♀: 27	Human body	80° 113°	99° 138°	90° 115°	19° 75°	86° 164°		30° 66°	Yes	
		n.s.	Hanson et al. (2006)	1) Study, 3D 2) laboratory, Mock-up (non-brand specific), driving simulator 3) Adjustable pedals, steering wheel,	38 ♂: 17 ♀: 21	Human body	MV: 97° ±5.5° Min-Max: 90°-111°	MV: 125° ±9.3° Min-Max: 109° 157°	MV: L: 100° ±4.4° R: 87° ±6.3°	MV: L: 39° ±15° R: 30° ±13°	MV: L: 128° ± 16° R: 135° ±15°	MV: L: 187° ±10° R: 168° ±18°		No	

(continued on next page)

Table 1 (*continued*)

Applicable to	Reference	Methods	Subjects	Objective	Ankle joint	Knee joint	Hip joint	Shoulder joint	Elbow joint	Wrist joint	Neck flexion	Gender difference	Additional
		driver seat in x and z dimension, backrest inclination, angle of footrest, depth of seat cushion 4) PCMan, questionnaire					Min-Max: L: 92° 109° R: 68° 99°	Min-Max: L: 14°-68° R: 9°-59°	Min-Max: L: 96°-160° R: 98°-163°	Min-Max: L: 159°-219° R: 130°-206°			
sedan; Because the standard deviation is not available, the data should be used with care.	RAMSIS Seidl (1994)	1) Study, 3D 2) Mock-up, driving simulator 3) Adjustable: steering wheel (in x-, y-, z-direction), pedals(in z-direction), seat (for-aft position, height, seat and backrest inclination) 4) 3D measurement system (Vicon) 5) 10 minutes test	47 ♂: 23 ♀: 24	Human body	103°	119°	99°	22°	127°			n.s.	
n.s.	Park et al. (1999)	1) Study, 3D 2) Seat buck 3) "Highly adjustable seating buck" 4) 3D measurement system (Vicon), body pressure distributions	36 ♂: 20 ♀: 16	Human body	MV: 100.3° ±6.87° Min-Max: 86° 116°	MV: 132.7 ° ±6.90° Min-Max: 120° 151°	MV: 115.8° ±6.52° Min-Max: 101° 127°	MV: 19.2° ±5.55° Min-Max: 7° 31°	MV: 111.5° ±11.40° Min-Max: 88° 137°			Yes	
n.s.	Park et al. (2000)	1) Study, 3D 2) Seat buck, "dead" pedal mounted at a 60° angle for the right foot 3) Front and back tilt function of cushion, reclining function of the back and sliding function 4) 3D measurement system (Vicon), questionnaire	43 ♂: 24 ♀: 19	Human body	MV: 100.8° ±8.61° Min-Max: 82° 124°	MV: 133.7° ±8.53° Min-Max: 120° 152°	MV: 117.4° ±7.71° Min-Max: 103° 131°	MV: 19.5° ±6.38° Min-Max: 7° 37°	MV: 113.0° ±14.01° Min-Max: 86° 116°			Yes	
sedan	Andreoni et al. (2002)	1) Study, 3D 2) Laboratory, mock-up: Alfa Romeo 155, subjects were looking at an imaginary road 3) Adjustable seat position: anterior-posterior, backrest inclination 4) Optoelectronic system, pressure mat system 5) Subjects choosed the most comfortable seat position	8, ♂: 7 ♀: 1	Human body		MV: 140°±10° Min-Max: 123° 149°	MV: 93°±6° Min-Max: 83-105° (Trunk-Thigh angle: lumbar +hip flexion)	MV: 32°±10° Min-Max: 12° 44°	MV: 115°±10° Min-Max: 104° 135°		MV: 8.17° ±4.95°	n.s.	Hip abduction: L: 6.39°±3.36° R: 8.45°±7.93° Shoulder abduction: L: 21.05° R: 34.20° Lumbar flexion: MV: 31.6°±4.17° (trunk-pelvis)
n.s.	Babirat et al. (1998)	1) Study, 3D 2) Laboratory, mock-up 3) Seat inclination 20° and 30° 4) 3 video cameras	30, ♂: 20 ♀: 10	Human body	seat incl. 20°: 115° seat incl. 30°: 110°	seat incl. 20°: 115° seat incl. 30°: 108°	seat incl. 20°: 22° seat incl. 30°: 28°		seat incl. 20°: 105° seat incl. 30°: 145°			n.s.	
MPV (multi	Ouden-huijzen	1) Study, 3D 2) Mock-up on an MPV	11 ♂: 11	Human body		111.5°						n.s.	

purpose vehicle)	et al. (2004)	design (Renault Espace), driving simulator with a visual, a 3D Sound system and a moving base; translations in the x, y, and z direction, a medium soft seat and a firm seat, backrest inclination: 105° to horizontal 3) 3 different knee angles 4) PRIMAS motion tracking system, questionnaire						
Table summary and recomm-endation by the study		77°–130°	84°–147°	79°–130°	0°–63°	80°–167°	130°–206° steering wheel-vertical:11°–25° steering wheel-wrist: 30°–31°	−30° to 66° head-trunk: 148°–170°

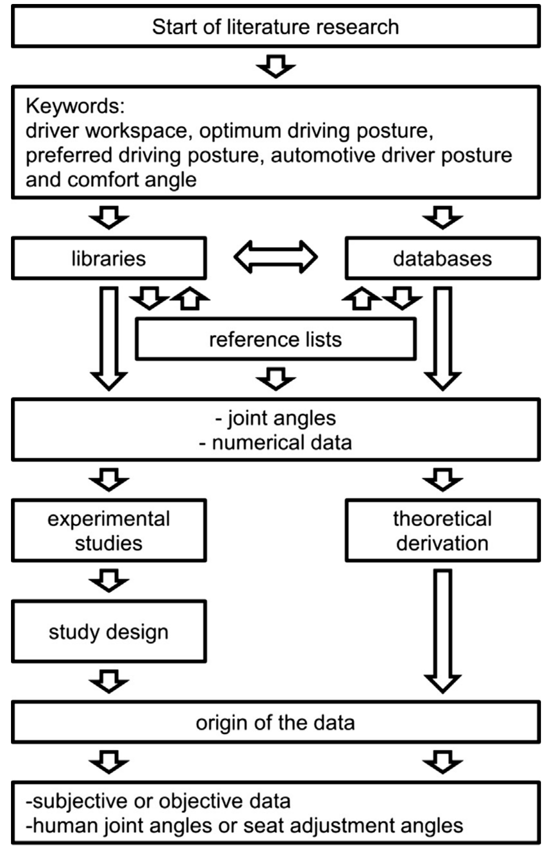


Fig. 1. Concept model of the research method.

bilateral research to make a comparison between both sides. Thirteen experiments have been done in laboratories and to the authors' knowledge only Kyung and Nussbaum (2009) and Hosea et al. (1986) performed their investigations in a real driving scenario. In addition, the recommended angles are sometimes reported as human body joint angles (e.g. Porter and Gyi, 1998) whereas others described the optimum angles in relation to the seat adjustment (e.g. Harrison et al., 2000). Furthermore, two different possibilities of optimum angle description were found: a single value of degrees on the one hand (e.g. Keegan, 1964) versus ranges of joint angles on the other (e.g. Tilley and Dreyfuss, 2002).

Further, a deviation in test situations was found. Kyung and Nussbaum (2009) and Diffrient et al. (1974) used different car models (e.g. SUV, sedan or roadster) for their work. All others used mock ups which were based mostly on the geometry of sedans.

The different methods used for measuring joint angles make a comparison between results difficult. Mostly optical measuring methods were utilized which showed variations because of the different technique used (e.g. PCMAN, VICON Motion Capture Sys tem, X ray). Due to the differing accuracy and focus of the methods, in most cases a comparison is problematic.

The laboratory studies dealt mostly with different driving simulation techniques which vary between well designed simula tions of driving scenes and single pictures showing the environ ment. Also different test designs in driving simulators were used e.g. mock ups without environment (e.g. Andersson et al.,1974), and more complex simulators that "consisted of a vi sual, a 3D sound system, a moving base and a vehicle mock up" (Oudenhuijzen et al., 2004, p. 2) or vibration simulators such as in the study of Dupuis (1983). The input for the vibration simulator was recorded in a real driving situation. In addition to this, some authors asked for subjective impressions with a questionnaire (e.g. Park et al., 2000). An overview of the main results of the studies focused on the recommended joint angles is given in the following table (see Table 1).

3.1. General findings on posture

As mentioned in the found literature the terms optimum and preferred posture were used quite often in a different way, some times there is an overlapped meaning. For this reason both expla nations will be used together.

The most mentioned joint is the hip. 29 authors recommend an optimum and preferred joint angle range of 79°–130°. Babirat et al. (1998) showed that there is a difference between the human body hip angle and the angle between the backrest and the seat. Considering this, it is of vital importance to note that 21 authors described a human body angle and eight authors gave their recommendation concerning the seat.

The knee is the second most joint mentioned in the literature with the optimum or preferred joint range of 84°–147°. Elbow, ankle and shoulder joint have a recommended range of 80°–167°, 77°–130° and 0°–63°.

Eleven authors described the optimum or preferred neck flexion angle (30° to 66°), the wrist angle (130°–206°) or the steering wheel declination (11°–31°) was described from ten authors. To compare the information on the neck flexion between the different authors a precise consideration and calculation is necessary. Preuschen and Dupuis (1969), Bubb (1992), Porter and Gyi (1998) and Kyung and Nussbaum (2009) took the vertical axis as a refer ence line, Harrison et al. (2000), Grandjean (1980), Dupuis (1983), Wallentowitz (1995) and Andreoni et al. (2002) took the torso. Similar problems exist at the wrist. For example Jones (1969) or Bubb (1992) described the angle between the steering wheel and a vertical axis, while Babbs (1979) or Kahlmeier and Marek (2000) related the wrist angle to the lower arm.

However not only single joint ranges are described in the liter ature. Kyung and Nussbaum (2009) combined the subjective results of the questionnaire with measured seat joint angles. The individ ual angle for each subject has been deleted if the test person was not satisfied regarding comfort. Kyung and Nussbaum (2009) came to the conclusion that there are two ranges for the optimal posture of each joint (except the neck for the sedan and except the right wrist and the left ankle for the SUV), for example in the left knee 95°–105° (sedan) and 135°–138° (SUV). The value in between was always related with discomfort and therefore eliminated.

3.2. Effects on posture

Several factors influencing optimum posture as well as preferred joint angles were found. The issues gender, vehicle class, seat design, driving venue, stature, symmetry and age are discussed in this chapter.

3.2.1. Gender

Five authors investigated if there is an influence of gender on posture, 25 authors gave no information concerning this matter (see Table 1). Hanson et al. (2006) found no differences in the preferred posture between males and females. Park et al. (1999, 2000) discovered partial variations. Park et al. (1999) mentioned: “Based on these results, it is concluded that there exists a gender difference in elbow angle, shoulder angle, and foot calf angle but not in trunk thigh angle, seat back reclining angle, seat pan incli nation angle, and AHP HP distance“ (p. 743). In another study of Park et al. (2000) significant differences only existed at the shoul der and the elbow angle between males and females. Porter and Gyi (1998) and Kyung and Nussbaum (2009) found differences in the posture, too. Kyung and Nussbaum (2009) found greater angles for males at the left elbow in a sedan and for both elbows in an SUV. Porter and Gyi (1998) found that men prefer larger joint angles with significant differences between gender at three joints (arm flexion, elbow angle, trunk thigh angle) and additionally the chosen seat back angle and the seat angle were significantly larger for men than for women. To investigate if this effect is based on gender or stature they selected a sub sample of subjects of average sitting height. They showed that significant differences in posture exist between men and women in the neck inclination and the trunk thigh angle, but not in the arm flexion and the elbow angle.

3.2.2. Vehicle class

Kyung and Nussbaum (2009) were the first authors investi gating the sitting posture in an SUV and compared it with the preferred posture in a sedan. Eight of sixteen joints showed sig nificant differences of 1.8°–8.4° between the vehicle classes. Therefore, their conclusion was that “[…] a distinct set of recom mended joint angles is needed for each vehicle class” (Kyung and Nussbaum, 2009, p. 950). In contrast to these findings, Tilley and Dreyfuss (2002) mentioned that the optimum postures “[…] are practically the same for all vehicles” (p. 65).

3.2.3. Seat designs

Oudenhuijzen et al. (2004) and Kyung and Nussbaum (2009) compared sitting postures in different seat designs. Kyung and Nussbaum (2009) tested one seat with a higher and one with a lower comfort rate in a sedan and in an SUV. For the sedan a dif ference was found for only one of the 16 joints between the two seat designs (right hip). Significant differences in two joints (left hip and left knee) appeared in the SUV.

Oudenhuijzen et al. (2004) investigated the relationship be tween comfort and knee angles. In this context they tested a me dium soft seat and a firm seat in three different heights and found variations in the angles of the knee joint between the two seat designs.

3.2.4. Driving venues

Most of the studies have been undertaken in a laboratory. Only Hosea et al. (1986) and Kyung and Nussbaum (2009) determined posture during a field test. Kyung and Nussbaum (2009) showed differences between the posture in a laboratory setup and a field test. In their study, the laboratory based sedan setting had more adjustability and the investigated joint angles were larger than in the field test (3.4°–12.6°).

3.2.5. Stature

Another parameter, the human stature, needed to be investi gated due to its possible influences on posture as shown in several papers. Hanson et al. (2006) found no differences in the preferred posture between small (<170 cm) and large (>190 cm) persons. In contrast, Kyung and Nussbaum (2009) found differences among small and large subjects in the SUV and the sedan.

3.2.6. Symmetry

The symmetry of the preferred or optimum human driving posture is only partially examined in literature. Bubb (1992) mentioned that his data has a high degree of symmetry. Most of the authors investigated and mentioned in their papers only one side of the body (Rebiffe, 1969; Dupuis, 1983;DIN 33408 1, 1987; Schmidtke, 1989; Bubb, 1992; Porter and Gyi, 1998; Park et al., 1999, 2000; Vogt et al., 2005). Just Kyung and Nussbaum (2009) and Hanson et al. (2006) investigated laterality and the results showed some significant differences between the left and the right side.

Kyung and Nussbaum (2009) found differences for the elbows, hips and knees in the sedan and for shoulders, elbows, hips, knees and ankles in the SUV. The results of the study of Hanson et al. (2006) showed a significant two sidedness of elbow, hip, shoulder and wrist joint.

3.2.7. Age

Age is an influencing factor on sitting posture and a factor of growing importance for the automobile industry (Herriotts, 2005). Kyung and Nussbaum (2009) mentioned that subjects over 60 years of age had a smaller angle in the right elbow and the left hip in the sedans. In the SUVs even six joint angles were smaller. This indicates that older people sit closer to the steering wheel which is an important factor in the ergonomic car design.

4. Discussion

Due to the complexity of measuring posture and the interdependence of joint angles, the main problem in comparing different studies is that the results are influenced by the heterogeneity of particular experimental settings.

First of all, instructions for the positioning of arms and hands, if at all, were very different. For example, in the study of Babbs (1979) the subjects were instructed to place their hands in a 10 to 2 position on the steering wheel. In contrast, Dupuis (1983) gave no requirements at all for his test setup. The position of arms and hands influence the wrist, elbow and shoulder angles. In the authors' opinion, this parameter is very important for the optimum or preferred sitting posture and should be standardized and taken into account for following research. The authors recommend hand placing in a 3 to 9 position. The 10 to 2 position is not recommended anymore because of the risk of injury during airbag deployment.

Furthermore, there is a different view of angles in two ways: human joint angles and angles relating to the seat. Babirat et al. (1998) showed in their study that both are hardly differentiable. A change of 10° of the backrest angle caused just a change of 6° of human torso angle. Hence, the comparison of recommendation for angles is only possible if the paradigm is the same. Nevertheless, there are drawbacks to both approaches. For seat related angles two capabilities of reporting the angle are given, the construction angle of the seat and the surface angle. Secondly, different seats can bolster up in different ways which have an influence on the sitting height. The foam material in the cushion will be compressed during sitting by the person's weight (Harrison et al., 2000). This collapsing effect can cause an influence on the sitting height that causes one to sink deeper into the seat. Additionally, the seat cover design and suspension have an effect as well. Jones (1969) for example called his results "compressed back" angles. This is rarely described in the literature.

For the human body related angles, detailed description of methodological assessment of joints is crucial. In general, little information is given on the method. For the neck, Preuschen and Dupuis (1969), Bubb (1992), Porter and Gyi (1998) and Kyung and Nussbaum (2009) used the vertical line as a reference and recommended a range between 30° and 66°. In contrast to this, Harrison et al. (2000), Grandjean (1980), Dupuis (1983), Wallentowitz (1995) and Andreoni et al. (2002) defined the human body as the reference line and described a range between 8.2° and 32°. Furthermore, the definition of the neck angle is different. Kyung and Nussbaum (2009) set the angle between the upper neck joint (infraorbitale and tragion) and the vertical line as their neck angle. The description of Porter and Gyi (1998) was "the angle between the vertical line and a line from the 7th cervical vertebra to the auditory canal" (p. 259). Both authors are using the vertical line as a reference but, nevertheless, the results are difficult to compare. The same can be seen for the torso angle. In the human model RAMSIS the reference line for the torso angle is a fixed line (Seidl, 1994) which does not correspond to the line from shoulder to hip joint, as seen in other models (e.g. Kahlmeier and Marek, 2000). The authors recommend for a standardized measurement instruction for reference lines and joint centers for further studies. As a proposal, the definition as seen in RAMSIS should be used because almost all car industries work with this model.

Furthermore, Preuschen and Dupuis (1969) recommended a neck angle <20° to the vertical because otherwise tension may occur which can cause ischemia in the brain. Additionally, for angles larger than 20° vibrations from the buttocks to the neck are amplified, which causes a higher strain on neck and head (Preuschen and Dupuis, 1969). Harrison et al. (2000) reported that a backrest angle of 120° generates an abnormal neck angle of 30°. For this reason, they recommended a backrest angle of 100° creating a tolerable neck flexion angle of 10°. In contrast, Andersson et al. (1974) reported a hip angle of 120°. Attention should be paid to the fact that one angle is related to the human body, the other is related to the seat.

Another fact is that there are different ways of dealing with laterality. Some studies recorded only one side, assuming a symmetrical driving posture (e.g. Porter and Gyi, 1998; Reed et al., 2002). However, recent studies (Hanson et al., 2006; Kyung and Nussbaum, 2009) measuring both sides of the human body found significant variations. Normally the optimum posture of humans is symmetric. But some authors found bilateral seat contact pressure data or asymmetrical driving posture (Kyung and Nussbaum, 2008).

Table 2
Overview of recommendations in literature: ankle.

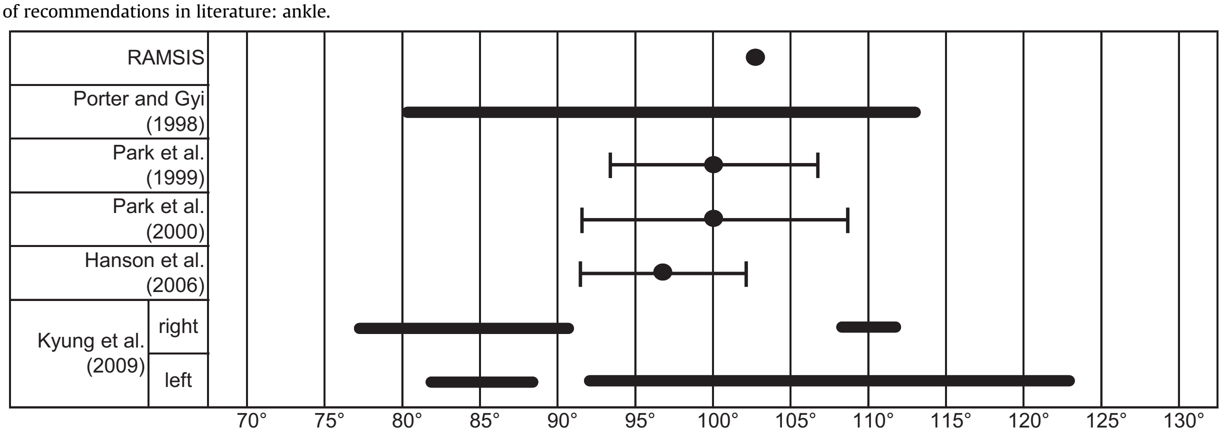
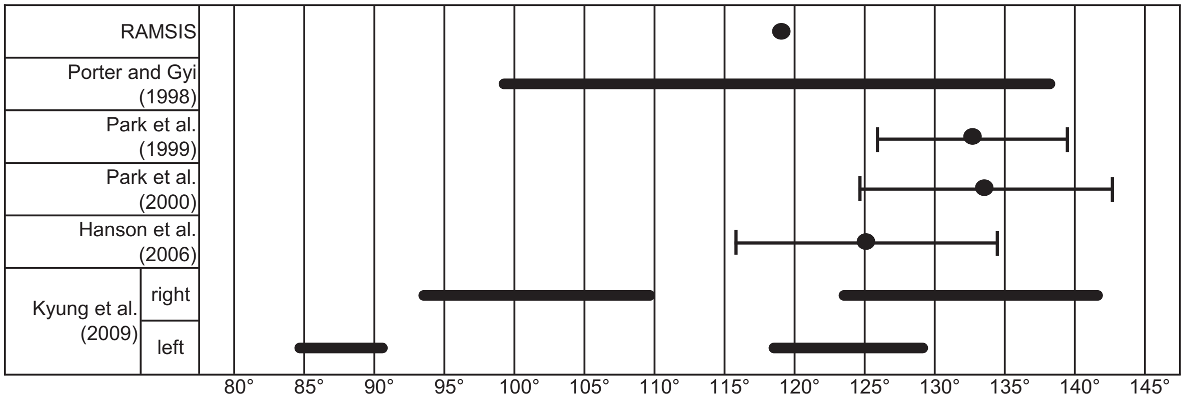


Table 3
Overview of recommendations in literature: knee.



The underlying reasons for these results remain unclear, but it might be that subjects adopt a bilateral posture because of the surrounding environment, and the difference in driving tasks given to bilaterally body parts (i.e., right side – controlling task; left side – supporting task). Because of this the asymmetrical task of the driver should be included in digital human models or the optimal joint angles should be defined by considering the effect of different tasks on each side.

Furthermore, the differences in the results can be explained by the measuring method. Some authors examined the angles on real humans; others used 2D or 3D models. A small difference arises if an angle is measured in a 3 or in a 2 dimensional space. For example, for the RAMSIS car posture model there is a 2° difference in the knee between the two methods. To enhance comparability between studies, the authors recommend only carrying out 3D measurements in future.

Another difference between the studies is the recording dura tion, and the point of time of getting into the posture respectively. The recording of Andersson et al. (1974) for example was 12 s for each posture; other authors examined the posture in duration of 25 min Hanson et al. (2006) found no significant differences of the posture between 5 min and 25 min of driving. On the contrary, Beermann (2003) claimed that the sitting posture changes or readjusts due to deformation of the cushion within the first 30 min, and then remains constant. To investigate the long term posture of humans in cars a test of at least 30 min duration is necessary.

The equipment of the car is an important factor on body posture, too, but, in general, there is little information on this topic. For example, different optimum elbow angles exist for vehicles with power steering than without, due to reduced demands on muscle force. Therefore, in former studies arm power was a more impor tant factor for the optimum position than it is today. The same applies to pedal power (Andersson et al., 1974). An current standard of car equipment e.g. power steering, is necessary and former studies should not be taken as a reference due to the assisting features that may influence body posture (Andersson et al., 1974; Hosea et al., 1986).

Furthermore, the test objects differed in their possible adjust ment range. For example Hosea et al. (1986) undertook a study in a real vehicle. In contrast to this, Hanson et al. (2006) conducted their study in a laboratory with a mock up of larger ranges of adjustment. Kyung and Nussbaum (2009) showed differences in the posture between laboratory and field tests. Hanson et al. (2006) emphasized that the resulting posture in their study is valid for mock up driving, but may be different from driving in real traffic. For that reason, the aim of a study should be clarified as to whether it is an optimum posture for a specific vehicle or common optimum posture. In the first case the possible adjustment range of the vehicle investigated has to be adapted in a specific way. If the results should be a general statement to an optimum or a preferred driving posture or if the results should be integrated in the development of new automotives it is worth increasing the options of adjustments.

Table 4
Overview of recommendations in literature: hip.

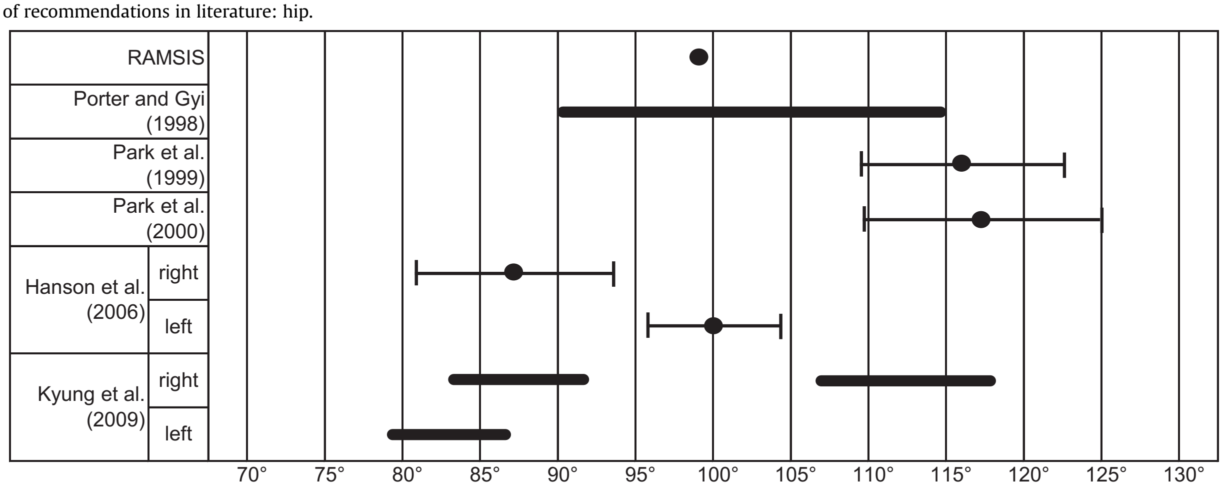
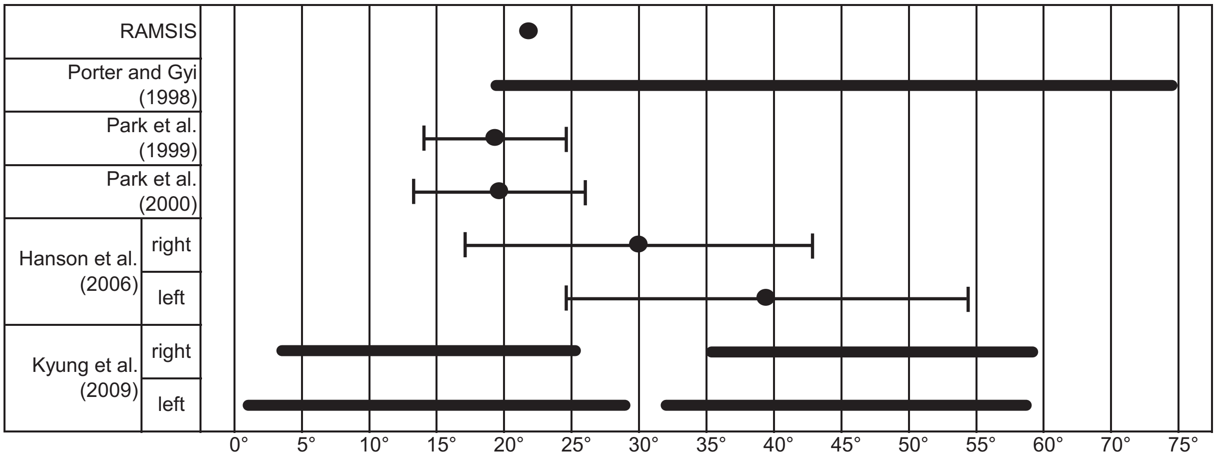


Table 5
Overview of recommendations in literature: shoulder.



It must be noted that literature is divided on the subject of posture. Some refer to “optimum posture” (e.g. Bubb, 1992; Kahlmeier and Marek, 2000) others to “preferred posture” (e.g. Hanson et al., 2006). A mixture of both can be found in Porter and Gyi (1998), who recorded preferred posture and recommended the results as optimum angle ranges. Therefore, several future research questions arise: Does one’s own preferred position fit the optimum position? Is the chosen preferred posture the only one the test subjects are familiar with? Is it possible to compare objective biomechanical methods to results which are formed by the subjective opinion? All these above mentioned facts should be investigated in further research.

Kyung and Nussbaum (2009) were the first to investigate if the preferred posture of the test subjects is also comfortable for them. They compared the results of given questionnaires with objective measured seat angles. As a result, the individual angles of the subjects were deleted when the test person was not satisfied regarding comfort. This method is ideal to investigate preferred position. It would be interesting to find out if these results will be found as well in research on physiological or biomechanical methods (e.g. high precision while steering or fatigue during long time driving).

Another point to be noted is the regional background of the test subjects. Humans of different countries and continents differ in their anthropometry; for example in their body size or the proportions of torso to leg length (Jürgens et al., 1989; Lin and Wang, 2004). Park et al. (1999) and Park et al. (2000) investigated a comfortable driving posture for Koreans. In contrast, the test subjects of Porter and Gyi (1998) were Western Europeans.

Another important fact which should be mentioned is the positions of the joint axes in human models in comparison to a real subject are different. The reason for this is the complex structure of the human joints. The joints in human models are simplified which leads to a certain error. Nevertheless it is the closest way for the most human models to get results in virtual reality.

To get an impression of the results which are of most relevance and best comparable, the authors kept on working with selected studies. In the next few lines the selection criteria are described.

Due to the huge differences and the difficulties described above when comparing all selected studies from the literature, a further analysis was done. In order to find a subset of studies that are most relevant and comparable additional selection and exclusion criteria were defined.

Table 6
Overview of recommendations in literature: elbow.

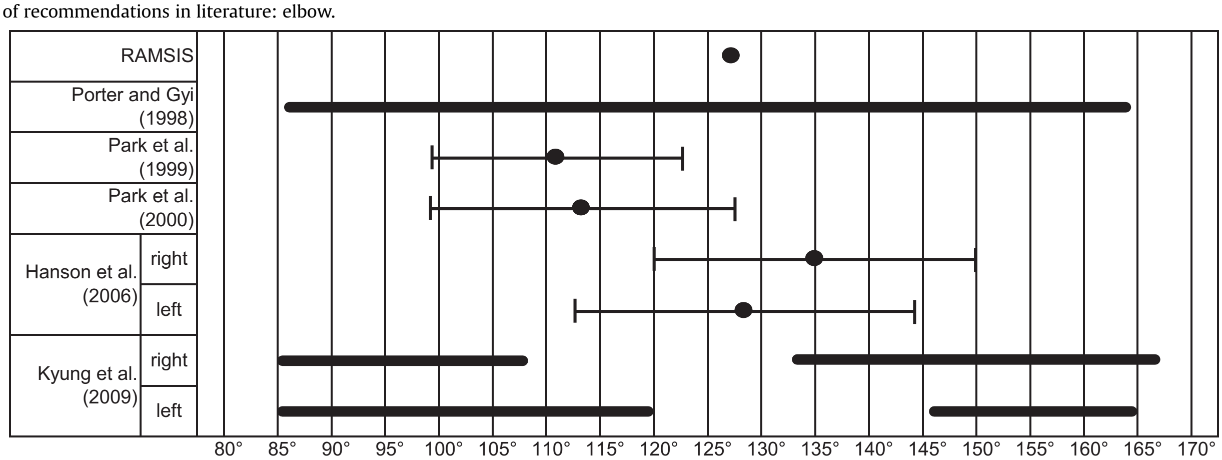
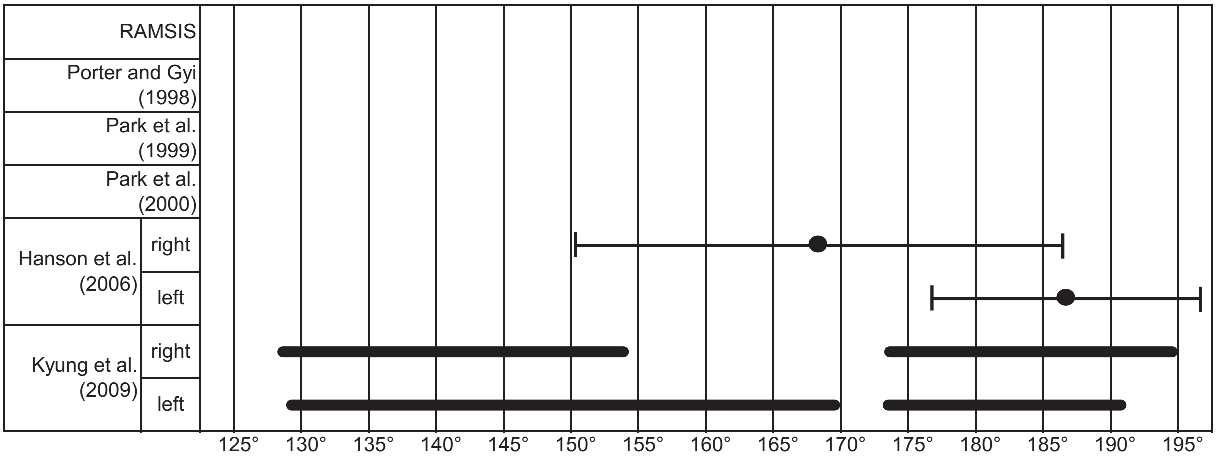


Table 7
Overview of recommendations in literature: wrist.



In seven studies no information of the origin of the data is given, for which reason they are not comparable (Picard and Wisner, 1961; Diffrient et al., 1974; Babbs, 1979; DIN 33408 1, 1987; Babirat et al., 1998; Wallentowitz, 1995; Kahlmeier and Marek, 2000). Further seven studies (Lay and Fisher, 1940; Keegan, 1964; Jones, 1969; Andersson et al., 1974; Dupuis, 1983; Hosea et al., 1986; Bubb, 1992) with 2D results were excluded because of the lack of relevance for the three dimensional digital human model (e.g. RAMSIS). This is also the case regarding studies with experimental design. The other mentioned studies are also relevant in this field, but we did not focus on them because we intended to concentrate only on studies with experimental design (McFarland and Stoudt, 1956; Preuschen and Dupuis, 1969; Rebiffe, 1969; Grandjean, 1980; Schmidtke, 1989; Fubini, 1997; Harrison et al., 2000; Tilley and Dreyfuss, 2002). A further two studies have a very small subject size (n 8 and 11) and have therefore been discarded for comparison (Andreoni et al., 2002; Oudenhuijzen et al., 2004). As a conclusion, the papers of Seidl (1994), Porter and Gyi (1998), Park et al. (1999, 2000), Hanson et al. (2006) and Kyung and Nussbaum (2009) are used in the comparison.

In the following tables the results of the six studies are pre sented (see Tables 2–8).

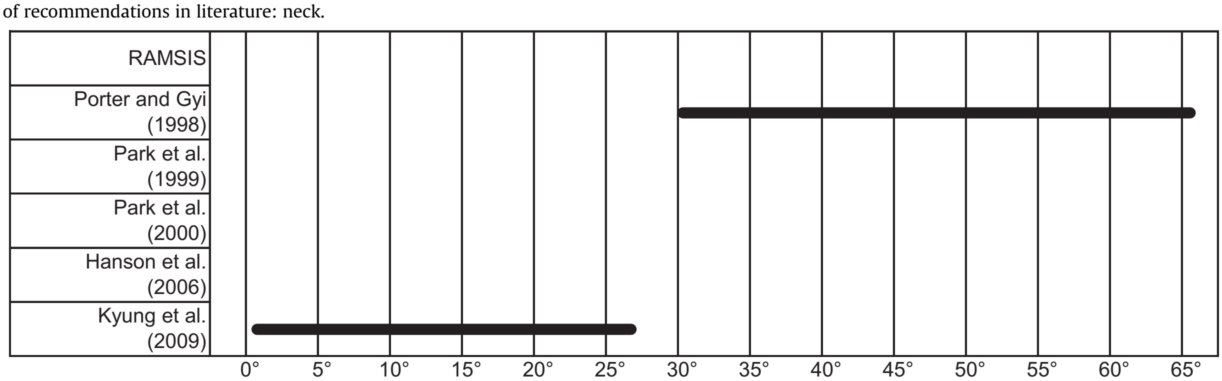
These values are the currently known joint angles from the scientific literature that can be used in a scientific way in digital human modeling.

While interpreting the results and the resulting comparisons several points should be considered: First, Seidl (1994), Park et al. (1999, 2000) and Hanson et al. (2006) gave their recommenda tions in a mean value and Porter and Gyi (1998) and Kyung and Nussbaum (2009) in ranges. Second, Hanson et al. (2006) declared that the median posture can be implemented in digital human models, "[...] individual postures are poorly predicted owing to intersubject posture variance" (p. 167). Third the data of Kyung and Nussbaum (2009) were filtered by the results of the questionnaire.

To get an overview to literature data the values of the six studies mentioned above are compared. The strategy used in data analysis has been to take the mean values of the recommendations (Tables 2–8). For this reason, mean values of the raw data of Kyung and Nussbaum (2009) were used (see 3.1). The angles were as fol lows: ankle: 98.26° ± 3.8°, knee 124° ± 7.8°, hip: 104.45° ± 9.8°, shoulder: 28.26° ± 10.2° and elbow: 121.14° ± 7.8°. Interpreting this data should be done with caution with regard to the method that was used. The values reflect only subjective meanings of preferred posture and may not in every case be comparable with data rep resenting optimum posture defined on biomechanical or physio logical principles.

A comparison of neck angles as well as data for the wrist has not been implemented because, values of only two studies could be found, angles were defined in different ways and the ranges of joint angles were not overlapping in their values in one case (neck angle Porter and Gyi (1998): 30°–66° and Kyung and Nussbaum (2009): 1°–27°).

Table 8
Overview of recommendations in literature: neck.



The importance of studying the field of posture, as formerly mentioned, can also be seen in an earlier paper. Hanson et al. (2006) recommended: “This is necessary because it is not sustainable for a company to rely on old recommendations when competing on a changing market. Nor is it sustainable for a company to only use standard recommendations” (p. 167).

5. Conclusion

30 papers dealing with recommendations for the optimum or preferred driving posture were analyzed in this review, with only five of them published within the last decade. In summary, there is a tremendous difference in methodological study designs, including angle definition and reference coordinate system, so a standardized measurement instruction for reference lines and joint centers for further studies should be determined.

Additionally, most of the studies described the preferred posture of the test subjects, which may not be comparable in every case with data representing optimum posture defined on biomechanical or physiological principles. It is possible to work with similar data relating to “preferred posture” because they are available for ankle, knee, hip, shoulder and elbow. Therefore, studies representing data of optimum posture determined on biomechanical and physiological principles (e.g. EMG) are missing. In addition there is a lack of knowledge concerning the definition of optimum and preferred position. The authors recommend that a standardized methodology should be used in further research. For these reasons it seems to be most important to define these parameters and the aim of the investigation when planning a study in this field.

Due to the diversity of humans it is further necessary to deal with more objective data reflecting the characteristics of people in order to define guidelines for automotive industry in a precise way.

Additionally the authors want to emphasize that comfort in cars does not depend only on sitting comfort, it is influenced by other factors like package, interior aesthetics or thermal comfort as reported in Kyung et al. (2008).

Based on the outcome of the study subsequent suggestions for future studies are stated by the authors:

- Clear description for the used terms
- Clarifying the aim of the study
- Statistic relevant number of test subjects
- Definition of the position of subjects
- Standardization of measurement instruction, reference lines and joint centers
- Execution of 3D measurements
- Taking into account, that if long term posture is to be recorded it will be necessary to perform a 30 minutes test
- Current standard of car equipment
- Considering regional background of the subjects

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