Future Vehicles: how to improve comfort and reduce discomfort. A comprehensive study of subjective and objective data.

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Ph.D. Course in Industrial Engineering
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Future vehicle: how to improve comfort and reduce discomfort.
A comprehensive study of subjective and objective data

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Don't stop believing
Hold on your feelings

Grazie di cuore
a tutti coloro che
mi sono stati sempre vicino,
nonostante tutto.

Publications list

a) Journal articles

1) *Towards comfortable communication in future vehicles*
Authors: Silvana Piro, Iolanda Fiorillo, Shabila Anjani, Maxim Smulders, Alessandro Naddeo, Peter Vink
Journal: Applied Ergonomics,
Date of publication: 23/03/2019
DOI: 10.1016/j.apergo.2019.03.008.

2) *Title: Future vehicles: the effect of seat layout on posture and conversation*
Authors: Iolanda Fiorillo, Silvana Piro, Shabila Anjani, Maxim Smulders, Yu Song, Alessandro Naddeo, Peter Vink
Journal: Ergonomics
Date of publication: 27/07/2019
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3) *Title: Identifying factors that influenced wellbeing and learning effectiveness during the sudden transition into eLearning due to the COVID-19 lockdown*
Authors: Alessandro Naddeo, Rosaria Califano, Iolanda Fiorillo
Journal: Work
Date of publication: January 2021
DOI: 10.3233/WOR-203358

4) *Title: Design for comfort and social interaction in future vehicles: a study on the leg space between facing-seats configuration*
Authors: Iolanda Fiorillo, Mario Nasti, Alessandro Naddeo
Journal: International Journal of Industrial Ergonomics
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DOI: 10.1016/j.ergon.2021.103131

5) *Title: Pressure distribution maps on seat-pan for aircraft seats: standard cushion VS shaped cushion*
Authors: Iolanda Fiorillo, Yu Song, Maxim Smulders, Peter Vink and Alessandro Naddeo
Journal: Applied Ergonomics (under review)

b) Book chapters

ADM Modena – September 2019 **-** Lecture Notes in Mechanical Engineering, Springer - Print ISBN: 978-3-030-31153-7; Electronic ISBN: 978-3-030-31154-4

1. Title: *Perceived comfort and muscular activity: a virtual assessment of possible correlations*
Authors: Nicola Cappetti, Alessandro Naddeo, Vittorio Maria Soldovieri, Ivan Vitillo, Iolanda Fiorillo
2. Title: *Experimental Comfort Assessment of a T-shirt for roadrunner*
Authors: Enrico Avagnale, Iolanda Fiorillo, Rosaria Califano

ADM Roma – September 2021 – will be published in Lecture Notes in Mechanical Engineering, Springer

1. Title: *The new ergonomic paradigm for academic learning environments during Covid-19 lockdown*
Authors: Rosaria Califano; Iolanda Fiorillo; Alessandro Naddeo

c) Proceedings:

The Second International Conference on Comfort ICC2019 Delft
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1) Title: *Car Control knob usability: a posture based on comfort assessment*
Authors: Iolanda Fiorillo, Rosaria Califano, Alessandro Naddeo, Renata Carenza, Domenico De Maria, Stefano Mordente, Silvana Piro, Alma Chiara Santoro
2) Title: *School combo-desk comfort assessment: a method for weighting postural factors that affect the overall perceived comfort while performing different activities*
Authors: Califano R., Fiorillo I., Naddeo A., Cecco M., De Cunzo G., Napolitano N., Rega E.,
3) Title: *A comfort evaluation tool for sitting postures: the case of Library chairs*
Authors: Iolanda Fiorillo, Federico Jacopo Anzisi, Alfonso Carbone, Rosaria Califano, Alessandro Naddeo.
4) Title: *A body-shaped lumbar-sacral support for improving car-seat comfort*
Authors: Alessandro Naddeo, Liliana Di Brigida, Carlotta Fontana, Jessica Montese, Manuel Quartuccia, Mario Nasti, Matteo Maria Pisani, Vito Turco, Marco De Stefano, Iolanda Fiorillo, Rosaria Califano.

JCM 2020 – Aix-en-Provence, France

1) Title: *Comfort driven redesign: the case of Library chairs*
Authors: Rosaria Califano, Iolanda Fiorillo*, Giovanni Baglivo, Claudia Chirico, Antonietta Dello Russo, Jose Garro, Michele Leo, Conrado Pacheco, Gianluca Vitolo, Alessandro Naddeo

AHFE 2021 – New York, USA

1) Title: *Sensitivity evaluation for hand and elbow regions: a basis for hand-held device design*
Authors: Liliana Di Brigida, Alessandro Naddeo, Iolanda Fiorillo, Alice Buso, Peter Vink
In book: Advances in Ergonomics in Design, Proceedings of the AHFE 2021 Virtual Conference on Ergonomics in Design, July 25-29, 2021, USA
DOI: 10.1007/978-3-030-79760-7_77

IEA 2021 – Vancouver, Canada

1) Flat *Cushion vs Shaped Cushion: Comparison in Terms of Pressure Distribution and Postural Perceived Discomfort*
Authors: Iolanda Fiorillo, Yu Song, Maxim Smulders, Peter Vink, Alessandro Naddeo
In book: Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021)
DOI: 10.1007/978-3-030-74605-6_31

ICED 2021 – Gothenburg, Svezia

1) Designing a shaped seat-pan cushion to improve postural (dis)comfort reducing pressure distribution and increasing contact area at the interface
Authors: Iolanda Fiorillo, Yu Song, Peter Vink, Alessandro Naddeo

Comfort Congress ICC2021 Nottingham

1) Title: *Objective comparison of two cushions: pressure distribution and postural perceived discomfort*
Authors: Iolanda Fiorillo, Yu Song, Rosaria Califano, Peter Vink and Alessandro Naddeo
Website: https://publications.ergonomics.org.uk/publications/objective-comparison-of-two-cushions-pressure-distribution-and-postural-perceived-discomfort.html
2) Title: *Smart-learning: home-workplace effect on (dis)comfort and lessons effectiveness during Covid-19 lockdown*
Authors: Rosaria Califano, Iolanda Fiorillo & Alessandro Naddeo
Website: https://publications.ergonomics.org.uk/publications/smart-learning-home-workplace-effect-on-discomfort-and-lessons-effectiveness-during-covid-19-lockdown.html

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Abstract

What will future vehicles[1] look like? A big question that designers and engineers are trying to answer by anticipating market expectations and introducing new levels of technology.

What do buyers and travelers expect? Among all the options/optional, one of the common factors is to have maximum comfort, a "quality" they take for granted when purchasing a vehicle or a ticket. The comfort can be defined as the measurement of the "well-being level" perceived by humans when interacting with objects and the environment. This level is hard to detect and measure because it is affected by individual judgements; thus, quantitative and qualitative methods are necessary for the analysis.

Therefore, what criteria/method can be used to ensure comfort or to include it in each vehicle design phases[2]? In other words: how the comfort can be improved and the discomfort reduced inside future vehicles?

So, in this PhD dissertation (result of 3 years' research), some applicable methodologies are shown starting from the distinction between comfort and discomfort. These entities are subjective perceptions, obtainable through the so-called "subjective data". By means of measurement tools, a validation to these perceptions can be achieved through the so-called "objective data".

Subjective data are gathered by questionnaires, where the cognitive answering process[3] has a predominant role in survey design to reduce errors.

Objective data are gathered from: sensors (for example, measuring the temperature or the pressure distribution at the interface); predictive software for vehicle (dis)comfort assessment (such as CA-Man, developed by professors Naddeo and Cappetti); or video observation where the people behaviors can be analyzed.

The basis of these methodologies concerns the field of Ergonomics (or Human Factors Engineering). As it is known, Ergonomics in the vehicle products developments considers all aspects (such as exterior design, interior design, instrument panel, seat design) to ensure that all-important ergonomic requirements and issues are contemplated at the earliest time and resolved to accommodate the needs of the users, such as drivers and passengers. The vehicle design process begins with a discussion on the vehicle size and types, considering the anthropometric data and the number of occupants the vehicle should accommodate. Furthermore, once defined the layout and the

[1] vehicle = anything that transports a person or things, such as cars, trucks, planes, buses, trams, trains

[2] design phases = concept, development, production, post-production

[3] cognitive answering process = see the Tourangeau model in Chapter 3

environment, the attention goes on the seat, that plays an important role in the passengers' wellness since the prolonged contact during a journey.

Going through literature studies, it is possible to acquire knowledge in comfort optimization in some vehicle elements. However, some literature gaps need to be filled; for instance, the analysis of interactions between passengers in terms of personal spaces to achieve the highest comfort while travelling. Or the comparison between car and aircraft seats in terms of pressure distribution maps. Hence, this PhD dissertation will consider the distances between seats, body movements, postures, social interactions, and contacts with others.

The graph in Figure 0-1 shows the conceptual map of this PhD dissertation: the involved factors can be analyzed and measured with subjective and objective data and are influenced by external perceptions (seat, environment, and interaction with people).

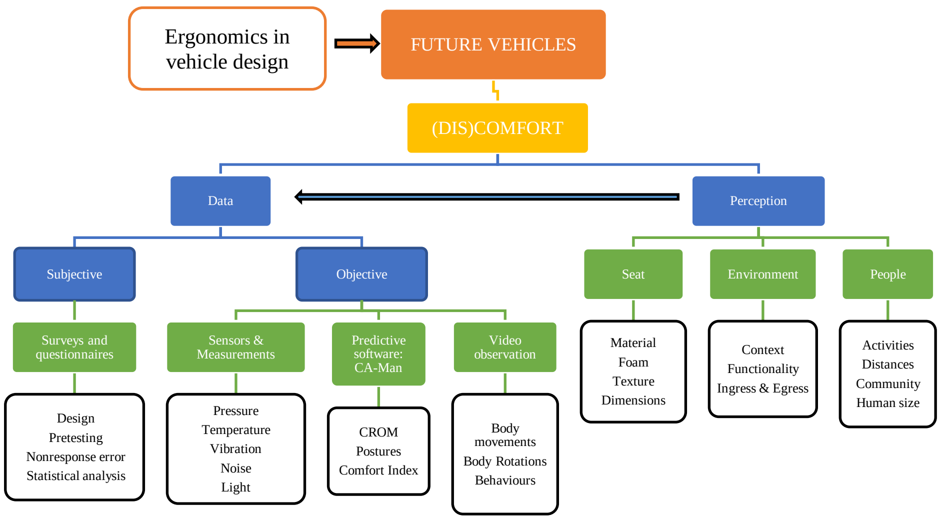


Figure 0-1*: PhD dissertation conceptual map*

In the end, this PhD dissertation aims to be a guideline for future vehicle design and development, showing how the external perceptions influence the (dis)comfort. Based on in-depth literature studies, literature gaps will be filled with experiments that adopt both subjective and objective data to gain a complete overview of the design process.

1 Introduction

Let's recreate the conceptual map shown in the Abstract (Figure 0-1), starting from the definition of "future vehicle" and the importance of Ergonomics in vehicle design (Figure 1-1).

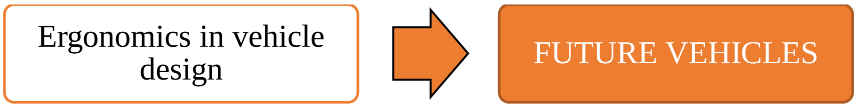


Figure 1-1: *PhD dissertation conceptual map - concepts explained in the First chapter*

1.1 Future vehicles

Technology is transforming transport with a speed and scale that are hard to comprehend. The transport systems of tomorrow will be connected, data-driven, shared, on-demand, electric, and highly automated. Ideas are moving swiftly from conception, research and design, testbed to early adoption, and, finally, mass acceptance. According to projections (Muzira and Quiros, 2018), the pace of innovation is only going to accelerate. Indeed, autonomous cars are expected to comprise about 25% of the global market by 2040, flying taxis are already tested in Dubai, Hyperloop systems are under constructions, Maglev trains are already operating in Japan, South Korea, and China, and being constructed or planned in Europe, Asia, Australia, and the USA.

Connected vehicles will benefit from intelligent transport systems (ITSs), smart cities, and the Internet of Things (IoT). They will combine data from inside the vehicle with external data coming from the environment (other vehicles, the road, signs, and the cloud). In such a scenario, different applications will be possible: smart traffic control, better platooning coordination, and enhanced safety in general (Mallozzi *et al.*, 2019). Intelligent vehicles will reach full automation, freeing the driver from performing any task. This is a path that will only be reached gradually. SAE international (ORAD, 2018) defined six levels of vehicle automation as shown in Figure 1-2:

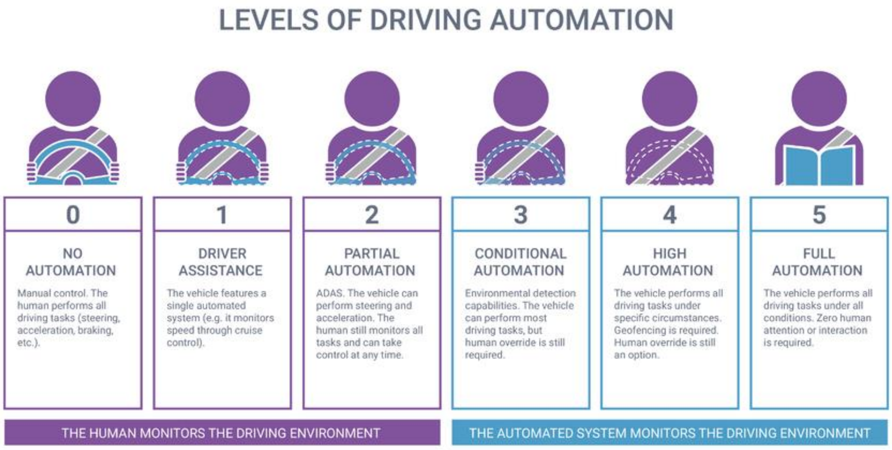


Figure 1-2: *Six levels of vehicle automation*

To date, almost all vehicles in circulation settle on the levels comprised between levels 0 and 2 (level 2 is defined as "partial automation"), in which the systems are limited to assist the driver without replacing them. Both companies and academia are putting an enormous effort into developing technical solutions to increase the levels of autonomy in vehicles.

1.1.1 The importance of Grid Modernization

Evolving customer expectations, the availability of new technologies, and increasingly favorable economics and incentives to adopt Distributed Energy Resources (DERs) all contribute to the need for many utilities to adopt some version of a grid modernization plan (Henderson *et al.*, 2017). "DERs are physical and virtual assets that are deployed across the distribution grid, typically close to load, and usually behind the meter, which can be used individually or in aggregate to provide value to the grid, individual customers, or both. Grid Modernization could save money and help fight climate change. Modernizing our electricity grid is a mix of policy changes and smaller investments that make the clean energy transformation possible" ((AEE), 2013). The smart grid uses computer technology to improve the communication, automation, and connectivity of the various components of the power network. This allows them to reduce production when less power is needed and quickly ramp up generation when peak periods approach.

By harnessing the power of computers, communications, and data analysis technologies, the smart grid improves the flexibility and efficiency of the traditional grid and opens up new opportunities for more intermittent generation methods -- like wind and solar -- and new stresses to the network, like electric cars (Shahidehpour and Fotuhi-Firuzabad, 2016).

1.1.2 Customers' expectation in future vehicles

Given the pace at which connected vehicle technologies are developing, it is paramount for companies to understand and incorporate the voice of the customer into not just the automotive development process, but also into product and service innovation. Understanding consumer interests and expectations can help shape which connected services are optimal for the market, how they are packaged, financed, marketed and distributed. The future of cars undoubtedly seems exciting. Up to this point, cars were viewed primarily as a convenient method of transportation (Steg, 2003). The main advancements were made in reliability, safety, performance, and overall comfort. However, the advent of the internet and artificial intelligence unlocked a whole new field of progress in the auto industry (Brown *et al.*, 2021). An automobile of the future won't be just a machine for driving to a desired destination. It will be a fully automated system that makes all the passengers' decisions while they are enjoying the trip. Indeed, according to a survey (Statista, 2019), car customers always expect more and more from future vehicles, especially maximal safety, economic mobility and highest comfort when travelling (Figure 1-3). Thus, as mentioned in the abstract, the methodologies applied in vehicle design to ensure comfort reside in Ergonomics.

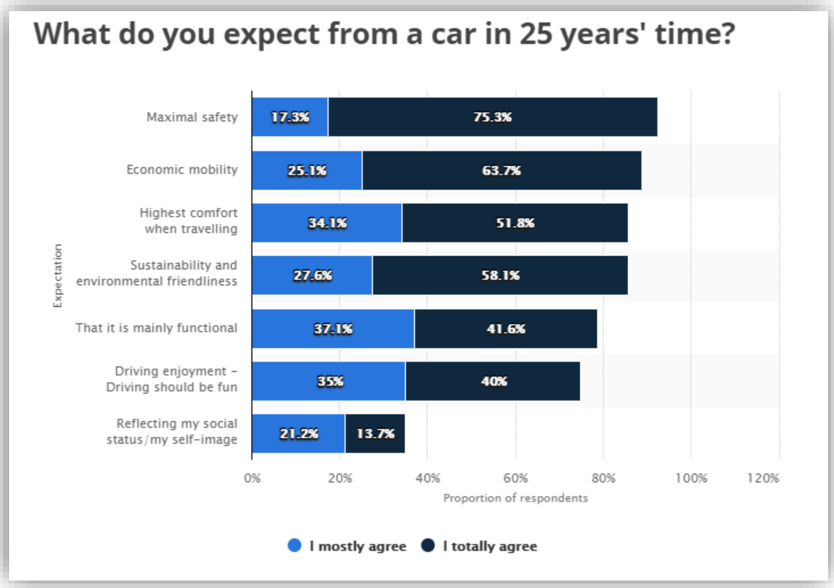


Figure 1-3: *Survey on customers' expectation (Statista, 2019)*

1.2 Ergonomics

According to the International Ergonomics Association (https://iea.cc/), Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance. The word *ergonomics* comes from the Greek word "ergon" which means work and "nomos" which means laws; it is essentially the "laws of work" or "science of work". Good ergonomic design removes incompatibilities between the work and the worker and creates the optimal work environment. A variety of aspects in which people play a significant role are involved, such as anthropometry (the measuring and description of the physical dimensions of the human body), biomechanics (describing the physical behavior of the body in mechanical terms), mechanical engineering, industrial engineering, industrial design, information design, kinesiology (studying human muscular movements), physiology (studying how people's bodies function), cognitive psychology (the mental processes, including thoughts and perceptions), industrial and organizational psychology (discussing people's attitude and behavior at work), and space psychology. For this reason, the field of ergonomics is also called "human engineering," "human factors engineering," "engineering psychology," "man–machine systems," or "human–machine interface design". Per the International Ergonomics Association, there are three broad domains of ergonomics: physical, cognitive, and organizational.

Physical ergonomics is concerned with human anatomical, anthropometric, physiological and biomechanical characteristics as they relate to physical activity. This ergonomic domain is more focused on creating a better workplace to reduce musculoskeletal disorders. When jobs are designed to match the capabilities of people, it results in better work being produced and a better experience for the person doing it.

Cognitive ergonomics is concerned with mental processes, such as perception, memory, reasoning, and motor response, as they affect interactions among humans and other elements of a system.

Organizational ergonomics is concerned with the optimization of sociotechnical systems, including their organizational structures, policies, and processes.

1.2.1 Designing for the most

In research, human factors employ scientific methods to study human behavior so that the resultant data may be applied to the four primary goals: <u>to reduce human error, increase productivity, and enhance safety, system availability and comfort</u> with a specific focus on the interaction between the human and the engineering system. In essence, it is the study of designing equipment, devices and processes that fit the human body and its cognitive abilities. Human factors and ergonomics are concerned with the “fit” between the user, equipment, and environment. This means that equipment should be designed to ensure people could fit and use the equipment comfortably without any awkward body postures, movements, or errors. It accounts for the user’s capabilities and limitations in seeking to ensure those tasks, functions, information, and the environment suit that user.

To assess the fit between a person and the used technology or environment, human factors specialists or ergonomists consider the job (activity) being done inside the environment (considering the space that it is necessary) and the demands on the user; the equipment used (its size, shape, and how appropriate it is for the task), and the information used (how it is presented, accessed, and changed). Moreover, to assure that most users within the intended population of the users of the product can fit within the product and the environment, the designers should know what the user population is, the distributions of characteristics, capabilities, and limitations of the individuals in that population. This strategy is called “designing for the most”. After the Second World War, the concept of “fitting something to humans” (not only workers) became a central component of User-centered design and Human-centered design (Naddeo, 2017).

The Human-centered design (HCD) is an approach to problem-solving commonly used in design and management frameworks that develops solutions to problems by involving the human perspective in all steps of the problem-solving process. Human involvement typically takes place in observing the problem within context, brainstorming, conceptualizing, developing, and implementing the solution (ISO 9241-210:2019).

User-centered design (UCD) is a framework of process in which usability goals, user characteristics, environment, tasks and workflow of a product, service or process are given extensive attention at each stage of the design process. These tests are conducted with/without actual users during each stage of the process from requirements, pre-production models and post production, completing a circle of proof back to and ensuring that "development proceeds with the user as the center of focus”. User-centered design is based on the understanding of a user, their demands, priorities and experiences and when used, is known to lead to an increased product usefulness and usability as it delivers satisfaction to the user (Henry, 2007).

1.2.2 Ergonomics & Human factors in vehicle design

The field of Ergonomics, or Human Factors engineering, in the vehicle product development involves many different vehicle design teams, such as exterior design, interior design, instrument panel, seat design, to assure that all important ergonomic requirements and issues are considered at the earliest time. The main goal is to accommodate the needs of users, such as drivers and passengers, while using the vehicle. Also, designing ergonomically means to reduce the driver's fatigue and distractions for safety's sake.

A vehicle is anything that transports people or goods, often it is associated as car but also other transport systems like a truck, a plane, a bus are vehicles as well. The inclusion of ergonomics engineers as a part of the vehicle development team is now an accepted practice in the industry. Ideally, the ergonomics engineers work from the earliest stages of new vehicle concept creation to the periods when the customer uses the vehicle, disposes it, and is ready to purchase his or her next vehicle.

The process of vehicle design begins with the determination of the context, the size, vehicle type and the number of occupants that the vehicle should accommodate (Vink, 2016). To assure that the required number of occupants can be accommodated, designers must consider the dimensions of drivers and passengers and their posture in the vehicle space. The very first step in designing a vehicle is to determine the user populations and their anthropometric and biomechanical characteristics. Then, there is the development of posture-prediction models for vehicle occupants to predict the people's postures and vehicle geometry. Once the final product is defined, the other steps include the optimization of layout, part of vehicle and other aspect.

The principal aim of ergonomics is to assure performance, health and safety, reduce discomfort and, thus, to increase comfort. Being ergonomically correct could not mean to be comfortable, being comfortable could mean to be ergonomically correct.

1.2.2.1 Primary role in vehicle design: the seat

The seat plays an important role in a vehicle and the wellness of the occupant as the human is in direct contact with the vehicle via the seat. As the cruising time, might be long, the activities occurring during the journey are sleeping, listening to music, reading, talking or doing nothing. These are highly relevant for seat design. The ingress and egress should be considered as well as the activities performed. For the short-haul routes, the time of ingress and egress is more relevant than the one spent sitting on the seat. All these aspects influence the seat design, such as the dimension of seat pan (width and length), seat height, legroom, headrest, backrest, cushion and so on. If the journey includes prolonged sitting in a single position, special attention should be given to stimulating human movement (Kamp, 2012; Van Veen *et al.*, 2015; Vink *et al.*, 2012; Zenk *et al.*, 2012).

1.2.2.2 The importance of range of motion in vehicle design

One of difficulties in designing a seat is to describe/predict exactly human body parts movements while interacting with vehicle components, since the large variety of users and the complexity of human joints articulations. For instance, the rotation of the hip joint, represented by the technical measure called "H-point" (SAE 1999-01-0965), which is linked with the movement system of the backrest and with many standards of seat design. Apart from the rotation point position between the different human body segments, the range of motion of the human joint is also relevant for designing interiors and seats. Range of motion is the extent of movement of a joint, measured in degrees of a circle. It is the Joint movement (active, passive, or a combination of both) carried out to assess, preserve, or increase the arc of joint motion. The definition of range of motion for human joints is important to ensure that people can reach objects in a comfortable way. Indeed, awkward postures, especially for a prolonged amount of time, could lead to discomfort (Vink *et al.*, 2017). Different studies showed that the most comfortable position corresponds to the neutral position of the joints or resting body, called *"Rest Posture"* (Andreoni *et al.*, 2001; Christensen and Nilsson, 1999). In the *"Rest Posture"* human muscles are relaxed or at minimum strain level, that minimizes muscle activity, strain in the ligaments and optimizes the comfort perception (Apostolico *et al.*, 2014a; Galinsky *et al.*, 2000; Naddeo, Cappetti, *et al.*, 2019). Therefore, to evaluate postural comfort, studying the postural angles might be helpful (see Ch. 4).

1.2.2.3 The importance of pressure distribution on seat in vehicle design

Considering the pressure distribution while sitting, the largest human-seat contact areas are on the backrest and the seat pan. This pressure distribution is influenced by several factors such as human body anthropometry, body mass distribution, and seat cushioning firmness and shape (Kilincsoy *et al.*, 2016; Wegner *et al.*, 2020). Although upholstery properties influence seat characteristics, it however does not influence the pressure distribution much (Wegner *et al.*, 2019). A pressure distribution map can provide much information, such as pressure values at specific points, the contact area, peak pressure value and peak pressure location. Pressure mapping is the most widely used objective measurement tool with a real sitting person to assess the perceived (dis)comfort, thanks to its relatively low cost and ease of use (Wang *et al.*, 2020; Zemp *et al.*, 2015), and statistical correlations with discomfort ((Hiemstra-van Mastrigt, Groenesteijn, *et al.*, 2016; De Looze, Kuijt-Evers, Lottie, *et al.*, 2003). In general, a lower average pressure is accompanied by less discomfort (Noro *et al.*, 2004). The concept of "optimal load distribution" occurs when at that pressure distribution corresponds to lowest perceived discomfort, and the pressure in the intervertebral disc is the lowest (Zenk *et al.*, 2012). Therefore, studying pressure distribution is not an aspect to neglect (see Ch.s 4 and 5).

2 Comfort and discomfort

Terms “comfort” and “discomfort” are mentioned often as they are important for future vehicle design. In this chapter, the difference between comfort and discomfort, (Dis)Comfort Models, and perceptions in the interaction with seat/environment/people are described. The outcome is the definition of subjective and objective data (Figure 2-1).

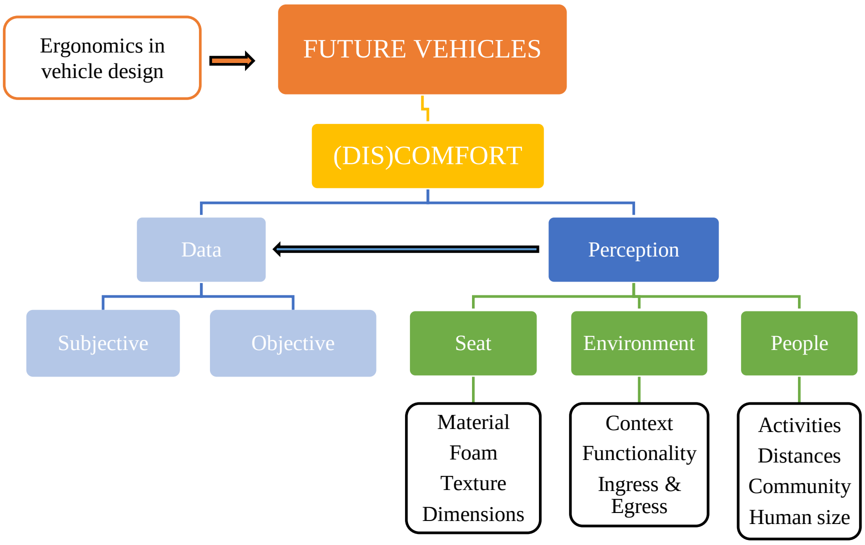


Figure 2-1: *PhD dissertation conceptual map - concepts explained in the Second chapter.*

2.1 Definition

Comfort (or being comfortable), in general can be defined as a sense of physical or psychological ease, often characterized by a lack of displeasure. People who are lacking in comfort are not necessarily uncomfortable or experiencing discomfort. Going into literature studies, two currents of thought about these entities are held. Some believe that comfort and discomfort are two entities opposite to each other on the same scale, where at the lowest level of comfort corresponds to the feeling of discomfort and vice versa. Others, instead, that they are two separate entities that can be measured on two different scales.

Helander and Zhang (Helander and Zhang, 1997; Zhang *et al.*, 1996) were pioneers in the field of comfort design research and they demonstrated the difference between comfort and discomfort. In their study, discomfort is related to physical characteristics of the environment including posture, stiffness and fatigue, furthermore, it is related to biomechanics and fatigue factors. Feelings of discomfort were associated with pain, tiredness, soreness and numbness. Furthermore, the discomfort increases with time during the workday. In the case of absence of discomfort, nothing is experienced. The absence of discomfort thus does not automatically result in an experience of comfort. Comfort, in the study of Zhang (1996), is related to luxury, relaxation or the sense of being refreshed, in other words to a sense of well-being and the aesthetics impression of the product. Since discomfort and comfort are based on independent factors, according to the authors, a reduction of discomfort does not necessarily bring about feelings of comfort. The following Figure 2-2 represents the conceptual model of authors.

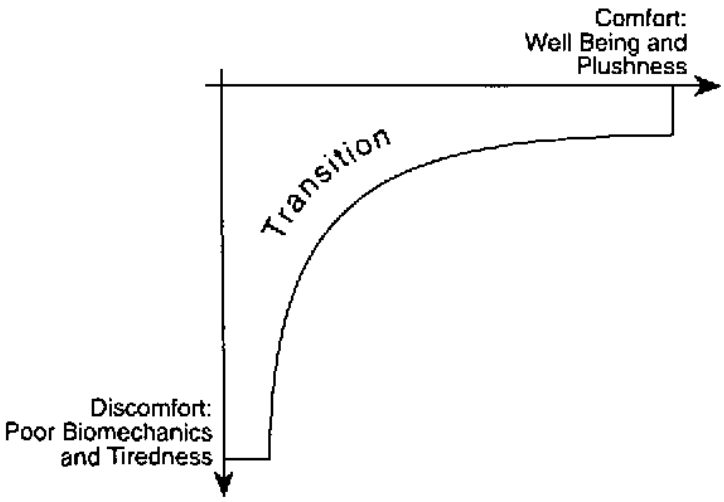


Figure 2-2*: Conceptual model of Helander and Zhang*

2.1.1 Model comfort/discomfort perception

Moes (Moes, 2005) defined a comfort model summarized in the following Figure 2-3:

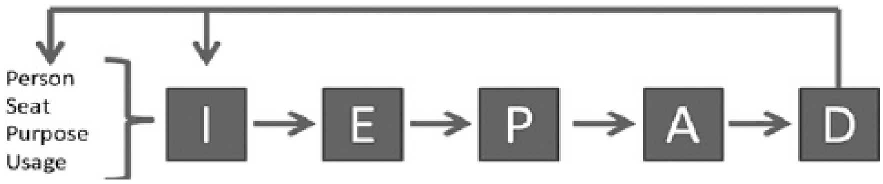


Figure 2-3*: Moes Comfort Model*

If a person uses an object, for example a seat with a specific purpose, the interaction (I) arises. An interaction results in internal body effects (E), that can be perceived (P) and interpreted, for instance as pain. The next step is the appreciation (A) of the perception, if these factors are not appreciated, it can lead to feelings of discomfort (D) and, in order to improve the experience, it arises the need to work on the interaction or to set a different environment by acting on factors in it.

Vink and Hallbeck (Vink and Hallbeck, 2011) have modified this model (Figure 2-4):

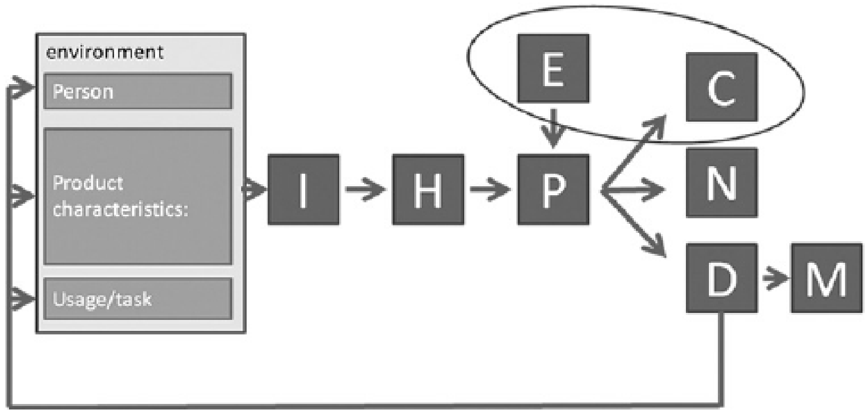


Figure 2-4: *Vink & Hallbeck Comfort Model*

In their opinion, the interaction (I) between an artefact and a human start in an environment where the person is doing a specific activity (Usage). This interaction (I) can result in internal body effects (H), such as changes in the sensors, tactile sensations, body posture, blood flow, and muscle activation. The perceived effects (P) are influenced by both body effects and expectations (E). Different studies demonstrated expectations influence our perception, and hence our comfort or discomfort (D). Often, people are not aware of comfort, and nothing is experienced (N). If discomfort is too high, the interaction is altered, which may lead to another product being chosen. This model is considered useful for objectifying or measuring comfort. A disadvantage of this model is that it does not show the comfort and discomfort effects over time. The interaction with the product usually begins with a visual interaction between the product and its environment, known as a "first impression". This first impression influences comfort, thus the influence of the design is important. For example, Bronkhorst (Vink and Brauer, 2011) showed the importance of visual information: considering four office chairs, that were the same physically and only differed in terms of color (three seats had a light color and one was ugly brown), the first impression was that the brown seat would be less comfortable. After an hour of office work that chair was evaluated positively and equal to the other chairs. This shows the importance of the first impression and the influence that it has on human experience of comfort for the first period of interaction.

Similarly, Naddeo (Naddeo, Cappetti, Califano, *et al.*, 2015) demonstrated the correlation between the expected comfort and the perceived comfort during the use of a product by the customer. They showed the level of expected comfort was also affected by the notoriety/cost of a mattress: the more the cost is, the higher the expectations. Thus, an increase of the expected comfort implied a decrease of the perceived one. A decrease of the expected comfort implied an increase of the perceived one. This is confirmed also by the common expectation that luxury cars lead to greater experiences of comfort than cheap cars. Equally, airline passengers expect greater comfort in a premium economy class or business class than in economy class. Comfort expectations are thus higher when passengers spend more money.

To incorporate this effect, Naddeo (Naddeo, 2017) modified the comfort model considering as part of the environment also the contribution of “Working environment” and “Satisfaction/Gratification level and emotions”, as shown in Figure 2-5:

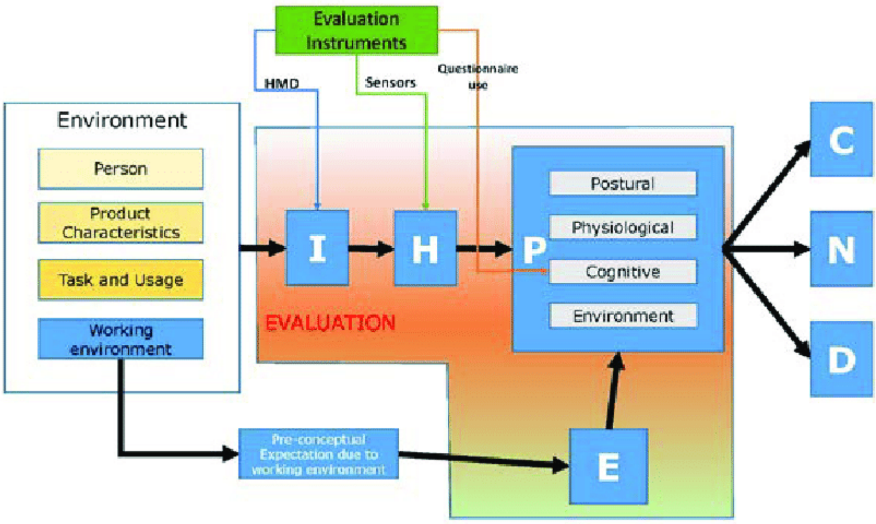


Figure 2-5: *Naddeo Comfort Model*

The “Working environment” references the location where the activity takes place, both under climate and layout points of view. The “Satisfaction/Gratification level and emotions” refers to job position in organization chart, gratification, salary and so on. Thus, Naddeo considers also the cultural/experience background of the worker. However, the outcomes in the model are:

- C (comfort)
- D (discomfort)

- N (nothing)

In this model the internal body effects and the perceived effects plays a fundamental role in the comfort or discomfort perception/evaluation. The definition of maximum level of comfort is one of the most important tasks in this kind of comfort evaluation model, especially if based on measurement of the angular range of motion (ROM) of each joint. Humans are often unaware of comfort and discomfort due to the fact that sensory input and perception does not always reach attention levels (Vink *et al.*, 2014). Also, human sensors are not able to record incremental changes and precise absolute values (Goossens *et al.*, 2005; Helander *et al.*, 2000; Kolarik *et al.*, 2007). Consequently, due to these limitations, assessing (dis)comfort perception is not as obvious as it seems.

Questionnaires (or “subjective data”), as was shown, are reliable tools for assessing (dis)comfort. The main issue is that they need attention focus and time, so in that sense they hinder the natural interaction with the product. Furthermore, using only measurement tools (or “objective data”) is not enough for (dis)comfort assessment since they have no meaning without subjective interpretation. For instance, a certain temperature can be cold to one person and perfectly acceptable to another.

However, focusing only on the seat or only one person could be limitative during a journey, since also interactions with the surrounding environments and other people could influence perceived (dis)comfort. In particular, the interaction with other people means to consider the comfort linked to interpersonal distances.

2.2 Comfortable community model

Indeed, traveling in a group is trending. For instance, a study of Homburg (Homburg, 2017) shows that more than 28% of passengers at Amsterdam Airport Schiphol travel within a group. Meanwhile, the “CWT Connected Traveler Study” (“CWT Connected Traveler Study”, 2017) indicates that millennials (people born between 1980-2000) like to travel in groups and are more sociable than older generations of business travelers. Both imply that the desire to socially interact and converse in transit will grow. However, interacting with seatmates in an airplane, or a car, might be difficult (Lille *et al.*, 2016). The main reason is that in the current seat configuration, passengers sit side by side and have to turn their eyes, head, shoulders, torso or even the whole body to be engaged in a conversation (Groenesteijn *et al.*, 2014). Awkward postures, especially for a prolonged amount of time, could lead to discomfort (Vink *et al.*, 2017). This is especially true for autonomous driving vehicles (electric), where passengers (and ‘drivers’) can spend more time conversing.

The comfortable community model (Dumur *et al.*, 2004) suggests that comfort can be increased in facilitating conversation between people through the improvement of cabin layout and services. To facilitate a more comfortable conversation, fewer rotations in the various segments of the body are preferable (Naddeo, Cappetti and D'Oria, 2015a). It can be presumed that, if the seat configuration allows people to have less torso and neck rotation in their conversation, people might feel more comfortable during the conversation. However, only one study (Nguyen, 2016) had been conducted regarding the relations between the configurations of the seat with social interactions. Thus, further studies (Fiorillo, Piro, *et al.*, 2019a; Piro *et al.*, 2019a), which will be further explained in this PhD dissertation, were conducted to study deeply the relationship between postural angles, perceived comfort and social interaction.

During social interaction, people surround themselves with implicitly defined and organized space, which is internalized at an unconscious level (Madanipour, 2003; Sommer, 1962, 1969). Respecting this space could improve comfort during social interaction. There are studies (Sorokowska *et al.*, 2017) on distances between standing persons to facilitate communication, e.g., Hall (Hall, 1966) studied the interpersonal distances in social interaction, concluding that there are four important interpersonal distances (Figure 2-6):

1) *Intimate distance* (between 0-0.45m), which is reserved for lovers, pets and family members;

2) *Personal distance* (between 0.45-1.2m), which reserved for friends;

3) *Social distance* (between 1.2-3.7m) for strangers and members of newly formed groups; and

4) *Public distance* (between 3.7-7.6m), which is for large audiences.

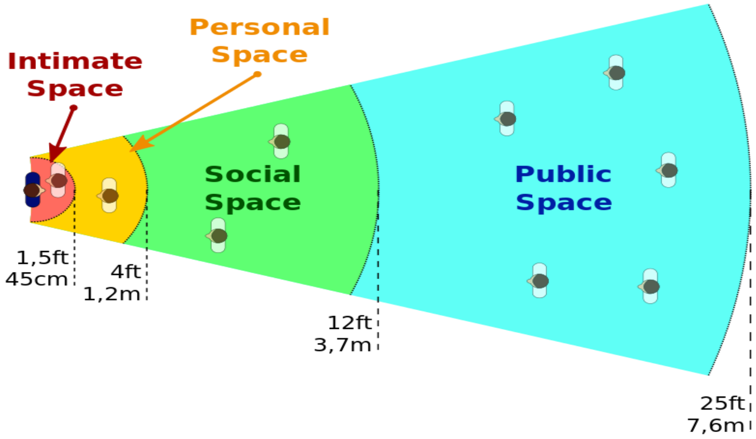


Figure 2-6: *Hall's interpersonal distances (Hall, 1966).*

These distances had been largely deepened with the recent study of Sorokowska (Sorokowska *et al.*, 2017) that takes into account even the cultural and ages differences.

There is also a research (see Figure 2-7*)* concerning interpersonal distance as a function of interpersonal relationships, attraction, and reactions to spatial invasion: a model that describes comfort-discomfort as a function of interaction distance in three situations (interacting friends, interacting strangers, and strangers who do not expects interaction) reveals that people seek an optimal distance from others that becomes smaller with friends and larger for individuals who do not expect to interact.

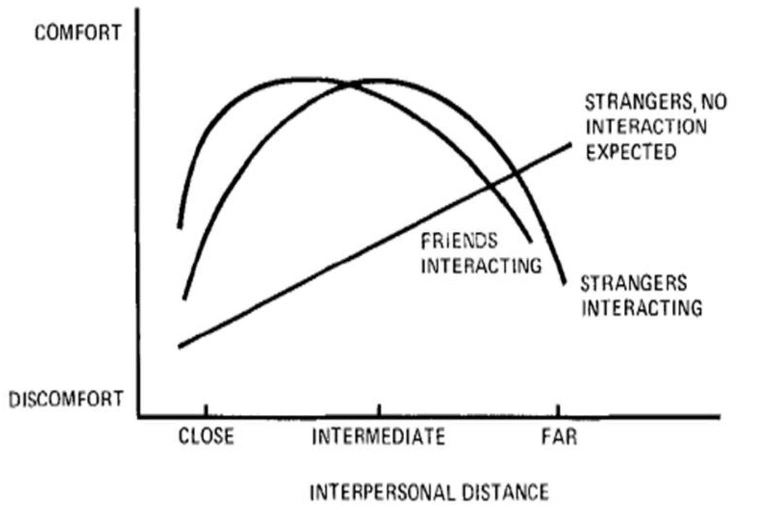


Figure 2-7*: Comfort-Discomfort over interpersonal distance.*

Sommer studied the way people use space for social interaction, founding that opposite seats are preferred to the side-by-side sitting at smaller distances. This is shows in the Figure 2-8 that is the result of his experiment:

Seating Preferences of Pairs of Subjects

	Number of Pairs Choosing to Sit:	
	Opposite One Another	Side-by-side
Distance opposite = side-by-side distance	16	3
Distance opposite < side-by-side distance	35	1
Distance opposite > side-by-side distance	12	24

Figure 2-8*: Sommer's study.*

However, there is no research regarding the (dis)comfort and quality of communication while sitting in different angles toward each other in airplane, and the best distances for the seat configuration face-to-face. Thus, following experiments (see Ch. 4) were performed:

1) Towards Comfortable Communication in Future Vehicles

2) Future vehicles: the effect of seat configuration on posture and quality of conversation
3) Design for comfort and social interaction in future vehicles: a study on the leg space between facing-seats configuration

2.3 How to evaluate (dis)comfort

Since (dis)comfort is related with subjective perception, it needs to be evaluated based on individual subjective data of a representative user population (Ch. 3). Research has shown that measurements of some parameters such as pressure, temperature, posture have a relationship to perceived (dis)comfort.

Consequently, both type data are useful to gain a possible complete overview of users' perceptions:

- subjective data (Ch. 3) can be obtained through surveys or questionnaires.
- objective data (Ch. 4) can be detected during human interaction with the object, environment and other people through sensors (to achieve pressure, temperature or environmental information), postural analysis (with video or photos), and predictive analysis.

3 Subjective data: surveys

The "subjective data" can be achieved through surveys, questionnaires specifically, to collect information about humans' perceptions when they interact with object, environment or people.

In this chapter concepts of survey and questionnaire are explained, showing the importance of cognitive psychology, the needing of pretesting, and usefulness of data analysis also in the case of nonresponse errors.

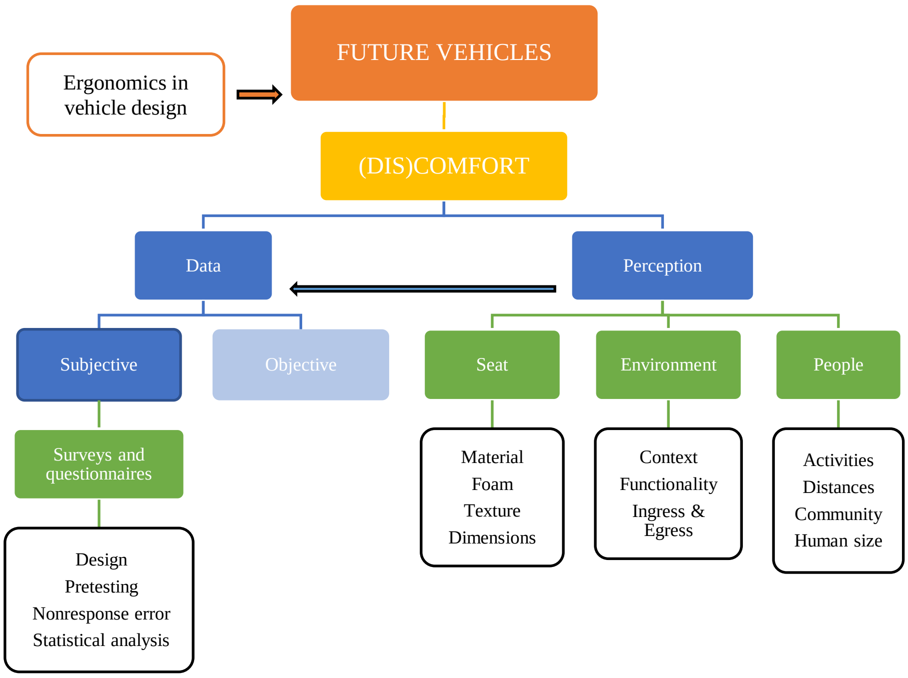


Figure 3-1: *PhD dissertation conceptual map - concepts explained in the Third chapter*

3.1 Surveys

A field of applied statistics of human research, survey methodology, studies the sampling of individual units from a population and associated techniques of survey data collection, such as questionnaire construction and methods for improving the number and accuracy of responses to surveys (Desselle, 2005; Glasow, 2005; Groves *et al.*, 2004; Presser and Blair, 1994; Stoutenborough, 2008; Tourangeau, 2003). Survey methodology includes instruments or procedures that ask one or more questions that may or may not be answered. Researchers carry out statistical analysis on surveys with a view towards making statistical inferences about the population being studied, and such inferences depend strongly on the survey questions used. Surveys provide important information for all kinds of public-information and research fields, e.g., marketing research, psychology, health-care provision and sociology (Desselle, 2005; Glasow, 2005; Groves *et al.*, 2004; Presser and Blair, 1994; Stoutenborough, 2008; Tourangeau, 2003).

A single survey is made of at least a sample (or full population in the case of a census), a method of data collection (e.g., a questionnaire) and individual questions or items that become data that can be analyzed statistically. Since survey research is almost always based on a sample of the population, the success of the research is dependent on the representativeness of the sample with respect to a target population of interest to the researcher.

The most important methodological challenges (Groves *et al.*, 2004) of a survey methodologist include making decisions on how to:

- Identify and select potential sample members.
- Contact sampled individuals and collect data from those who are hard to reach (or reluctant to respond).
- Evaluate and test questions.
- Select the mode for posing questions and collecting responses.
- Train and supervise interviewers (if they are involved).
- Check data files for accuracy and internal consistency.
- Adjust survey estimates to correct for identified errors.

Furthermore, while survey includes the set of questions and the process of collecting aggregating, and analyzing the responses from those questions, questionnaire includes any written set of questions. In other words, “questionnaire” describes content, while “survey” is a broader term that describes content, method, and analysis.

3.1.1 Surveys in Ergonomic and Human Factors

In the field of Ergonomics and Human Factors, surveys can be applied in different design phases:

1. To analyze the expectation of the market or to identify the satisfaction level of users.
2. To test the prototype or to improve the design
3. To test the final product
4. To compare different products

Once the design phase and the hypotheses to test are defined, the survey design begins. In my opinion, the generally adopted approach is:

- Identify the issue inside the considered environment
- Analyze the human body part involved in this issue

- Identify the current state of art[4]
- Identify the research question
- Identify the target population
- Select the survey mode
- Formulate possible questions (questionnaire design)
- Predict the respondents' behavior to the questions
- Optimize the survey/questionnaire
- Take the surveys/interviews (or experiments with surveys)
- Analyze the data
- Propose solutions

In survey research, independent and dependent variables are used to define the scope of study, but cannot be explicitly controlled by the researcher. Before conducting the survey, the researcher should predicate a model that identifies the expected relationships among these variables. Surveys can be used to assess needs, evaluate demand, and examine impact.

Surveys can obtain information from large samples of the population. They are also well suited to gathering demographic data that describe the composition of the sample. It is important to note, however, that surveys only provide estimates for the real population, not exact measurements, and the success of the research is dependent on the representativeness of the sample for a target population of interest to the researcher.

The aim of survey research is to collect data about sample units, from which researchers can **infer** to the population. Infer means to deduce or conclude (something) from evidence (observed data) and reasoning rather than from explicit statements. Statistical inference makes propositions about a population using data drawn from the population with some form of sampling. Given a hypothesis about a population, for which we wish to draw inferences, statistical inference consists of (first) selecting a statistical model of the process that generates the data and (second) deducing propositions from the model. Inferential statistics can be contrasted with descriptive statistics. Descriptive statistics is solely concerned with properties of the observed data, and it does not rest on the assumption that the data come from a larger population.

Survey data need to be accurate in order to minimize error. Survey errors consist of two components: bias and variance. Bias is a systematic error introduced into sampling or testing by selecting or encouraging one outcome or answer over others. Variance, or dispersion, roughly refers to the degree of scatter or variability among a collection of observations.

[4] state of art = the level of development (as of a device, procedure, process, technique, or science) reached at any particular time usually as a result of modern methods.

3.1.2 Total Survey Error (TSE) Framework

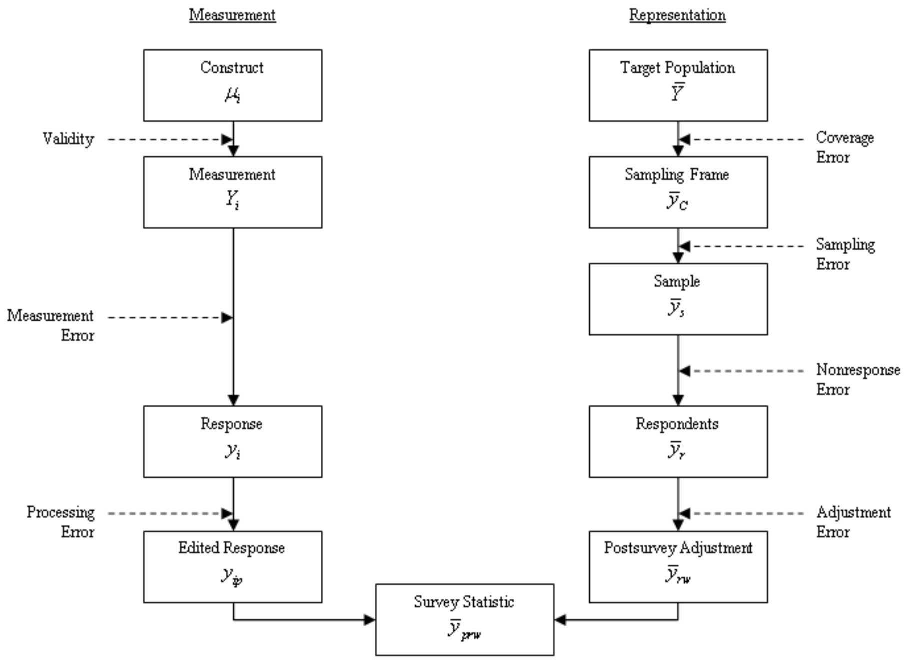


Figure 3-2: *Domains of survey and errors* (Groves *et al.*, 2004)

Figure 3-2 (Groves et al., 2004) is useful to understand which errors can arise from a survey, starting from the two domains: measurement and representation. The measurement domain concerns how questions, desired data and actual responses are developed. The representation domain is correlated on the represented population.

Starting from the representation domain, the “target population” is the group of elements for which the survey investigator wants to make inferences by using the sample statistics. Since the population changes over time, the time of the survey also define the target population. A set of materials, or "sampling frame," is used to identify the elements of the target population. Sampling frames are lists or procedures intended to identify all elements of a target population. The coverage error is the discrepancy between target population and available sampling frames. When available sampling frames miss the target population partially or entirely, the survey researcher faces two options: l) Redefine the target population to fit the frame better; 2) Admit the possibility of coverage error in statistics describing the original target population.

Sampling error originates from not observing all units in a sampling frame, but just a random sub-sample. Therefore, the statistical data (standard errors, confidence interval, etc.) are calculated. Cluster sampling typically increase sampling variance, while stratified sampling typically decreases it. The nonresponse error is the discrepancy between the gross sample and the net sample of observed unit (since not all respondent considered in the sample will take the survey). Adjustment Error are generated by means of post-survey adjustments (e.g. weighting and imputations) aiming to correct for coverage, sampling and nonresponse errors.

Considering the measurement domain, Construct Validity is the discrepancy between construct and measurement instrument. Measurement Error is the discrepancy between ideal measurement and actual answers given, e.g. because of: misunderstandings; social desirability bias; satisficing (less efforts to provide optimal responses). Processing Error is the discrepancy between the variable used in the estimation and respondents' actual answers, e.g. because of post-survey coding and editing.

Since several errors can arise from a survey, performing the pretesting (para. 3.5) while designing a survey is recommended to reduce errors, especially nonresponse errors (para. 3.6).

3.2 Survey design: developing questionnaires

A questionnaire is a set of questions typically used for research purposes which can be both qualitative as well as quantitative in nature. A questionnaire may or may not be delivered in the form of a survey, but a survey always consists of questionnaires.

The main parts of the questionnaire consist of statements or questions that should match the respective research design, and the response categories.

In general, a brief introduction could help respondents to understand the topic, and the interviewer instructions help them to carry out the interview or experiment in the right way, being aware that this also may influence the response.

On one side questionnaires are inexpensive, quick, and easy to analyze, but, on the other side, they can present more problems than benefits. For example, unlike interviews, the people conducting the research may never know if the respondent understood the question that was being asked. Also, because the questions are so specific to what the researchers are asking, the information gained can be minimal.

One key concern with questionnaires is that they may contain quite large measurement errors. These errors can be random or systematic. Random errors are caused by unintended mistakes by respondents, interviewers and/or coders. Systematic error can occur if there is a systematic reaction of the respondents to the scale used to formulate the survey question. Thus, the exact formulation of a survey question and its scale are crucial, since they affect the level of measurement error.

To reduce errors, Porst (Porst, 2000) stated 10 commandments of question design that can be used as general tips for questionnaire design:

1. Use simple and unambiguous terms, which are understood in the same way by all respondents!
2. Avoid long and complex questions!
3. Avoid hypothetical questions!
4. Avoid double stimuli and double negations!
5. Avoid loaded and leading questions!
6. Avoid questions which some (or all) respondents cannot answer!
7. Use unambiguous temporal references!
8. Use answer categories that are comprehensive and disjunct!
9. Ensure that the context of a question does not influence the answer!
10. Define terms that may be unclear!

3.2.1 Questionnaire design: cognitive process

Questionnaire is considered as a conversation between interviewer and respondent whose questions behavior should be predicted.

According to the psychology of survey response, the Tourangeau model (Tourangeau, 2003) shows that in between the stimulus (questions) and response (answer) there is the cognitive information processing task. The four phases (Figure 3-3) of the cognitive process occur simultaneously in a very short time:

- ➢ Comprehension: the respondent interprets the question. Interpretation can be influenced by the clarity of the question, by previous questions, by the respondent's previous knowledge.
- ➢ Information retrieval: the respondent must retrieve information from memory.
- ➢ Judgment: Can the information recovered be used to answer the question?
- ➢ Reporting an answer: The final answer is a compromise between the internal answer and the answer categories. The judgment may have changed if no response category matches the internal response.

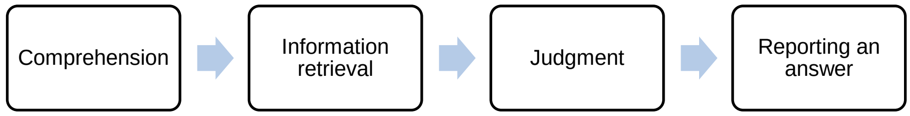


Figure 3-3: *Tourangeau's model of the response process* (Tourangeau, 2003)

Furthermore, the presence of an interviewer it is always required both to explain the experiment and to achieve feedbacks from participants.

Indeed, the advantages of having an interviewer are:

- Higher response rate, in which respondent can be motivate to answer. Indeed, monitoring the participant behavior, the interviewer could be able to understand the needs and be ready to reply them.

- It's possible to conduct more complex interviews in order to study the cognitive and postural comfort perception

Instead, the disadvantages:

- Interviewer bias: because the question and the topic are always explained, the use of the words can alter the perception of question from participants.
- Interviewer effect: participants can be influenced by the interviewer themselves while answering.

3.2.2 Questionnaire design: questions developments

Once defined the research question, the questionnaire design begins with questions developments. In general, there are two questions drafting approaches (Glasow, 2005; Groves *et al*., 2004), one is the "Bottom Up" method in which all questions that come up are written down and then ordered in a logical way identifying which ones are needed for the data collection. This procedure is time consuming, so in opposition there is the "Top Down" method where all constructs are defined from theory and operationalized into questions or items considering these following aspects:

- the items should measure aspects of the research question;
- be aware of the use of additional information;
- be aware whether respondents are able answer the question truthfully and understanding them in your same way.

Considering the question type, a distinction is made between close-ended, open and semi-closed questions (Glasow, 2005):

- Closed-ended questions: categories are limited and exactly defined and respondents need to fit their answer in those categories. These questions are easy to implement, to respond and to analyze but, on the other hand, respondents might not find their answer in any of the categories provided or may feel not being taken seriously (especially problematic in long / longitudinal surveys). The response options for a closed-ended question should be exhaustive and mutually exclusive. Four types of response scales for closed-ended questions are distinguished:
    - Dichotomous, where the respondent has two options.
    - Nominal-polytomous, where the respondent has more than two unordered options.
    - Ordinal-polytomous, where the respondent has more than two ordered options.
    - (Bounded)Continuous, where the respondent is presented with a continuous scale.

- Open questions: only the question is pre-defined and respondents answer in their own words. In this case, respondents can answer exactly as they see fit providing their most relevant information, but research results depend on the verbal skills of the respondents and information on the intended meaning of the questions cannot be deduced from answer categories. Thus, there is a labor-intensive analysis.
- Semi-closed (open ‘other’ category) questions: they consist on closed pre-defined answer categories with open ‘other’ answer option, where the presence of the ‘other’ answer option is due to the indecisiveness of researchers. This is useful when the universe of potential answer categories can be well-estimated, but not perfectly defined, but the closed categories may influence on answering.

3.2.3 Questionnaire design: level of measurements

The level of measurement is the relationship of the values that are assigned to the attributes for a variable (Glasow, 2005; Groves *et al.*, 2004). In statistics, there are four variable measurement scales: nominal, ordinal, interval and ratio. These measurement scales are ways to categorize different variables (an element, feature or factor that is likely to vary). By default, all variables fall in one of the four scales mentioned above. Understanding their properties and assigning variables to one of the four measurement scales is important mathematically because they determine what mathematical operations are allowed.

In summary, nominal variables are used to “name,” or label a series of values. Ordinal scales provide good information about the order of choices, such as in a customer satisfaction survey. Interval scales provide0 the order of values, plus the ability to quantify the difference between each one. Finally, Ratio scales provide the ultimate–order, interval values, plus the ability to calculate ratios since a “true zero” can be defined.

Nominal scale - It is a measurement scale, in which numbers serve as “tags” or “labels” only, to identify or classify an object. A nominal scale measurement normally deals only with non-numeric (quantitative) variables or where numbers have no value. These scales are mutually exclusive (no overlap) and none of them have any numerical significance. People either belong to a group or they do not. Sometimes numbers are used to designate category membership. Note: a sub-type of nominal scale with only two categories (e.g. pass/fail, professional/amateur, or positive/negative) is called “dichotomous.”

From a statistic point of view nominal scale is one of the measurement scales which is easiest to understand measurement scale. As mentioned earlier, nominal scale is assigned to items that are not quantitative or number oriented.

For example, let's assume there are 5 colors, orange, blue, red, black and yellow. They could be numbered in any order we like either 1 to 5 or 5 to 1 in ascending or descending order. Here numbers are assigned to colors only to identify them. Another example of a nominal scale from a research activity point to view is YES/NO scale. It essentially has no order.

Ordinal scale - It is the 2nd level of measurement (of the four measurement scales) that reports the ranking and ordering of data without establishing the degree of variation between them. "Ordinal" indicated "order". Ordinal data is quantitative data which have naturally occurring orders and the difference between is unknown. It can be named, grouped and ranked.

For example: "How satisfied are you with our products?"

1- Totally Satisfied
2- Satisfied
3- Neutral
4- Dissatisfied
5- Totally Dissatisfied

Survey respondents will choose between these options of satisfaction but the answer to "how much?" will remain unanswered. The understanding of various scales helps statisticians and researchers so that the use of data analysis techniques can be applied accordingly.

Thus, an ordinal scale is used as a comparison parameter to understand whether the variables are greater or lesser than one another using sorting. The central tendency of the ordinal scale is Median.

Likert Scale is an example of why the interval difference between ordinal variables cannot be concluded. In this scale the answer options usually polar such as, "Strongly agree" to "Strongly Disagree" (Figure 3-4).

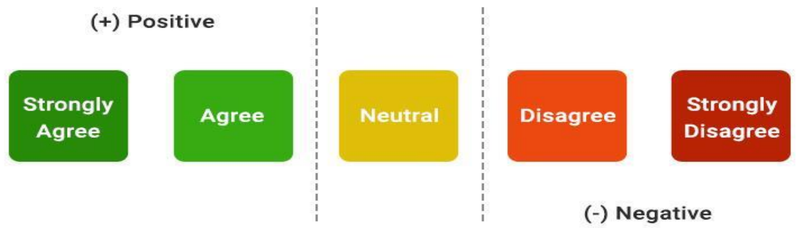


Figure 3-4*: Example of Likert ordinal scale*

The intensity of difference between these options can't be related to specific values as the difference value between totally satisfied and totally dissatisfied will be much larger than the difference between satisfied and neutral. If someone loves Mercedes Benz cars and is asked "How likely are you to recommend Mercedes Benz to your friends and family?" will be troubled to choose between Extremely likely and Likely. Thus, an ordinal scale is used when the order of options is to be deduced and not when the interval difference is also to be established.

Interval scale - It is defined as a quantitative measurement scale where the difference between 2 variables is meaningful. Interval scale is the 3rd level of measurement. In other words, the variables are measured in actuals and not as a relative manner, where the presence of zero is arbitrary. This means that the difference between two variables on a scale is an actual and equal distance. For example, difference between 68 degrees F and 58 degrees F is the exact same as 101 degrees F and 91 degrees F. In this example, it is not sure that 98 degrees F is double the temperature in terms of "heat" or "cold" of 49 degrees F. This is because there is no absolute zero on the Fahrenheit scale – that is at zero temperature doesn't exist. It is easy to remember the objective of this scale as "interval" equates to the interval or distance between two variables. Another easy way to remember interval scale is that subtraction is defined between the two variables. This is unlike the ratio scale where division is defined between two variables. Interval data can be discrete – with whole numbers like 8 degrees, 4 years, 2 months etc. or continuous – with fractional numbers like 12.2 degrees, 3.5 weeks or 4.2 miles. This statistical method is also known as scale, quantitative or parametric.

In the interval scale, the survey is required to be designed in such a way that the dimension to be measured is scaled appropriately and this can be anchored ideographically, numerically or verbally (see for example Figure 3-5).

Figure 3-5: *example of Net Promoter Score*

One of the most commonly used interval scale question, the question is arranged in a 5-point Likert Scale where the level of agreement or disagreement are associated with a number.

Ratio scale - It is defined as a variable measurement scale that not only produces the order of variables known along information on the value of true zero. It is calculated by if the variables have an option for zero, the difference between the two variables is the same and there is a specific order between the options. Characteristics of previous scales plus an absolute zero point. Examples: weight, height, number of children, age. Ratio scales provide a wealth of possibilities when it comes to statistical analysis. These variables can be meaningfully added, subtracted, multiplied, divided (ratios). Central tendency can be measured by mode, median, or mean; measures of dispersion, such as standard deviation and coefficient of variation can also be calculated from ratio scales.

Ratio scale has most of the characteristics of the other three variable measurement scale i.e. nominal, ordinal and interval. Nominal variables are used to "name," or label a series of values. Ordinal scales provide a sufficiently good amount of information about the order of choices, such as one would be able to understand from using a customer satisfaction survey. Interval scales give us the order of values and about the ability to quantify the difference between each one. Ratio scale helps to understand the ultimate-order, interval, values, and the true zero characteristic is an essential factor in calculating ratios. A ratio scale is the most informative scale as it tends to tell about the order and number of the object between the values of the scale. The most common examples of ratio scale are height, money, age, weight etc. With respect to market research, the common examples that are observed are sales, price, number of customers, market share etc.

3.2.4 Summary of Scale Types

Table ***3-1*** shows in summary some examples of scale types present in literature. Information were collected and summarized identifying the type scale, the restrictions present, the scale items and points, and the data type.

Table 3-1: *Summary of scale types*

Rating scales				
Type	Restrictions	Scale Items	Scale points	Data Type
Simple Category	Needs mutually exclusive choices	One or more	2	Nominal
Multiple Choice Single-Response Scale	Needs mutually exclusive choices; may use exhaustive list or "other"	Many	2	Nominal
Multiple Choice Multiple-Response Scale (checklist)	Needs mutually exclusive choices; Needs exhaustive list or "other"	Many	2	Nominal
Likert Scale	Needs definitive positive or negative statements with which to agree/disagree	One or more	5	Ordinal
Likert-type Scale	Needs definitive positive or negative statements with which to agree/disagree	One or more	7 or 9	Ordinal
Semantic Differential Scale	Needs words that are opposites to anchor the graphic space	One or more	7	Ordinal

Rating scales				
Type	Restrictions	Scale Items	Scale points	Data Type
Numerical Scale	Needs concepts with standardized or defined meanings; Needs number to put anchor the end-points or points along the scale; Score is a measurement of graphical space from one anchor	One or many	3-10	Ordinal or Interval
Multiple Rating List Scale	Needs words that are opposites to anchor the end-points on the verbal scale	Up to 10	5-7	Ordinal
Fixed Sum Scale	Participant needs ability to calculate total to some fixed number, often 100	Two or more	none	Interval or Ratio
Stapel Scale	Needs verbal labels that are operationally defined or standard	One or more	10	Ordinal or Interval
Graphic Rating Scale	Needs visual images that can be interpreted as positive or negative anchors; Score is a measurement of graphical space from one anchor	One or more	none	Ordinal (Interval or Ratio)
Paired Comparison Scale	Number is controlled by participant's stamina and interest	Up to 10	2	Ordinal
Forced Ranking Scale	Needs mutually exclusive choices	Up to 10	Many	Ordinal or Interval
Comparative Scale	Can use verbal or graphical scale	Up to 10		Ordinal

3.3 Examples of scales and questionnaires used to evaluate (dis)comfort

Selecting proper questionnaires for investigating the comfort of users can be a challenging task, even for experienced researchers and practitioners. Anjani (Anjani *et al.*, 2021) created a list of Preferred Comfort Questionnaires for product design to help researchers in the selection of questionnaires for comfort research based on 15 questionnaires. Similar researches were done in this PhD thesis analyzing following scales and questionnaires in order to understand how use them in (dis)comfort evaluation.

Ten-point Borg scale CR-10 (BORG, 1982): it allows to express a judgment expressing a number on a 10-point scale of category ratio (CR). The scale (Figure 3-6), characterized by ratios, can assess only comfort (no comfort / extreme comfort) or only discomfort (no discomfort / extreme discomfort), but not both. The validity and reliability of the scale in assessing physical and mental effort was extensively tested (Shen and Parsons, 1997).

0	Nothing at all
0.5	Very, very slight (just noticeable)
1	Very slight
2	Slight
3	Moderate
4	Somewhat severe
5	Severe
6	
7	Very severe
8	
9	Very, very severe (almost maximal)
10	Maximal

Figure 3-6*: Example of 10-point Borg scale*

Corlett and Bishop scale (Corlett and Bishop, 1976): a simple ordinal scale formed by a continuous horizontal line with descriptors at the ends and intermediate (Figure 3-7). The user evaluates the comfort or discomfort stimuli by marking a bar along the continuous horizontal line. Clear and easy to use. This scale can be used in the Body Part Discomfort (BPD), described in detail later.

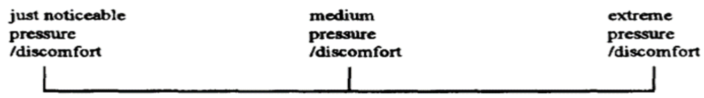


Figure 3-7: *Example of Corlett and Bishop scale*

Likert scale (Joshi *et al.*, 2015): conceived by the American psychometric Rensis Likert in 1932, it is a scale known for its simplicity of construction that allows one to express an attitude or a positive or negative opinion concerning a specific object or a situation to be evaluated. Intuitive and straightforward, the scale comprises a series of questions and affirmations linked to the attitudes to be investigated. The interviewee is called to express his degree of agreement/disagreement with each statement choosing among the various points ordered by mark (Figure 3-8). The number of points on the scale, also defined levels, depends on two factors: the presence of a central neutral element and the level of precision. The central neutral element allows the user to express an indifferent judgment concerning the attitude (that can be considered as nonresponse in some cases). The odd-point scales (3/5/7/9-point) present a central neutral element, positive elements on its right and negative elements on its left. The even-point scales (2/4/6/8/10-point) do not provide a central neutral element but have positive and negative elements at the extremities. A higher number of point scales correspond to higher data precision. In contrast, respondents need more time to answer on a high point scale since they have to project their perception on the scale. According to some literature studies (“5 or 7 point scale”, n.d.; “7 or 10 point scale”, n.d.), the most used Likert scales are:

- the 7-point scale, suitable for assessing body part (dis)comfort and presents better significant statistical correlations;
- the 10-point scale, suitable for assessing general perceived (dis)comfort since it offers a higher level of precision, is essential for detecting differences between responses, and needs more time to answer (projecting overall perceptions on the scale).

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5
-2	-1	0	1	2

Figure 3-8*: Example of a Likert scale*

Semantic differential (Oborne and Clarke, 1975): technique developed by Charles Osgood (1952), is characterized by ordered points (usually 5 or 7 points), with the possibility of using negative numbers, and the use of bipolar or opposite adjectives (Figure 3-9). The aim is to detect the meaning that a certain perception assumes that the individual assesses, answering the question: "What does it mean for you?". The interviewee crosses at the position corresponding to his degree of perception between the two adjectives. It is an appropriate scale for measuring the individual's perception of a subjective event that is difficult to define with a precise label or when the required evaluation involves subjective aspects that could be expressed in a reticent manner.

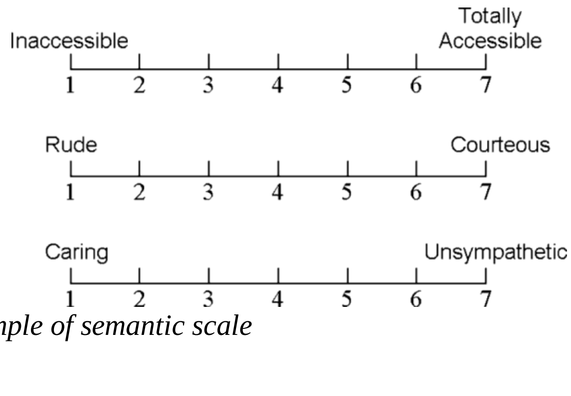


Figure 3-9: *Example of semantic scale*

This type of scale is suitable for a profile analysis of the subject through graphic representation obtained by joining the scores with a line (Figure 3-10). The only difficulty is to convert the line in a numerical scale or relevant result during data analysis (the researcher should define the conversion a priori). This analysis is used to identify the strong and weak points of the object under examination. A semantic differential scale is a tool suitable for detecting mental representations, the image of objects or concepts, the perception of stimuli, rather than the subjects' attitudes towards them.

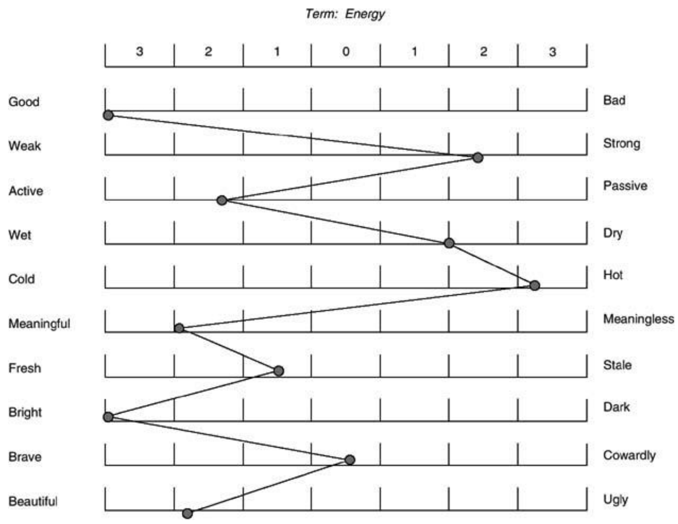


Figure 3-10*: Example of result representation using a semantic scale*

CP-50 scale (Shen and Parsons, 1997): created by Shen and Parsons (1997), the category partitioning scale (CP-50) is used to assess the intensity of pain or discomfort. It is arranged vertically (Figure 3-11), presenting the 5 categories of discomfort perception (from very high to very low) on the left side. Each category is associated with a 10-point scale. Thus, the scale on the right starts from 0 (no sensation) at the bottom and ends with 50 (maximum pain/discomfort) at the top. Additional points can be added above 50 to exceed.

The procedure for using this scale is composed of two phases. Firstly, the subjects categorize the stimuli about their experience with pain intensity. Then they refine the perception using the numerical subdivisions within that category. It is widely used as it is accurate and easy to use.

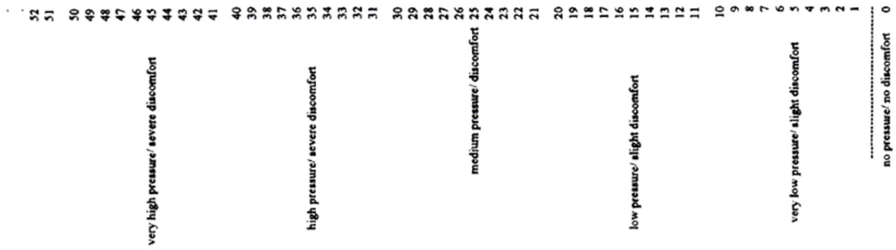


Figure 3-11*: Example of CP-50 scale*

ASHRAE 7-point scale*:* a scale for thermal sensations created by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). It is a 7-point scale (Figure 3-12) about heat perception ranging from -3 (cold state) to +3 (warm state), and 0 is neutral. It is used in the context of thermal perception analysis that it always needs to be accompanied by a scale assessing (dis)comfort to make results meaningful (since “warm” and “cold” could be either comfortable or not).

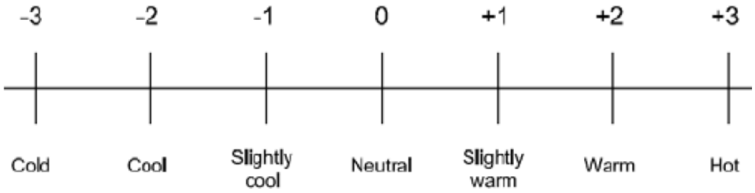


Figure 3-12*: Example of ASHRAE scale*

The Body Part Discomfort (BPD) Method (Corlett and Bishop, 1976)*:* Idealized by Corlett and Bishop (1976), this method (Figure 3-13) was developed for studies of the discomfort effects on postures. It consists of a human body map divided into sections linked with 5-point scales (from 0 = no sensation to 5 = extreme sensation). The method, simple and easy, was widely used by many researchers to evaluate a prototype or a final product, like a chair/seat.

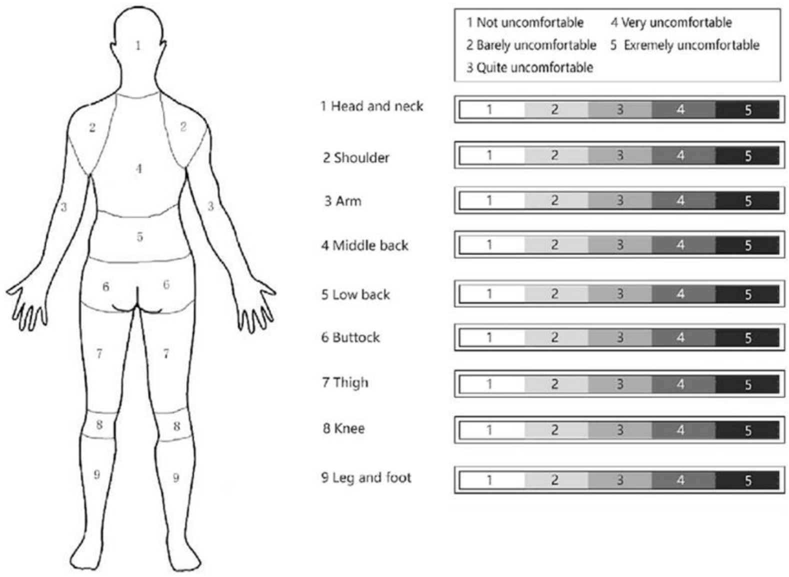


Figure 3-13*: Example of BPD method*

The Local Postural Discomfort (LPD) Method (Van der Grinten and Smitt, 1992)*:* this method could be useful in seat tests for more than one hour. It consists of Borg 10-point scale and a body map divided into sections where the most discomfortable areas are crossed (Figure 3-14). The advantage of this method is that it reveals the location of areas to be improved, which provides input for a redesign.

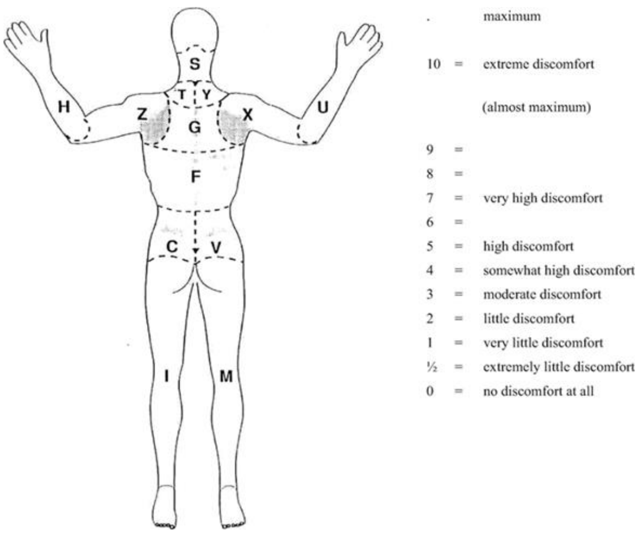


Figure 3-14*: Example of LPD method*

3.4 Survey: data analysis

The answers obtained from the questionnaires (and also from the "objective data" – see Ch. 4) need to be analyzed. Data analysis is a process of visualizing and modelling data to highlight information that suggests conclusions and supports decisions. Data analysis has many approaches and facets, which includes very different techniques. In this paragraph, some examples most used in Ergonomics & Human Factors are shown to comprehend the statistical analysis used in experiments reported in Ch.s 4 - 5.

3.4.1 Data analysis: graphic types

The data can be represented through multiple graphical representations, useful to facilitate the data analysis and reasoning work. Some examples are reported.

Bar chart (Figure 3-15): it consists of non-adjacent bars aligned on a horizontal axis. The bar length is proportional to the frequency or percentage of observations. The purpose of the representation is linked to the readability of the data. There are two types of bar charts: columnar if the bar length is vertical; ribbons if the length extends horizontally.

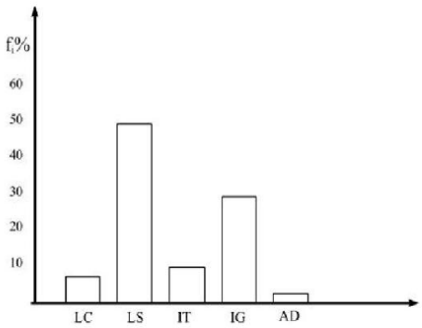


Figure 3-15*: Example of bar chart*

Pareto chart (Figure 3-16): it is a bar chart where the frequencies appear in descending order. The Pareto diagram is often completed with the spinner of the cumulated frequencies represented with points at the center of bars. It is advantageous when there are numerous classes, allowing an immediate visualization of the relevant facts.

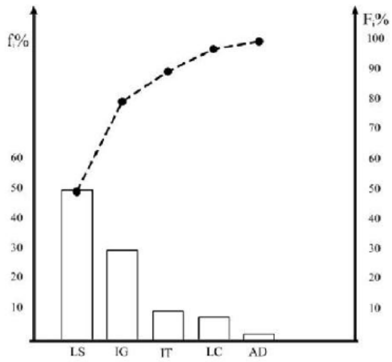


Figure 3-16*: Example of Pareto chart*

Histogram (Figure 3-17): it is a bar graph for continuous data, consisting of adjacent rectangles whose bases are aligned on an oriented axis and equipped with units of measurement. Each rectangle corresponds to a class, and the height is defined either by the absolute or relative frequency. Frequencies are proportional to rectangles' areas in both dimensions.

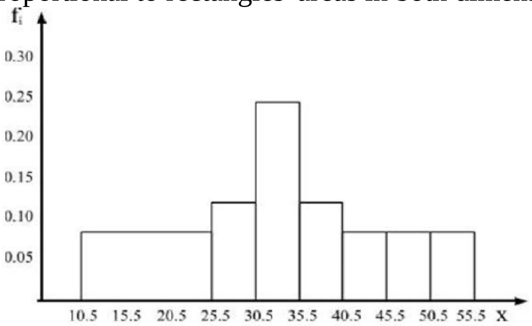


Figure 3-17*: Example of histogram chart*

Pie chart (Figure 3-18): defined also as an aerogramme because it refers to a flat or three-dimensional geometric figure. It is constructed by dividing a circle into wedges or slices whose angular amplitudes are proportional to the percentage frequency classes. Classes usually follow one another in clockwise order. This representation is widely used as it has a good visual impact.

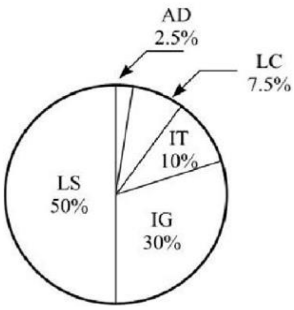


Figure 3-18*: Example of pie chart*

Box-plot (Figure 3-19): it describes the distribution of a sample through a box with some information included. The box is delimited by the first quartile Q1 and the third quartile Q3. The line inside the box indicates the position of the median Me. The two segments outside the box represent the extreme values of the distribution, i.e. the maximum and the minimum. The four equally populated intervals are graphically represented, delimited by quartiles. Sometimes the box plot is enriched by indicating the average, usually with an asterisk. The box gives a good visual idea of the sample's behavior and the dispersion of its data.

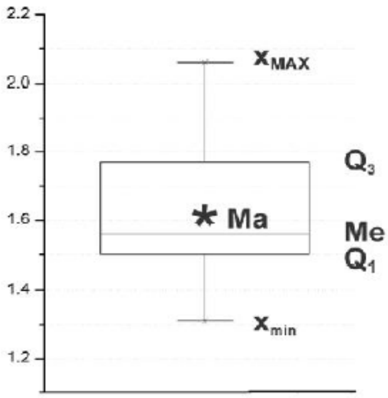


Figure 3-19*: Example of Box-plot*

3.4.2 Data distribution

Once obtained the “subjective” and the “objective” data, the next step is to perform data evaluation through statistical analysis. It consists of comparing the distributions of the data in question to assimilate the final information that expresses the progress of the simulation project synthetically (Figure 3-20).

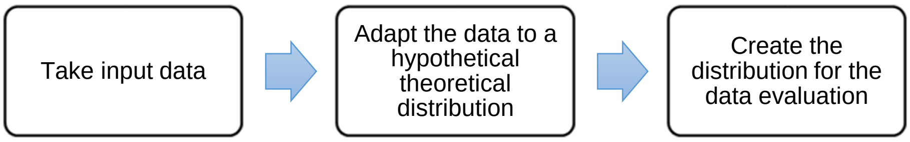


Figure 3-20: *Scheme for creating a distribution with the collected data*

Since questionnaire data are related to the discrete rating scales, they assume a finite or countable quantity of values; its possible values can be listed and indicated with a succession. In contrast, the data of the measuring instruments and the anthropometric ones, such as height and weight, are continuous because they assume a continuous uncountable quantity of values; they can assume all the intermediate values of an interval. The objective data available are finite and time-dependent. The smaller the distance range between one instant of measurement to another, the more values there are in the complex. Furthermore, data are deterministic when the event occurs in the same (or predictable) way every time, meaning that this type of data could be collected only once. Instead, a probabilistic process does not occur with the same type of regulation and will follow a probabilistic distribution. The observed data can be fit on a theoretical distribution to gain an assessment guide. Some examples of data distribution are described below.

Uniform*:* in a range [a, b] contained in a data set, the same probability is attributed at each point (Figure 3-21). It can be either discrete with the finished set, or continuous, in which case the distribution can be defined as rectangular. It can be used as an attempted distribution when there is not enough information about the data.

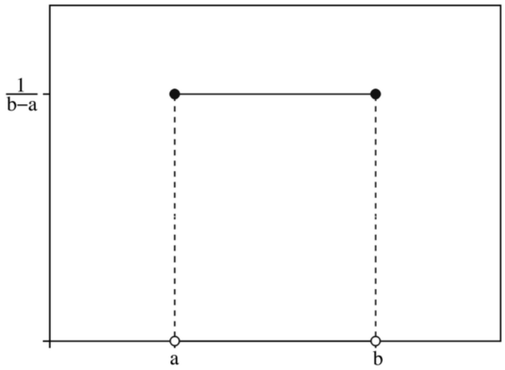


Figure 3-21: *Example of uniform distribution*

Normal (or Gaussian): a continuous probability distribution often used as a first approximation to describe random variables that tend to concentrate around a single average value. The graph of the associated function is symmetrical and has a bell shape, known as a Gaussian bell (or even as an error curve, bell curve, ogive, as shown in Figure 3-22). The normal distribution is considered the basic case of continuous probability distributions due to its role in the central limit theorem. Assuming certain conditions, the sum of n random variables with finite mean and variance tends to a normal distribution with the tendency of $n \to \infty$. Thanks to this theorem, normal distribution is often encountered in practical applications as a simple model for complex phenomena. The normal distribution depends on two parameters, the mean μ and the variance σ^2, and is traditionally indicated with: N (μ; σ^2). A normal distribution is obtained with parameters $\mu = 0$ and $\sigma = 1$.

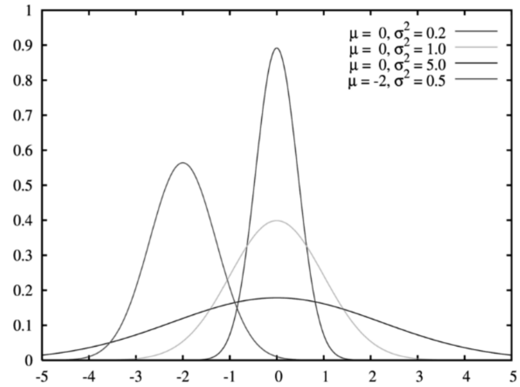


Figure 3-22*: Example of Normal distribution*

Poisson*:* is a discrete probability distribution used to show how many times an event is likely to occur over a specified period, knowing that an average λ number occurs (Figure 3-23). Poisson distributions are often used to understand independent events at a constant rate within a given time interval.

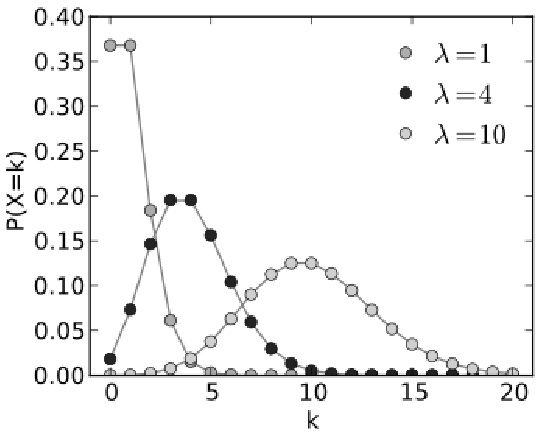


Figure 3-23*: Example of Poisson distribution*

Weibull: is a continuous probability distribution defined on positive real numbers by two parameters: λ (scale parameter or characteristic life) and k (shape parameter), as shown in Figure 3-24. It describes systems with a time-varying failure rate as an extension of the exponential distribution that provides constant failure rates over time. The Weibull distribution of parameters (λ, 1) c corresponds to the exponential distribution ε (λ).

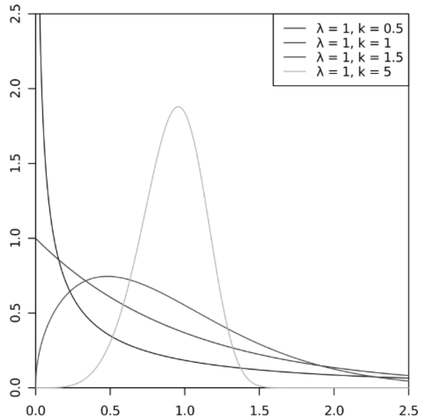


Figure 3-24*: Example of Weibull distribution*

3.4.3 Statistical analysis

Once data distributions are known, the next step is data comparison. For instance, objective data obtained from measurement tools are compared with historical data to compare trends and analyze variations. Subjective data from questionnaires need to be compared to check whether there is consistency in the answers provided.

If data present normal distribution (or parametric distribution), the comparison test can be performed, for example, by T-test, Shapiro-Wilk, Shapiro -France and Chi-Quadro Pearson test. Although, if there is a nonparametric distribution, the non-parametrized test needs to be performed, such as the signed-rank Wilcoxon test. In the case of several groups, to check if they have the same distribution, the technique used is *the analysis of variance (ANOVA, Analysis of Variance*). The ANOVA eventually found the type of variability present for the data and its significant differences. At this point, possible relations between two or more variables are sought, which in many cases indicate the conditioning of variables that lead to specific results. The parameters influence analysis is required for prediction or simulation. A relationship between two statistical variables is not necessarily a cause-effect relationship but simply the tendency of one variable to vary in function of another. To ensure a better understanding, the study of these relationships in the statistical analysis of the data can be treated by Correlation Analysis and Regression Analysis.

In statistics, correlation is linked to dependence or association, relations between two random variables or bivariate data. The correlation is a statistical association, which in common usage refers to how close two variables are to having a linear relationship. ***The Analysis of Correlation*** is a bivariate analysis that measures the strength and direction of association between two variables. In terms of the strength of the relationship, the value of the correlation coefficient varies between +1 and -1. A value of ± 1 indicates a perfect degree of association between the two variables. The closer the value of the correlation coefficient to 0, the weaker the relationship between the two variables will be. The direction of the relationship between two variables is indicated by the sign of the coefficient: a positive sign or indicates a positive relationship; a negative sign indicates a negative relationship.

A preliminary method for analyzing a possible link between two variables is to construct a correlation diagram, a scatter plot to identify the position of the points according to the two variables, thus creating a set of pairs of values. The vertical axis is for the dependent variable, while the horizontal is for the independent variable (Figure 3-25). A correlation could exist when the diagram presents points close to each other, forming a squashed ellipse. The direction of the independent variable growth determines whether the correlation is positive (increasing) or negative (decreasing). The value of the correlation coefficient determines the arrangement of the points. The more points are grouped around a line, the stronger the relationship between the variables. If the scores are uniformly dispersed, however, there is no relationship between the variables.

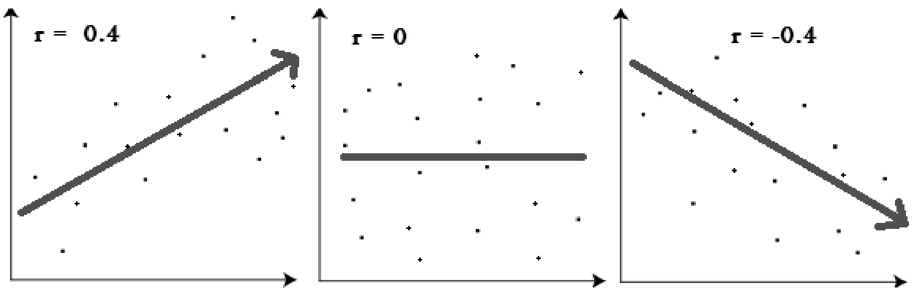


Figure 3-25*: Example of correlation directions*

In statistics, the correlation between variables is measured using one of the four types of correlation coefficients, also called degree of correlation: Pearson correlation, Kendall rank correlation and Spearman correlation.

Pearson correlation is the most common correlation statistic to measure the degree of the relationship between linearly related variables. The hypotheses to be put for the Pearson correlation are that both variables should be normally distributed and linearity and homoskedasticity. Linearity presupposes a linear relationship between the two variables, and homoskedasticity presupposes that the data are equally distributed on the regression line, i.e. the same variance.

Kendall*'s rank correlation* is a nonparametric test that measures the force of dependence between two variables.

The correlation of rank Spearman is a nonparametric test used to measure the degree of association between two variables. It bears no hypothesis on data distribution and is the appropriate correlation analysis when variables are measured on a scale that is at least ordinal. On an ordinal scale, the variable levels are ordered so that one level can be considered higher or lower than another. However, the magnitude of the difference between live shows is not necessarily known.

The other statistical technique used is ***regression analysis*** (Figure 3-26), which aims to determine a functional relationship between the dependent and independent variables. An approximate mathematical model, with a degree of quantizable accuracy, assumes the dependent variable, y is a linear combination of the parameters. Regression models predict a variable y starting from the values of another variables x. The interpolation exists when the forecast values are included in the range of the variables x used for constructing the model. Extrapolation is when the values are outside the range of the explanatory variables. In this case, the forecast becomes riskier.

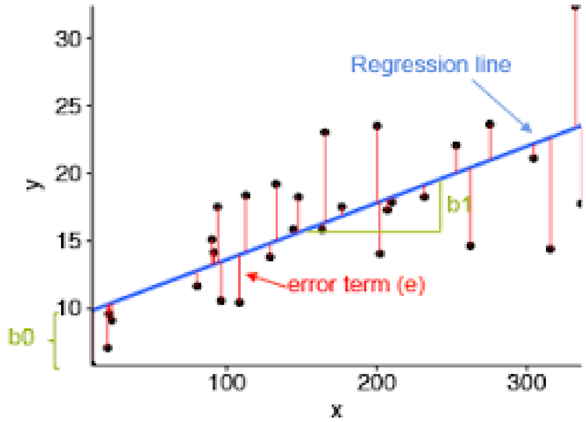


Figure 3-26*: Example of regression analysis*

3.5 Survey: Pretesting

Designing the perfect survey questionnaire is impossible. However, researchers can still create effective surveys by performing the pretesting and incorporating the results into the questionnaire. Pretesting helps to determine the strengths and weaknesses of the survey concerning question format, wording and order (Rothgeb *et al.*, 2007). It is used specifically for question variation, meaning, task difficulty, and respondent interest and attention, including also any borrowed questions from other similar surveys, even if they have already been pretested, because meaning can be affected by the context of the current survey. Researchers can also pretest the following: flow, order, number of questions, patterns, timing, and overall respondent well-being. Researchers might also want to pretest the reliability and validity of the survey questions. To be reliable, a survey question must be completely understood by respondents. Also, researchers can assess reliability by comparing the answers respondents give in one pretest with answers in another pretest (Weisberg, 2008). Then, a survey question's validity is determined by how well it measures the concept(s) it is intended to measure. Both convergent validity and divergent validity can be determined by first comparing answers to another question measuring the same concept, then by measuring this answer to the participant's response to a question that asks for the exact opposite answer. Thus, the goal of pretesting is to improve data quality in which measurement should meet the survey's objectives; to identify and to fix problems encountered by respondents and interviewers to:

- Reduce respondent mistakes
- Reduce respondent burden
- Reduce interviewer mistakes
- Reduce interviewer burden

The aim is to test and refine question wording checking if:

- Respondents can understand questions;
- Interviewers can ask the questions;
- The questions are sufficient for the research design.

Then, the whole questionnaire is checked to have a good flow of questions and sections, to reduce potential order effects and analyzing the behavior of respondents and interviewers. However, even the cognitive pretesting could show some pitfalls because people might interpret a question differently from intended, or they might find it hard to understand what they are meant to do to answer the question, or might find it difficult to retrieve the information needed to answer the question.

The purpose of a pretest is to gather information about:

- The comprehensibility of survey questions
- Variability in question interpretation across respondents

- Task difficulty
- Respondent interest and attention
- Respondent well-being
- Distribution of answers
- The order of the questions
- Context effects
- Interviewer problems
- Technical difficulties with administering or completing the questionnaire
- Timing of the survey

The Pretesting Methods (Presser and Blair, 1994) are listed below and used according to the desired scope. In my opinion, only some of them are more useful in the field of ergonomics:

- Conventional Pretest
- **Expert Review**
- **Behavior Coding**
- Respondent Debriefing
- **Focus Groups**
- **Cognitive Interviewing**
- Eye Tracking
- Web Probing
- Split
- Ballot Experiments
- **Usability Testing**

Expert Review - Experts are survey methodologists or other people familiar with questionnaire design able to identify potential problems with a survey questionnaire without empirical testing. The "Classic" Expert Reviews (generally 2-6) are asked to identify question problems and to propose suggestions to fix these problems (Willis *et al.*, 2002). This is a relatively quick and inexpensive method for evaluating questionnaires because experts can identify many potential problems and they can overcome the "operational blindness" of questionnaire designers. However, the ratings of different experts are often inconsistent with each other, perhaps due to unsystematic and subjective approach, experience, or invested time. In addition, this method can be considered only as a supplement, not a substitution of the empirical pretesting methods.

Otherwise, there is the question appraisal system that is an instrument that helps evaluators to systematically review survey questions and to identify potential question problems. Question appraisal systems are only used for evaluating individual survey questions and not the questionnaire.

An example is the application of **QAS 2004 (Dean et al., 2004)** in which each question is reviewed individually and the user examines the questions by considering specific categories of question characteristics in a step-wise fashion. At each step, the user decides whether the question exhibits a feature or features that are likely to cause problems, trying to modify and improve the questions.

Behavior Coding (Ongena and Dijkstra, 2006) concerns the systematic assignment of codes to the overt behavior of interviewer and respondent in survey interviews. The method was developed by Charles Cannell and his colleagues at the University of Michigan in the 1970s. Behavior coding is a major tool used to evaluate interviewer performance and questionnaire design. Behavior coding is sometimes referred to as "interaction analysis," although interaction analysis is usually more specifically used in the sense of applying behavior coding to study the course of the interaction between interviewer and respondent.

The three main uses of behavior coding are:

1. evaluating interviewer performance,
2. pretesting questionnaires, and
3. studying the course of the interaction between interviewer and respondent to identify problematic questionnaire aspects.

Analyzing the interactions between interviewer and respondents, it is possible to say that there are some issues in the survey when the respondent:

1. **Interrupts** question reading
2. Asks for **clarification** of question
3. Gives answer **qualified** about accuracy
4. Gives answer **inadequate** for question
5. Answers "**don't know**"
6. **Refuses** to answer

The behavior coding it is able to analyze only the observable problems, to understand how frequently there was a problem, but not necessarily why. So, it is more used to check if the survey can be conducted in the expected way.

Focus Group refers to a small group discussions carried out under the guidance of a moderator which can be used to explore and develop topics and items for questions. They are often used in qualitative research to test survey questionnaires and survey protocols (Morgan, 1993). One advantage of using focus group rather than individual interviews is that greater amounts of information can be gathered in shorter and more efficient time spans. Also, the group synergy fosters more creativity and therefore provides for a greater range of thought, ideas, and experiences (Gerger Swartling, 2007).

Cognitive Interviewing - In an ideal survey, each respondent interprets the question in the way we intended. But in reality, survey questions are misunderstood. Participants may find the answers hard to recall, difficult to estimate, and struggle to map their answer to the choices we provide. The cognitive interview (Willis, 2013) provides a useful method to evaluate survey questions and remove these problems. The cognitive interview is a technique for pilot testing the questions on surveys. Interviews are typically run as 1-1 interviews with a handful of volunteers. As with any pilot test, participants reply the questions on the survey but their answers are not important. With a cognitive interview, the focus is in how participants arrived at their answers. In some ways, a cognitive interview is similar to a usability test: participants are asked to “think aloud” as they try to answer the question.

There are three main cognitive pretesting techniques:

2. *Probing* - A technique that uses follow-up (or probing) questions administered either immediately after the subject provided an answer or at the end of the interview. The goal is to gather specific information about subjects’ understanding of key terms, questions or answer categories and about the processes by which they arrived at their answers. There are two ways to gather that, one is the concurrent technique where for each question the interviewer asks a probing question, other is the retrospective technique where the probing questions are asked only after all questions.
3. *Think Aloud* - Subjects are asked not only to answer a question but also to vocalize all thoughts that lead to their answer. The goal is to uncover the processes that the subject uses in arriving at an answer. Easy to implement, interviewers’ influence is reduced, but most respondents, especially ones without higher education, find thinking aloud difficult and many are not capable of vocalizing the cognitive processes that led to their answer.
4. *Paraphrasing* - After answering a question, respondents are asked to repeat the question text in their own words. Paraphrasing provides information about how respondents understand a question and whether their interpretation is the same as the one intended by the researcher, thus some information about question comprehension.

Usability Testing - Surveys are not always make face-to-face; indeed, the use of tablet, phone and notebook is a common aspect. Thus, it is necessary to perform usability testing (Presser and Blair, 1994) in order to check if surveys fit well on the technological tool intended for use.

This means that the surveys have to be designed ad hoc for cell phones and tablets with different layouts. The participants are then asked to fill them out freely while the interviewers analyze them and take notes on what they find erroneous. In this way, it is possible to reduce further errors while the participants fill out the questionnaire during the experiment.

3.6 Missing Data or Non-response errors

Even if attempts are made to design the best questionnaires, errors can occur during data collection, for example, when data are missing.

In statistics, missing data, or missing values, occur when no data value is stored for the variable in an observation. Missing data are a common occurrence and can have a significant effect on the conclusions that can be drawn from the data.

Missing data can occur because of nonresponse: no information is provided for one or more items or for a whole unit ("subject"). Some items are more likely to generate a nonresponse than others: for example, items about private topics such as income. Attrition is a type of missingness that can occur in longitudinal studies, for instance studying development where a measurement is repeated after a certain period of time. Missingness occurs when participants drop out before the test ends and one or more measurements are missing.

Data often are missing in research in economics, sociology, and political science because governments or private entities choose not to, or fail to, report critical statistics, or because the information is not available. Sometimes missing values are caused by the researcher, for example, when data collection is done improperly or mistakes are made in data entry.

There are three different types of missingness, with different impacts on the validity of conclusions from research: Missing completely at random, missing at random, and missing not at random. Missing data can be handled in a similar manner as censored data.

Understanding the reasons why data are missing is important for handling the remaining data correctly. If values are missing completely at random, the data sample is likely still representative of the population. However, if the values are missing systematically, analysis may be biased. For example, in an ergonomic study that concerns the healthy user group, if participants with an above-average age tend to skip the question "Which is your level of health?", analyses that do not consider this missing at random (MAR pattern) may falsely fail to find a positive association between age and health. Because of these problems, methodologists routinely advise researchers to design studies to minimize the occurrence of missing values. Graphical models can be used to describe the missing data mechanism in detail, for example in the free software R[5] there is the VIM[6] package (Kowarik and Templ, 2016) in which frequencies, combinations, the sorting and the distribution can be analyzed.

Thus, missing data can occur in many situations:

- Unit-nonresponse
- Item-nonresponse
- Data fusion
- Split questionnaire survey design
- Synthetic data

The goal of the statistical analysis of missing data is to make valid and efficient inference about population parameters from an incomplete dataset.

[5] R is a free software environment for statistical computing and graphics.

[6] VIM = Visualization and Imputation of Missing Values

This means we have to model the data generating process as closely as possible and we have to incorporate extra uncertainty caused by (originally) non-observed data. Furthermore, with the statistical analysis of missing data is not possible to predict missing values as precisely as possible.

3.6.1 Type of Missing Data

Furthermore, values in a data set are **missing completely at random (MCAR)** if the events that lead to any particular data-item being missing are independent both of observable variables and of unobservable parameters of interest, and occur entirely at random. It means, the propensity for a data point to be missing is completely random. There is no relationship between whether a data point is missing and any values in the data set, missing or observed. When data are MCAR, the analysis performed on the data is unbiased; however, data are rarely MCAR.

In the case of MCAR, the missingness of data is unrelated to any study variable: thus, the participants with completely observed data are in effect a random sample of all the participants assigned a particular intervention. Indeed, the missing data are just a random subset of the data. With MCAR, the random assignment of treatments is assumed to be preserved, but that is usually an unrealistically strong assumption in practice.

Missing at random (MAR) occurs when the missingness is not random, but where missingness can be fully accounted for by variables where there is complete information. It means, the propensity for a data point to be missing is not related to the missing data, but it is related to some of the observed data. Whether someone answered #13 on the survey has nothing to do with the missing values, but it does have to do with the values of some other variable. Since MAR is an assumption that is impossible to verify statistically, we must rely on its substantive reasonableness. An example is that males are less likely to fill in a depression survey but this has nothing to do with their level of depression, after accounting for maleness. Depending on the analysis method, these data can still induce parameter bias in analyses due to the contingent emptiness of cells (male, very high depression may have zero entries). However, if the parameter is estimated with Full Information Maximum Likelihood, MAR will provide asymptotically unbiased estimates. Under MAR, we can obtain correct likelihood/Bayes inferences about population parameters without modeling the missingness (Imbens and Rubin, 2010).

Missing not at random (MNAR) (also known as non-ignorable nonresponse) is data that is neither MAR nor MCAR (i.e. the value of the variable that’s missing is related to the reason it is missing). To extend the previous example, this would occur if men failed to fill in a depression survey *because* of their level of depression.

Missing data reduces the representativeness of the sample and can therefore distort inferences about the population.

3.6.2 Solutions

To overcome the problem of incomplete data, there are several analysis techniques, for instance, methods which use only the available or the complete cases; or weighting in general to adjust for Unit-Non-Response or "Oversampling"; or Likelihood-based parameter estimation (e.g. via Expectation Maximization-algorithm of Dempster); or single imputation (without or with adjustment of the variance estimators); or Multiple Imputation Method according to Rubin.

Thus, generally speaking, there are three main approaches to handle missing data:

1. *Imputation*: where values are filled in the place of missing data;
2. *Omission*: where samples with invalid data are discarded from further analysis and;
3. *Analysis*: by directly applying methods unaffected by the missing values.

In some practical application, the experimenters can control the level of missingness, and prevent missing values before gathering the data. For example, in computer questionnaires, it is often not possible to skip a question. A question has to be answered, otherwise one cannot continue to the next. So, missing values due to the participant are eliminated by this type of questionnaire, though this method may not be permitted by an ethics board overseeing the research. In survey research, it is common to make multiple efforts to contact each individual in the sample, often sending emails to attempt to persuade those who have decided not to participate to change their minds. However, such techniques can either help or hurt in terms of reducing the negative inferential effects of missing data, because the kind of people who are willing to be persuaded to participate after initially refusing or not being available are likely to be significantly different from the kinds of people who will still refuse or remain unreachable after additional effort.

In situations in which missing values are likely to occur, the researcher is often advised on planning to use methods of data analysis methods that are robust to missingness. An analysis is robust when we are confident that mild to moderate violations of the technique's key assumptions will produce little or no bias, or distortion in the conclusions drawn about the population.

3.6.2.1 Imputation

Some data analysis techniques are not robust to missingness, and require to "fill in", or impute the missing data. Rubin (1987) argued that repeating imputation even a few times (5 or less) enormously improves the quality of estimation. For many practical purposes, 2 or 3 imputations capture most of the relative efficiency that could be captured with a larger number of imputations. However, a too-small number of imputations can lead to a substantial loss of statistical power, and some scholars now recommend 20 to 100 or more. Any multiply-imputed data analysis must be repeated for each of the imputed data sets and, in some cases, the relevant statistics must be combined in a relatively complicated way.

The expectation-maximization algorithm is an approach in which values of the statistics which would be computed if a complete dataset were available are estimated (imputed), taking into account the pattern of missing data. In this approach, values for individual missing data-items are not usually imputed.

3.6.2.2 Interpolation (example: bilinear interpolation)

In the mathematical field of numerical analysis, interpolation is a method of constructing new data points within the range of a discrete set of known data points.

In the comparison of two paired samples with missing data, a test statistic that uses all available data without the need for imputation is the partially overlapping samples t-test. This is valid under normality and assuming MCAR.

Several predictors of the variable with missing values are identified using a correlation matrix. The best predictors are selected and used as independent variables in a regression equation. The variable with missing data is used as the dependent variable. Cases with complete data for the predictor variables are used to generate the regression equation; the equation is then used to predict missing values for incomplete cases. In an iterative process, values for the missing variable are inserted and then all cases are used to predict the dependent variable. These steps are repeated until there is little difference between the predicted values from one step to the next, that is they converge.

It “theoretically” provides good estimates for missing values. However, there are several disadvantages of this model which tend to outweigh the advantages. First, because the replaced values were predicted from other variables they tend to fit together “too well” and so standard error is deflated. One must also assume that there is a linear relationship between the variables used in the regression equation when there may not be one.

3.6.2.3 Multiple Imputation

Multiple imputation is a general approach to the problem of missing data that is available in several commonly used statistical packages. It aims to allow for the uncertainty about the missing data by creating several different plausible imputed data sets and appropriately combining results obtained from each of them. Multiple imputation is necessary when we need to analyze confidence intervals, the hypothesis testing, the model uncertainty, it is, to analyze the Inferential Statistics. However, it is useless where descriptive statistics are to be applied.

The first stage is to create multiple copies of the dataset, with the missing values replaced by imputed values. These are sampled from their predictive distribution based on the observed data—thus multiple imputation is based on a Bayesian approach. The imputation procedure must fully account for all uncertainty in predicting the missing values by injecting appropriate variability into the multiple imputed values; we can never know the true values of the missing data.

The second stage is to use standard statistical methods to fit the model of interest to each of the imputed datasets. Estimated associations in each of the imputed datasets will differ because of the variation introduced in the imputation of the missing values, and they are only useful when averaged together to give overall estimated associations. Standard errors are calculated using Rubin's rules, which take account of the variability in results between the imputed datasets, reflecting the uncertainty associated with the missing values. Valid inferences are obtained because we are averaging over the distribution of the missing data given the observed data.

Consider, for example, a study investigating the association of pressure with the risk of lumbar pain, in which data on pressure are missing for some people. If data are assumed to be missing at random and the pressure data are on a representative sample of individuals within strata of age, height, and weight, then multiple imputation can be used to estimate the overall association between pressure and the perception of lumbar pain.

Multiple imputation has potential to improve the validity of ergonomics and comfort research. However, the multiple imputation procedure requires the researcher to model the distribution of each variable with missing values, in terms of the observed data. The validity of results from multiple imputation depends on such modelling being done carefully and appropriately. Multiple imputation should not be regarded as a routine technique to be applied at the push of a button—whenever possible specialist statistical help should be obtained.

Many multiple imputation procedures assume that data is normally distributed, so including non-normally distributed variables may introduce bias. For example, if a biomechanical factor had a highly-skewed distribution but was implicitly assumed to be normally distributed, then imputation procedures could produce some implausibly low or even negative values. A pragmatic approach here is to transform such variables to approximate normality before imputation and then transform the imputed values back to the original scale. Different problems arise when data are missing in binary or categorical variables. Some procedures may handle these types of missing data better than others, and this area requires further research.

Some data are inherently missing not at random because it is not possible to account for systematic differences between the missing values and the observed values using the observed data. In such cases, multiple imputation may give misleading results. For example, consider a study investigating predictors of depression. If individuals are more likely to miss appointments because they are depressed on the day of the appointment, then it may be impossible to make the missing at random assumption plausible, even if a large number of variables is included in the imputation model. When data are missing not at random, bias in analyses based on multiple imputation may be as big as or bigger than the bias in analyses of complete cases. Unfortunately, it is impossible to determine from the data how large a problem this may be. It is the responsibility of the data analyst to consider all possible reasons for missing data and to assess the likelihood that non-random missing data is a serious problem.

Multiple imputation is computationally intensive and involves approximations. Some algorithms need to be run repeatedly in order to yield adequate results, and the required run length increases when more data are missing. Unforeseen difficulties may arise when the algorithms are run in settings different from those in which they were developed—for example, with high proportions of missing data, very large numbers of variables, or small numbers of observations.

4 Objective data

After explaining the concept of "subjective data" previously, this chapter focuses on the concept of "objective data", expanding the conceptual map (Figure 4-1). The subjective and objective data need mutual scientific support to explain the subjective perception of (dis)comfort.

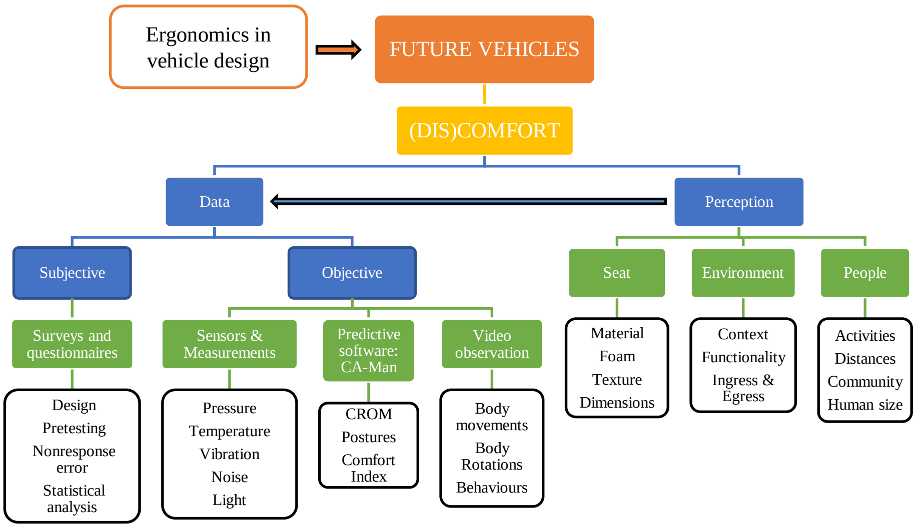


Figure 4-1: *PhD dissertation conceptual map - concepts explained in the Fourth chapter*

4.1 Definition of objective data

In the field of Ergonomics and Human Factors, objective data are required to detect and analyze the interactions between human and study object that could be a virtual/physical prototype, an environment, a situation or a context. Since perceptions are personal feelings, objective and subjective data are preferred as a mutual support, accomplishing the limits of one with the other. For instance, the discomfort perception emerged from subjective data can be supported or explained with the objective data analysis, such as peak of pressures, thermal excursions or awkward postures. Vice versa, results emerged from objective data can be confirmed by subjective data. The statistical analysis can also support their mutual relationship.

The objective analysis considered in this PhD dissertation to evaluate (dis)comfort perceptions can be structured in three macro areas:

Video/photo observations for postural analysis: achieving postural analysis is useful to study human behavior, postural comfort and reachability. Postural tracking methods (Fiorillo, Nasti, *et al.*, 2021; Fiorillo, Piro, *et al.*, 2019b, 2019a) are a direct method to acquire angles from photos and videos, as reported in this PhD dissertation (see para. 4.2).

Tools to predict postural (dis)comfort: since postural (dis)comfort was deeply studied, the software CA-Man (Ch. 4.2) was developed by Alessandro Naddeo and Nicola Cappetti from University of Salerno to predict postural (dis)comfort knowing the postural angles (Cappetti *et al.*, 2020; Cecco *et al.*, 2019; Naddeo, Cannavacciuolo, *et al.*, 2018; Naddeo, D'Ambrosio, *et al.*, 2018; Trapanese *et al.*, 2016; Vallone *et al.*, 2015). Examples are also explained in the conference proceedings (see para. 4.4)

Sensors data analysis: devices that respond to a physical stimulus (such as heat/thermal perception (Califano *et al.*, 2017; Cui *et al.*, 2016; Rosaria *et al.*, 2020), light/visual comfort (Korsavi *et al.*, 2016; Md Tamrin *et al.*, 2013), sound/acoustic comfort (Steg, 2003; Zannin and Marcon, 2007), pressure (De Looze, Kuijt-Evers, Lottie, *et al.*, 2003; Wang *et al.*, 2020), or vibrations/motion (Bretz *et al.*, 2009; Dong *et al.*, 2019; Lis *et al.*, 2007; Mansfield *et al.*, 2015)) and transmits a resulting impulse (as for measurement or operating a control). In this PhD dissertation, pressure measurement method on seats is focused and explained in detail in Ch.5.

4.2 Photo and video observation

In this paragraph are described two main instrument used as photo (Kinovea) and video (ArUco markers) acquisition method in experiments described in para. 4.2.

Kinovea® is a free 2D motion analysis software that can be used to measure kinematic parameters. This low-cost technology was used in sports sciences, as well as in the clinical and research fields. However, the angles need to be detected manually (with the help of anatomical landmarks or stickers on human body) and sometimes could be the cause of time-consumption and manual errors. These limitations can be overcame using the tracking method with ArUco markers (Fiorillo, Piro, *et al.*, 2019a; Mondéjar-Guerra *et al.*, 2018; Zubair *et al.*, 2017).

Before to start recording videos for the experiment, calibration of cameras was needed in order to obtain correct values of coordinates referenced to camera coordinate system.

Camera calibration is the determination of the calibrated focal length, the location of principal point with respect to the fiducial markers and the lens distortion effective in the focal plane of the camera referred to the particular calibrated focal length. Camera calibration and the evaluation of high-quality interior orientation parameters is a major topic in vision research such photogrammetry or marker detection. Photogrammetry is the science of making measurements from photographs, especially for acquiring the exact positions of surface points. The use of the highest possible resolution for photogrammetric purposes is recommended (Balletti *et al.*, 2014). A calibration procedure using a chessboard pattern and OpenCV algorithms are applied in order to generate distortion-free images. Detecting and tracking markers is a useful process in augmented reality. This technique gives augmented reality applications a simple way to estimate the position and orientation, in 3-space, of an object in a video stream. Several projects used one method of detecting and tracking the so-called "fiducial markers" in a video, using the OpenCV computer vision library.

Geometric camera calibration, also referred to as **camera re-sectioning**, estimates the parameters of a lens and image sensor of an image or video camera. These parameters are used to correct for lens distortion, measure the size of an object in world units, or determine the location of the camera in the scene. These tasks are used in applications such as machine vision to detect and measure objects. They are also used in robotics, for navigation systems, and 3-D scene reconstruction.

Two major distortions are radial distortion and tangential distortion.

Radial distortion (Figure 4-2) occurs when light rays bend more near the edges of a lens than they do at its optical center. The smaller the lens, the greater the distortion. Thus, due to radial distortion, straight lines will appear curved. Its effect is more visible moving away from the center of image.

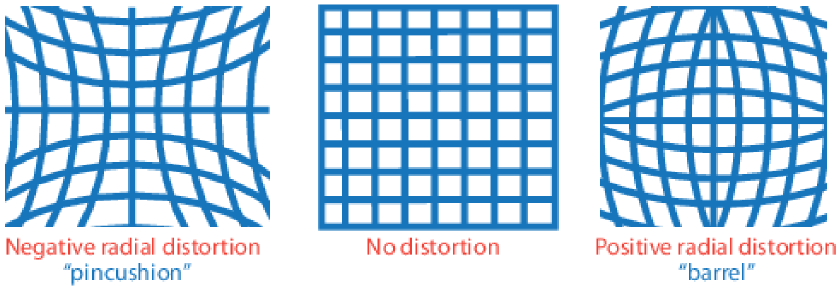


Figure 4-2: *Radial distortion*

Tangential distortion (Figure 4-3) occurs when the lens and the image plane are not parallel. So, in some areas in image may look nearer than expected. The tangential distortion coefficients model this type of distortion.

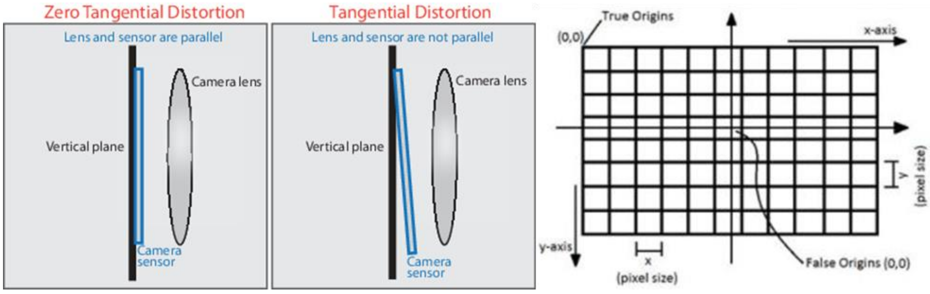


Figure 4-3*: Tangential distortion*

To correct these distortions and have a correspondence between the 3D real space and the 2D image space, some sample images of a well-defined pattern, e.g. chessboard, are required. Knowing its coordinates in real world space and its coordinates in image, it is possible to solve some mathematical problem in background to get the distortion coefficients with these data.

To gain better results, at least 10 test patterns are needed for camera calibration. Considering an image of a chessboard, important input data needed for camera calibration is a set of 3D real world points and its corresponding 2D image points, that were easily found from the images. Thus, these image points are locations where two black squares touch each other in chessboards.

3D points are called "object points" and 2D image points are called "image points".

4.2.1 Calibration with chessboard & Python language

Calibration had been done with Python language. **Python** is an interpreted high-level programming language for general-purpose programming. The interpreted language means that the written code is not actually translated to a computer-readable format at runtime. Whereas most programming languages do this conversion before the program is even run. This type of language is also referred to as a "scripting language" because it was initially meant to be used for trivial projects. The term general-purpose programming language is another way to say that it can be used for nearly everything. Additionally, Python supports the use of modules and packages, which means that programs can be designed in a modular style and code can be reused across a variety of projects. Once a needed module or package were developed, it can be scaled for use in other projects, and it is easy to import or export these modules. One of benefits of Python is that both the standard library and the interpreter are available free of charge, in both binary and source form. There is no exclusivity either, as Python and all necessary tools are available on all major platforms.

To use Python language, the **Spyder** software had been downloaded. Spyder is an open source cross-platform integrated development environment (IDE) for scientific programming in the Python language with advanced editing, interactive testing, debugging and introspection features, and a numerical computing environment thanks to the support of IPython (enhanced interactive Python interpreter) and popular Python libraries such as NumPy (linear algebra), SciPy (signal and image processing) or matplotLib (interactive 2D/3D plotting).

A **7x10 squares chessboard** for calibration was used ("Open CV: calibration", 2015). Once placed the Go-Pro in their place, assuring that the human movements will be inside the field of view, all the movements of chessboard inside that field of view had been recorded. Then, each frame of videos had been saved such as images (format JPG), because to do calibration images are needed, of which only one hundred useful photos had been selected for each video-camera. In the selection, it was made sure that the chessboard was in all corners and at all distances.

4.2.1.1 ArUco markers detection and Python codes

Once defined the video-cameras setting and done the calibration, the next step had been to test marker detection algorithm for the pose estimation. The specific task of determining the pose of an object in an image is referred as **pose estimation**. The pose estimation problem can be solved in different ways depending on the image sensor configuration, and choice of methodology. The method used in this experiment is the analytic or geometric one. Given that the image sensor (camera) is calibrated, the mapping from 3D points in the scene and 2D points in the image is known. If also the geometry of the object is known, it means that the projected image of the object on the camera image is a well-known function of the object's pose. Once a set of control points on the object, typically corners or other feature points, was identified, it is then possible to solve the pose transformation from a set of equations which relate the 3D coordinates of the points with their 2D image coordinates. Algorithms that determine the pose of a point cloud with respect to another point cloud are known as point set registration algorithms. This is usually a difficult step, and thus it is common the use of synthetic or fiducial markers to make it easier.

One of the most popular approach is the use of binary square fiducial markers. To detect body movements, **ArUco markers** (OpenCV, 2015a) had been used. The main benefit of these markers is that a single marker provides enough correspondences (its four corners) to obtain the camera pose. In addition, the inner binary codification makes them especially robust, allowing the possibility of applying error detection and correction techniques. The ArUco module is based on the "ArUco library", a popular library for detection of square fiducial markers developed by Rafael Muñoz and Sergio Garrido (Ferrão *et al.*, 2018; Mondéjar-Guerra *et al.*, 2018). An ArUco marker is a synthetic square marker composed by a wide black border and an inner binary matrix that determines its identifier (id). The black border facilitates its fast detection in the image and the binary codification allows its identification and the application of error detection and correction techniques. The marker size determines the size of the internal matrix. For instance, a marker size of 4x4 is composed by 16 bits. The Figure 4-4 shows some examples of ArUco markers:

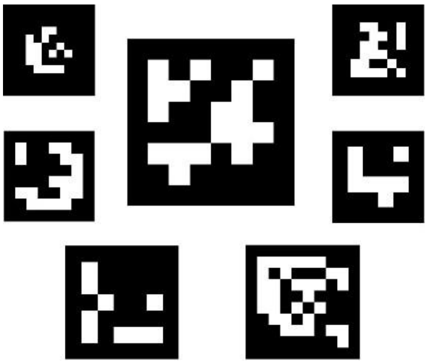


Figure 4-4*:Examples of ArUco markers*

It must be noted that a marker can be found rotated in the environment, however, the detection process needs to be able to determine its original rotation, so that each corner is identified unequivocally. This is also done based on the binary codification. A dictionary of markers is a set of markers that are considered in a specific application. It is simply the list of binary codifications of each of its markers. The main properties of a dictionary are the dictionary size and the marker size.

- The dictionary size is the number of markers that composed the dictionary.
- The marker size is the size of those markers (the number of bits).

The ArUco module includes some predefined dictionaries covering a range of different dictionary sizes and marker sizes. One may think that the marker id is the number obtained from converting the binary codification to a decimal base number. However, this is not possible since for high marker sizes, the number of bits is too high and managing so huge numbers is not practical. Instead, a "marker id" is simply a number that represent the marker index inside the dictionary it belongs to. For instance, the first 5 markers inside a dictionary has the ids: 0, 1, 2, 3 and 4. Having already the ArUco dictionary, each marker had been detected before the experiment to know the ids of head's and shoulders' markers. Only once checked if the marker detection code was working well, the experiment was done. Given an image where ArUco markers are visible, the **detection process** has to return a list of detected markers. Each detected marker includes:

- The position of its four corners in the image (in their original order).

- The id of the marker.

The marker detection process is comprised by two main steps:

1. **Detection of marker candidates**. In this step, the image is analyzed in order to find square shapes that are candidates to be markers. It begins with an adaptive thresholding to segment the markers, then contours are extracted from the threshold image and those that are not convex or do not approximate to a square shape are discarded. Some extras filtering is also applied (removing too small or too big contours, removing contours too close to each other, etc.).
2. **Cleaning**. After the candidate detection, it is necessary to determine if they are actually markers by analyzing their inner codification. This step starts by extracting the marker bits of each marker. To do so, first, perspective transformation is applied to obtain the marker in its canonical form. Then, the canonical image is segmented using Otsu method to separate white and black bits. The image is divided in different cells according to the marker size and the border size and the amount of black or white pixels on each cell is counted to determine if it is a white or a black bit. Finally, the bits are analyzed to determine if the marker belongs to the specific dictionary and error correction techniques are employed when necessary.

The Figure 4-5 is an example of marker detection algorithm. The marker coordinate system is placed at the center of the marker with the Z axis pointing out, as in Figure 4-5. Axis-color correspondences are X=red, Y=green, Z=blue.

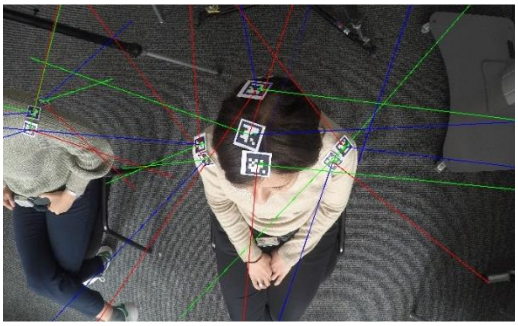


Figure 4-5*: Example of marker detection.*

4.3 Applications of Photo/Video observation methods

In following pages are shown 3 papers as applications of photo/video observation methods, combining postural analysis and social distancing:

- Paper No. 1: Towards Comfortable Communication in Future Vehicles (Postural analysis & Communication)

- Paper No. 2: Future vehicles: the effect of seat configuration on posture and quality of conversation (Postural analysis & Quality of conversation)
- Paper No. 3: Design for comfort and social interaction in future vehicles: a study on the leg space between facing-seats configuration (Postural analysis & Social distancing)

Paper No .1 – Published on March 2019 in the Journal Applied Ergonomics

Towards Comfortable Communication in Future Vehicles

Silvana Piro, Iolanda Fiorillo, Shabila Anjani, Maxim Smulders, Alessandro Naddeo, Peter Vink

Abstract This research aims to study the effect of seat and/or backrest rotation on comfort and quality of conversation. Different sitting arrangements were tested to study the effect of the seat layout on: 1) (dis)comfort experience; 2) conversation quality and 3) postures. Two seats were arranged in different angles (0°, 45°, 90°, and 180°) at the same distance (1 meter) and participants were asked to talk to each other. The participants' postures were acquired by using cameras and markers on the participants' body. Questionnaires were used to rate the perceived (dis)comfort and quality of conversation. Results show that 90° configuration scored the best both in overall comfort and quality of conversation; while the 0° configuration scored the lowest in both ratings. A strong correlation was established between high comfort and good quality of conversation.

Keywords: Comfort; Communication; Sitting arrangement, Quality of Conversation

Introduction

While travelling in trains, aeroplanes or future autonomous driving cars passengers perform various activities. The most mentioned are sleeping, listening to music, reading, talking and doing nothing (Groenesteijn *et al.*, 2014; Kamp *et al.*, 2011; Lille *et al.*, 2016; M. Greghi *et al.*, 2012). There are indications that the trend for travelling in groups is rising. In 2017 more than 28% of the passengers at Schiphol airport travelled with more than one accompanying passenger (Homburg, 2017). Young people are the driver of this trend, as millennials (born 1980s-2000s) are found to be more keen on social interaction than older business travellers ("CWT Connected Traveler Study", 2017): 58% of millennials prefer to travel with others, in contrast, only 29% of the Baby Boomers (born 1940s-1960s) prefer to travel in groups. This implies that the need for conversation during travel will probably increase. However, it is often hard to interact with anyone in the plane or in the car, even though some vehicles, such as autonomous driving cars, already allow their passengers to have more time for conversation (Lille *et al.*, 2016). Furthermore, improving aircraft passenger's comfort requires knowledge about their perception and eliciting conditions (Ahmadpour *et al.*, 2014).

This paper focuses on the comfortable communication model (Dumur *et al.*, 2004) where comfort means that passengers can behave socially, that people travelling together can talk to each other, and can interact with their neighbours in a comfortable way, so they can have the sensation that all passengers form a group sharing a common experience.

During a social interaction, people surround themselves with a bubble of defined and organized space, which is internalized at an unconscious level (Hall, 1966). Respecting this space could improve the comfort during a social interaction. There were studies on the distances between standing persons to facilitate communication. Hall (Hall, 1966) stated there are four interpersonal distances important in social interactions (Figure 4-6): intimate (from 0 to 45cm) reserved for lovers, pets and family's members; personal (from 45 cm to 1.2 m) reserved for friends; social (from 1.2m to 3.7m) reserved for strangers and newly formed group; and public (from 3.7m to 7.6m) for a large audience.

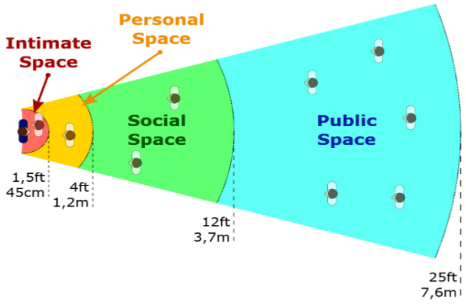


Figure 4-6: *Four interpersonal distances during social interaction according to Hall, 1966*

In addition, Sommer (Sommer, 1962) found that, during a social interaction, opposite seats are preferred to the side-by-side sitting at smaller distances. Concerning the interpersonal communication that is the communication between one person and another (or others), both verbal and nonverbal communication, or body language, play a part in how one person understands another. The aim of this work is not to analyse the quality of communication, but the people's perceived discomfort while they are engaged in a conversation in a tested configuration, thus through the conversation quality and postures analysis.

However, for the design of autonomous car and aircraft interiors information on seated positions for social interactions is needed. A study from Nguyen (Nguyen, 2016) indicated that the best sitting arrangement for communication and comfort was a L-shaped configuration. In most vehicles, passengers sit aside and should turn their eyes, heads, shoulders, torso or whole body to be engaged in the conversation (Groenesteijn *et al.*, 2014). However, rotating the body too much – especially for a prolonged amount of time – could cause discomfort. Regarding the neck, Naddeo (Naddeo, Cappetti and D'Oria, 2015a) showed that the comfortable range of the head rotation is limited (Figure 4-7).

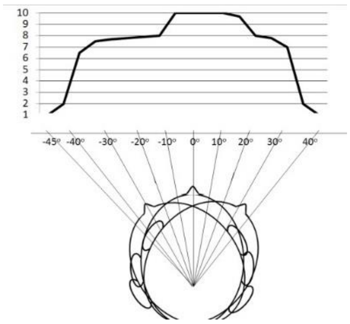


Figure 4-7: *Comfort scores for different head rotations on a scale from 1-10 (10 is most comfortable) (Naddeo, 2017)*

As concluded by Helander and Zhang (Helander and Zhang, 1997; Zhang *et al.*, 1996), sitting discomfort and comfort are based on different factors. Feelings of discomfort are associated with pain, tiredness, soreness and numbness, where comfort is associated with feelings of relaxation and well-being.

Different studies (Andreoni *et al.*, 2001; Christensen and Nilsson, 1999) show that the most comfortable position corresponds to the neutral position of the joints or resting body, called Rest Posture. In the Rest Posture human muscles are relaxed or at minimum strain level, that minimizes muscle activity, strain in the ligaments and optimizes the comfort perception (Galinsky *et al.*, 2000). It would be ideal if seats and/or backrests could rotate to facilitate the conversation and to ensure the highest comfort.

Despite this background, there is no research regarding the (dis)comfort and quality of conversation while sitting in different angles towards each other. Therefore, the aim of this study is to find the best configuration to improve the quality of conversation, improve postural comfort and reduce discomfort. The output of this research could be a basis for designing autonomous car, train and aircraft interiors.

The research question is: *What is the effect of seat layout on: 1) (dis)comfort experience; 2) conversation quality and 3) postures?*

Method

To answer this research question, the effect of four different sitting arrangements on quality of conversation, perceived (dis)comfort and taken posture was studied. For each sitting arrangement, two seats were placed in different angles (0°, 45°, 90°, and 180°) to each other at a distance of 1 meter, that is in the personal space suitable for friends during social interaction (Hall, 1966). This distance was set up considering the centre of each seat as a reference point (Figure 4-8).

The experiment was done in a classroom at Delft University of Technology where 18 office chairs were set up using rulers, measuring tapes, goniometers and markers on the floor. The room was divided into 4 zones; each representing a configuration (0°, 45°, 90° and 180°).

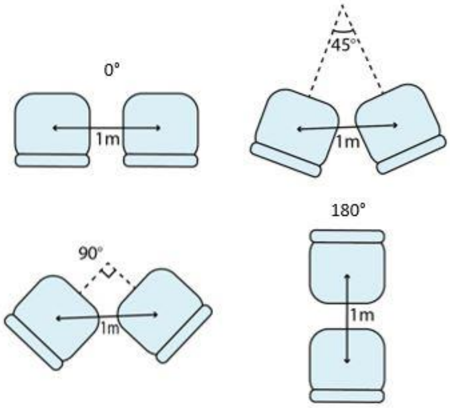


Figure 4-8*: Seating arrangements examined*

Thirty-six healthy participants, randomly recruited among students of TU Delft, 14 females and 22 males, took part in this study. Table 4-1 represents the demographic data of the participants.

Table 4-1: *Demographics of the samples (n=36)*

	Range	Mean	SD
Age (years)	21-28	22,86	1,74
Height (cm)	160-195	177,10	9,53
Weight (kg)	53-110	71,08	11,49

All participants belong to the millennial age group ("CWT Connected Traveler Study", 2017). It is assumed that the participants in this test are categorized as acquaintances, since most knew each other before the experiment.

The participants were divided in 9 groups of 4 persons. Of each group two were sitting-participants and the other two were observers, switching roles after each session. The order of the experiment was determined using a Latin square scheme (Fisher, 1992) to minimize the order effect.

During the experiment, the observers took pictures from three different views (top view, lateral view and frontal view) at three different moments in the experiment (start, middle and end) to capture information about postural angles. The pictures were analyzed through Kinovea® software to collect postural angles.

Protocol

Each subject was given a written experiment protocol and asked to sign an informed consent prior to the experiment. After that, the instructions of the experiment were explained and the participants were divided into groups of 4 persons. In each group two people were asked to sit for 10 minutes and talk about a given topic previously discussed in the classroom:

- the paper of Molenbroek (Molenbroek *et al.*, 2017)
- chapter 4 of the book "Aircraft interior comfort and design" (Vink and Brauer, 2011)

The given topic was meant to make the sitting-participants feel at ease in having the conversation (Sommer, 1962). At the end of the 10-minute conversation, the participants were asked to complete the questionnaire on the (dis)comfort and quality of conversation.

The two observers watched the sitting participants and took pictures (at the beginning, minute 4:30 until 5, and minute 9:30 until 10). The pictures were taken from the front-, side-, and top-view of each person. At the end of the 10-minute conversation, the observer rated the overall comfort and quality of conversation of the sitting participant. After 15 minutes (10 minutes in a seats configuration and 5 minutes to complete the questionnaire) each participant in each group changed his/her role from sitting to observer and vice versa. After 30 minutes, each group went to a different sitting configuration. Figure 4-9 shows the protocol of the experiment in a timeline.

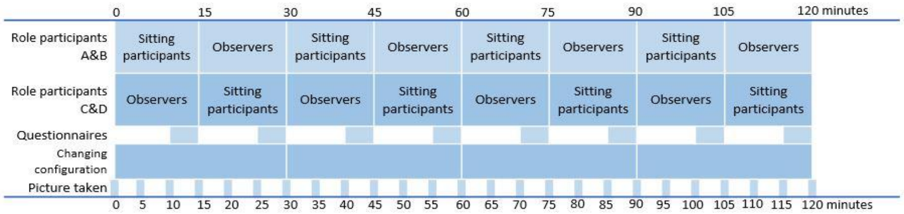


Figure 4-9: *Protocol of experiment plotted along the time axis*

Questionnaire

Questionnaires were used to evaluate each sitting arrangement (see Appendix). Each sitting participant was asked to rate the Localized Postural Discomfort (LPD) for their upper-body (eyes, neck, shoulder, trunk, lumbar spine, pelvic). A 7-point Likert scale was used to assess this discomfort (1 = No discomfort and 7 = Extremely discomfortable). The LPD instrument (Grinten, 1992) was meant to help the participant in answering during the experiment. The visual map helps to focus on the various body regions and the 7-point scale helps to give an immediate response, without losing the discomfort perception. Several authors, such as Hiemstra-van Mastrigt, Bouwens and Van Veen (Bouwens *et al.*, 2018; Hiemstra-van Mastrigt, 2015; Hiemstra-van Mastrigt *et al.*, 2015; Hiemstra-van Mastrigt, Meyenborg, *et al.*, 2016; Lille *et al.*, 2016; Van Veen *et al.*, 2015), used the LPD questionnaire to analyze discomfort perception.

To evaluate the quality of conversation, four questions (Figure 13-7) were included using a seven-point Likert scale (Joshi *et al.*, 2015) (from 1 =

Extremely Disagree to 7 = Extremely Agree). Those questions were meant to get an idea about the participants' feelings during the social interaction in a specific configuration, focusing on if they felt at ease or not. An appropriate questionnaire model for this case had not been found in the literature.

Participants also had to give an overall rating for comfort (10-scale: 1 = No comfort and 10 = Extremely comfortable) and for quality of conversation (10-scale: 1 = Very bad and 10 = Very Good) for each configuration. At the end of the experiment, after experiencing all configurations, each participant was asked to choose which configuration they preferred, both for overall comfort and quality of conversation, and they were asked to add an argument for the choice. Additionally, the observers were also asked to rate their impression of the overall comfort and the quality of conversation with a 10-point scale, to see whether people outside the conversation could correctly rate the comfort and conversation quality.

Analysis

Comfort and discomfort analysis

All questionnaire data and results from analyzing the pictures were gathered and analyzed using IBM® SPSS® Statistics version 24. A Wilcoxon signed ranked test was performed to compare results of the questionnaire for each participant and for each configuration. It was useful to understand if participants answered properly for each configuration. In this case, Wilcoxon is used to analyse comfort and discomfort as discomfort may be not normally distributed (Groenesteijn, 2015). With the Wilcoxon test the significance was determined at P=0.05 for each configuration.

Posture analysis

In order to acquire the postural angles, the photos were processed using Kinovea® software. Analysis was made of the following upper limbs movements: head rotation, head bending, shoulder rotation, shoulder bending, trunk rotation, trunk bending and trunk flexion. Body rotation was analyzed in the transverse plane, body flexion in the frontal plane and body bending in the sagittal plane. The angles found are defined as the angles between two segments: the first is the line passing corresponding body part in the Rest Posture (when the body leans back against the chair) and the second is the same line after the movement. And more specifically, for the shoulder rotation the line is the one between the acromion processes, while for the head rotation the line is the one passing the centre of the neck and the nose base. An example of the postural angle acquisition is shown in the Figure 4-10.

Figure 4-10: *Example of neck and shoulders postural angle acquisition*

Results

(Dis)comfort experience

Table 4-2: Mean Values from LPD questionnaire, where 1 = no discomfort and 7 = extremely discomfortable.

	Eyes	Neck	Shoulders	Upper back	Lower back	Buttock
0°	2,14	3,86	3,49	3,29	3,23	2,86
45°	1,57	2,74	2,57	2,51	2,20	2,26
90°	1,47	2,21	2,12	1,85	1,88	1,97
180°	1,71	1,94	1,88	2,15	2,12	2,15

Table ***4-2*** and Figure 4-11 show that the neck scored the highest values of discomfort for the 0˚, 45˚ and 90˚ configurations. The 0° configuration has the highest discomfort for all recorded body parts, followed by 45°, except for the eyes, which was the second most uncomfortable in the 180° configuration. In questionnaires, often the participants mentioned that the 180° configuration forced them to have eye to eye contact.

The 90° configuration showed the lowest discomfort, apart from the neck and the shoulders, where the 180˚ configuration scored less discomfort. The recordings of the angles show that participants tend to rotate the neck and the shoulder to make the face-to-face contact.

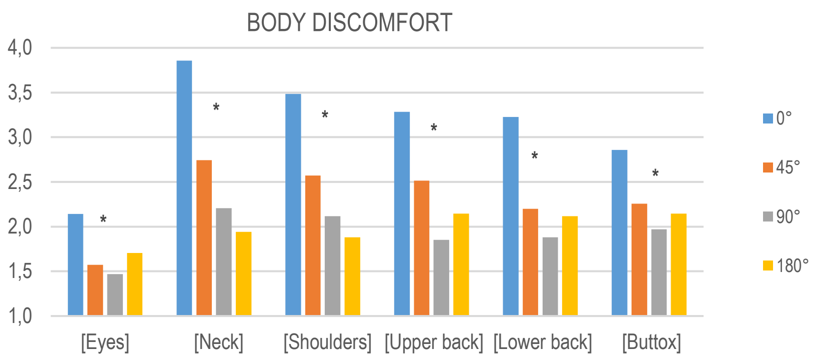


Figure 4-11*: Mean values from LPD questionnaire (* means significant differences between configurations)*

Conversation quality

Regarding the quality of conversation, a majority of the participants felt restricted in the social interaction in the 0° configuration. In the 180° configuration participants reported that they could easily understand each other in the conversation, but felt invaded in their personal space. The 90° configuration scored the highest value of “I feel at ease during the conversation”, meaning participants could feel more at ease during the conversation in this configuration than the others (Figure 4-12).

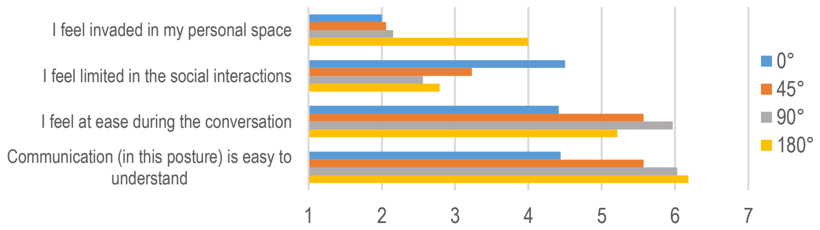


Figure 4-12: *Results from questionnaire quality of conversation (1=extremely disagree, 7=extremely agree)*

The 90° configuration scored the highest values both in overall comfort and quality of conversation, followed by 180°, 45° and 0° configurations (Figure 4-13), thus on the whole it could be the best configuration.

After sitting in each seat configuration, each participant was asked to choose their most preferred configuration (Figure 4-14). The majority of participants rated the 90° as the preferred configuration explaining that this configuration allows them to have a comfortable posture with less discomfort during the social interaction.

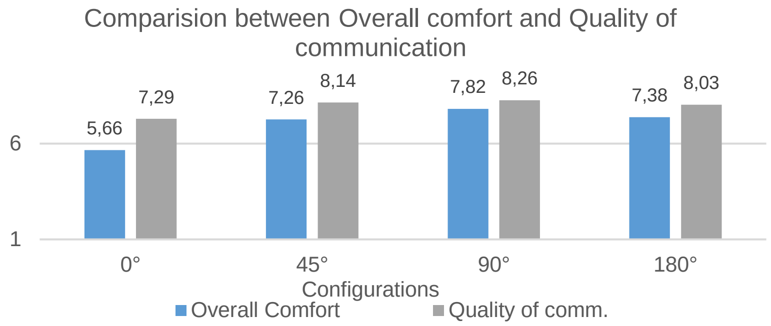


Figure 4-13: *Mean Values of Overall comfort (1=no comfort, 10=extremely comfortable) and Quality of conversation (1=very bad, 10=very good)*

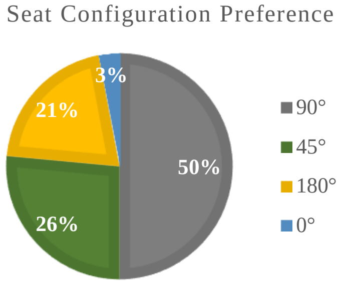
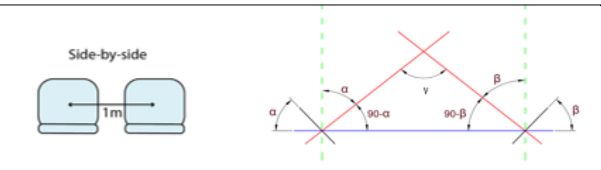
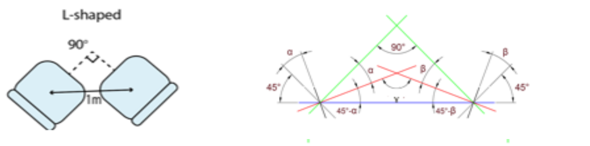


Figure 4-14: *Percentile of preferred configuration that participant rated*

Table 4-3: *Mean values of angles for the best sitting arrangement*

	Mean α or Mean β	Mean γ
	52.6°	105.2°
	36°	116.5°
	31.25°	149.7°

Postures

The results of posture analysis show that for each configuration, with the exception of 180° configuration, the sitting participants rotated the upper part of their body. There were individual differences. In the 0° configuration, the participants rotated or the shoulders (19%) or the neck (38%) or less the shoulder and more the neck or vice versa (43%).

Finally, the results of the mean values of the postural angles (α and β) are shown in Table 4-3.

α and β represent the rotation of neck and shoulders of participants, γ is the angle between the two participants recorded during the conversation (considering a triangle, having two angles at the basis, the third angle can be easily found and it represents the ideal configuration, where participants might be in Rest Posture).

Table 4-3 shows that increasing the angles of the sitting arrangement, the mean values of α and β decrease because the people need to rotate less their body parts to have an eye-to-eye contact.

Correlations

To understand the correlation between the acquired data a statistical analysis was performed using SPSS. Pearson correlation coefficients were calculated to determine the strength of the relationships between all the variables.

Some relevant results were obtained from the correlations between the outcomes:

(** Correlation is significant at the 0.01 level)

- There is a moderate correlation between the overall comfort and the quality of conversation (r=.542**);
- There is a negative correlation between the angles regarding the neck rotation and shoulder rotation for the 0˚ configuration (r=-.503**) and a positive correlation for the 180° configuration (r=.694**);
- There is a weak correlation between the postural angles and overall comfort and between postural angles and body discomfort.

The effect of the quality of conversation to body part discomfort?

The absence of correlations between postural angles and discomfort and between postural angles and overall comfort could be caused by the relative weight of the quality of conversation on overall comfort. In order to support the hypothesis, a sensitivity analysis was done by building a mathematical function in order to determine the impact of the variable "Quality of conversation" on the overall comfort. The mathematical function was built through the weighted means of data derived from postural comfort and quality of communication, it means defined as the linear combination of two factors: body part discomfort and quality of conversation.

Sensitivity Index=A*(body part discomfort) + B*(quality of conversation)

In which: $A + B = 1$

Table 4-4: *Combination of A and B for the New Global Index.*

A	0.2	0.4	0.6	0.8
B	0.8	0.6	0.4	0.2

The Sensitivity analysis consist of changing the factors assigning complementary values to the coefficients A and B (Table 4-4) to see what effect is produced on the sensitivity index.

A statistical analysis, with Pearson's correlation coefficients, was performed to verify a possible correlation between the sensitivity index and the overall comfort. This analysis revealed that increasing B, thus increasing the weight of the quality of conversation, the sensitivity index shows a stronger correlation with the overall comfort for each configuration (Figure 4-15).

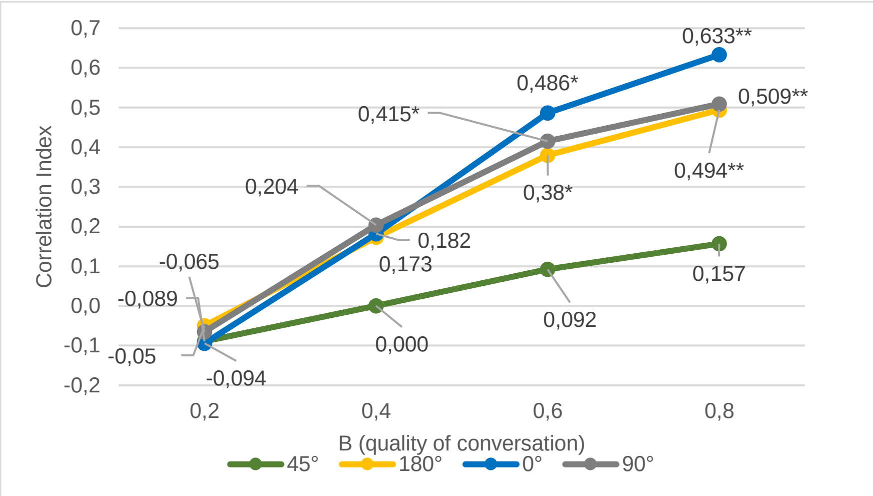


Figure 4-15: *Sensitivity analysis for each configuration*

Discussion

Answering the research question, the results show that 90° is more preferred for both comfort and communication. This is in align with the study of Nguyen (Nguyen, 2016) where the L-shaped configuration performed better than the Opposite (180˚) and Side-by- Side (0˚) set up. Maines (Maines, 1979) describes that in the 180° configuration people felt uncomfortable as they are forced to face each other, which was affirmed in this study as well.

The 0° configuration scored the lowest in both comfort and quality of conversation since the sitting arrangement does not facilitate conversation and requires rotation of the body. This sitting configuration however, is most frequently used in cars, buses, trains and aeroplanes.

Thus, the 90° configuration represents the best compromise for a conversation, since it allows to have a comfortable posture with minimal discomfort and a good quality of conversation, while avoiding the forced eye-to-eye contact between neighbors.

However, the postural analysis shows that even in the highest scored configuration (90° configuration) participants have to rotate parts of their body, which could cause discomfort in the long run. Several studies show that discomfort increase over time (Hiemstra-van Mastrigt, Meyenborg, *et al.*, 2016; Sammonds *et al.*, 2017; Smulders *et al.*, 2016; Vink *et al.*, 2017). Further research is advised to look at long term effects and check the effect of angles in between the 90° and 180° configurations.

The strong correlation between the overall comfort and the quality of conversation confirms the studies by Helander and Zhang (Helander and Zhang, 1997; Zhang *et al.*, 1996); the quality of conversation, that is associated with the emotions, influences the overall comfort perceived by each participant while it doesn't influence the LPD, that is associated with physical pain.

Furthermore, it confirms also the work of Ahmadpour (Ahmadpour *et al.*, 2014) which, in relation to passenger comfort, showed the importance of psychological and social experiences for creating comfort.

Limitations of the setup

There are some limitations of this study that need to be acknowledged. Firstly, there are not literature studies on methods, tools, techniques to evaluate the quality of conversation. Then, the group of participants were homogeneous, as they were all young (21-28y) and most of them students. However, literature research showed that young people do travel more in groups. Thus, this sample might represent the group involved in this trend.

During the experiment the participants were asked only to talk about a given topic without defining precisely other conditions. This resulted in too many degrees of freedom for the participants, who sometimes assumed unexpected postures or used devices like books or mobile-phones during social interaction to substantiate their conversation. This aspect caused some problems with the pictures analysis, giving the possibility to analyze only pictures taken at minute 4:30 until 5. Therefore, it was not possible to have a deeper postural analysis, e.g. based on time. Future studies could consider a different method for postural acquisition to prevent these issues. On the other hand, this kind of freedom represents reality as well.

Furthermore, it was not possible to reproduce a realistic context during the experiment. The context was simulated in a classroom using normal office chairs. This also influences the validity of the experiment. It is advised to do the experiment again in a moving vehicle where the environment can be seen or in a restricted area of a cabin, using also seat belts to be nearer to cars or aeroplanes environment.

In addition, the distance of 1 meter theoretically is within the personal space between friends as presented in Figure 4-6. However, in reality most vehicles cannot afford to provide a 1-meter in-between seat allowance because the car size is usually limiting. Current vehicles have the side by side (0°) configuration to save space, thus a further analysis is required to save space and money with a more adequate distance.

Conclusions

In most of the current vehicles, passengers travel side by side. There is a growing number of passengers travelling in groups ("CWT Connected Traveler Study", 2017) and for these passengers the side by side configuration is not optimal.

The 90° sitting arrangement was found to be the most preferred for both comfort and quality of conversation, allowing to obtain a comfortable posture with minimal discomfort and a qualitative conversation without forced eye-contact. In interior design, more attention is advised for using a similar configuration.

Regarding the (dis)comfort experience and conversation quality, the 0° configuration was found to score the lowest on both aspects and also was the least preferred of all arrangements.

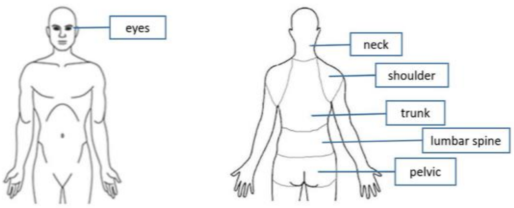
Regarding the postures, it was observed that for 0°, 45° and 90° configurations the participants needed to rotate their body to engage in a conversation. These postural angles may be used as guidelines for future interior and seat designs.

There was no correlation between (dis)comfort and local postural discomfort and postural angles, though it was found that there is a strong correlation between comfort and quality of conversation. A sensitivity analysis was performed and a new index was calculated as a linear weighted of the body postural discomfort and the quality of conversation. A strong correlation between the new index and the overall comfort was found in correspondence of the highest value of the quality conversation weight. This shows that the perceived overall comfort was strongly influenced by the quality of conversation the participants had.

Acknowledgements We want to thank Mr B.J. Naagen for his help in setting up this study and MD students from IDE – TU Delft for helping us by taking part, as participants, in this study.

Appendix: Questionnaire of LPD and Quality of conversation

9\. **Please rate your experienced discomfort/pain for each body part(s)** *



Mark only one oval per row.

	1. No discomfort	2	3	4. Quite discomfortable	5	6	7. Extremely discomfortable
Eyes	◯	◯	◯	◯	◯	◯	◯
Neck	◯	◯	◯	◯	◯	◯	◯
Shoulders	◯	◯	◯	◯	◯	◯	◯
Upper back	◯	◯	◯	◯	◯	◯	◯
Lower back	◯	◯	◯	◯	◯	◯	◯
Buttox	◯	◯	◯	◯	◯	◯	◯

10\. **Communication (in this posture) is easy to understand** *

Mark only one oval.

	1	2	3	4	5	6	7	
Extremely Disagree	◯	◯	◯	◯	◯	◯	◯	Extremely Agree

11\. **I feel at ease during the conversation** *

Mark only one oval.

	1	2	3	4	5	6	7	
Extremely Disagree	◯	◯	◯	◯	◯	◯	◯	Extremely Agree

12\. **I feel limited in the social interactions** *

Mark only one oval.

	1	2	3	4	5	6	7	
Extremely Disagree	◯	◯	◯	◯	◯	◯	◯	Extremely Agree

13\. **I feel invaded in my personal space** *

Mark only one oval.

	1	2	3	4	5	6	7	
Extremely Disagree	◯	◯	◯	◯	◯	◯	◯	Extremely Agree

14\. **Please rate the overall comfort** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
No comfort	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Extremely comfortable

15\. **Please rate the quality of the conversation** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very Bad	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very Good

Part of questionnaire used for the experiment. Question 9 is the LPD, questions from 10 to 13 are about the quality of conversation, questions 14 and 15 about overall comfort and overall quality of conversation, respectively.

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Future vehicles: the effect of seat configuration on posture and quality of conversation

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Abstract The percentage of passengers that prefer travelling in groups is increasing. In most vehicles, passengers sit side by side and need to turn their body to be engaged in the conversation with their fellow travellers. However, rotating the body could lead to discomfort which influences conversation quality. The aim of this research is to study the effect of seat configuration on the (dis)comfort experience, conversation quality and posture. Experiments in which participants were asked to talk to each other while sitting at the same distance (1 meter) were conducted in four seating arrangements (with seat-belts on), where the angle between the forward directions of two seats were positioned at 0° (side by side), 22.5°, 90° and 120° (almost opposite each other), respectively. Optical tracking was deployed and the collected data were processed with MatLab® to acquire postural angles over time. Questionnaires were also used to evaluate the perceived (dis)comfort and the quality of the conversation. Experiment results indicate that the 120° configuration scored the best in the overall comfort and the quality of conversation, but only slightly better than the 90° configuration.

Keywords: comfort, seating arrangement, conversation quality, seat layout, vehicle design.

Practitioner Summary Seating side by side is not optimal to have a comfortable conversation with your seatmate. To improve comfort and quality of conversation in future vehicles, we tested 4 seating arrangements analyzing the effect of seat layout on (dis)comfort experience. Statistical analysis of objective and subjective data shows the optimal configuration for a comfortable conversation.

Introduction

The number of passengers travelling in groups is increasing. A study of Homburg (Homburg, 2017) shows that more than 28% of passengers at Amsterdam Airport Schiphol travel within a group (≥2 people). Meanwhile, “CWT Connected Traveler Study” (“CWT Connected Traveler Study”, 2017) indicates that millennials (people born between 1980-2000) like to travel in groups and are more sociable than older generations of business travellers. Both imply that the desire to socially interact and converse in transit will grow.

However, interacting with seatmates in an aeroplane, or a car, might be difficult (Lille *et al.*, 2016). The main reason is that in the current seat configuration, passengers sit side by side and have to turn their eyes, head, shoulders, torso or even the whole body to be engaged in a conversation (Groenesteijn *et al.*, 2014). Awkward postures, especially for a prolonged amount of time, could lead to discomfort (Vink *et al.*, 2017). This is especially true for autonomous driving vehicles (electric), where passengers (and 'drivers') can spend more time conversing.

The comfortable community model (Dumur *et al.*, 2004) suggests that comfort can be increased in facilitating conversation between people through the improvement of cabin layout and services. To facilitate a more comfortable conversation, fewer rotations in the various segments of the body are preferable (Naddeo, Cappetti and D'Oria, 2015a). It can be presumed that, if the seat configuration allows people to have less torso and neck rotation in their conversation, people might feel more comfortable during the conversation. However, only few studies (Nguyen, 2016; Piro *et al.*, 2019a) were conducted regarding the relations between the configuration of the seats, the comfort of people and the quality of their conversation. Both research, however, did not gather angles over time, thus more information is needed.

The aim of this research is to study the effect of seat configuration on (dis)comfort experience, conversation quality and posture for finding the best seat configuration which is able to maintain postural comfort in relatively long time, therefore improve the quality of conversation. For this, using both subjective and objective measures, an experiment was designed to investigate the seat configurations on 1) (dis)comfort experience, 2) the quality of the conversation and 3) taken postures.

The output of this study could be a basis for designing interiors of vehicles, such as autonomous cars, trains and aircrafts.

Literature Review

During social interaction, people surround themselves with implicitly defined and organized space, which is internalized at an unconscious level (Hall, 1966; Madanipour, 2003; Sommer, 1969). Respecting this space could improve comfort during social interaction. There are studies (Sorokowska *et al.*, 2017) on distances between standing persons to facilitate communication, e.g., Hall (Hall, 1966) studied the interpersonal distances in social interaction, concluding that there are four important interpersonal distances: 1) *Intimate distance* (between 0-0.45m), which is reserved for lovers, pets and family members; 2) *Personal distance* (between 0.45-1.2m), which reserved for friends; 3) *Social distance* (between 1.2-3.7m) for strangers and members of newly formed groups; and 4) *Public distance* (between 3.7-7.6m), which is for large audiences. These distances had been largely deepened with the recent study (Sorokowska *et al.*, 2017) that takes into account even the cultural and ages differences.

Comfort of people is an important factor (Dumur *et al.*, 2004) in social interaction. In general, comfort can be defined as a sense of physical or psychological ease. Helander and Zhang (Helander and Zhang, 1997; Zhang *et al.*, 1996) investigated the difference between comfort and discomfort in the field design for comfort, and they found that feelings of discomfort were associated with pain, tiredness, soreness and numbness, while comfort was more related to luxury, relaxation or the sense of being refreshed. For passengers in vehicles, e.g., aeroplane, Ahmadpour (Ahmadpour *et al.*, 2014) affirmed that the comfort experience of passengers during the flight contains physical, physiological and psychological elements, and is configured through the thematic structure of contextual perceptions and their eliciting features. Therefore, the interior design of modern aircraft provides a level of comfort by meeting the design standards that incorporate passengers' physical health and safety issues as well as facilitating social interaction.

Among different elements of the interior design, seats have an important role when considering passenger interaction, attracting the attention of researchers (Bouwens *et al.*, 2018; Hiemstra-van Mastrigt, 2015; Vink *et al.*, 2012; Vink and Brauer, 2011). Many factors in the seat design have profound impacts on human body comfort perception, e.g., the dimensions of seat, side support and hardness or softness of seat material (Kamp, 2012). As concerns the seat layout, researches are generally linked with passengers' ingress and egress (Vink and Brauer, 2011) and there are few studies concerning body comfort during conversation. For instance, a study from Nguyen (Nguyen, 2016) indicated that the best seating arrangement for communication and comfort was an L-shaped configuration, which was confirmed in the study of Piro (Piro *et al.*, 2019a).

Different studies showed that the most comfortable position corresponds to the neutral position of the joints or resting body, called *"Rest Posture"* (Andreoni *et al.*, 2001; Christensen and Nilsson, 1999). In the *"Rest Posture"* human muscles are relaxed or at minimum strain level, that minimizes muscle activity, strain in the ligaments and optimises the comfort perception (Apostolico *et al.*, 2014a; Galinsky *et al.*, 2000; Naddeo, Cappetti, *et al.*, 2019). Therefore, in order to evaluate postural comfort, studying the postural angles might be helpful.

In the evaluation of the (dis)comfort of people during the conversation, the perception of subjective data had been gathered through questionnaires, using the Localized Postural Discomfort (LPD) and questions regarding the quality of conversation (Grinten, 1992). Objective data, instead, had been gathered through the acquisition of postural angles, using optical tracking. The LPD instrument was meant to help participants while they were answering questions during the experiment. The visual map helps to focus on the body region and meanwhile, the 7-point scale helps to give an immediate response, without losing the discomfort perception. Several authors, such as Hiemstra-van Mastrigt (Hiemstra-van Mastrigt, 2015; Hiemstra-van Mastrigt, Meyenborg, *et al.*, 2016), Bouwens (Bouwens *et al.*, 2018), Van Veen (Van Veen *et al.*, 2015) used the LPD questionnaire to analyse discomfort perception. To evaluate the quality of conversation, four questions (see Figure

4-20) were included using a seven-point Likert scale (Joshi *et al.*, 2015), scoring from 1 = “Extremely Disagree” to 7 = “Extremely Agree”. Those questions were meant to have an idea about participants’ feelings during the social interaction in a specific configuration, focusing on whether they felt at ease or not. An appropriate questionnaire model for this case has not been found in scientific literature.

In the study of human posture, images and videos are often used to identify and track the anatomical landmarks (Hung *et al.*, 2004). For instance, using the photogrammetric method, researchers were able to estimate the posture of the subjects based on images taken in the frontal and/or the sagittal planes (Jung *et al.*, 2017; Naddeo, Cannavacciuolo, *et al.*, 2018). With the development of computer vision and artificial intelligence technology, extracting feature points regarding particular colour and shape in the images (frames of videos), e.g. landmarks on human faces (Ranjan *et al.*, 2016) were made possible. Those methods are powerful (Foudeh *et al.*, 2018; Yuan *et al.*, 2017), however currently, only have limited application due to the complexity in different scenarios as well as the needed computing power.

Infrared camera motion capture systems (Frankton, 2018) were widely used in studying human motions. It is accurate and is able to capture the motions at a relatively high frequency, but at a high cost. Alternative solutions, e.g., using a motion capture-analysis system combining HD VideoCam and Kinovea (Commentale *et al.*, 2018; Muaza Nor Adnan *et al.*, 2018), were explored by researchers. Among those solutions, using fiducial markers can be a useful solution due to easiness in the setup and the growing availability of high-resolution cameras.

In computer vision, design fiducial markers are often used for tracking particular landmarks (Hung *et al.*, 2004). Those designs often allow the real-time calculation of the position and the orientation of the markers based on a frame(s) of the video stream with limited computing power (Avola *et al.*, 2016). By attaching such a marker(s), e.g. an ArUco Marker (Garrido-Jurado *et al.*, 2014; Mondéjar-Guerra *et al.*, 2018), to a particular (anatomical) landmark(s) of a subject, postures of the subject, as well as the motion, can be estimated based on 3D position, orientation and trajectory of this landmark(s).

Materials & Method

Materials

The experiment was conducted in the Comfort Lab at Faculty of Industrial Design Engineering, Delft University of Technology. Prior to the experiment, the materials, the procedure and the data management plan were approved by the Ethical Committee of Delft University of Technology. Two office chairs with aeroplane seat-belts were placed side by side to simulate aircraft seats. The distance between the centres of two seats is 1 (one) meter, which is in the region of personal space suitable for friends during social interaction, for all ages and nationalities (Hall, 1966; Sorokowska *et al.*, 2017). Four different seat configurations, where the seats were rotated toward each other, were investigated as Figure 4-16. Using the centre of the seat as the rotation centres, the angles between the forward directions of the seats were set as 0°, 22.5°, 90° and 120° (see Figure 4-16) in the four configurations. The configurations were set-up using rulers, measuring tapes, goniometers and markers on the floor with angles' number.

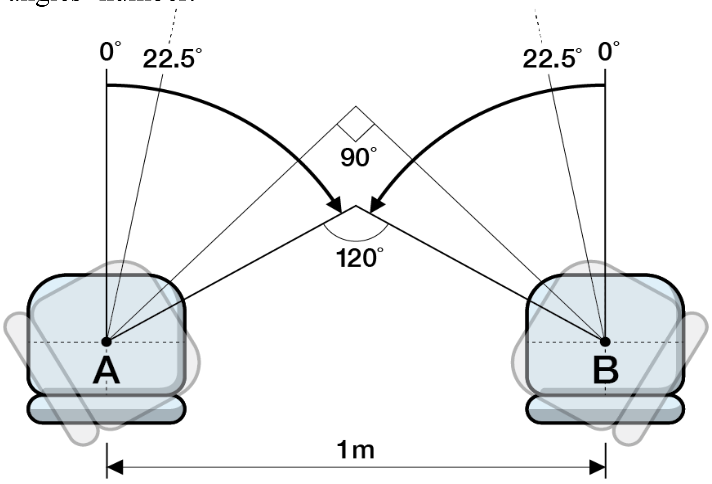


Figure 4-16: *Seating arrangements examined. On right, seat rotations are highlighted*

These configurations had been chosen for specific reasons. Nowadays, inside aeroplanes and vehicles the 0° configuration and the 90° configuration are present in some buses, tram and train; 22.5° represents the hypothetical max rotation allowed inside current cars and aeroplanes; the 120° comes from the postural angles results of a recent study (Piro *et al.*, 2019a). The 180° configuration, where each subject is in front of his/her interlocutor is not included because people felt forced to have conversation (Piro *et al.*, 2019a).

Seat-belts were used to simulate a realistic transit scenario, where passengers are restricted in their degrees of freedoms for safety reasons (Figure 4-17). Four GoPro HERO5 Black cameras were used to record the participants' conversation. For each participant, a camera was placed on the top of him/her. Two others were placed in front and behind the setup, capturing both participants at the same time. The videos were recorded in 2.7k Linear mode (2704x2028 pixels, aspect ratio 4:3) with 60 frames/sec.

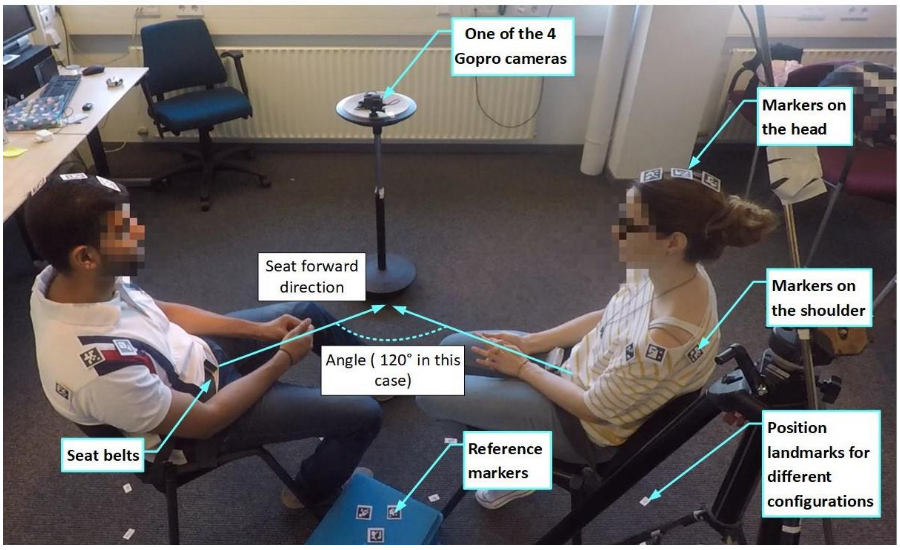


Figure 4-17: *A cropped image from one camera used during the experiment. Highlights of participants' posture, using seat-belts to fix their hip on the seat.*

Questionnaires

Questionnaires were used to evaluate the comfort of participants and the quality of the conversation in each seating arrangement (see Figure 4-29 in Appendix A). Prior to the experiment, information about gender, age, stature and weight was gathered. Then, at the end of 10 minutes sitting in each configuration, participants were asked to fill the questionnaire while remaining seated. The questionnaire consists of questions on LPD (Grinten, 1992) for their upper-body (eyes, neck, shoulder, trunk, lumbar spine, pelvic) with a 7-point Likert scale (Joshi *et al.*, 2015); four statements on the psychological perception of interaction using a 7-point Likert scale; an overall rating for comfort (10-scale); and an overall rating for quality of conversation (10-scale). The visual map of the LPD was included to show clearly body regions to the participants allowing them to give an immediate response without losing the discomfort perception (Bouwens *et al.*, 2018; Hiemstra-van Mastrigt, 2015; Hiemstra-van Mastrigt, Meyenborg, *et al.*, 2016; Van Veen *et al.*, 2015).

Participants

Due to the fact that the distance between seat was in the personal space suitable for friends, one recruiting requirement was only pairs of friends could participate. Thus, ten groups, that is twenty participants, 10 males and 10 females, were tested in all configurations. The choice of testing only pairs of friends was meant to help them in having a comfortable conversation, in which they were able to feel at ease. Table 4-5 represents the demographic data of the participants. All participants belong to the millennial age group ("CWT

Connected Traveler Study", 2017). All participants had previous experiences with journeys in an aircraft or car.

Table 4-5: *Demographics of the subjects (n=20)*

	Male (n=10)		***Female (n=10)***	
	Mean	**SD**	**Mean**	**SD**
Age [years]	25.8	2.3	24.3	3.6
Stature height [cm]	177.8	6.9	164.3	3.4
Weight [kg]	82.4	16.2	57.2	5.6

Protocols

Using a 7x10 checkerboard, all GoPro cameras prior to the experiment had been calibrated following the procedure suggested by OpenCV. The purpose of the calibration was to identify the intrinsic parameters of each camera and use them to undistort the capture videos for a better accuracy of the locations of ArUco markers. Before the experiment, participants were asked to sign an informed consent form. Personal information on gender, stature, weight and age were collected. All information gathered was treated anonymously where each participant was identified with a number and a letter: the number was associated with the group, the letter with the chair where the participants sat (A or B).

Moreover, participants were asked to stick ArUco markers on the body (Figure 4-18):

- 3 on head (lined up, from frontal to parietal bone);
- 3 on left shoulder (one on infraspinous fossa, one on subscapular fossa, one on clavicular shaft);
- 3 on right shoulder (one on infraspinous fossa, one on subscapular fossa, one on clavicular shaft).

In addition, three reference markers were placed on a board, which is allocated between the two seats as shared reference points for all cameras (highlighted in Figure 4-17 and visible in Figure 4-18). By keeping these three reference points in the view of each cameras, it was possible to associate all camera coordinates to one global coordinates. Synchronization using common shared points was important to combine all the information from different cameras.

Figure 4-18: *A photo of the GoPro camera located on the top of a participant, markers on the subject, the seat-belt, reference marker on the floor are visible*

In order to obtain the Rest Posture, at the beginning of each configuration, the participants were asked to sit upright, leaning on the backrest and to look forward for 10 seconds. After that, participants were left alone and asked to talk to each other for 10 minutes while their movements were recorded. Recordings from cameras were remotely controlled by smartphones throughout the experiment. Each part of the experiments (one configuration) lasted 10 minutes. Subsequently, participants were asked to fill the questionnaire while remaining seated. Then they were able to have a 5 minutes' break. With four different configurations, the complete experiment lasted approximatively 1 hour for each group. After experiencing all configurations, each participant was asked to choose the preferred configuration regarding the overall comfort and quality of conversation, and the reason for choosing it. For different groups, the order of the configurations was different for each pair, determined by using Latin square (Fisher, 1992).

Data analysis

In order to acquire the postural angles, videos were processed with a self-developed Python program to obtain 3D coordinates of different markers. Since each marker represents a point in the 3D-space, vectors for the head (forward) direction and the shoulders had been created by selecting the corresponding markers. Two vectors were calculated as follow:

- A vector representing the head was obtained by connecting one marker on the parietal bone to another marker on the frontal bone. The markers selection criteria were based on the highest number of frames in which they had been detected;

- A vector representing the shoulders was obtained by connecting one marker on the left shoulder to another marker on the right shoulder. The markers selection criteria were based on two factors: the highest number of frames in which they had been detected and the same specular place. It means, on the majority of the cases, markers on the clavicular shaft per each shoulder had been chosen, otherwise the ones on the infraspinous fossa or on the subscapular fossa.

These vectors were used to track neck and shoulder rotations compared with the Rest Posture which was the reference position. This Rest Posture was calculated using data from the first 10 seconds of the video. Consequently, angles between the rest posture vector and the other vectors were calculated to obtain angles over time using MatLab®. The output of this process was exported to Excel and graphic plots were made (see Figures 4-30 to 4-33 in Appendix B). These plots show head rotation (degrees) and shoulder rotation (degrees) over time (seconds).

Additionally, weighted averages and frequencies were calculated to specify the probability of a random variable falling within a particular range of values. Probability Density Function (PDF) of neck rotation for each configuration had been evaluated using Weibull distribution.

All questionnaire data and angles detected in videos were gathered and analyzed using IBM® SPSS® Statistics (version 24). A Wilcoxon signed rank test was performed to compare questionnaire results for each participant in each configuration. This test is selected to compare mean scores when the dependent variable might be not normally distributed or at least of an ordinal scale. For example, when comfort and discomfort may not be normally distributed (Groenesteijn, 2015). Significance was determined at P=0.05 for each configuration.

Results

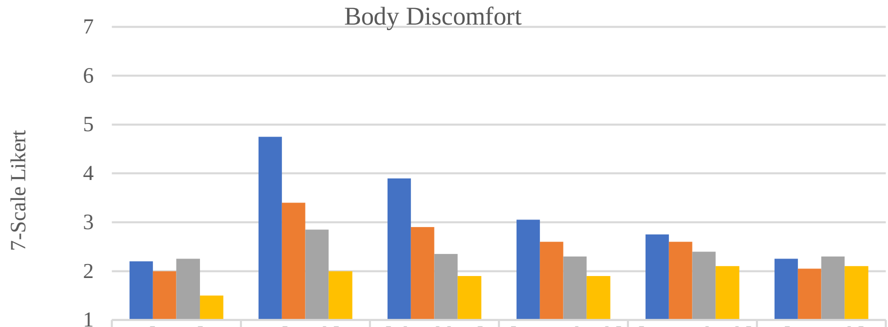
Discomfort experience

Figure 4-19 presents the results of the LPD questionnaire. The 0° configuration has the highest discomfort for all recorded body parts, except for the eyes and buttocks, which were the most uncomfortable in the 90° configuration. The 22.5° configuration showed the second highest discomfort for all recorded body parts, except for the eyes and buttocks, which were the second most uncomfortable in the 0° configuration. The 90° configuration is the second configuration with the lowest discomfort, apart from eyes and buttocks, where the 22.5° and 120° configurations scored less discomfort respectively. Finally, the 120° position showed the lowest discomfort, apart from the buttocks where the 22.5° configuration scored less discomfort. For each part, the neck scored the highest value of discomfort for 0°, 22.5° and 90° configuration. A Wilcoxon test, with the Bonferroni correction, was done to check the significance for each configuration (Table 4-6). Each participant was considered as an independent data because postural (dis)comfort is strictly a subjective data and there was not any kind of influence while filling the questionnaire, thus N=20. Due to the fact that each configuration was compared with the other three configurations, the critical p-value was p=0.05/3=0.017.

Table 4-6 shows the statistical significance of the neck and the shoulders, which are the body parts with higher discomfort scores. In particular, the 0° configuration has significant differences with all configurations, and there no differences between 22.5° & 90° and between 90° & 120°.

Table 4-6*:* Wilcoxon test with Bonferroni correction for Neck (at left) and Shoulders (at right) - significance was determined at p-value=0.017 for each configuration. (* are significant results).

Neck (N=20)					**Shoulders (N=20)**				
Variables comparison	*0°*	*22.5°*	*90°*	*120°*	*Variables comparison*	*0°*	*22.5°*	*90°*	*120°*
0°	-	0.00528*	0.00208*	0.00018*	*0°*	-	0.01552*	0.00528*	0.00108*
22.5°	0.00528*	-	0.18024	0.00288*	*22.5°*	0.01552*	-	0.17384	0.00634*
90°	0.00208*	0.18024	-	0.03662	*90°*	0.00528*	0.17384	-	0.22246
120°	0.00018*	0.00288*	0.03662	-	*120°*	0.00108*	0.00634*	0.22246	-



	[Eyes]	[Neck]	[Shoulders]	[Upper back]	[Lower back]	[Buttock]
0°	2,2	4,75	3,9	3,05	2,75	2,25
22.5°	2	3,4	2,9	2,6	2,6	2,05
90°	2,25	2,85	2,35	2,3	2,4	2,3
120°	1,5	2	1,9	1,9	2,1	2,1

Figure 4-19: *Mean values from the LPD questionnaire (1="no discomfort" and 7="extremely discomfortable", N=20)*

Conversation quality

Considering the quality of the conversation, the majority of participants felt limited in the social interaction in the 0° configuration. While in the 90° configuration they were at ease during the conversation, and in the 120° configuration, communication was easier to understand (Figure 4-20).

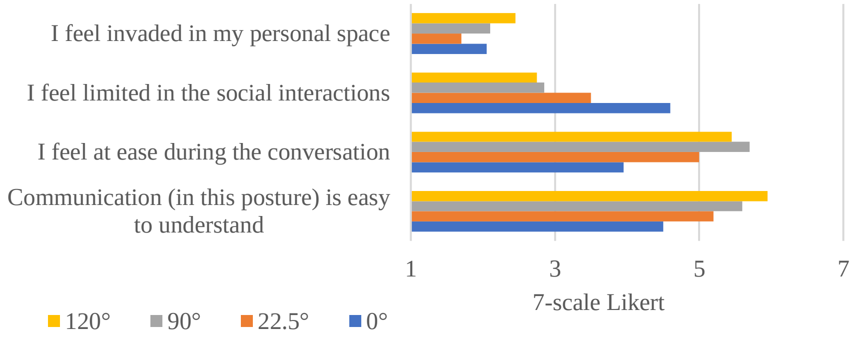


Figure 4-20: *Results from questionnaire quality of conversation (1=extremely disagree, 7=extremely agree, N=20)*

After trying all configurations, 60% of participants rated the 120° as the preferred configuration, while 35% preferred the 90° configuration. Common reasons were that the preferred configuration allows them to have a comfortable posture with less discomfort during the social interaction, and they were not forced to have eye-to-eye contact for the entire time. Based on the overall questionnaires results, the 120° configuration scored the highest values both in overall comfort and in quality of conversation, however, only slightly higher than the 90° configuration (Figure 4-21). Indeed, the performed Wilcoxon test, with the Bonferroni correction (Table 4-7), did not showed significant differences between the configurations 90° and 120°.

Table 4-7: *Wilcoxon test with Bonferroni correction for Overall Comfort (on left) and Conversation Quality (on right) - significance was determined at p-value=0.017 for each configuration, with N=20. (* are significant results).*

Overall Comfort (N=20)					Conversation Quality (N=20)				
Variables comparison	*0°*	*22.5°*	*90°*	*120°*	*Variables comparison*	*0°*	*22.5°*	*90°*	*120°*
0°	-	0.01684*	0.0003*	0.0028*	*0°*	-	0.0455*	0.01314*	0.00634*
22.5°	0.01684*	-	0.00072*	0.00104*	*22.5°*	0.0455*	-	0.02574	0.01828
90°	0.0003*	0.00072*	-	0.6384	*90°*	0.01314*	0.02574	-	0.53526
120°	0.0028*	0.00104*	0.6384	-	*120°*	0.00634*	0.01828	0.53526	-

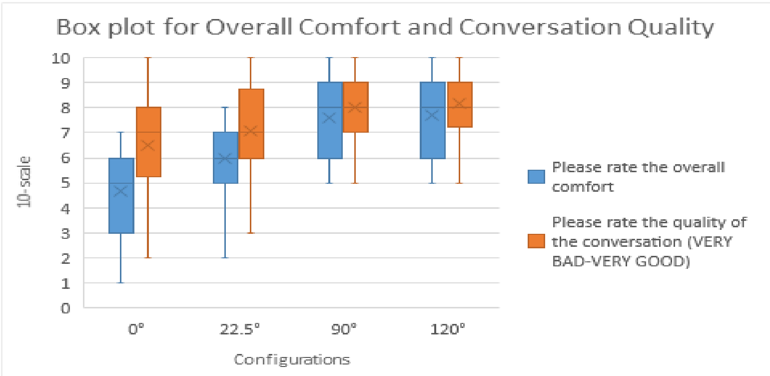


Figure 4-21*: Boxplots of Overall Comfort and Quality of conversation (N=20)*

A Wilcoxon test was performed on data coming from "dyads" (couple of subjects performing the test together); there will be 10 pairs of participants, so N=10 instead of N=20 (see Figure 4-19, Figure 4-21, Table 4-6 and Table 4-7), as each dyad contains two non-independent data points. The mean of "quality of conversation" evaluation between the dyad was used as data set for the test, but, due to the low number of dyads (only 10) and to the repetition of some values, the Wilcoxon test cannot be usefully performed.

Postures

The angles over time were calculated using MatLab® and the findings were as follows:

- In the 0° configuration, participants tended to rotate their neck for a prolonged amount of time. Generally, the neck rotation is between 60° and 80°, and shoulder rotation between 10° and 30°.
- In the 22.5° configuration, the neck rotation is between 40° and 60° for almost the complete conversation. The shoulder rotation is around 30°.
- In the 90° configuration, participants tended to rotate the neck less, having an angle of about 30°. Shoulder rotation is between 10° and 30°.
- In 120° configuration, neck rotation is more or less 20° with the absence of shoulder rotation for the majority of the time.

The weighted averages for postural analysis, where frequencies determined the weight, has shown that with the increase of angle in the sitting arrangement, the rotation of the shoulders and head (Figure 4-22) decreases:

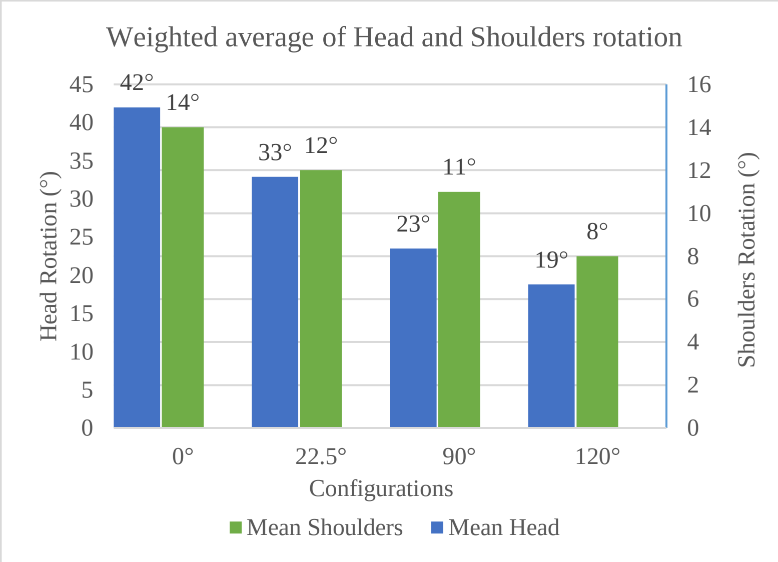


Figure 4-22: *Weighted average of shoulders and head rotation for each configuration*

Figure 4-23 shows the frequency of head rotation in each configuration. Increasing the angle of the seating arrangement, the frequency of the higher angles decreases and meanwhile the one with the lowest angles increases. This means that participants assumed, for a prolonged amount of time, angles between 40° and 60° in 0° configuration (for 35% of total time) and angles between 1° to 20° in 120° configuration (for 51% of total time). Thus, the 0° represents the worst configuration, 120° the best one followed by 90° (where participants assumed angles between 20° and 40° for 55% of total time).

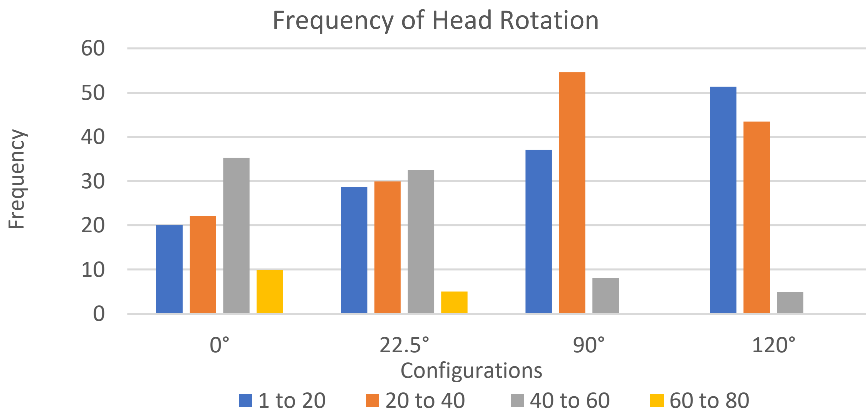


Figure 4-23: *Frequency of head rotation for each configuration*

This frequency was also calculated for shoulder rotation (Figure 4-24). It was found that the wider the configuration angle, the more 1º to 20º rotation occurred. This indicates that participants use the backrest more in wider angles, as these rotations are the closest to Rest Posture.

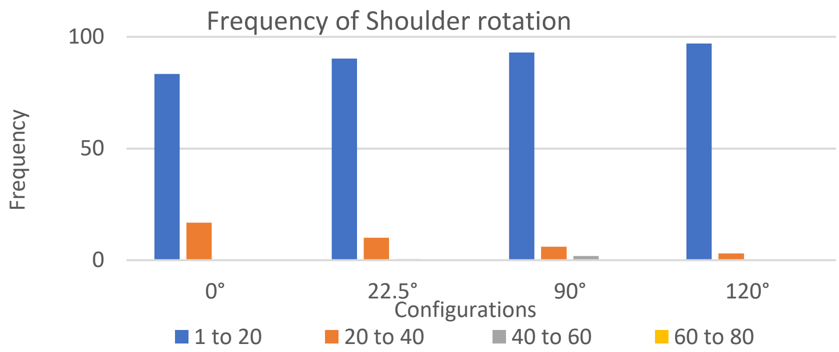


Figure 4-24: *Frequency of shoulder rotation for each configuration*

To specify the probability of a random variable falling within a particular range of values, as opposed to taking on any one value, the Probability Density Function (PDF) had been evaluated with Weibull distribution. Each configuration has the highest value of PDF in a specific range, except for 120° (Figure 4-28) where there is a large distribution in low angles, that is, the probability that participants assumed low angles is more or less equal, with a little prevalence around 15°. Instead, in the other configurations, a particular range with higher probability exists:

- 0° : range between 35° and 40° (Figure 4-25)
- 22.5° : around 30° (Figure 4-26)
- 90° : around 26° (Figure 4-27)

In the figures 4-25 to 4-26, graphs about density probability of neck rotation over angles are showed through curves, while the frequencies are shown by histograms.

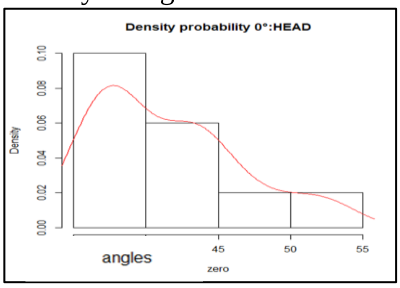


Figure 4-25: *Density probability in 0° configuration*

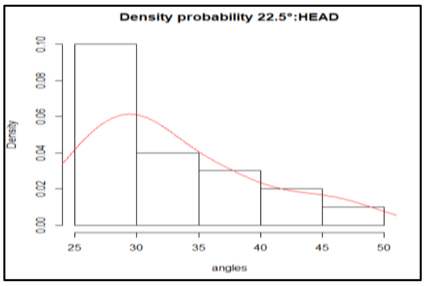


Figure 4-26: *Density probability in 22.5° configuration*

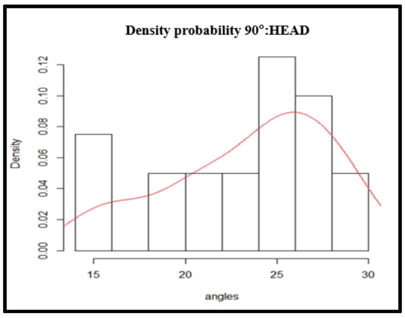


Figure 4-27: *Density probability in 90° configuration*

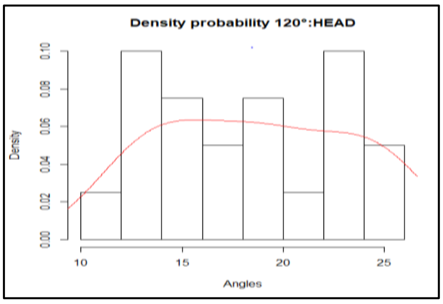


Figure 4-28: *Density probability in 120° configuration*

Correlations

To understand the correlation between the acquired data a statistical analysis was performed using SPSS®. Since data are normally distributed and homogeneous, Pearson correlation coefficients (r) were calculated to determine the strength of the relationships between all the variables.

Main findings regarding the correlations are:

- There was no significant correlation between Overall Comfort and local postural discomfort and postural angles (max r was 0.165, p=0.487);
- There is always a strong correlation between the overall comfort and the quality of conversation (r=0.713 To 0.857, p<0.01),
- In the 0°, 22.5° and 90° configurations there is a moderate negative correlation between the angles regarding the neck rotation and shoulder rotation, it means the more neck rotation the less shoulder rotation or vice versa (r=0.514 To 0.359, p=0.05).

Discussion

Regarding the research question on the effect of seat configuration, it is clear that (dis)comfort and the quality of the conversation are significantly influenced by the seat layout, where out of all tested configurations the 120° seems most favourable. An explanation could be given by the higher postural angles, specifically the torso and neck rotation, that cause discomfort.

For the 0° configuration, the results show that it scored the lowest in both comfort and quality of conversation since the sitting arrangement does not facilitate conversation and requires rotation of different parts of the body. This seating configuration, however, is most frequently used in cars, buses, trains and aircrafts. In contrast, the 120° configuration represents the best compromise for a conversation, as it allows to have a comfortable posture with minimal discomfort with a good quality of conversation while avoiding the forced eye-to-eye contact between neighbours that is present in a 180° configuration (Piro et al., 2018). Moreover, it is a more preferred configuration for both comfort and conversation quality, scoring slightly better than the 90°. This indicates that the 120° could be the optimised configuration of 90°, which still remains a good configuration for social interaction during a journey according to Nguyen (2016) and Piro (2018).

The strong correlation between the overall comfort and the quality of the conversations is in line with studies of Helander & Zhang (1997), Zhang (1996) and Ahmadpour (2014), which state that the quality of conversation associated with emotions, influences the overall perceived comfort. Thus, in conversations, the psychological and social experience are more important for passenger comfort.

Our findings that show that the comfort is higher closer to the neutral posture are not unique. Indeed, the OCRA guidelines also show this trend (Colombini *et al.*, 2013), and even Naddeo (2015) described this phenomenon. According to the data of Naddeo et al. (2015) the comfort in the neck is highest (around 10 on a scale 1-10, with 10 maximal) without rotation. Above 30° neck rotation, the comfort reduces fast to below 7 on 10. Also in our data, it is possible to see that sitting parallel (0° configuration) results in the highest discomfort. In this position, the head angle is 42° and the shoulders 14°, which means that the neck angle is around 28°. Thus, in our study, the corresponding discomfort in the neck is 4.7 on a scale 1-7 (where 7 is the max discomfort). Both studies are not completely comparable as in our case the shoulders were rotated, which could increase the discomfort more. Another interesting finding is that humans tend to divide the rotation over the various joints. In Table 4-8 it is shown how a fixed buttock and a changing viewpoint is divided over the joints. Interesting is that with an angle of more than 78° only the shoulders and head rotate further, which might explain why this position shows the highest discomfort, especially in the neck and shoulders.

Table 4-8: *Division of the rotation over body regions*

Seat configurations	**0°**	**22.5°**	**90°**	**120°**
Angle between the seat pan and viewpoint per person	90°	78°	45°	30°
Head angle	42°	32°	23°	19°
Shoulder angle	14°	12°	11°	8°
Other body parts/eyes	34°	34°	11°	3°

For the experiment methods, in the proposed research, ArUco Markers had been introduced to detect body movement of people during a conversation. The main benefit of using these markers is that: 1) it provides a fast, robust and accurate measure of the movements of the attached body part; 2) a fiducial single marker provides enough correspondences (its four corners) to be easily detected and to obtain the camera pose. Furthermore, considering the fact that, during a conversation, people like to move freely, the use of markers has the least restrictions on the users for different postures, and 3) the acquired videos can be processed in a high level of automation, therefore it improved the efficiency of data analysis.

Limitations of the setup

Some limitations of this study need to be acknowledged. Firstly, the group of participants were homogenous, as they were all young (22-35 years). However, "CWT traveler study" showed that young people do travel more in groups and will be the future travellers. Thus, this sample might represent the group involved in this trend. Further research on different age groups using the same protocol is recommended.

Using office chairs in a room might influence the validity of the experiment. The office chairs without armrest were selected to give free space around participants and to focus on the conversation and the (dis)comfort of the taken posture, not on how comfortable the seat was. However, in aircraft seats armrests are commonly used, which can influence postures and perceived discomfort. The seat-belts limited the degrees of freedom of participants in order to simulate sitting in an aircraft. Despite that, for future research, this study can be conducted in a vehicle or in a restricted area of a cabin to provide a more realistic context.

In addition, doing the experiment inside a car or an aircraft, other aspects of the research can be evaluated such as the impact of vibrations on passengers (Dong *et al.*, 2019). This aspect was neglected in this study.

Moreover, the set distance of 1m between seats is, according to Hall (1966), in the range of personal space between friends. However, such a configuration is not possible in many applications (e.g. economy class seats of aircraft, cars, trains, buses, etc.) due to the limited space. Thus, other configurations in which the distance between seats is reduced need to be explored in future studies.

As far as statistical analysis, pseudoreplication occurs when individual observations are heavily dependent on each other. Indeed, participants had been considered as independent data, even though the experiment was based on the research of a comfortable configuration for people having a conversation. Thus, the task of conversation had influenced participants responses. For further researches, it is suggested to perform experiments gathering data also from each group, in order to have physical data that involves the group itself.

Conclusion

In most of the current vehicles, passengers travel in a side by side configuration. There is a growing number of passengers travelling in groups and for these passengers, the side by side configuration is not optimal as the rotation of the upper body could lead to discomfort. In this study, it was found that a seat configuration of 120° is the most preferable seating arrangement for both postural comfort and quality of conversation, scoring slightly better than the 90° configuration. The 120° configuration was preferred as it was allowing participants to obtain a comfortable posture with minimal discomfort with a good quality of the conversation without forced eye-contact. It is therefore recommendable to consider a similar configuration for vehicle interior design. The (dis)comfort experience and conversation quality in the 0° configuration scored the lowest, with no participant voting it as a preferred configuration out of all arrangements, though this configuration is mostly used in vehicles nowadays.

In the 120° configuration, it was found that participants had the lowest head rotation for most of the time, reducing the risk to perceive discomfort. There was no correlation between (dis)comfort and local postural discomfort and postural angles, though it was found that there is a strong correlation between comfort and quality of the conversation. The perceived overall comfort was strongly influenced by the quality of conversation the participant had.

Further research is advised on realistic aircraft environment in order to analyze other aspects, e.g. distance, space efficiency, and their influence on the body comfort perception, especially in the long run.

Relevance for the industry

The use of a 120˚ seating configuration in vehicles could positively influence the comfort experience and quality of conversation. It is therefore recommended to consider such seating configurations for group travel and social interactions in transit. However, as space in transit is limited and thus an optimal space efficient arrangement is unclear, further research is needed.

Acknowledgements We want to thanks Mr. B.J. Naagen for his help in setting up this study and all participants who were so kind to take part in this study.

Appendix A: Questionnaire of LPD and Quality of conversation

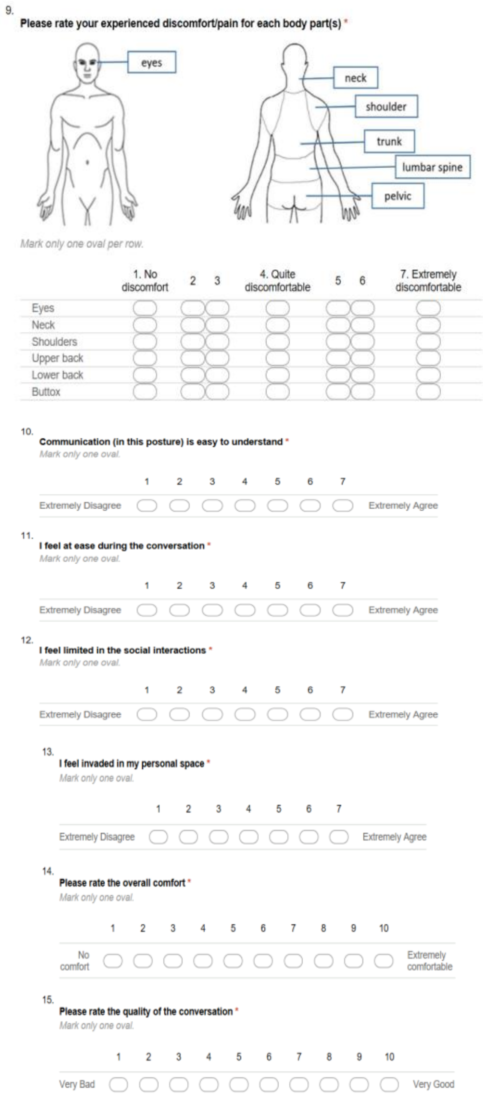


Figure 4-29: Part of the questionnaire used for the experiment. Question 9 is the LPD, questions from 10 to 13 are about the quality of conversation, questions 14 and 15 about overall comfort and overall quality of conversation, respectively.

Appendix B: Example of angles over time from MatLab®

Examples of angles over time gathered for one participant in each configuration, where the first graphic is head rotation (degrees) over time (seconds), and the second one is shoulder rotation (degrees) over time (seconds). It is clearly possible to see: 1) the angles in 0° configuration are higher than the 120° configuration; 2) how the angles decrease through all configurations.

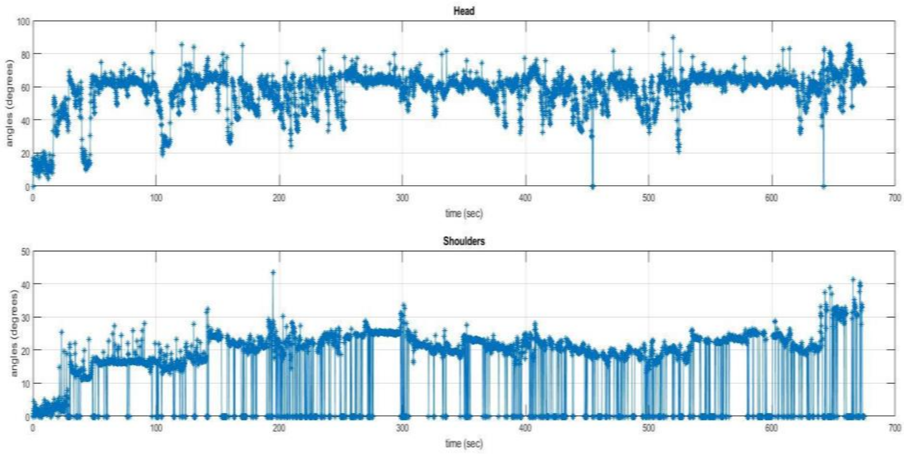


Figure 4-30*:* angles over time for head and shoulders - 0° configuration

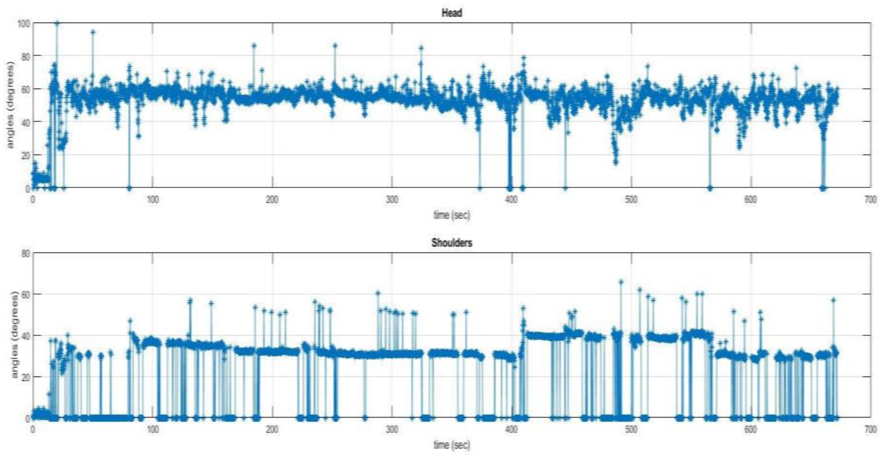


Figure 4-31: angles over time for head and shoulders - 22.5° configuration

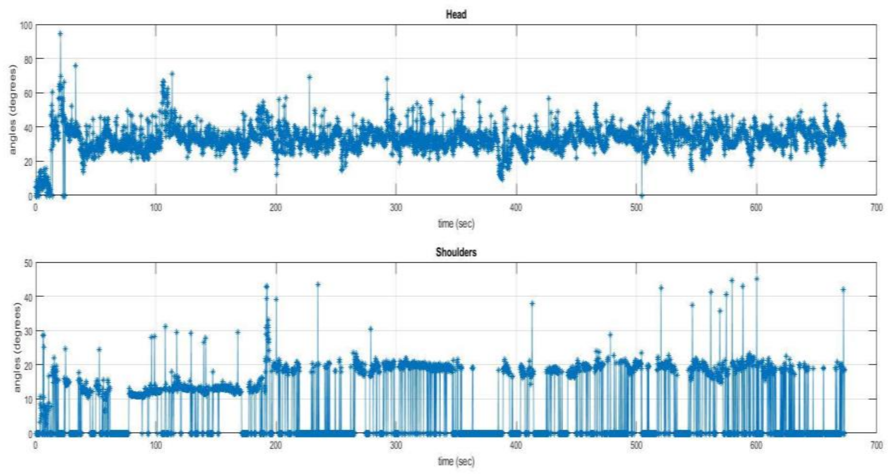


Figure 4-32: angles over time for head and shoulders - 90° configuration

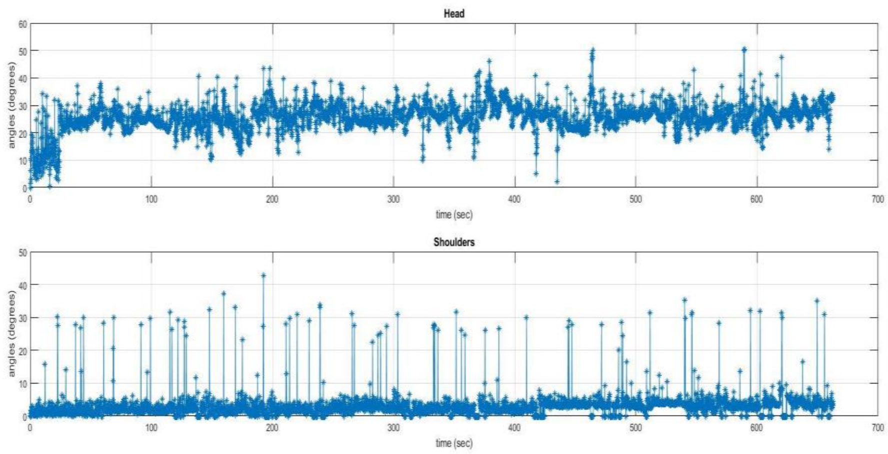


Figure 4-33: angles over time for head and shoulders - 120° configuration

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Design for comfort and social interaction in future vehicles: a study on the leg space between facing-seats configuration

Iolanda Fiorillo, Mario Nasti, Alessandro Naddeo

Abstract With the advent of future vehicles, passengers expect to travel in comfort, and the free leg space between facing-seats could be an issue due to the unsuitability for all people, according to their anthropometric variability. A previous investigation survey showed the need to increase the leg-space between facing seats and, if installed, to improve the surface of the table placed in between. So, four different distances between seat-pans front edges of facing seats were set-up and tested (44cm, 51 cm, 58 cm, 65 cm) with a table in between. 13 couples of participants with different heights took part to experiments. The aim was to investigate the relationship between facing-seat distances and passenger wellbeing in terms of postural comfort and social interaction. Postural comfort was analysed through optical tracking (for postural angles over time) and questionnaires (perceived comfort). Social interaction feelings were investigated with questionnaires. Experiment results showed the suitable distance could be 51 cm keeping the same table surface; otherwise, the 65 cm one could be ideal changing the table surface.

Relevance to industry: With the advent of autonomous driving, vehicle manufacturers and designers are working hard to define new paradigms of public transportation in terms of seat layout, passenger wellbeing and interiors' design. This paper contributes to increasing the general knowledge on the effects of distance between facing seats on postural comfort and social interaction.

Keywords: seat layout, vehicle interiors design, passengers' well-being

Introduction and state of the art

The number of passengers travelling by train and buses is growing (Eurostat, 2020) thanks to the track network that connects towns and the widespread of high-speed trains (UITP, 2020). Moreover, with the presence of automated vehicles, it is expected that people will spend less time driving or being a passenger in a car (Litman and Steele., 2018; UNECE, 2020). Indeed, autonomous vehicle technology will offer the possibility of fundamentally changing transportation. Equipping cars and light vehicles with this technology could (without any certain) reduce crashes, energy consumption, pollution, and reduce the costs of congestion (Anderson *et al.*, 2016; UITP, 2020; UNECE, 2020). Thus, in the future people will be more likely to travel with future vehicles that could be a mixture of public and private transports.

An advantage of public transport (Steg, 2003) compared to private transport systems is to provide higher levels of comfort for passengers by ensuring a wide range of services for carrying out daily activities such as reading, writing or eating during the journey (Hiemstra-van Mastrigt *et al.*, 2017). Different aspects influence the comfort level, such as the seat layout, the environment, the materials, the lights, the noise and vibrations (Ahmadpour *et al.*, 2014). Those aspects will be considered in the design of future vehicles.

The advent of autonomous vehicles can represent a new revolution in public and private transport (Anderson *et al.*, 2016; Mallozzi *et al.*, 2019). Consequently, a new paradigm for interior designers will be involved and will change the way of living the interior space of a car completely (Hofmann, 2018). Probably, in next 30/40 years (Chan, 2017; Litman and Steele., 2018; Mallozzi *et al.*, 2019) passengers will be allowed to spend their time in resting, reading or working inside a car (Kilincsoy, 2018) in a new fully configurable seat layout that will be inspired to the train/bus ones or the first-class flight cabin.

A literature overview allowed to find studies on the activities carried out during train travel, or in public transport (Bretz *et al.*, 2009; dell'Olio *et al.*, 2011; Fellesson and Friman, 2008; Groenesteijn *et al.*, 2014; Hiemstra-van Mastrigt, 2015; İmre and Çelebi, 2017; Jianghong and Long, 1994; Kamp *et al.*, 2011; Kremser *et al.*, 2012; Vink, 2016), but there are no studies concerning specifically people seated in the facing-seats configuration. For example, Kamp et al. (Kamp *et al.*, 2011) observed the correlation between activities and the adopted postures in leisure situations during train travel as input for the design of seats in cars, without considering participants' morphology and activity durations.

Also, the Groenesteijn's study (Groenesteijn *et al.*, 2014) focused on the relationship of individual body positions assumed by passengers during the train journey concerning various activities such as reading, sleeping, speaking and working on the computer. The result was that posture changes for each activity, as does the comfort score that differs in the different combinations of posture and activity. The seat should include different adjustment options to be optimal in different situations.

Moreover, personal space is a broad concept that includes legroom, seat pitch and cabin environment. These variables affect the perception of comfort and discomfort and are representative elements of a vehicle interior when testing seat comfort (Ahmadpour *et al.*, 2016; Hiemstra-van Mastrigt, Groenesteijn, *et al.*, 2016). For example, Kremser et al. (Kremser *et al.*, 2012) found that the comfortable distance between the seats in an airplane varies from 865 to 1065 millimeters, which corresponds to the legroom, depending on the passenger's anthropometry. The distance between the seats significantly influences passengers' sensations, exceptionally being constrained or limited to the environment.

The occupation of a specific seat had an impact on the passenger experience of a train journey that affects perceived comfort. Wardman and

Murphy (Wardman and Murphy, 2015) researched passenger preferences on the various seating arrangements. Travel time, the precise position of a configuration, the level of occupation and the sitting location within a layout were assessed. The result was that among the best arrangements, those 2 + 2 are preferable to the 3 + 3.

As concerns the seat layout or the interior design, researches are generally linked with passengers' ingress and egress (Vink and Brauer, 2011), and there are few studies concerning perceived comfort during conversations. For instance, some studies (Nguyen, 2016; Piro *et al.*, 2019b) indicated that the best seating arrangement for communication and comfort was an L-shaped configuration, investigated more with the work of Fiorillo et al. (Fiorillo, Piro, *et al.*, 2019a) where researchers found out the best seating arrangement was between 120° and 90° (the L-shaped configuration).

However, these studies only considered interactions between the passenger and the environment or seat. Thus, the need for evaluating interactions among passengers has arisen. This work aims to investigate (dis)comfort perception for passengers seated on facing-seats configuration during a journey involving the social interaction aspects, in particular the personal space or social proximity (Fiorillo, Piro, *et al.*, 2019a; Hall, 1966; Sommer, 1969; Sorokowska *et al.*, 2017).

Investigative survey

Since several factors involve facing seats, the first step was to conduct a preliminary investigation with an online survey, created with the free Google Form platform and spread among Italian people through social media (like Facebook©, Linkedin©, Researchgate©, etc.) and Internet communication channels (mailing lists, Google groups, etc..), without a specific population target to understand the public opinion. No regional distinctions were considered because public transport is almost the same all over Italy.

The investigation was done on train journeys because trains are the public transportation systems in which is usual to find facing-seats configuration with and without a table in the middle.

This survey is mainly composed of two parts. The first one focused on the passengers' sensations while sitting in the facing-seats configuration, it is, where seats face each other with a table between them. The second part on the passengers' suggestion on how to improve the perceived (dis)comfort by modifying the seat configuration. The proposed solutions were (see Figure 4-34):

a. Decrease distance between facing-seats
b. Increase distance between facing-seats
c. Remove the table between the facing-seats
d. Increase table surface
e. Create more space below legs
f. Increase distance between adjacent seats

g. Other (explain)

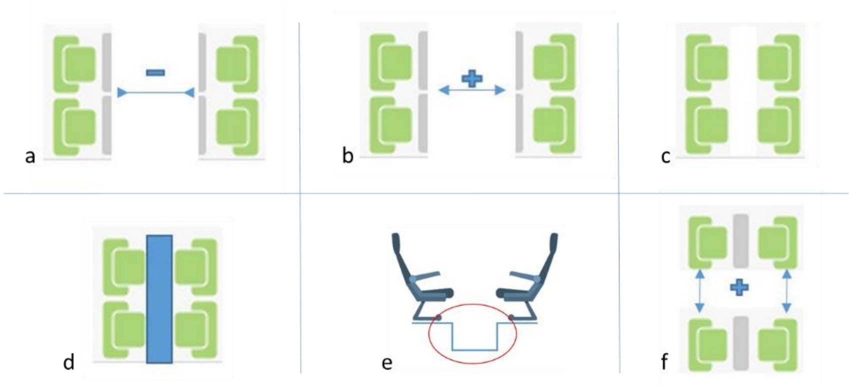


Figure 4-34: *Proposed solution inside the investigative survey*

All questions were imposed as mandatory in order to avoid non-response errors (Glasow, 2005; Groves *et al.*, 2004; Salant and Dillman, 1994; Stoutenborough, 2008). Furthermore, demographic data (gender, height and age) were asked at the end of the questionnaire for the sample identification and classification (Groves *et al.*, 2004).

Results of investigative survey

Three hundred eighty-three (383) people answered the online survey, 170 females and 213 males, aged between 13 and 59 but most of them were 17 and 30 years old. Table 4-9 shows the summarized information.

Table 4-9 *Statistical data of participants' age and height*

	Range	***Mean***	***Standard deviation***	***Median***	***Mode***
Age	13 – 59	24.92	6.77	23	21
Height (cm)	149 - 200	172.15	10.35	172	170

Table 4-10 shows the results of the first part of the online survey regarding respondents' experience in trains as passengers. The train, as a means of transport, is used by 70% of respondents and only less than half of them travelled by high-speed train. Furthermore, the possibility of touching the other passenger legs is high as the discomfort feeling. Then, only 57,70% of the respondent stated the table surface is large enough for their needs, and 51,17% of them felt quite comfortable with the current facing-seats configuration. According to these results, modification of the existing seat layout is needed in order to improve perceived comfort.

Table 4-10 *Questions and results from the online survey about the passengers' experience on trains*

Questions	*Many times (once a week)*	*Few times (once per month)*	*Rarely (1-3 times per year)*
Do you travel by train?	33,16%	37,08%	29,77%
Have you ever used high-speed train?	17,75%	55,87%	26,37%
Did you happen to sit in the facing-seat configuration inside trains?	27,15%	37,60%	35,25%
In facing-seats configuration, have you ever touched the front passenger's legs?	27,94%	35,25%	36,81%

As far as the second part of the online survey, the proposed solution most selected was the possibility of increasing the distance between facing-seats (70%), followed by the need to increase the table surface (40%), to create more space below legs (2 people out of 5), and to increase the distance between adjacent seats (30%).

Thus, according to these results, there is the need to increase distances between facing-seats and this could be influenced mainly by two factors: postural comfort, (Commentale *et al.*, 2018; Helander and Zhang, 1997; Naddeo, Cappetti, *et al.*, 2013; Naddeo, Cappetti, Vallone, *et al.*, 2014; Naddeo, Cappetti, *et al.*, 2019; Naddeo and Memoli, 2009a; Zhang *et al.*, 1996) or passengers' wellbeing on seats or during a journey (Bouwens *et al.*, 2018; Kilincsoy *et al.*, 2014; Vink, 2016), and social interactions (Dumur *et al.*, 2004; Hall, 1966; Madanipour, 2003; Sommer, 1969; Sorokowska *et al.*, 2017). Indeed, during social interactions, people surround themselves with implicitly defined and organized space, which is internalized at an unconscious level (Dumur *et al.*, 2004; Hall, 1966; Madanipour, 2003; Sommer, 1969; Sorokowska *et al.*, 2017). Respecting this space in a defined environment could improve comfort during social interaction. Consequently, the relation between facing-seats' distances and passenger wellbeing in terms of postural comfort and social interactions (personal space or social proximity) was analyzed in this paper.

The research question is: *Given the anthropometric variability of people, which could be the suitable leg space for the facing-seats configuration inside vehicles for improving postural comfort considering social interactions?*

Literature basis for the experiment

Prior conducting experiments, literature studies about human body movements had been done. Human body movements, in amplitude and frequency, can be a good indicator of the postural comfort/discomfort perception evolution-in-time. As shown in (Fasulo *et al.*, 2019) amplitude and frequency of body movement are related to the variation of comfort in time, especially while seated. Moreover, the same concept was confirmed in several studies, such as Telfer et al. (Telfer *et al.*, 2009) that found a direct link between subjective discomfort and movement increases over time, with the amount of movement greater in chairs rated most uncomfortable. Also, Vergara and Page (Vergara and Page, 2002) proposed macro-movements as a good indicator of discomfort, and even Fujimaki and Noro (Noro *et al.*, 2004) found that discomfort increases over time. Based on literature studies, the subjects' movements were recorded and acquired during the experiments to monitor the discomfort perception objectively.

Images and videos are often used to identify and track the anatomical human-joints to acquire human posture and movements (Hung *et al.*, 2004; Jung *et al.*, 2017; Naddeo, Cannavacciuolo, *et al.*, 2018). The Infrared camera motion capture systems (Frankton, 2018) are accurate and can capture the motions at a relatively high frequency, but at a high cost. Alternative solutions, e.g., using a motion capture-analysis system combining HD VideoCam and Kinovea software (Commentale *et al.*, 2018; Muaza Nor Adnan *et al.*, 2018), were explored by researchers. Among those solutions, using fiducial markers can be a useful solution due to easiness in the setup and the growing availability of high-resolution cameras (Avola *et al.*, 2016; Hung *et al.*, 2004). For instance, by attaching the ArUco Markers (Avola *et al.*, 2016; Garrido-Jurado *et al.*, 2014; Kam *et al.*, 2018; Mondéjar-Guerra *et al.*, 2018; Zubair *et al.*, 2017) to anatomical points of a participant, body postures, as well as the motion, can be estimated based on 3D position, orientation and trajectory of this anatomical points. The adoption of video recording with a body tracking system in combination with a well-structured questionnaire (Corlett and Bishop, 1976; Grinten, 1992; Joshi *et al.*, 2015) is useful to evaluate human postures and social interactions (Fiorillo, Piro, *et al.*, 2019a). Thanks to data acquisition, subjective and objective data have to be compared in order to validate the experiment itself (Fiorillo, Piro, *et al.*, 2019a; Piro *et al.*, 2019a).

The research question is: *Considering the anthropometric variability of people, which could be the suitable leg space for the facing-seats configuration inside vehicles for improving both postural comfort and social interactions?*

Materials and methods

Experimental setup

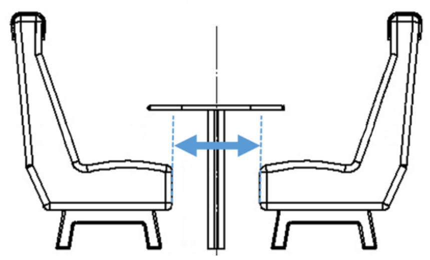
Experiments measures and layout were imagined for a general-purpose autonomous vehicle. The basic idea was to create a layout with facing-seats and a table in between. As a matter of fact, some concepts of future cars are adopting the layout of facing seats with a table in between, such as the Panasonic Concept (Weiss, 2017). However, there are no specific distances for facing-seats inside future vehicles. Thus, an existing four-seats layout of the wagon of Frecciarossa ETR 1000 – Economy Premium Class was used for experiment layout to recall a real situation that could be familiar for participants. So, the configuration with two facing-seats was simulated inside the Design Engineering Method lab at the University of Salerno through a fully reconfigurable seating buck, by adopting the real measures of train layout. Two seats that faced each other and a foldable table between them were used (Figure 4-35). Since the concept was for autonomous vehicles or future cars, it was hypothesized that a standard car-seat should be used as referral seat. The height of car-seats was increased up to reach the train-seat one: it was acceptable (under a car-cabin design point of view) because authors hypothesized to overcome some limitations due to standard vehicle height, driving position and to safety requirements, like anti-submarining shapes. This change allowed people to have a more relaxed and natural position for the legs, like being on a sofa or an office chair (Groenesteijn *et al.*, 2012; Naddeo, Cappetti, *et al.*, 2019).

In order to focus on facing-seats configuration distances, two automotive seats of Fiat Grande Punto with a previously comfort-assessed lumbar supports (Naddeo, Di Brigida, *et al.*, 2019) were used, avoiding the lumbar pain due to the long-time sitting (Naddeo, Di Brigida, *et al.*, 2019). The angle at backrest was 101 degrees, a comfortable angle for seat car (Naddeo, Di Brigida, *et al.*, 2019). The seats were translated on a linear guide in order to set different distances (Figure 4-35). This setup allowed to reproduce the previously experienced comfortably posture (with a change only in knee and ankle bending angles) and to reduce the lumbar effect (Naddeo, Califano, *et al.*, 2019) on overall perceived (dis)comfort.

Four configurations were tested (Table 4-11), starting from the minimum distance of 44 cm, the one present in the current trains, to the maximum of 65 cm, with an interval of 7 cm between configurations. Moreover, considering future car concepts, starting from the reference configuration and considering the rear seat fixed in the back of the vehicle, the distance of 65 cm was obtained with the maximum reachable distance along a linear guide. As a reference point, the outer extremity of seat pan was chosen due to its simple individuation and measurement.

Table 4-11: *Configurations tested*

Configuration name	Distance between facing-seats [cm]
A	44
B	51
C	58
D	65



During the experiment, cards with the current configuration name and distance were used (Figure 4-35). The choice of assigning a letter and color for each distance was meant even to help participant remembering the tested configuration through the visual memory. Three digital SLR (Single Lens

Reflex) cameras (one Nikon D3100 and two Nikon D3300) were used to record videos from three different views, two side views and one top-view. The two side-cameras were mounted on tripods at 1520mm from the table center in order to obtain an image large enough to capture legs movements, and the top-camera on a linear guide in order to achieve the legs abductions. The cameras were connected via USB cables to a central computer to monitor the three views simultaneously in real-time with the video recording software DigiCamControl. For the video-recording, frame size of 1920x1080 pixels and an acquisition frequency of 24fps was chosen.

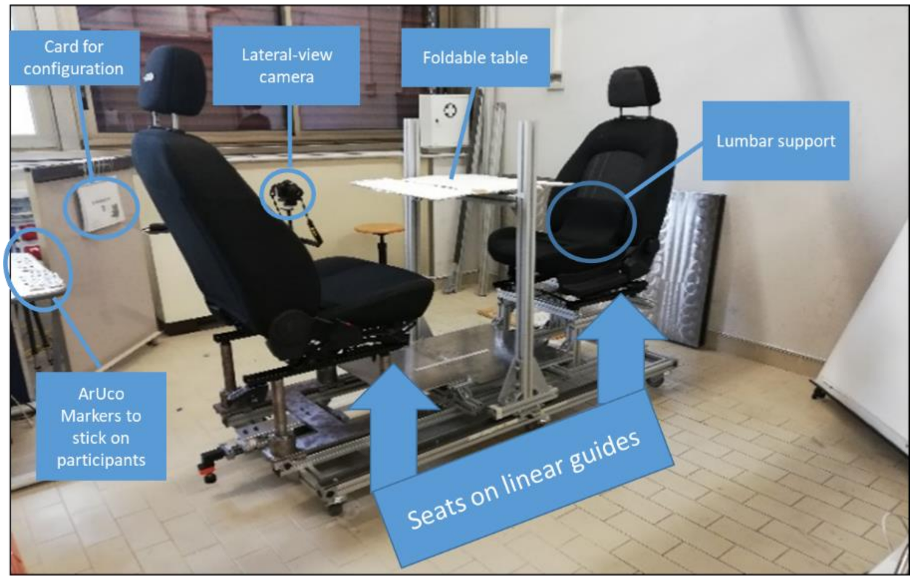


Figure 4-35*: Experiment set-up*

Questionnaire:

Questionnaires were used to evaluate the comfort of participants for each configuration. Before the experiment, information about gender, age, stature and weight were gathered. Moreover, thigh (along the femur. from the great trochanter to lateral condyle), calf (from the head of tibia to medial malleolus of ankle) and foot lengths were measured with a measuring tape. After testing each configuration, participants were asked to fill the questionnaire while remaining seated. The questionnaire consists of:

- questions on Localized Postural Comfort (LPC), based on the Van der Grinten's work of LPD (Localized Postural Discomfort) (Grinten, 1992), to rate on a 7-point scale the perceived comfort (from 1="No comfort" to 7="Maximum Comfort") on the lower-body (lumbar zone, thigh, calf, foot);
- an overall rating for body comfort (on a 11-point scale, from 0="No comfort" to 10="Maximum Comfort");

- two statements on the psychological perception of social interactions using a 7-point Likert scale (Joshi *et al.*, 2015): 1) Did you feel at ease? (from -3="Extremely disagree" to 3="Extremely agree"), and 2) Did you feel invaded in your personal space? (from -3="Extremely disagree" to 3="Extremely agree");;
- one statement to check if the table surface was large enough for their needs rating on a 7-point Likert scale (from -3="Extremely disagree" to 3="Extremely agree");
- a close question (with adjectives) to express a judgment on the tested configuration: "How do you feel about this configuration? Cozy, Adequate, Indifferent, Annoying, Intrusive, or Other (specified from participants)".

The visual map of the LPD was included to clearly show body regions to the participants allowing them to give an immediate response without losing the discomfort perception (Bouwens *et al.*, 2018; Fiorillo, Piro, *et al.*, 2019a; Hiemstra-van Mastrigt *et al.*, 2015; Hiemstra-van Mastrigt, Meyenborg, *et al.*, 2016; Piro *et al.*, 2019a; Van Veen *et al.*, 2015). The adoption of short-term sessions (10 minutes for each configuration) (Zenk *et al.*, 2006) respected the aim of this study: to focus more on subjective comfort perceptions that are more related to psychological aspects (Helander and Zhang, 1997; Zhang *et al.*, 1996), and social experiences (Ahmadpour *et al.*, 2016; Fiorillo, Piro, *et al.*, 2019a; Piro *et al.*, 2019b). Furthermore, participants were asked to put a cross on the body map in the areas of legs that were more often in contact with the opposite seat occupant's ones. After testing all configurations, participants were asked, always through the questionnaire, to choose the preferred configuration and to explain the reason for it, answering the open question.

Participants

Participants were recruited among students of the University of Salerno to respect the age group (between 20 and 30 years old) with more experience in trains journey, per the online survey. Thirteen groups of two participants, 14 males and 12 females (26 participants in total), were analyzed. Table 4-12 shows the demographic and anthropometric data of participants.

The groups were heterogeneous per height and sex to reproduce as many cases as possible:

- about gender, five groups were selected using only men, four groups with only women and four mixed-sex groups;
- instead, for height, there are seven groups with participants of almost equal height (with a tolerance of ±5 cm) to each other and six groups with a very different height (combination of medium-high, medium-low, low-high height compared to the 50th percentile of the Italian population).

Table 4-12 *Demographic and anthropometric data of participants*

Males (n=14)	**Age**	**Height (cm)**	**Weight (Kg)**	**Euro Shoe Size**	**Thigh Length (cm)**	**Calf Length (cm)**
Mean	24.86	178.64	76.86	43.14	93.71	53.50
Max	27	205	100	48	105	63
Min	22	155	60	39	77	42
Median	25	180	76	43	95	54.5
Mode	24	180	70	42	95	56
Variance	1.72	124.60	153.00	5.51	40.06	28.04
Females (n=12)	**Age**	**Height (cm)**	**Weight (Kg)**	**Euro Shoe Size**	**Thigh Length (cm)**	**Calf Length (cm)**
Mean	23.75	164.42	58.92	38.50	91.83	50.42
Max	26	172	75	42	99	54
Min	21	156	53	37	87	46
Median	23.5	163.5	57	38	91.5	50.5
Mode	23	160	53	38	87	50
Variance	2.57	23.23	42.12	2.47	20.74	4.84

Through the R Software, a Shapiro-Wilk test was performed to verify whether data have Gaussian distribution: all data were positive to “normal distribution”.

Protocol

With a 7x10 checkerboard, all Nikon cameras before the experiment had been calibrated following the procedure suggested by OpenCV (“Open CV: calibration”, 2015). The purpose of the calibration was to identify the intrinsic parameters of each camera and use them to undistort the capture videos for better accuracy of the locations of ArUco markers (OpenCV, 2015b). Before starting the experiment, participants were informed about the nature of the study and asked to sign an “Informed consent” form as required by the Ethical Guidelines of the University of Salerno (IT). Personal information on gender, stature, weight, age and euro size foot were collected. Then, leg and calf lengths were measured by a flexible meter. All information gathered were treated anonymously. Indeed, each participant was identified with the group number and the letter of the seat where they sat (A or B).

Moreover, 32 ArUco markers were stick-on participants’ legs (Figure 4-36) to track legs movements. So, 8 specific positions for each leg were established to create vectors with 2 markers at least:

- For the thigh abduction, 2 markers were placed on top of the thigh. The presence of the table influenced the marker positions in order to be captured from the top-camera. Consequently, one was placed at the beginning of the thigh, on the femur line. The other was placed on the femur line, slight forward than the previous marker and before the table edge projection on the thigh.

- For the leg flexion and foot flexion, angles at the knee and ankle were needed, respectively. Principal anatomical landmarks were used as referral points: great trochanter (at hip level), lateral condyle (at the knee), and medial malleolus (at the ankle). Thus, 3 markers were used for referral points; other 2 makers were placed between referral points, on the femur line and tibia line, respectively. Then, 1 marker was placed at the end of the foot.

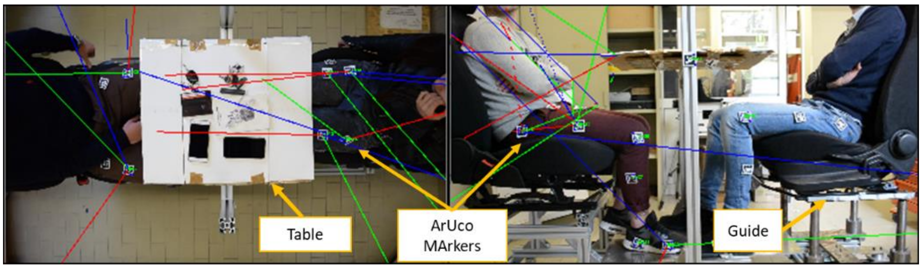


Figure 4-36 *Top and lateral views of the experiment – positions of ArUco markers are shown.*

With four different configurations and including the breaks, the complete experiment lasted approximatively 1 hour for each group:

- 5 minutes to collect anthropometric data and prepare the participants for the experiment
- 10 minutes in the first configuration
- 5 minutes of break
- 10 minutes in the second configuration
- 5 minutes of break
- 10 minutes in the third configuration
- 5 minutes of break
- 10 minutes in the fourth configuration

At the beginning of each configuration, participants were asked to assume their comfortable posture sitting upright, leaning on the backrest and raising their legs at 90° without abduction for 10 seconds: this was the reference posture in order to calculate the leg angles as the deviation from the assumed starting posture. Then, participants were left alone freely performing some activities for 10 minutes while their legs movements were recorded. A central computer remotely controlled recordings from cameras throughout the experiment. The performing freely any activity, such as the use of notebooks or smartphones, chatting, playing cards, studying, reading and consuming food and drinks, have led to more considerable variability in the experiment and was meant to simulate a real situation inside vehicles. After 10-minutes-configuration, participants were asked to fill the questionnaire while remaining seated to be aware of their perception (Vink, 2016). Then, they had a 5-minutes break to minimize the effects of postural discomfort over time (Vink *et al.*, 2014) before to set a different seat distance. After experiencing all configurations, each participant was asked to choose the preferred configuration and the reason for choosing it. For different groups, the order of the configurations was different for each pair, determined by using Latin square (Fisher, 1992).

Data analysis

In order to acquire the legs movements, videos were processed with a self-developed Python™ program to obtain 3D coordinates of different markers (Ferrão *et al.*, 2018; Fiorillo, Piro, *et al.*, 2019a; Mondéjar-Guerra *et al.*, 2018; OpenCV, 2015a, 2015b). Since each marker represents a point in the 3D-space, vectors for each leg part had been created by selecting the corresponding markers.

For each participant, two vectors for thigh abduction were obtained selecting the markers on the left and right thigh respectively (from the top-view camera). Leg flexions were calculated through two vectors on the lateral side of the leg obtained selecting the corresponding markers on the thigh and the calf (from the lateral-side cameras).

These vectors were used to track the legs movements compared with the reference posture gained within the first 10 seconds of video recording, where participants had to stand still in that posture. Consequently, angles between the rest posture vector and the other vectors were calculated to obtain angles over time using MatLab®. Histograms with angles frequencies and probability distribution were calculated with R software, while scattered plots with trend lines through MatLab® software.

Finally, all questionnaire data and detected angles were analyzed using IBM® SPSS® Statistics (version 24) to analyze correlations.

Results and discussions

Questionnaire results

Table 4-13 shows the results of the Body Part Comfort questionnaire (n=26):

- The comfort level of the Lumbar zone remained the same through the four configurations. Thus, the presence of lumbar supports helped participants to focus more on the problem of the distance of the facing-seats than the other factors that could influence the perceived comfort. This aspect significantly strengthened the effectiveness of the lumbar support prototype (Naddeo, Di Brigida, *et al.*, 2019) and justified the use of an automotive seat instead of a train seat.
- Apart from the lumbar zone, perceived comfort levels are higher in configuration D (65 cm). Also, the thigh scored the same comfort level in configurations B (51 cm) and D.

- The foot comfort perception presented the highest variance values; thus, data are more dispersive than the other lower limbs areas;
- The configuration A (44 cm) scored the lowest perceived comfort values for the calf and foot, while scored the same comfort level of configuration C (58 cm) for the lumbar zone and thigh.

Table 4-13 *Results from the Body Part Comfort questionnaire rated on a 7-point scale (1=no comfort; 7=maximum comfort) of 26 participants. Me=Mean; Mo=Mode; V=Variance.*

	A			B			C			D		
	Me	*Mo*	*V*	*Me*	*Mo*	*V*	*Me*	*Mo*	*V*	*Me*	*Mo*	*V*
Lumbar Zone	5.46	6	2.34	5.54	6	1.86	5.27	6	2.52	5.38	6	2.41
Thigh	5.19	6	1.44	5.54	6	1.54	5.15	5	2.46	5.54	7	2.18
Calf	3.92	3	2.55	4.77	5	2.1	4.92	5	1.59	5.12	6	2.35
Foot	3.77	3	3.54	4.58	5	2.89	4.92	5	2.63	5.31	6	2.38

Furthermore, Table 4-14 shows the areas that are most subject to contact during the experiment. As expected, the higher distance between facing-seats, the lower contact probability.

Table 4-14: *Areas most subject to contact during the experiment (Values are the participants' crosses)*

Configuration / *Area*	**A (44 cm)**	**B (51 cm)**	**C (58 cm)**	**D (65 cm)**
No contact	6	7	13	16
Foot	17	18	12	9
Calf	8	5	2	2
Elbow	0	0	1	0

The global comfort scored the highest value in configuration D, slightly overcoming the one of configuration B (see Table 4-15). On the other side, configuration D presents the highest variance, while configuration C the lowest one. It means that collected data for configuration D are more dispersive than configuration B. Moreover, configuration A, that represents the referral distance (coming from train design experience), scored the lowest value of global comfort. There were no significant differences between males and females.

Table 4-15: *Results from questionnaires about the global comfort, rated on a 10-point scale (0= no comfort, 10=maximum comfort) of 26 participants (A=44 cm; B=51 cm; C=58 cm; D=65 cm).*

	GLOBAL COMFORT		
	Mean	Mode	Variance
A (44 cm)	5.88	5	4.11
B (51 cm)	6.62	8	3.69
C (58 cm)	6.54	7	4.74
D (65 cm)	6.73	10	8.6

Through the Wilcoxon Sign Test calculated in SPSS, there was a significant difference between configuration A and B, with p-value=0.003 and significant for $p<0.005$ but there were no significant differences between configurations B, C, and D.

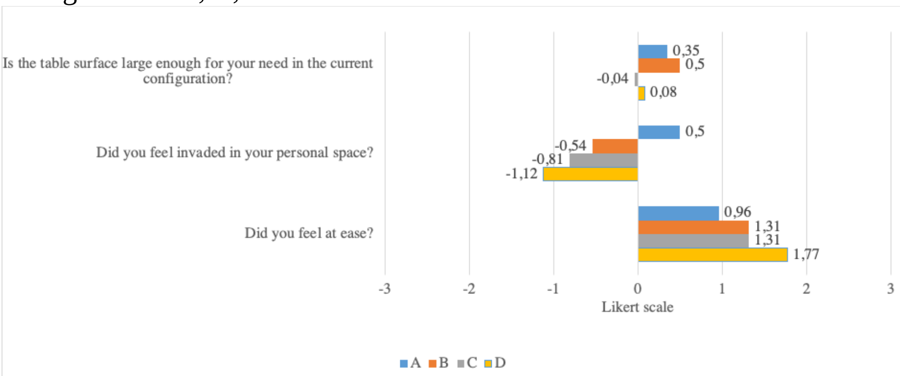


Figure 4-37 *Results from questionnaires about the social interactions (n=26), questions were rated on a 7-point Likert scale (-3=Extremely disagree, +3=Extremely agree).*

Figure 4-37 shows the results gained from the second part of the questionnaire related to social interactions. Participants felt invaded in their personal space in configuration A (44 cm), while the table surface is large enough in configuration A (44 cm) and B (51 cm). They felt more at ease in configuration D (65 cm), followed by B (51 cm) and C (58 cm). It means the need for an improved design that involves an increased facing-seats distance and a larger table.

According to Table 4-16, the feeling of cosy is higher as the distance increases. Nevertheless, configuration D presents conflicting feelings of “Adequacy” and “Annoyance” at the same level. Thus, the overall best configuration was the one with facing-seats at 51 cm distant (configuration B).

In summary, with the results relating to the specific questionnaires, it emerged that the most appreciated configurations are D (65 cm) and B (51 cm).

Table 4-16 *Results from the questionnaires related to the adjectives to describe the feelings about a configuration (n=26)*

How do you feel about the configuration…	A (44 cm)	B (51 cm)	C (58 cm)	D (65 cm)
Cozy	11%	15%	23%	27%
Adequate	23%	39%	23%	34%
Indifferent	19%	23%	31%	4%
Annoying	31%	19%	19%	31%
Intrusive	12%	4%	0%	0%
Other	4%	0%	4%	4%

As far as the preferred configuration (see Table 4-17), analyzing also the open-question where participants were asked to explain the choice reasons, 42% of participants preferred configuration B (51 cm) because it represents the best compromise in terms of personal space and table reachability (and consequent usability). Configuration D (65 cm) is optimal for who prefers having more space for legs. Also, this result was disaggregated according to gender and stature, as shown in Table 4-17:

Table 4-17 *Results of the preferred seat configuration gathered from questionnaires (n=26), and disaggregation of results according to gender and stature*

		Configurations			
Aggregated Data		**A (44 cm)**	**B (51 cm)**	**C (58 cm)**	**D (65 cm)**
Preferred seat configuration for 26 participants		8%	42%	19%	31%
Disaggregated Data		**A (44 cm)**	**B (51 cm)**	**C (58 cm)**	**D (65 cm)**
Gender	Males (n=14)	7%	43%	14%	36%
	Females (n=12)	8%	42%	25%	25%
Stature	Population ≤ p50 (n=9)	11%	56%	11%	22%
	Population > p50 (n=17)	6%	35%	24%	35%

The choice of preferred configuration did not depend on gender but only on stature. Indeed, participants belonging to the population lower than 50th percentile chose mostly the configuration B (51 cm), while the population higher than 50th percentile chose the configurations B (51 cm) and D (65 cm) equally. From these results, it emerged that a greater distance corresponds to a higher sensation of "own space". Configuration B (51 cm) that is larger than the configuration A (44 cm) of only 7 cm scored high comfort values like configuration D (65 cm). If the goal had been not to make changes to the table, configuration B would be the most suitable for this purpose. Configuration D was not considered the best one due to the distance between the seat and the table that worsened the usability of the table itself.

Angles results

Thanks to the utilization of ArUco markers, and analyzing data through Python™ and MatLab®, postural angles of lower limbs was detected. The leg flexion was obtained calculating the angle between the vectors on the thigh and the calf for each side and each participant; it is, the knee angle. While the leg abduction was detected as angle variation of each thigh respect to the rest posture through the top-view camera, it is, the angle of the single thigh variation. Through R software, statistical analysis was performed by calculating angles frequency and probability distribution. For the leg flexion (Figure 4-38), configuration A (44 cm) showed lower angle values than the other three configurations, but configuration B (51 cm) presented a Gaussian probability distribution; this means participant used to assume the same posture in this configuration for more time towards the others.

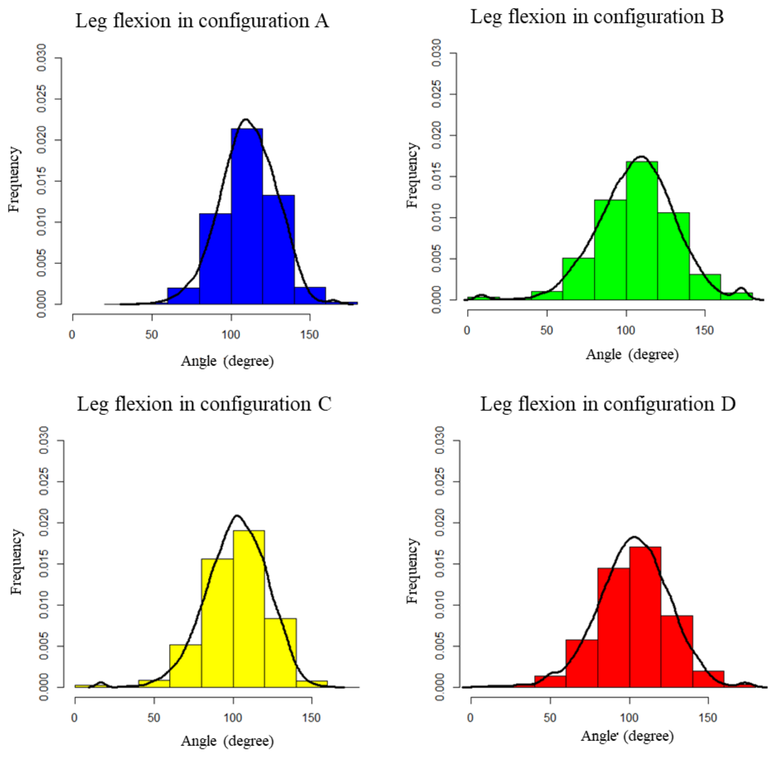


Figure 4-38: *Leg flexion angle frequency and Probability Distribution in each configuration.*

As far as the leg abduction (Figure 4-39), in configuration A (44 cm) participants used to change frequently the thigh's position on the seat, as demonstrated to the broad range of angles and the absence of a Gaussian curve, due to the legs contact with the facing participant and the limited movements space. Instead, the other three configurations presented a narrow angles range going from 0° (that represent the initial position) to 50° around, and Weibull distribution.

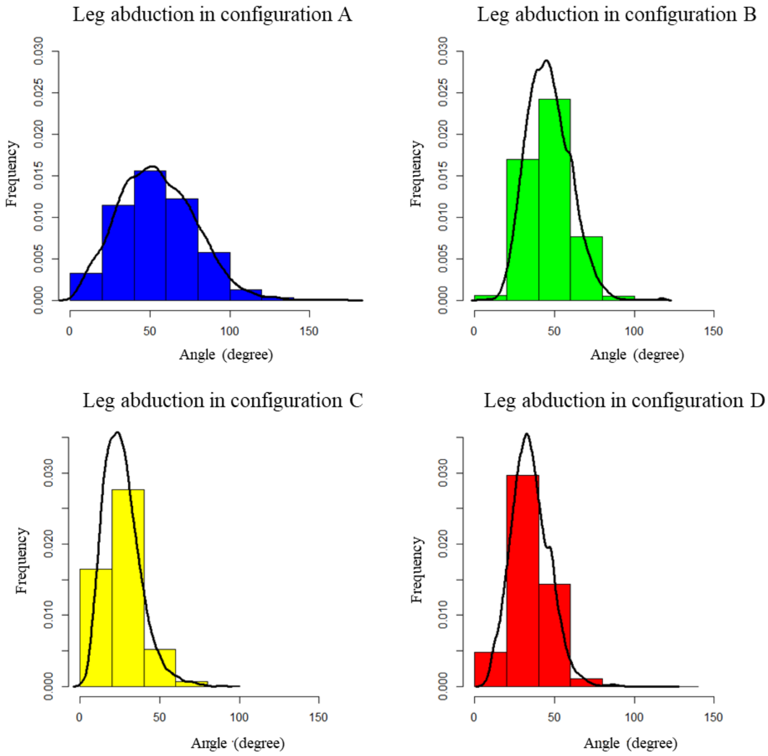


Figure 4-39 *Leg (or thigh) abduction angle frequency and Probability Distribution in each configuration*

As far as angles over-time, scattered-plots were created overlapping the MatLab® graphics of angles over-time for each participant (Figure 4-40 & Figure 4-41). For each frame of a configuration, an average angle of the 13 groups was calculated. Thus, scattered-plots of angles in degrees on the ordinate axis (which range between 0° and 180°) and time in seconds on the abscissa axis (which maximum value is 600 seconds that corresponds to 10 minutes) were plotted for each configuration. Then, for better clarification, a trend line was obtained through the MatLab® "polyfit" function, choosing a third-order polynomial trend line.

As already seen in the histograms, the angles of leg flexion (Figure 4-40) have taken on values around 100°, within a range of 60° and 140°. As for the trend lines, in configuration A (44 cm), the trend line has grown without undergoing oscillations, reaching the angle of 120° at the end of the session. In configuration C (58 cm), participants used to start with a flexion angle of 115°, then to reach almost 90° at the end. While configurations B (51 cm) and D (65 cm) presented trend-lines oscillating around 100°.

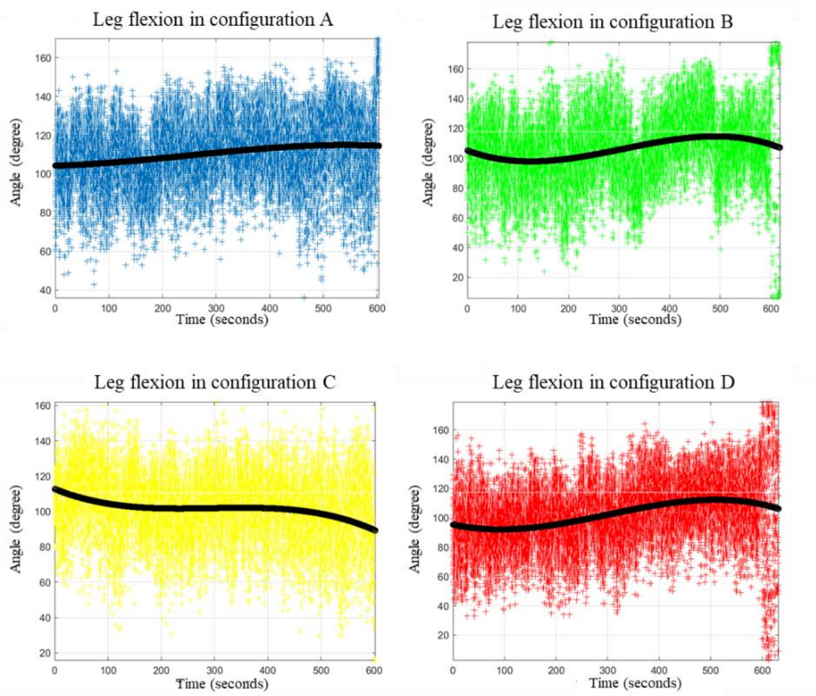


Figure 4-40*: Scattered plots and trend lines for leg flexion*

Regarding the leg abduction (Figure 4-41), scattered-plots gave further information. As was shown in the histograms, in configuration A (44 cm) participants assumed higher angles than the other ones, but there was also a higher angles dispersion. The phenomenon could be interpreted as a continuous search for comfortable posture due to the legs invasion by the facing participant. In case B (51 cm), the value of the trend line started from 30° and grew until it reached 50°, remaining constant afterwards; this means the reach of comfortable posture. This result is aligned with the finding from questionnaires and confirms literature studies (Fasulo *et al.*, 2019; Noro *et al.*, 2004; Telfer *et al.*, 2009; Vergara and Page, 2002), it is, the more movements, the higher is the probability to perceive more discomfort. Indeed, fewer changes are present in case B (51 cm), so, participants perceived higher comfort in case B than case A (44 cm). Moreover, Case C (58 cm) presented the smallest angles among the four configurations but the trend line, as for case D (65 cm), grew slowly, without reaching a constant value.

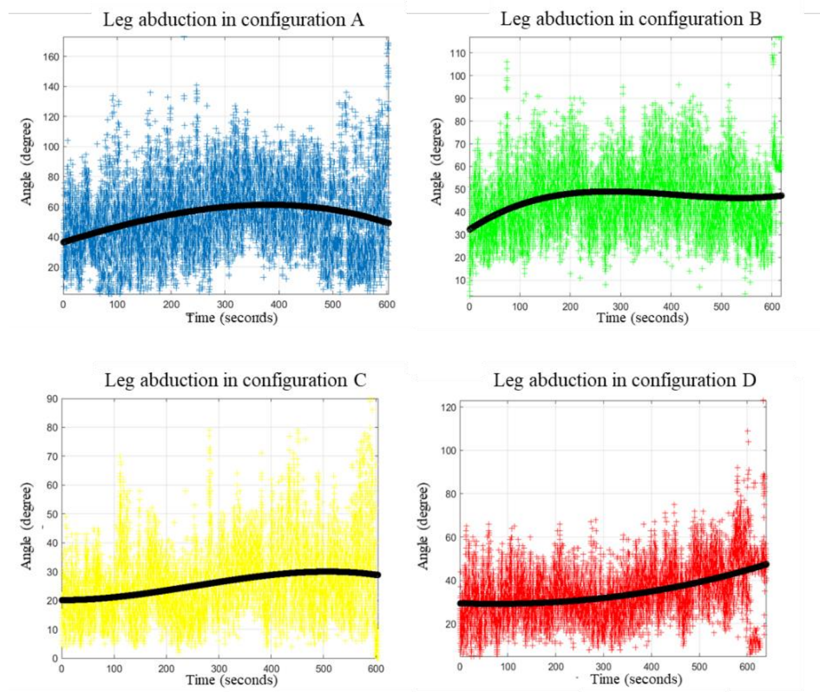


Figure 4-41 *Scattered plots and trend lines for leg (or thigh) abduction*

Correlations

Since the angles had non-parametric distributions, Spearman's bivariate correlation analysis was calculated with SPSS for each configuration. Table 4-18 shows the most relevant correlations found between subjective data and the objective data of leg flexion:

Table 4-18: *Correlations between leg flexion angles and other variables*

Locations	*Correlation between:*	**LEG FLEXION ANGLES**
From the Body Part Comfort Questionnaire	**THIGH COMFORT**	In configuration A: p = -0,484*
	CALF COMFORT	In configuration D: p = 0,523**
	FOOT COMFORT	In configuration D: p = 0,482*
From questions regarding the social interactions	**FEELING AT EASE**	In configuration B: p = 0,419* In configuration D: p= 0,484*
	SURFACE TABLE ADEQUACY	In configuration C: p = -0,427*
From the adjectives about the perceived feelings	**INTRUSIVE FEELING**	In configuration A: p = 0,410* In configuration D: p = -0,460*

*** The correlation is significant at level 0.01 (2-queues)*
** The correlation is significant at level 0.05 (2-queues)*

In configuration A (44 cm), increasing the leg flexion angle decreases the thigh comfort and increase the intrusive feeling, because the distance is not large enough for two passengers seated on facing-seats. Furthermore, the table limits the visual of facing passenger's legs, not allowing changing postures without touching the legs' others. In configuration B (51 cm), the feeling at ease is positively correlated with leg flexion angles. Indeed, as before mentioned, participants preferred this configuration because it represented the right compromise for postural comfort and social interactions. Already in the configuration C (58 cm), the table surface is not adequate for passengers' needs due to the distance, while in configuration D (65 cm), the postural comfort and the positive feelings increase. Moreover, there were negative correlations between height and the "cozy" sensation in configurations A (p=-0.410*), B (p=-0.499**), and C (p=-0.451*): this means the coziness perception is lower for participants higher in facing-seats configurations with smaller distances.

Conclusions

Through an investigative survey, it had been found out that passengers are not satisfied with the current distance between facing-seats. Consequently, the research question was: considering the anthropometric variability of people, which could be the suitable leg space for the facing-seats configuration inside vehicles for improving both postural comfort and social interactions?

In order to answer the research question properly, four distances between facing-seats had been analyzed. The minimum distance was 44 cm (configuration A), and it represented the leg space between two facing-seats from train design experience (wagon of Economy Premium class of the Frecciarossa ETR 1000 train). The other three distances were 51 cm (configuration B), 58 cm (configuration C) and 65 cm (configuration D – suitable for the future autonomous cars, as seen in the current concepts, as the one of Panasonic (Weiss, 2017)). Subjective data were gathered through questionnaires to evaluate postural comfort and feelings related to social interactions while legs movements and postural angles were tracked through the utilization of ArUco Markers.

Thirteen couples of participants (12 females and 14 males) experienced the configurations. The height ranges were 155-205 cm for males and 156-172 cm for females; so, the sample represents a wide Italian (or international) population, including P5 female and P95 male. Moreover, real situations of people of different height travelling together were represented with this sample. Seven groups with participants had almost equal height (with a tolerance of ±5 cm) to each other. Six groups had a very different height (a combination of medium-high, medium-low, low-high height compared to the 50th percentile of the Italian population).

Results showed that the suitable distance for facing-seats configuration is 51 cm (configuration B) because it represents the perfect compromise between postural comfort, social interactions and table reachability, satisficing a wide population range. Reducing this distance, feelings of comfort were decrescent. This aspect was confirmed from questionnaire results and analyzing the body movements. Indeed, literature studies showed that small movements in a static posture are indicators of perceived discomfort. In this configuration, participants reached a comfortable position assuming it for a prolonged amount of time. Besides, the distance of 65 cm (configuration D) leads to postural comfort but lacks on the table reachability and, consequently, usability; thus, new table design is required. Also, the analysis of the movements showed the presence of small movements in this configuration, indicating the need for improvements, confirmed even by the presence of negative correlations between height and the “cozy” sensation in configurations A, B, and C.

Thus, this work is able to give guidelines for further autonomous vehicles design considering the postural comfort and the respect of social interactions, respecting the findings of literature studies.

Furthermore, in this work, ArUco Markers had been used to detect body movement during the performed activities, allowing people to move freely like as they were inside train (Fiorillo, Piro, *et al.*, 2019a). The precision of the acquisition method, as well as the fact that by not using complicated, expensive acquisition methods, gave us the possibility to obtain the remarkable results shown in this paper. Indeed, the movements of all lower limbs’ joints were analyzed and correlated with the physical parameters of setup (distances) and anthropometric characteristics of participants. Furthermore, the movements have also been correlated with the perceived comfort and the sensation of invasion, obtaining noteworthy results of interpretation. The technique can be easily reproduced for other applications.

Limitations

Some limitations of this study need to be acknowledged. Firstly, the group of participants were homogenous, as they were all young (20-30 years). However, the preliminary survey showed that young people do travel more on trains; thus, this sample might represent the group involved in this trend. Further research on different age groups using the same protocol is recommended.

Data regarding the feet movements were missing due to the presence of physical objects at feet level that did not allow the correct detection of markers on feet. Thus, another solution is recommended in order to detect movements of all leg parts. However, in this case, leg flexion and abduction were enough to obtain valid data.

Ingress and egress problems were neglected because they are not the focus of this study. Further studies are needed to understand what happens by putting four seats together with just one access on one side (train layout). This aspect can be neglected in autonomous vehicles with bilateral access (car layout). Nevertheless, the study was conducted with the hypothesis of a partial foldable table (like the ones installed in the high-speed trains), and that solved the ingress/egress problems also in the case of four seats with single side access.

Side interaction between people and, particularly, between upper limbs (arms and shoulders) were neglected in this study. This aspect obviously affects the whole postural comfort and needs to be investigated in further experiments. Nevertheless, several results were already shown in (Kremser *et al.*, 2012; Vink, 2016) and highlight how the chosen seat is comfortable for its width.

Influences of seat height on comfort have not been investigated in this study since the focus was on the facing seats distances at fixed height inside the future vehicles. Thus, it is recommended to make further studies considering the variation of seats height and related comfort perceptions.

Fiat Punto car seats had been chosen out of convenience and for the presence of lumbar support for the postural comfort on the lumbar area. Further researches with different seats are recommended. Also, in this study, the presence of a table with fixed dimensions was considered to focus more on facing-seats distances. This aspect could have influenced experiment results in term of table reachability since with larger distance could be expected a larger table. Thus, it is also recommended to investigate further influences of both table differences in size or styles and the absence of the table on passenger wellbeing.

Acknowledgements: We want to thanks our colleagues for their support, and all participants who kindly took part in this study.

4.4 Predictive analysis: CA-Man – Vehicle ergonomic assessment

Spending prolonged periods in a vehicle increases the risk of experiencing discomfort or body aches. Drivers are bound to their driving position in terms of the position of the seat, steering wheel and dashboard. Passengers are limited by vehicle space or environment and perform activities. Designing the vehicle without ergonomic assessment could increase risks of discomfort, body aches, or in the worst case, musculoskeletal disorders. Small changes in how the vehicle is set up can significantly affect a (occupational) drivers' and passengers' long-term health. It is also important to note that poor vehicle ergonomics increase driver fatigue, a key contributor to accidents on the road.

A vehicle ergonomic assessment is an objective measure of the risk factors in a vehicle that may lead to musculoskeletal disorders. Once these risk factors were identified and quantified, improvements can be made. Some possible modifications concern the seats, panel instruments and vehicle occupancy. At its core, conducting a successful ergonomic assessment is a process of evaluating the environment, the human, products, and humans' interactions with the environment and products.

However, ergonomics assessment tools available in the public domain can analyze the ergonomic risk factors in a workplace but cannot be applicable in a vehicle properly. For instance, considering some known ergonomics assessment tools:

- The *NIOSH Lifting Equation* (Konz, n.d.; R. Waters *et al.*, 1993) was developed to help predict the risk of lifting injuries. The Lifting Equation defines a Lifting Index (LI) based on the Recommended Weight Limit (RWL) for specific lifting tasks that most workers could perform in an eight-hour day without increasing the risk of developing low back pain.
- The *Rapid Entire Body Assessment* (REBA) (Hignett and Mcatamney, 2000) was created to "rapidly" evaluate the risk of musculoskeletal disorders (MSD) associated with certain job tasks. The Rapid Entire Body Assessment tool uses a systematic process to evaluate the musculoskeletal system's upper and lower parts for biomechanical and Musculoskeletal Disorders (MSD) risks associated with the job task being evaluated. A single-page worksheet can be used to evaluate required or selected body posture, forceful exertions, type of movement or action, repetition, and coupling.
- The *Rapid Upper Limb Assessment* (RULA) (McAtamney and Nigel Corlett, 1993) was developed to "rapidly" evaluate the exposure of individual workers to ergonomic risk factors associated with upper extremity MSD. The RULA ergonomic assessment tool considers biomechanical and postural load requirements of job tasks/demands on the neck, trunk and upper extremities.

- Liberty Mutual Manual Material Handling Tables (SNOOK Tables) are based on Snook & Ciriello's research (Potvin *et al.*, 2021). The tables provide design goals, in pounds of weight or force, that are deemed to be acceptable to a defined percentage of the population.

These tools were configured for workplace analysis at manufacturing sites and have only limited applicability to mainly static seated (work) postures in vehicles. Thus, could be useful to introduce another tool for vehicle (dis)comfort assessment.

4.4.1.1 The importance of CA-Man software in vehicle (dis)comfort assessment

Since human motion is based on joint movements, accessibility and repetitive actions are highly relevant in the ergonomic evaluation of the vehicle; therefore, a posture analysis tool is recommended. The CA-Man® software, based on experimental studies conducted by A. Naddeo and N. Cappetti (Naddeo, Cappetti and D'Oria, 2015a), aims to perform a postural analysis through (dis)comfort indexes.

4.4.1.2 Definition of ROM, CROM and RRP

The human body can perform active or passive movements through articular joints. Each articular joint has a Range Of Motion (ROM) (Hallaceli *et al.*, 2014; Lantz *et al.*, 1999; Lee *et al.*, 2004), a joint movement extent measured in degrees of a circle. The natural Rest Posture exists within the ROM (Christensen and Nilsson, 1999), where human muscles are entirely relaxed or at the minimum strain level. This position seems to minimize musculoskeletal disease and optimize comfort perception. Naddeo et al. (Apostolico *et al.*, 2014a; Naddeo, Cappetti and D'Oria, 2015a; Naddeo, Cappetti, *et al.*, 2019) described the comfort ranges of upper limbs (neck, shoulder, elbow, and wrist) and lower limbs (hip, knee, and ankle), demonstrating that comfort presents higher values within the Range of Rest Posture (RRP). He defined the existence of three ranges (Figure 4-42):

- Range of Motion (ROM)
- Comfort Range of Motion (CROM) within the ROM, a subset of position in which humans feel to stay in comfort.
- Range of Rest Posture (RRP) within the CROM where the comfort assumes the highest values.

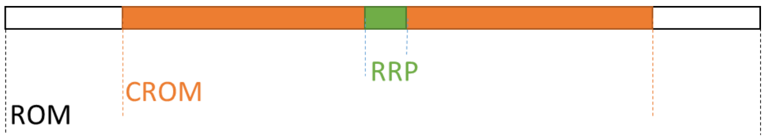


Figure 4-42: *Example of ranges definition*

Within the CROM, Naddeo described postural comfort curves for each joint. Comfort indexes are rated on an 11-point scale where 0 = ”no comfort” and 10 = ”maximum comfort”. These comfort indexes consider the limbs moving freely in the space, without any physical support. For instance, considering the neck movements, Figure 4-43 shows the CROM for each movement and the comfort curve associated with lateral flexion and rotation. In RRP, the comfort values are higher.

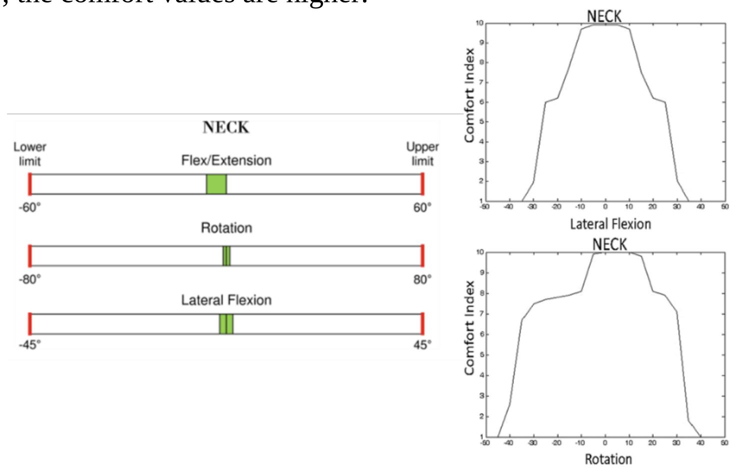


Figure 4-43: *Comfort Curves for neck*

4.4.2 The CA-Man software: from the first to the last version

Thus, for each assumed postural angle, a comfort index is associated. Through predictive postural analysis, it is possible to identify comfortable postures. The CA-Man® (Comfort Assessment for Man) software was created through MatLab, using the GUI that recalls the mathematical comfort curves. Comfort curves of upper limbs were studied by Naddeo, Cappetti and Apostolico (Apostolico *et al.*, 2014a), and the first CA-Man interface (Figure 4-44) was developed by D’Oria (Cappetti *et al.*, 2011; Naddeo, Cappetti and D’Oria, 2015a). The validation of this software was performed with several experiments in different situations (Naddeo, Cannavacciuolo, *et al.*, 2018; Naddeo, Cappetti, *et al.*, 2013; Naddeo, D‘Ambrosio, *et al.*, 2018; Trapanese *et al.*, 2016; Vallone *et al.*, 2015), also with two examples described in paragraph 4.4.

Figure 4-44: *First version of CA-Man interface*

Then, comfort curves of lower limbs were studied by Naddeo, Cappetti and Vallone (Naddeo, Cappetti, *et al.*, 2019), and the CA-Man interface was updated by Fiorillo (Figure 4-45).

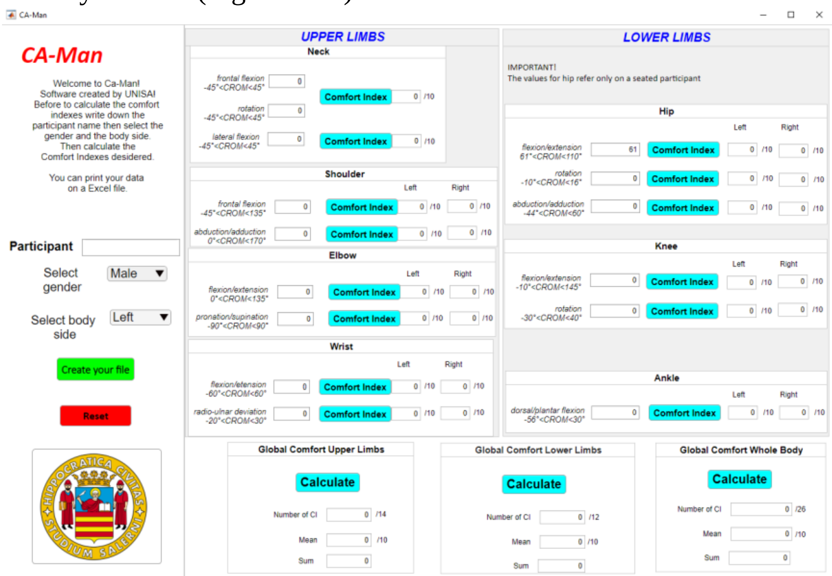


Figure 4-45: *Second version of CA-Man interface*

The first two versions of the software made it possible to perform and save the postural evaluation only for one body side. To overcome this limitation, Fiorillo updated another interface, as shown in Figure 4-46, where it was possible to insert the detect angles for each side and save an Excel file with all information for both body sides.

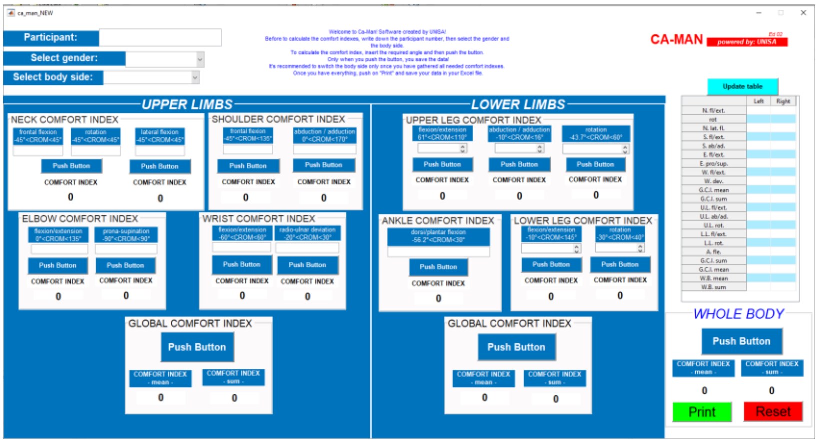


Figure 4-46: *Third version of CA-Man interface for a single posture*

In the case of postural evaluation over time, another interface (Figure 4-47) was created to study the variation of comfort indexes over time. It is possible to update an excel file with detected postural angles over time and automatically obtain the associated comfort indexes.

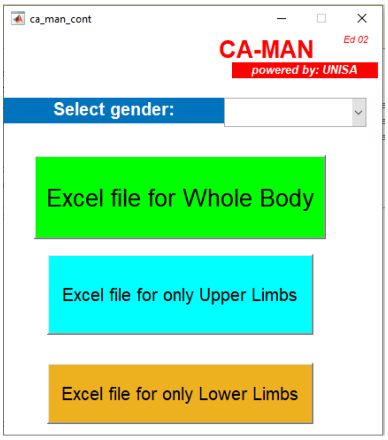


Figure 4-47: *Third interface of CA-Man for a posture evaluation over time*

4.5 Examples of using CA-Man as comfort evaluation tool

In following pages are shown 2 publications as example of using CA-Man as comfort evaluation tool:

- Paper No. 3: A comfort evaluation tool for sitting postures: the case of Library chairs (CA-Man for sitting postures)
- Paper No. 4: Car Control knob usability: a posture based comfort assessment (Ca-Man for car control knob usability)

Paper No. 4 - ICC2019 Conference Proceedings

A comfort evaluation tool for sitting postures: the case of Library chairs

Iolanda Fiorillo, Federico Jacopo Anzisi, Alfonso Carbone, Rosaria Califano, Alessandro Naddeo

Abstract According to ergonomic researches regarding a good sitting posture, the chair, the desk and the objects on the desk, have to be aligned in a certain way to ensure to users a natural curve of the back in order to prevent musculoskeletal disorders. A brief observation among the main Scientific Technology Library inside the University campus showed that students used to complain about neck and lumbar pain, especially after a study day. Thus, a sitting posture comfort analysis had been performed on chairs inside the library. A long-time sitting posture during the daily study activity had been simulated with fifteen volunteer students performing 1-hour tests (divided into four tasks of 15 minutes each). Subjective perceptions had been gathered through questionnaires rating on a 5-point Likert scale both the expected comfort at the beginning of the experiment, and the Localized Postural Comfort at the end of each task. Moreover, just before the end of each task, postural angles had been detected by photographic acquisition and processed by Kinovea®; in addition, CAMan® software had been used to calculate the (dis)comfort indexes by detected postural angles. Finally, subjective and objective data had been statistically processed and compared. Results showed the lumbar area as the most suffering area (lower perceived comfort) while perceived (dis)comfort was independent on participants and tasks, but dependent on the time.

Keywords: comfort, office seat, university students, library, postural comfort

Introduction

Students spend the majority of their time studying, thus sitting on a chair. The importance of the environment cannot be underestimated due to the fact that negative feelings can affect the learning, especially for a long time sitting (Ng *et al.*, 2016; Sanjog *et al.*, 2015). Indeed, uncomfortable and awkward body postures can decrease a student's interest in learning, even during the most stimulating and interesting lessons (HIRA, 1980). Considering the position of chair and desk, in literature there were several studies regarding the correct sitting posture and the awareness of a good sitting posture (Asundi *et al.*, 2012; Lis *et al.*, 2007; Muhammad Hussain, 2015; Netten *et al.*, 2013). Furthermore, it exists even an equation to quantify the comfort in function of measurements and distances between chairs, student and desk (Castellucci *et al.*, 2015).

Any seat design is influenced by the context. Some studies, moreover, gave guidelines to design a comfortable seat, taking into account the natural curve of backbone, the body sensitivity (Goossens *et al.*, 2005; Helander *et al.*, 2000;

Vieira *et al.*, 2015; Vink, 2016), the performed activities and anthropometric measurements of the target group (Groenesteijn *et al.*, 2014; Hiemstra-van Mastrigt *et al.*, 2015; Kamp *et al.*, 2011; Van Veen *et al.*, 2015; Vink and Brauer, 2011). Different target groups have different body sizes and this implies differences in seat width, backrest length, seat pan length, armrest height, that should be designed to fit at least the 99% of the population (Vink, 2016). However, the body's optimal position in terms of comfort requires every joint and eye position to be close to the neutral position, where the perception of comfort is high (Cappetti *et al.*, 2017; Delleman, 1999; Fagarasanu *et al.*, 2004; Naddeo, Cappetti and D'Oria, 2015a).

'Postural comfort' is commonly defined as the absence of discomfort, or a state where the need to change position is not present (Kölsch *et al.*, 2003; Pearson, 2009). The comfort zone, defined as the area of the most comfortable motions/postures for a given task, does not predicate an absolute measure of well-being. Users within their comfort zone are unlikely to change into other postures.

The evaluation of postural comfort can be achieved through subjective or objective data. Subjective data are related with questionnaires, such as Localized Postural (Dis)comfort (LPD), Body Part (Dis)comfort (BPD) and so on (Helander and Zhang, 1997; Joshi *et al.*, 2015; Zhang *et al.*, 1996), while the objective one can be obtained with tools such as pressure mate, sensors and so forth (Califano *et al.*, 2017; Smulders *et al.*, 2016). One of these tools is the software CAMan® (Apostolico *et al.*, 2014a; Naddeo, Cappetti and D'Oria, 2015a; Naddeo, Cappetti, Vallone, *et al.*, 2014; Trapanese *et al.*, 2016) realized by University of Salerno: the software considers the human joints and the comfort curves over angles associated with them. Thus, for a given angle of a human joint, the software gives the associated comfort index (on an 11-point scale where 10 is the maximum comfort).

Despite this background, some applications on the daily life do not follow the ergonomists' tips, as in the case of this study. The Science and Technology Library (S&T Library), designed by the architect Nicola Pagliara (Pagliara, n.d.), is collocated inside the campus of the University of Salerno (UNISA) and is actually used as a place to study ("The Science and Technology Library of UNISA", n.d.). With a brief analysis among students inside the S&T Library, it came out there had been several complaints about neck and lumbar pain after a study day. Regarding this, one hypothesis was the students used to assume wrong sitting posture on those chairs. Since the students tended to change posture frequently, a sitting postural comfort analysis had been done (Commentale *et al.*, 2018; Li *et al.*, 2017; Piro *et al.*, 2019b).

Materials & Method

Experiment setup

The experiment had been setup on the last floor of the S&T Library when there was less affluence of students, by permission of the library staff. On each floor, there are 36 desks with corresponding chairs, grouped six by six, where three are aligned and the other three are opposed to them. For the experiment, three consecutive desks had been occupied to have a clear space.

Three Nikon D3300 cameras had been used and fixed on tripods among the desks: one had been placed on the left and one on the right to obtain the lateral views; and the last one behind the chair, at an adequate distance, to obtain the rear view. In addition, one phone-camera had been fixed on selfie-stick support to take photos from the top view.

To simulate a study day, two main tasks of the studying had been performed: writing and reading. Thus, books, pens, papers had been provided. To consider the time effect, each experiment lasted 1 hour, where the two tasks had been performed for 15 minutes each one, switching them at the end of the 15 minutes. Between the tasks, a pause of 1 minute had been given in order to fill the questionnaire. Photos had been taken from all cameras simultaneously at the end of each task to capture body posture and obtain then postures over time.

Experimental sample

Fifteen students of University of Salerno, 8 males and 7 females with the age between 23 and 31, took part to the experiment. Table 4-19 shows demographic data of participants. All students enjoyed good health. These anthropometric data had been gathered measuring directly the participants' body with a meter, and recorded in an Excel file.

Table 4-19: *Demographics of participants*

	Male (n=8)			*Female (n=7)*		
	Mean	*SD*	*Range*	*Mean*	*SD*	*Range*
Height (cm)	*178.5*	*6.2*	*168 – 185*	*162.7*	*5.7*	*154 – 169*
Weight (kg)	*72.5*	*10.2*	*57 – 90*	*57.1*	*4.8*	*50 – 63*

The chair

To obtain a complete overview, dimensions of the chair had been compared with human body measurements. The dimensions of the chair are showed in Figure 4-48. The high of armrest is about 61 cm from the ground, while the lower part of the desk is 60 cm high from the ground: it means the chair cannot be positioned under the desk. Moreover, there is a gap between the backrest and the seat-pan about 14 cm (66,1cm – 52,4 cm); it means students have to move backward their back in order to lay on the backrest.

Figure 4-48: *Pictures of the chair in three views. Measurements of the chair are reported.*

From DINED ("DINED", n.d.), choosing the international population, values regarding the sitting height, the hip breadth, popliteal height, buttock-knee depth and elbow-grip length had been gathered, as shown in Figure 4-49:

Measures sitting (mm)	International, female		International, male		International, mixed	
	Mean	SD	Mean	SD	Mean	SD
17) Sitting height	800	40	935	40	868	78
14) Popliteal height	365	29	460	27	413	55
33) Buttock-knee depth	505	33	615	33	560	64
25) Hip breadth	305	27	395	27	350	52
31) Elbow-grip length	305	21	375	21	340	41

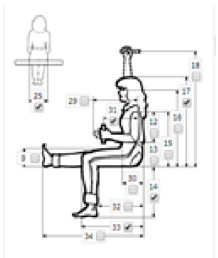


Figure 4-49: *Anthropometric measurements from DINED. The numbers refer on the picture placed on the right. Measurements refers on 50-percentile of the population, for both genders.*

Comparing the measurements, it had been figured out:

- Popliteal height is not suitable for 50% of female population;
- Buttock-knee depth is not suitable for 50% of female population;
- The hip breadth for both population is smaller than the seat pan length.

Questionnaires

Questionnaires of Localized Postural Comfort were used to collect subjective data regarding the postural comfort of participants. Prior the experiment, participants were asked to rate on a 5-point Likert scale (from 1=No comfort to 5=High comfort) the expectation of perceived comfort once sitting on the chair, that is, how the chair seemed comfortable at the first sight (Naddeo, Cappetti, Califano, *et al.*, 2015).

At the end of each task participants were asked to rate on a 5-point Likert-scale (Joshi *et al.*, 2015):

- The perceived comfort on the following body parts: neck, left shoulder, right shoulder, left arm, right arm, left forearm, right forearm, left wrist, right wrist, thoracic zone, lumbar zone;
- The global comfort.

Experiment protocol

Prior the experiment, participants was asked to sign an informed consent and instructed about the experiment. Then participants sat on the chair, positioning it closer to the desk and assuming a correct sitting posture, that is, forearms on desk, raised back, 90 ° legs, and feet leaning against the ground. Tasks were performed in sequence, alternating between writing and reading, both among the tasks and the sequential participants (Table 4-20). Each one lasted 15 minutes, which a stopwatch that told the time, and with a pause about 1 min between the tasks to fill the questionnaire; photos were taken just before the end of the task.

Survey data were analyzed calculating weighted averages and the comfort trend over time starting from the expectation.

Table 4-20: *Protocol regarding time*

	Task 1	**Task 2**	**Task 3**	**Task 4**
Participant A	Reading	Writing	Reading	Writing
Participant B	Writing	Reading	Writing	Reading
	15 min	*15 min*	*15 min*	*15 min*

1 min *1 min* *1 min*

Postural angles and the simulation

A total of 240 photos (15 participants x 4 tasks x 4 views) were analyzed with Kinovea® to gather postural angles, trying to be as accurate as possible, aware of any human errors, both in visual perception and in the program operation. Analysis was made of the following upper limbs movements: head rotation, head bending, head flexion, shoulder rotation, shoulder bending, shoulder flexion, trunk rotation, trunk bending and trunk flexion. Body rotation was analyzed in the transverse plane, body flexion in the frontal plane and body bending in the sagittal plane. Considering the aforementioned correct sitting posture as a reference posture, the gathered angles were defined as the deviations from the reference posture.

A virtual environment of S&T Library was realized in Delmia® (Figure 4-50), representing one floor with fifteen students. French mannequins, that represent the European standard, were used to simulate participants' movements through the gathered postural angles. Anthropometric data, movements and tasks were respected. Through the simulation, it was possible to see the temporal changes for each student, going from a correct posture to the last one gathered.

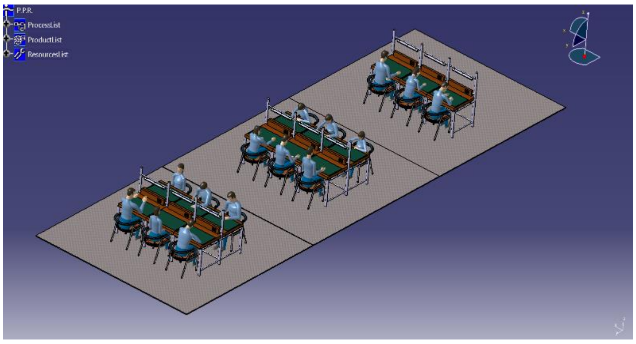


Figure 4-50: *Virtual representation of S&T Library on Delmia.*

CAMan: objective comfort indexes

To obtain objective comfort indexes from the collected angles, the CAMan® software (Naddeo, Cappetti and D'Oria, 2015a) was used. The CAMan® software is based on experimental studies conducted by A. Naddeo et al. to give a comfort index according to postural angles assumed, especially the angles of the human joint. As far as upper limbs, it considers:

- neck: frontal flexion, rotation and lateral flexion
- shoulder: frontal flexion, abduction/adduction
- elbow: flexion/extension, pronation/supination
- wrist: flexion/extension, radio/ulnar deviation

For each joint, curves of postural comfort over angles are used. Comfort indexes are rating on an 11-point scale where 0="no comfort" and 10="maximum comfort". These comfort indexes consider the limbs moving freely in the space, without any kind of support. Since students used to lay their wrist, forearms and elbow on the desk for the whole of time, only neck and shoulder comfort indexes were evaluated.

Results

As regards the trend of global comfort over time, results are shown in Figure 4-51. The values represent the average of expected comfort and global comfort for each task. There was a decay over time, starting from a higher comfort expectation to the lower perceived comfort in "Task 4".

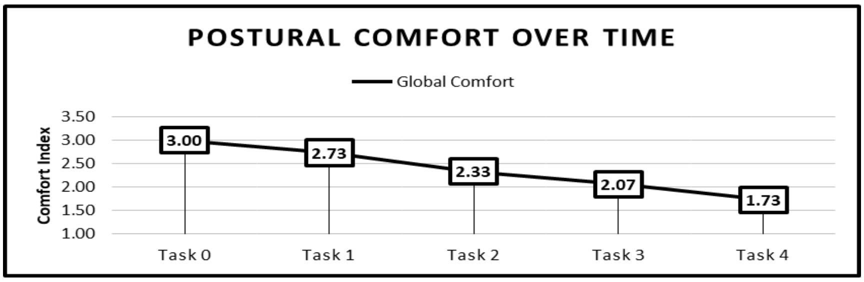


Figure 4-51: *Evolution of the average global comfort over time (Task 0 represents the expected comfort, while the other tasks the evaluation given by*

participants). Values are the average mean on a scale from 1=”no comfort” to 5=”maximum comfort”.

Analyzing the questionnaire results, Figure 4-52 shows the values of average mean of postural comfort for each body part. Comfort indexes in “Task 4” scored lower values than the ones in “Task 1”: this confirms the comfort decay over time. Furthermore, the lumbar zone scored the lowest values of comfort, followed by the neck, torso and shoulders, while the arms, forearms and wrist scored the highest values. Wilcoxon test were performed to compare each task and results were significant at $p<0.05$, especially between “Task 1” and “Task 4”. It means there are significant differences between the first task and the last task.

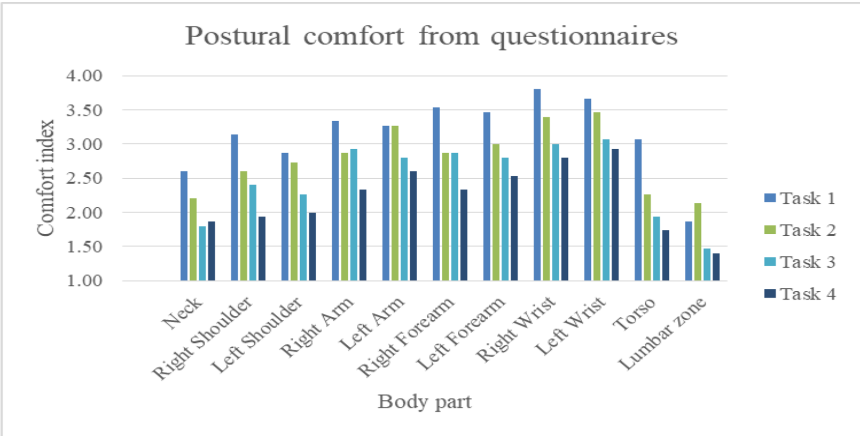


Figure 4-52*: Mean values from questionnaires for each body part (1=no comfort; 5=maximum comfort)*

Correlations

Correlations between subjective comfort indexes from questionnaires and objective comfort indexes from CAMan were calculated with IBM® SPSS® Statistics version 24, taking into account even the dependence on type of activity, it means to evaluate whether the comfort depends or not on the initial activity. Thus, correlations were calculated between the following comfort indexes:

- body parts from Questionnaires & body parts by CAMan®
- body parts from Questionnaires & Global Comfort from Questionnaires
- body parts by CAMan® & Global Comfort from Questionnaire

It was found that height, weight and gender did not affect the Global Comfort. There have not been correlations between the first task and the last task: this is coherent with the decrease of the Global Comfort over time. Each single task affected only the next one. Outcomes from results:

- strong correlations between body part questionnaire & body part CAMan (mean p~0.8)
- strong correlations between body part questionnaire & Global Comfort Questionnaire (mean p~0.7)
- strong correlations between body part CAMan & Global Comfort Questionnaire (mean p~0.6)

Doing the same analysis by grouping the participants that began with the same task, only few correlations had been found out, therefore the postural comfort depends only on the time evolution.

Discussion

Due to students' disorders and complaints, a postural comfort analysis had been done, following the existent methods in literature (Commentale *et al.*, 2018; Naddeo and Memoli, 2009a; Piro *et al.*, 2019a). A brief evaluation showed the chair was not suitable for students (Figure 7-1 & Figure 7-2); it means there were already prerogatives to force students moving on the chairs to find a comfortable posture.

As a matter of fact, considering the correct sitting posture, it means sitting up straight, leaning arms on the desk, keeping feet on the floor, the chair seems too large to fit an international population (Figure 7-2) with medium anthropometric measurements ("DINED", n.d.). Indeed, even if the chair is completely close to the desk, due to the height of armrests, the backrest is too far away from the edge of the desk (Figure 7-1). Thus, the students, in order to assume a good posture, are frequently forced to change the posture going from the one near to the desk to the one distant from the desk and the back leaned on the backrest. During the tests, all participants accused pain in the lumbar region, because to sit properly they were unable to lean their back on the backrest and to unload the weight of the head and the back. Furthermore, as far as the people with the height approximatively lower than 1.60 m, they have some problems with the chair because their knees lean on the seat-pan when their back is leaned on the backrest, thus they are not able to bend the knees and to put their feet on the ground.

The postural comfort trend over time, starting from the correct sitting posture, had been simulated through the two main tasks of the study (writing and reading). To keep the importance of time effect, tasks had been performed in succession without a long pause. Results showed a decay over time; it means the chair was not comfortable as expected at the beginning, scoring the lowest value of global comfort in the last task. There had not great differences between expectation and the values of global comfort because some students had already some experience with the chair and this could have influenced the answers about the expectation. Postural angles had been gathered by Kinovea® using pictures taken during the experiment. The virtual simulation had been done in Delmia® to see the postures assumed by students over time: starting from the correct sitting posture, they used to assume a slouched one at the end of the experiment. It is recommended to make modifications to the virtual environment and test the renovation to improve students' postural comfort, by assuming the correct sitting posture.

Objective indexes of postural comfort had been collected by CAMan®, where for each human joint angle a comfort index had been obtained. There are some limitations of CAMan® software to be acknowledged. Firstly, the software considered the participant itself positioned in the space without any kind of support: comfort perception is different in the presence of support. Indeed, if someone bends the upper limbs in the space, without any support, the feeling of comfort is very low; instead, with a presence of a support to unload the weight, the comfort perception is higher. Since during the tests, participants laid their forearms on the desk, the comfort perception on this posture was higher than the same posture without the desk. This was even confirmed by questionnaire results (Figure 7-5). Thus, objective comfort indexes of elbow and wrist had been excluded. Secondly, when the experiment had been performed, the CAMan® version did not consider the lower limbs. Thus, it was not possible to compare the subjective results of the lumbar zone with the objective indexes of lower limbs from CAMan®. Thus, it is recommended to repeat the experiment implementing the evaluation of lower limbs. Using CAMan® allowed comparing subjective comfort indexes with the objective ones, given more validity to the experiment and its results.

The chair could be improved by increasing the area of backrest using, for example, a pillow in the lumbar region. Otherwise, it could be better to amend the chairs by reducing the width in order to reduce the gap between the seat pan and the backrest. Actually, modifications were already implemented and analyzed with another student project, where a prototype (Figure 4-53) was realized based on the results of the work described in this paper. Results showed an improvement of comfort perception, especially in the lumbar area thanks to the presence of physical support.

Figure 4-53: *Comparison between the chair analyzed in this work (on the left, "before") and prototype realized by a student project (on the right, "after")*

Conclusions

After a brief investigation among students inside the S&T Library, it had been found out a general physical complaint. Thus, a postural analysis had been performed following a systematic method. A typical study-day had been represented through two tasks: writing and reading. During the experiments, photos had been taken from four different views to detect postural angles by Kinovea®. Those postural angles had been used both to realize a simulation inside the virtual environment of Delmia®; and to obtain objective postural indexes by CAMan®. In summary, this paper argued that:

- The comfort perception decreased over time;
- The lumbar region scored the lowest value of comfort, thus, this region influences all postural performance, as confirmed by literature studies;
- Software CAMan® had been used as a tool to obtain objective data of postural comfort;
- There had been correlations between subjective and objective comfort indexes;

The main goal was to demonstrate through the postural comfort analysis that the chair was few comfortable, so it is necessary to do some modifications, like an extension of the back-support area or a reduction of the seat-pan width. These renovations can be simulated with Delmia® through a careful analysis, in order to detect quickly the areas to be improved, then to realize a prototype already optimized.

Furthermore, in this work, a method for the definition of comfort indexes was shown. All the acquisition methods used are 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 us the possibility to reach a very good numerical/experimental level obtaining important results revealed by this paper. The method can be easily reproduced for other applications.

Acknowledgments The research work reported here was made possible by students' help that kindly took part to experiment.

Paper No. 5 - ICC2019 Conference Proceedings

Car Control knob usability: a posture based comfort assessment

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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 were 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 was 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

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 (Italian Government, n.d.)) 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 dis-traction 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 (Naddeo, Apicella, *et al.*, 2015; Naddeo, Cappetti and Ippolito, 2014; Da Silva *et al.*, 2012; Zhang *et al.*, 1996). 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. (Reed *et al.*, 1994), Kolich (Kolich, 2003, 2008; Kolich *et al.*, 2004), Fazlollahtabar (Fazlollahtabar, 2010), dealed with the anthropometric measures as one of the most important aspects in vehicle design process; in Naddeo and Memoli (Naddeo and Memoli, 2009b), and Naddeo et al. (Naddeo, Cappetti and Ippolito, 2014), driver comfort was studied to assess postural comfort, reachability and usability; in Vergara & Page (Vergara and Page, 2002), the sitting comfort was evaluated through the relationship between comfort and back posture and mobility; in Seokhee et al. (Na *et al.*, 2005), and in Kolich and Tabourn's (Kolich and Taboun, 2004) the evaluation of driver's discomfort and postural change was made using dynamic body pressure distribution; in Reed et al. (Reed *et al.*, 1994) and in Kolich (Kolich, 2003), 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 (Kuijt-Evers *et al.*, 2004), position (Dempsey *et al.*, 2004; Groenesteijn *et al.*, 2012; Hanson *et al.*, 2003; Naddeo, Apicella, *et al.*, 2015; Naddeo, Cappetti and Ippolito, 2014) and orientation (El Falou *et al.*, 2003). Dauris et al. (Dauris *et al.*, 2008) 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 (Dingus *et al.*, 2006). Therefore, many of these systems were especially optimized for this purpose (Niedermaier *et al.*, 2009). 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 (Annarumma *et al.*, 2008; Naddeo, Apicella, *et al.*, 2015; Norman and Shallice, 1980) 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.

Material and methods

Experimental sample

Twenty-three students of University of Salerno, 17 males and 6 females, took part to the experiment. All students enjoyed good health. Table 4-21 shows anthropometric data of participants.

Table 4-21: *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*

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 Figure 4-54:

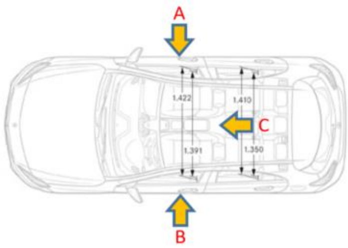

Figure 4-54 *Camera system*

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.

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 leads 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 (Figure 4-54);
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.

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.

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 (Naddeo, Barba, *et al.*, 2013). In Figure 4-55, two examples of the cameras' shooting angle can be observed.

Figure 4-55: *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;
3. 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 (Annarumma *et al.*, 2008; Bassi *et al.*, 2016; Califano *et al.*, 2016; Naddeo *et al.*, 2017; Di Pardo *et al.*, 2008; Vallone *et al.*, 2015). 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 was evaluated in (Naddeo, Barba, *et al.*, 2013) and (Naddeo, Cappetti, *et al.*, 2013). Figure 4-56 shows an example of the three postures involved in the analysis.

Figure 4-56: *Simulations carried out in DELMIA®*

Evaluation Technique for Postural Comfort

Comfort evaluations were performed by CaMAN® (Apostolico *et al.*, 2014b; Naddeo, Apicella, *et al.*, 2015; Naddeo, Cappetti and D'Oria, 2015b; Naddeo, Cappetti and Ippolito, 2014; Naddeo and Memoli, 2009c) 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.

Data analysis

For each participant and for each task, the global postural comfort index, obtained by CaMAN® software, is shown in Figure 4-57.

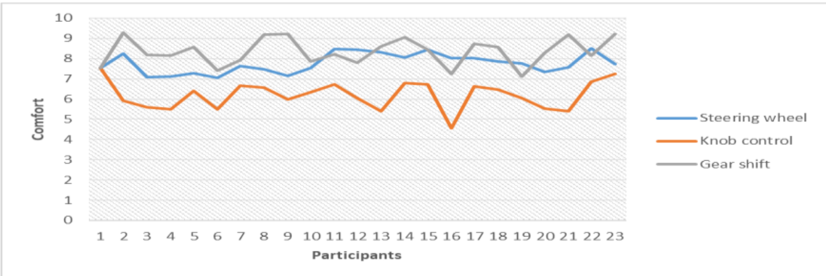

Figure 4-57: *Global comfort index related to the three tasks involved in the study*

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 4-22. *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 (Figure 4-57) 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 4-22).

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 body part;
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.

Table 4-23 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. These results were expected because higher subjects were easily able to reach the knob.

Table 4-23. *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 4-24 shows the most significant correlations between the objective comfort indexes obtained by CaMAN® and the subjects' anthropometrics data.

Table 4-24. *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 4-25 shows the most significant correlations between the subjective and objective comfort indexes.

Table 4-25. *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 (Apostolico *et al.*, 2014b; Naddeo, Cappetti and D'Oria, 2015b). 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.

Conclusions

In this work, both the postural comfort related to the use of a car control knob, steering wheel, the gearshift, 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 useful support during the problem solving and directly suggest, to designers, easy solution to replace the knob. The analysis showed that a possible solution was to place the knob near the gearshift. The proposed solution takes into account the characteristics of the tasks that the subjects have to carry out and the subject's anthropometric 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 a 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.

Acknowledgments The research work reported here was made possible by the support of students that kindly participated.

5 (Dis)comfort on seats

Among all measurement tools available for (dis)comfort assessment, the pressure distribution mapping is still the most reliable measure of (dis)comfort on seats. Focusing on seats is relevant because passengers will be seated most time during a journey inside future vehicles. After all, wearing a seatbelt is still mandatory. Thus, the seat and the surrounding environment are crucial for passengers' comfort and well-being.

This chapter describes the importance of vehicle seat comfort, the relevance of pressure distribution, and experiments on the shaped cushion.

5.1 Vehicle seat comfort

Vehicle seat comfort may be divided into static comfort and dynamic comfort (Ebe and Griffin, 2001). Both types of comfort should be considered when designing vehicle seats.

"Dynamic comfort" refers to the sitting impressions of seat occupants while being exposed to vibration, and is related to the vibration transferred through the seat to the occupants.

"Static comfort" refers to the sitting impressions of seat occupants when there is no vibration. The static seat characteristics, such as the shape, size and hardness, are thought to affect static comfort. Interactions between humans and seats are influenced by the indentation process and the way the occupant behaves after indentation (Wegner *et al.*, 2020). Seat cushion structure and cushion support characteristics significantly influence the body pressure distribution, an important factor in seat comfort determination (Antal, 2020).

5.1.1 First steps

When designing a seat, the first steps involve the study of the context and activities (Hiemstra-van Mastrigt, Meyenborg, *et al.*, 2016; Vink, 2016). One context factor is, for example, the length of a journey. Designing a vehicle for short distances or the city is different from the one designed for long distances. Indeed, according to time duration, some factors assumes more relevance than others. For instance, the speed of ingress and egress is more relevant for very short distances, as it takes up a relatively high proportion of the total travel time. For long distances, conversely, seat comfort is of greater importance (Vink, 2016), and, for example, sleeping activity is more common in this case.

So, once the context and activities are defined, the second step of seat design involves the human body. Anthropometric measurements, body shape, body sensitivity, postures, perceived comfort are factors involved in this design phase. Indeed, there are correlations between anthropometric variables and interface pressure variables, and that this relationship is affected by body posture (Hiemstra-van Mastrigt, Groenesteijn, *et al.*, 2016). The main goal of this step is to design a comfortable and suitable seat for any considered population.

5.1.2 Anthropometric measurements

Anthropometric measurements are a series of quantitative measurements (Casadei and Kiel, 2020; Choi and Garlie, 2014; Masson *et al.*, 2015; National Health and Nutrition Examination Survey III, 1988) of the muscle, bone, and adipose tissue used to assess the composition of the body. The core elements of anthropometry are height, weight, body circumferences (waist, hip, and limbs), and skinfold thickness (Casadei and Kiel, 2020). There are many publications with anthropometric information of different populations (Castellucci *et al.*, 2010; Dianat *et al.*, 2013; Gouvali and Boudolos, 2006; Hung *et al.*, 2004; Parcells *et al.*, 1999), even an online dataset (property of TU Delft) that collects these studies ("DINED", n.d.). Furthermore, these anthropometric measurements remain the same for so many years (Molenbroek *et al.*, 2017).

These anthropometric measurements are relevant even for the biotypology, a branch of biology that deals with the classification and study of the human body constitution. There are different schools of classification, but all recognizable under the adjective of biotypes, constitutional biotypes, morphotypes, phenotype or somatotypes. In particular, phenotypes by Jean Vague (Vague, 1956; Vialettes, 2015) identify the characteristic areas of distribution and accumulation of body fat in humans, to which particular morphologies and pathological predispositions are correlated. Vague's constitutional phenotypes are divided in two categories: android (typical male) and gynoid (typical female), to which is added the model with the intermediate or mixed constitution. The anthropometric measurements/ratios used are the BMI (Body Mass Index), the WHR (Waist Hip Ratio) and the WC (Waist circumference) (Lam *et al.*, 2015; Moysidis *et al.*, 2011). People with WHR>0,85 for women or WHR>0,95 for men belong to android obesity where the fat accumulation is localized more in the abdominal area. Instead, people with WHR<0,78 for women and WHR<0,85 for men, the fat accumulation is more localized in the lower body part, especially in the buttock and femoral areas. This fat accumulation could influence the blood pressure while seated (McManus *et al.*, 2015; Moysidis *et al.*, 2011; Schubert *et al.*, 1994) and used as predictors of cardiovascular diseases (Lam *et al.*, 2015). However, there are no literature studies whether fat accumulation could influence body sensitivity and, consequently, (dis)comfort perception.

In vehicle-seat design, the anthropometric data influence not only the seat dimension but also the space around the seat (see the experiment performed in paragraphs 5.2-5.3) and the pressure distribution measured on the seat.

5.1.3 Pressure distribution

When the passenger sits, the relevant contact areas are on the backrest and the seat-pan. The interface pressure on the seat-pan varies over the area of the seat surface because the human buttocks are not flat. Moreover, the pressure beneath the ischial bones may reflect both comfort factors: the bottoming feeling (the lowest part of the seat pan) and the foam hardness feeling (Ebe and Griffin, 2001). This local variation of pressure on the seat surface, namely the "pressure distribution", is affected by several factors, such as the seat hardness, seat shape and anatomical characteristics of the passenger's buttocks. A pressure distribution can provide much information, such as pressure values at specific points, the contact area, the peak pressure and its location.

Indeed, to assess the perceived(dis)comfort, the pressure mapping system is the most widely used thanks to its relatively low cost and easy use (Wang *et al.*, 2020; Zemp *et al.*, 2015), and the established statistical correlations with perceived discomfort (Hiemstra-van Mastrigt, Groenesteijn, *et al.*, 2016; De Looze, Kuijt-Evers, Lottie, *et al.*, 2003). Moreover, interface pressure depends on postures, seat characteristics (also the shape), assumed postures, anthropometric measurements (Hiemstra-van Mastrigt, Groenesteijn, *et al.*, 2016). Hiemstra-van Mastrigt (Hiemstra-van Mastrigt, Groenesteijn, *et al.*, 2016) made a conceptual model where the relationship between variables involving human, seat and context level were highlighted and analyzed, as shown in Figure 5-1. Furthermore, the arrows illustrate the evidence that was found for the relationships between the variables. Three levels of evidence were distinguished in this way: statistically determined relationship (dark line), a tendency for a relationship without statistical evidence (dashed line) and no studies available (light line).

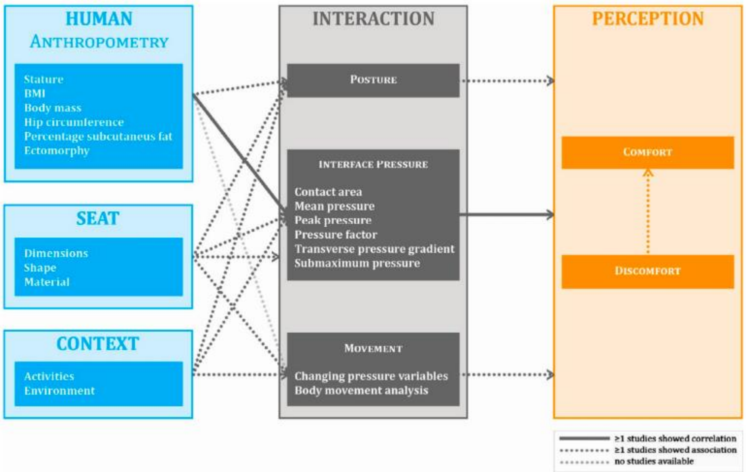

Figure 5-1*: From Hiemstra-van Mastrigt - Overview of relationship between variables where differences in the level of evidence are indicated by the different arrow styles.*

Considering Figure 5-1, this PhD dissertation aims to investigate and evaluate correlations between seat and interaction, considering even the anthropometry of humans (always per literature studies).

A work (Wang *et al.*, 2020) investigated the pressure distributions self-selected by participants using a reconfigurable experimental seat. Results show that preferred pressure proportion on the seat pan depended on sitter's body size and seat pan angle, implying that a unique 'ideal' pressure distribution cannot be applied to all sitters and all seating configurations (Wang *et al.*, 2020). For these reasons, literature studies show ideal pressure distributions for only upright sitting posture for drivers and passengers.

5.1.3.1 Ideal seat pressure distribution

The concept of "optimal load distribution" (Zenk *et al.*, 2012) occurs in the seat position with the pressure distribution corresponding to the most comfortable posture and the pressure in the intervertebral disc is lowest.

Zenk (Zenk *et al.*, 2006) and Kilinscoy (Kilincsoy *et al.*, 2016) worked out general guidelines for an ideal seat pressure distribution in car seats for sitting upright postures. Mergl (Mergl, 2006) also reported that the pressure distribution in the cushion (seat pan) influences the pressure distribution in the backrest and vice versa. Vink and Lips (Vink and Lips, 2017) confirmed the results of the previous studies by studying sensitivity and described a higher sensitivity in the shoulders and at the front of the seat pan. Less sensitivity was found in the middle area of the back close to the spine. All in all, the methodology to objectifying the seat characteristics is reduced to the evaluation of various foam properties, seat contours and the relation to individual pressure distributions.

For instance, in a work of Smulders (Smulders *et al.*, 2016), a human contour shaped seat shell and cushioning was developed to improve comfort, reduce weight and optimize space used. The prototype seat had a significantly lower average pressure between subjects' buttocks and the seat pan over a traditional seat. Zemp (Zemp *et al.*, 2016) analyzed the seat pan and backrest pressure distribution while sitting in different office chairs stating pressure distribution measurements are strongly influenced by different material properties and geometry of the padding material.

The cover characteristics and the cushion suspension caused by the foam might cause a different effect than predicted by the foam alone (Wegner *et al.*, 2020). For instance, the cover is connected in most cases to the foam and the seat- frame. If the cover is stretchable and loosely connected, the foam characteristics could be more predominant as the foam is able to perform in a wide scope. In contrast, a stiff cover tightly connected to the foam could limit the foam deformation influencing its performance. Additionally, the comfort of a seat might not only be dependent on the foam and the cover, but also by the seat dimensions, seat adjustment and other seat components such as the seat suspension (Wegner *et al.*, 2020).

5.1.4 Gaps in literature studies

Literature studies were performed to find out the gaps: there were no literature studies about pressure distribution and (dis)comfort on airplane seats. Moreover, only upright and slouched postures had been investigated on car seats. Thus, experiments were performed at TU Delft in order to investigate the pressure distribution on airplane seats according to 6 different postures. A comparison between 2 seat-pan, flat cushion and shaped cushion, was made (Fiorillo, Song, Smulders, *et al.*, 2021). The shaped cushion was designed to follow the buttock-thigh shape on international population (Iolanda Fiorillo, Yu Song, Peter Vink, n.d.). With this shape, the pressure should be more uniform and lower, the contact area at interface bigger, and the perceived comfort higher. Furthermore, anthropometric measurements were measured to study correlations between BMI, WHR and perceived (dis)comfort. More details are explained in following paragraphs.

5.2 Designing the shaped cushion: from virtual to physical prototype

*Published also in **ICED2021** Conference Proceedings*

Designing a comfortable seat is of great importance but is complicated (Hiemstra-van Mastrigt, Groenesteijn, *et al.*, 2016; Kamp, 2012; Vink, 2016). Several factors concerning the interaction between human and seat (Vink, 2016) should be considered early in the design process, such as anthropometric measurements (Molenbroek *et al.*, 2017), body shape (Hiemstra-van Mastrigt, Groenesteijn, *et al.*, 2016) body sensitivity (Di Brigida *et al.*, 2021; Vink and Lips, 2017), postures (Groenesteijn *et al.*, 2014), and perceived comfort (El Falou *et al.*, 2003; Kyung *et al.*, 2008; Naddeo, Di Brigida, *et al.*, 2019; Naddeo and Memoli, 2009a; Smith *et al.*, 2015; Zenk *et al.*, 2006).

Since there are many factors involved in seat design, realizing a prototype early in the design process is beneficial, especially to reduce the Time To Market (Gibson *et al.*, 2004). The purpose of building a prototype (i.e. prototyping) is usually to embody design hypotheses, test the function and feel of the new design and elicit market feedback prior to production of a product (LIU, 2011). Nowadays, the new product development process makes use of both virtual and physical prototypes. Virtual Prototyping (VP) and Physical Prototyping (PP) are two techniques that have many similar goals, but which achieve them in very different ways. With VP, the approach is to create a precise numerical model, which can be manufactured in a simple way, whereas in PP a physical model is created (Gibson *et al.*, 2004; LIU, 2011). Sometimes, virtual prototyping needs support from physical prototyping in some product evaluations, such as product ergonomics, due to the natural sensation of human perceptions (Anderl *et al.*, 2007).

Assessing seat comfort and discomfort is a topic widely discussed in the literature (Helander and Zhang, 1997; Kolich and Taboun, 2004; Zhang *et al.*, 1996), and seat manufacturers appear to still rely strongly on subjective evaluations as the main indicator of seat comfort and discomfort (Cascioli *et al.*, 2016). The main goal is to design a comfortable and suitable seat for any considered population preventing health issues and creating well-being. For instance, remaining seated for extended periods increases the risk of pressure ulcers in the buttocks area, as the soft tissue in this area is squeezed between two surfaces: the seat and the bones of the pelvis (A consensus document, 2010; Krouskop *et al.*, 1983; Schubert *et al.*, 1994; Stephens and Bartley, 2017). Moreover, the blood flow is significantly decreased when sitting 3 hours without moving the body (McManus *et al.*, 2015; Thosar *et al.*, 2014). One way to solve this problem could be the adoption of a massage system to stimulate blood circulation (Franz *et al.*, 2008). Another way could be improving seat design. In particular, the seat pan design could be mainly influenced by two factors: pressure distribution and seat contour (Kamp, 2012).

When people sit, the relevant contact areas are on the backrest and the seat-pan. The interface pressure on the seat-pan varies over the area of the seat surface because the human buttocks are not flat. This local variation in pressure on the seat surface, namely the "pressure distribution", is affected by several factors, such as the seat hardness, seat shape and anatomical characteristics of the passenger's buttocks. Furthermore, the pressure distribution on the seat pan influences the discomfort in the lower back (Zenk *et al.*, 2006). A physiological link exists as well: too much pressure on the buttocks in addition to the muscle tension to erect the pelvis can be perceived as pain in the lower back (Zenk *et al.*, 2006). The concept of "optimal load distribution" (Zenk *et al.*, 2006) might be helpful and occurs between human and seat in finding the most comfortable posture, and there are indications that the pressure in the intervertebral disc is lowest in the optimal position (Franz *et al.*, 2010). The pressure distribution is the objective measure with the most evident association with subjective ratings of discomfort compared to other measures (De Looze, Kuijt-Evers, Lottie, *et al.*, 2003). Also, to assess the perceived (dis)comfort, the pressure mapping system is the most widely used thanks to its relatively low cost and easy use (Wang *et al.*, 2020; Zemp *et al.*, 2015), and presents statistical correlations with discomfort (Hiemstra-van Mastrigt, Groenesteijn, *et al.*, 2016; De Looze, Kuijt-Evers, Lottie, *et al.*, 2003). Moreover, interface pressure depends on postures, seat characteristics (also the shape), assumed body positions, anthropometric measurements (Hiemstra-van Mastrigt, Groenesteijn, *et al.*, 2016; Naddeo, Califano, *et al.*, 2018).

Furthermore, there are indications that a seat contour resulting in a larger contact area could be correlated to more comfort (Fang, Gao, *et al.*, 2016; Zemp *et al.*, 2016; Zenk *et al.*, 2012). One way to achieve this would be to use soft foam in the cushion, which follows the contour of the user's buttocks. Another way would be to use a shaped contour shell derived from the human body and less use of foam. Ideally, this suits to a large population from P5 females to P95 males ("DINED", n.d.). Smulders (Smulders *et al.*, 2016) developed a human contour shaped seat shell using a 3D scanner and adapted the cushion form to improve comfort, reduce weight and optimize the space. The prototype seat had significantly lower average pressures between subjects' buttocks and the seat pan compared with a traditional seat.

Since literature studies showed a low-pressure distribution and a human contour shaped seat could lead to more comfort, this work aims to combine these two important factors. Based on pressure mapping, a shaped seat pan was developed using 3D software (virtual prototype) and manufactured as a physical prototype. A comparison with a standard flat seat pan was made to verify this hypothesis. The research question is: has the designed-shaped seat-pan reached the goal of better pressure distribution and larger contact area than a standard flat seat-pan?

5.2.1 Shaped seat - Basic idea

The basic idea for the shaped cushion (for seat-pan) was to follow the human body contour at the buttock-thigh area (see Figure 5-2). The formulated hypotheses were (whose discussions are in following paragraphs):

1) The contact area is higher with the new cushion shape.
2) Resulting pressure distribution is more uniform, peak pressures are lower.
3) The higher contact area and more uniform pressure distribution result in higher perceived comfort and lower postural discomfort.
4) The shaped cushion accommodates the target of P5-P95 of an international population.

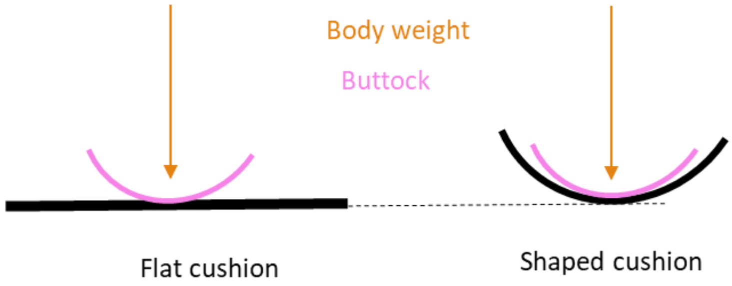

Figure 5-2: *Examples of differences in contact area and pressure distribution, considering the same bodyweight*

5.2.2 Data acquisition

The design is based on a dataset of pressure maps gained with previous experiments of prof. Yu (Wolf) Song at TU Delft. Experiments involved 22 participants (10 females and 12 males, see Table 5-1) that were asked to sit on a standard seat assuming three different postures (sitting upright, slouched and bending forward) for 30 seconds. Reliability of the experiment was respected with participants seated for all experiment duration (Hartung *et al.*, 2004).

Table 5-1: *Anthropometric measurements of a previous experiment of prof. Yu (Wolf) Song*

	Age	*Weight (kg)*	*Stature (cm)*	*BMI*	*Buttock Knee length (cm)*	*Hip Width (cm)*
Mean	24,18	71,55	175,64	23,00	61,32	36,57
Standard Deviation	2,23	14,22	9,96	3,03	5,13	2,33
Range	21 - 31	48 - 96	155 - 193	17- 29	51,50 - 76	29,70 - 41

Pressures were recorded after 10 second sitting (assessing time) and for 20 seconds (recording time), obtaining a data set of 39 frames for each second (780 acquisition for each participant). Then, these data were merged to obtain an average pressure distribution, as shown in Figure 5-3.

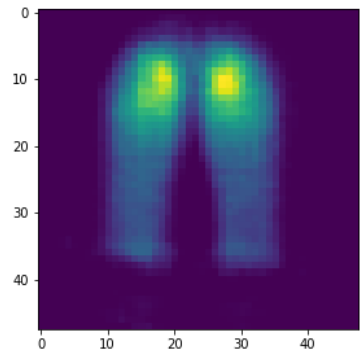

Figure 5-3: *Result of average pressure distribution data acquisition*

5.2.3 3D model

Once calculated the average pressure map, the shape/contour was realized using as a third dimension the value of pressure:

- X- and Y-axis: pressure map gained (the shape obtained with pressure distribution)
- Z-axis: local pressure values

The pressure profile was mapped to “0-1” domain within the Grasshopper to obtain a modelled surface. Grasshopper is a visual programming language and environment that runs within the Rhinoceros 3D computer-aided design

(CAD) application. Then the domain was custom to a new domain "0-maximal depth".

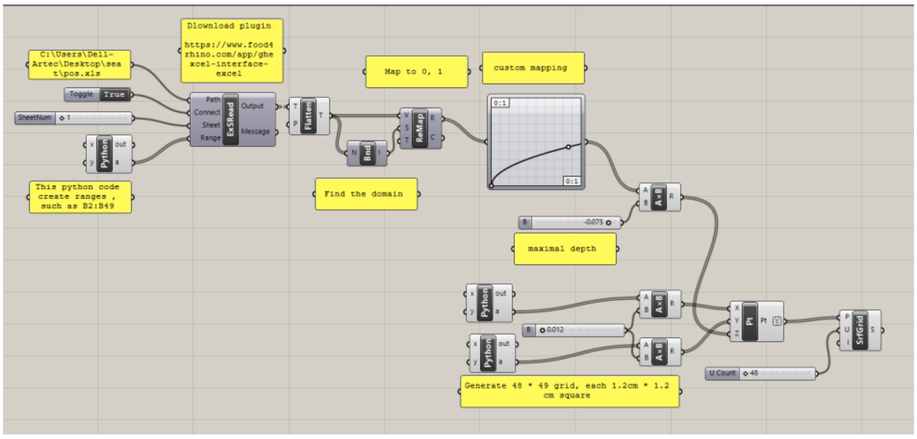

Figure 5-4: *Grasshopper scheme used. Pressure distribution data as input, converted into 3D domain and obtaining as output the 3D surface.*

Once set values for "maximal depth" and "custom mapping" (as shown in Figure 5-4), which the profile was displayed in Rhinoceros environment, the surface was baked (Figure 5-5) and exported into IGES format. The file was a NURBS surface that can be easily edited in any CAD software or directly in Rhino.

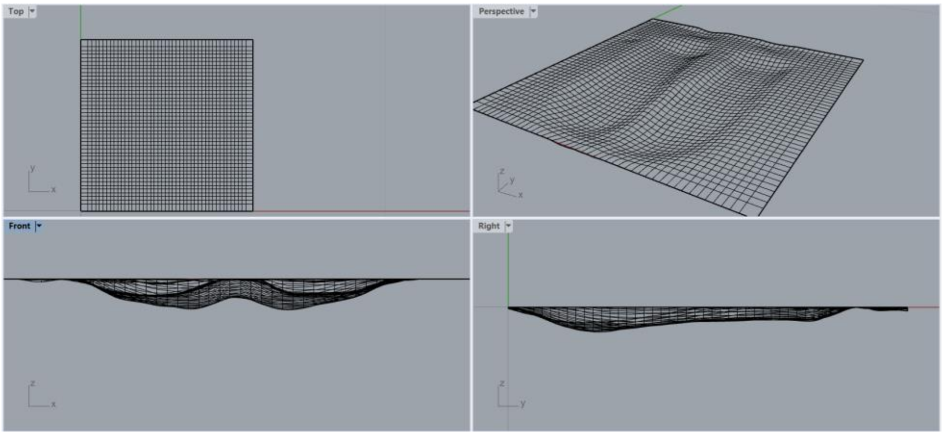

Figure 5-5*: 3D surface obtained from Grasshopper*

For the easiness of surface mathematical model, the software Solidworks® was used realizing an appropriate model in real dimensions always respecting the obtained profiles (Figure 5-6).

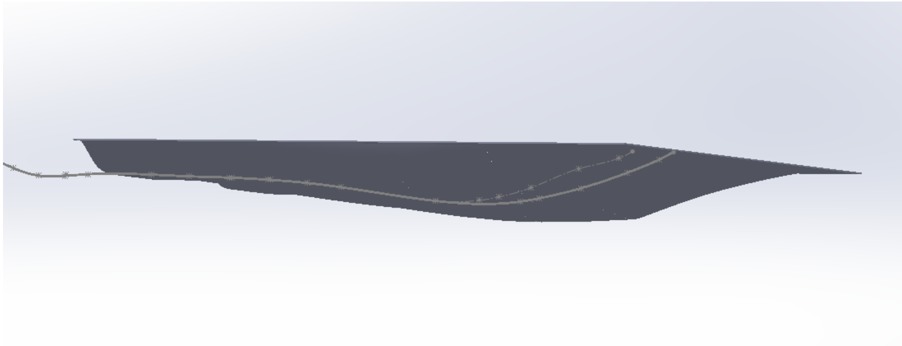

Figure 5-6: *Surface model in Solidworks, the line of buttock-thigh is highlighted*

Indeed, SolidWorks® is parametric and feature-based CAD system, which allow users to edit the modelling at any time and go back on each time interval by feature design tree. Also, the user can enter the dimension to control the model shape and another related feature. Rhino is NURBS-based 3-D modelling software that user can edit any surface by the control point. It is straightforward to create an organic shape modelling, but, it is quite hard to re-modify when the model was completed. Moreover, Solidworks® can export or import a Solid format that makes sure all edges and faces can be appropriately connected, and it exports or imports about 25 CAD formats (Parasolid, IGES, step, STL, Rhino, AI, etc.). In contrast, Rhino has some limitation to export\import Solid-body, and it could be lacking on accuracy between the edges and faces since it is more a surface modeler. Other CAD\CAM system is tough to works on these. Therefore, the choice of Solidworks® for 3D design is justified for the planned output: the 3D model (Figure 5-7) needed to be printed with the CNC machine that reads STL files.

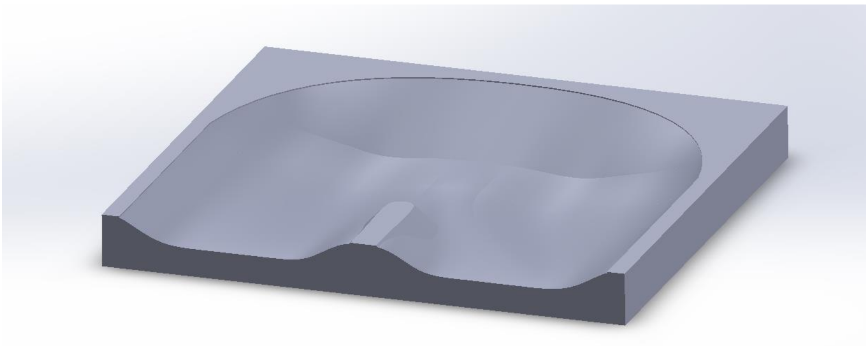

Figure 5-7: *Prototype developed in Solidworks according to international population*

The seat-pan shape of 40x37x4 cm was milled by the CNC machine and the smoothed at the edges (Figure 5-8).

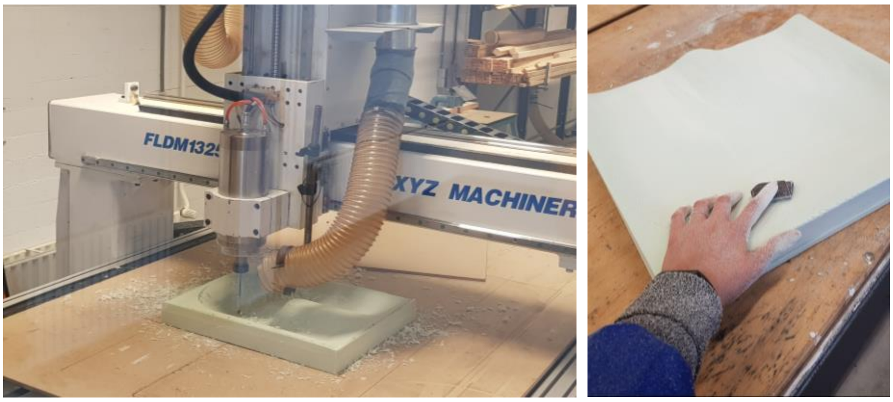

Figure 5-8*: Process of printing with CNC machine and smoothing surfaces*

Then, a cover of 2 mm of a thermoplastic sheet (Figure 5-9) was applied with the thermoforming machine to obtain a shape strong enough for a 100kg weight approximatively. Finally, a layer of standard foam was added on top, fixed with a cover, without gluing aiming to follow the buttock shape for every participant. The foam density allowed to follow the shape without being loose. Another reason for not gluing was to hide the shape (Figure 5-9), in order not to influence participants' expectation (Naddeo, Cappetti, Califano, *et al.*, 2015).

Figure 5-9*: On the left: the prototype after thermoforming machine (to add the plastic layer) and the foam layer. On the right: the final model where the shape is hidden not to influence participants' expectations*

5.2.4 Validation of the prototype

The validation of the prototype was made through the experiment described in para. 5.3 that compared perceived (dis)comfort, pressure distribution and contact area between the shaped seat-pan and the standard flat seat-pan. Experiment results showed that the main goal had been reached, i.e. using the shaped seat pan, the average pressure is lower, and the contact area is larger than using the flat seat-pan.

Recalling the hypothesis, all of these were confirmed through the validation of prototype (para. 5.3):

- ✓ The contact area is higher with the new cushion shape
- ✓ Resulting pressure distribution is more uniform, peak pressures are lower.
- ✓ The higher contact area and more uniform pressure distribution result in higher perceived comfort and lower postural discomfort.
- ✓ The shaped cushion accommodates the target of P5-P95 of an international population.

These results are aligned with literature studies (Fang, Gao, *et al.*, 2016; Kamp, 2012; Zemp *et al.*, 2016; Zenk *et al.*, 2012). Besides, the proposed prototyping approach (Gibson *et al.*, 2004; LIU, 2011) also highlights the possibility of realizing a modifiable and reproducible design (Virtual Prototype) and then a Physical Prototype in a short time and with few iterations. This design approach, easily reproducible and adaptable for every type of chair or seat-pan, was based on the simultaneous use of three standard methods:

1) the analysis of pressures (Hiemstra-van Mastrigt, Groenesteijn, *et al.*, 2016; De Looze, Kuijt-Evers, Lottie, *et al.*, 2003; Wang *et al.*, 2020; Zemp *et al.*, 2015) and contact areas (Fang, Gao, *et al.*, 2016; Zemp *et al.*, 2016; Zenk *et al.*, 2012);

2) the analysis of different fixed postures (Groenesteijn *et al.*, 2014; Hiemstra-van Mastrigt *et al.*, 2015; Naddeo, Califano, *et al.*, 2018);

3) the analysis of perceived discomfort through questionnaires (Anjani *et al.*, 2021; El Falou *et al.*, 2003; Kyung *et al.*, 2008; Mansfield *et al.*, 2015; Naddeo, Califano, *et al.*, 2019; Naddeo, Cappetti and D’Oria, 2015a; Naddeo and Memoli, 2009a; Zenk *et al.*, 2006).

The originality, therefore, lies in the triple evaluation and in the project proposal. However, some limitations need to be acknowledged: even though the sample was statistically significant according to the GPower calculator, experiments could be executed with a higher number of people so managing a more significant sample to increase accuracy; also, the choice of the material, in particular the foam, could have influenced results. As future development, the experiment should be replicated comparing several types of foam. Also, further test with different contours could be useful to understand better the impacts of materials and different contour selected.

5.3 Pressure distributions: flat cushion VS shaped cushion

*Published also in **IEA2021** and **ICC2021** Conference Proceedings, and under review at **Applied Ergonomics Journal***

5.3.1 Introduction

When designing a seat, there are many factors to consider. The context of using a seat and the activities performed on the seat (Hiemstra-van Mastrigt, Meyenborg, *et al.*, 2016; Smulders *et al.*, 2016; Smulders and Vink, 2021; Vink, 2016) are often highlighted first. For example, the length of a journey (Vink *et al.*, 2017) is an important factor as fatigue develops over time; passengers might need more space to regain their comfort by performing different activities (Bazley and Vink, 2016; Smulders, 2018; Vink, 2016).

The term "passengers" coins a variety of anthropometric measurements (Casadei and Kiel, 2020; Molenbroek *et al.*, 2017), body shape (Hiemstra-van Mastrigt *et al.*, 2019; Smulders *et al.*, 2016), body sensitivity (Di Brigida *et al.*, 2021; Rosaria *et al.*, 2020; Vink and Lips, 2017) that should be considered in seat design.

The anthropometric variables (Huysmans *et al.*, 2020; Molenbroek, 2000) and body postures (Hiemstra-van Mastrigt, Groenesteijn, *et al.*, 2016; Kamp *et al.*, 2011; Naddeo, Califano, *et al.*, 2018) influence the pressure distribution on the seat that, in turn, is correlated to perceived discomfort. Moreover, investigating in discomfort perception on seats could help in preventing health issues (A consensus document, 2010; Krouskop *et al.*, 1983; McManus *et al.*, 2015; Schubert *et al.*, 1994; Stephens and Bartley, 2017; Thosar *et al.*, 2014).

Considering the pressure distribution while sitting, the largest human-seat contact areas are on the backrest and the seat pan. This pressure distribution is influenced by several factors such as human body anthropometry, body mass distribution, and seat cushioning firmness and shape (Kilincsoy *et al.*, 2016; Wegner *et al.*, 2019). Although upholstery properties influence seat characteristics, it however does not influence the pressure distribution much (Wegner *et al.*, 2019). A pressure distribution map can provide much information, such as pressure values at specific points, the contact area, peak pressure value and peak pressure location. Pressure mapping is the most widely used objective measurement tool with a real sitting person to assess the perceived (dis)comfort, thanks to its relatively low cost and ease of (Wang *et al.*, 2020; Zemp *et al.*, 2015) and statistical correlations with discomfort (Fang, Gao, *et al.*, 2016; Fasulo *et al.*, 2019; Franz *et al.*, 2010; Hiemstra-van Mastrigt, Groenesteijn, *et al.*, 2016; De Looze, Kuijt-Evers and Van Dieen, 2003). In general, a lower average pressure is accompanied by less discomfort (Noro *et al.*, 2004). The concept of "optimal load distribution" occurs when at that pressure distribution corresponds to lowest perceived discomfort, and the pressure in the intervertebral disc is the lowest (Naddeo, Califano, *et al.*, 2018; Zenk *et al.*, 2012).

Most literature on ideal pressure distributions for seats focuses on the context of the car (Kilincsoy *et al.*, 2016; Mergl *et al.*, 2005; Zenk *et al.*, 2006). It is unclear if these ideal pressure distributions can also be applied in the context of aircraft seating. Thus, this paper aims to fill this knowledge gap by performing a pressure distribution study for aircraft seats and comparing them with the one on cars (Kilincsoy *et al.*, 2016; Mergl *et al.*, 2005; Zenk *et al.*, 2006).

Moreover, as mentioned in para. 5.2, there are indications that a seat contour resulting in a large contact area is correlated to more comfort (Dangal *et al.*, 2021; Fang, Shen, *et al.*, 2016; De Looze, Kuijt-Evers and Van Dieen, 2003; Zemp *et al.*, 2016; Zenk *et al.*, 2012). Thus, Fiorillo et al. realized a shaped cushion (see para. 5.2) following the buttock-thigh shape of an international population (including P5 females and P95 males) aiming to have both an ideal pressure distribution and a large contact area (Fiorillo, Song, Smulders, *et al.*, 2021; Fiorillo, Song, Vink, *et al.*, 2021).

To validate the hypothesis, a comparison was between two cushions for seat pan: flat (the standard one existing in the current airplane seats) and shaped cushions.

The use of aircraft seats has a specific reason. Most literature on ideal pressure distributions for seats focuses on the context of the car (Kilincsoy *et al.*, 2016; Mergl *et al.*, 2005; Zenk *et al.*, 2006). It is unclear if these ideal pressure distributions can also be applied in the context of aircraft seating. Thus, this paper aims also to fill this knowledge gap by performing a pressure distribution study for aircraft seats and comparing them with the one on cars (Kilincsoy *et al.*, 2016; Mergl *et al.*, 2005; Zenk *et al.*, 2006).

<u>The research questions are</u>:

1) Having two cushions that are different in shape, which cushion is preferable in terms of postural comfort and pressure distribution and why?
2) Are there significant differences in pressure distributions per each assumed posture in aircraft seats?
3) How do the pressure distribution on aircraft seats differ from pressure distribution maps studied in a car (Kilincsoy *et al.*, 2016; Mergl *et al.*, 2005; Zenk *et al.*, 2006)?

5.3.2 Materials & Method

Considering that passengers could assume different postures (Hiemstra-van Mastrigt, 2015) during a flight, a first step to overcoming literature gaps is to detect pressure distributions according to different assumed postures. Consequently, the adopted approach in this paper is based on two methodologies: acquisition of pressure distribution with a pressure mat; and acquisition of postural angles through cameras and software Kinovea®.

The postural angles acquisition method has some broader applications with satisfying results (Fiorillo, Nasti, *et al.*, 2021; Fiorillo, Piro, *et al.*, 2019a; Mondéjar-Guerra *et al.*, 2018): while the tracking method is helpful to acquire angles over time (Fiorillo, Nasti, *et al.*, 2021; Fiorillo, Piro, *et al.*, 2019a; Zubair *et al.*, 2017), the use of Kinovea® is useful for static or one-time posture analysis (Avagnale *et al.*, 2020; Cecco *et al.*, 2019; Fiorillo, Anzisi, *et al.*, 2019; Muaza Nor Adnan *et al.*, 2018; Piro *et al.*, 2019b).

5.3.2.1 Informed consent and experiment set-up

The experiment protocol was approved by the Human Research Ethical Committee at Delft University of Technology (TU Delft), in the Netherlands. Participants were informed about the protocol and asked to fill the Informed Consent before participation.

Since experiments were conducted during the COVID-19 sanitary emergency pandemic (World Health Organization, 2020), several precautions were used (see Figure 5-10), such as delimiting spaces reserved to participants and researchers, always maintaining distances of 2 meters, ventilating the room before and after experiments. Everything needed for the experiment was prepared in advance to minimize interactions between participants and researchers, such as a table with the Informed Consent to sign, disposable gloves and sanitizing gel. All devices and objects that participants interacted with had been disinfected and cleaned before and after participation.

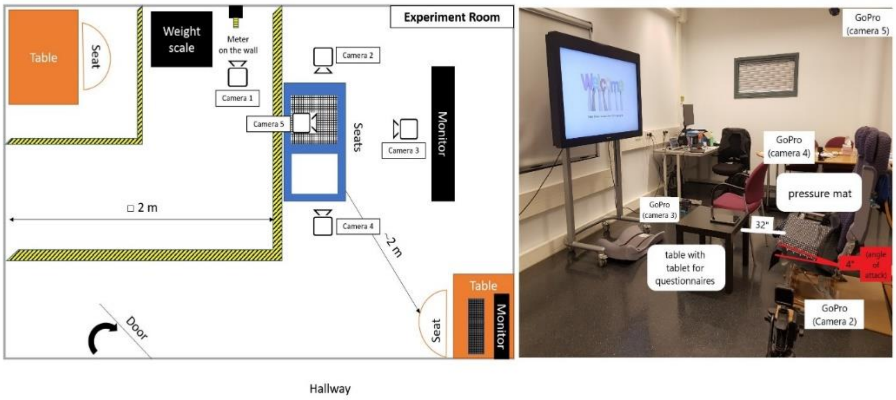

Figure 5-10: *Map of experiments room configuration (on left) and experiment set-up (on right).*

5.3.2.2 Seat-pan cushions

Two aircraft seats with their cushions were used. Seats' inclination was fixed at 4 degrees in respect to the floor, simulating the aircraft's real condition (as an seat cushion angle of 4˚ is normal in cruise). Also, to simulate the seat pitch distance, a table was placed in front of seats at 32 inches (Anjani *et al.*, 2020). The seat-pan cushions (Fiorillo, Song, Smulders, *et al.*, 2021) used were:

- "Flat cushion": having a fixed foam thickness, as commonly used in standard aircraft seats.
- "Shaped cushion" (Fiorillo, Song, Vink, *et al.*, 2021): made by the same type of foam as the flat cushion but with a different shape and contour (for details see para. 5.2).

5.3.2.3 Pressure mat

The Pressure mat Xsensor LX210:48.48.02 (Force, 2016) was used to evaluate the pressure distribution (Table 5-2**)**. The total sensing area is 24 inches x 24 inches (about 60.9 cm x 60.9 cm) with a very low thickness (0.03 inches, that is about 0.9 mm) allowed to detect a wide range of population. The pressure mat was already placed on the first cushion to be tested before starting experiments (see Figure 5-10).

Table 5-2*:Technical characteristics of pressure mat*

Physical characteristics		
Total area	32" x 32"	81.3cm x 81.3 cm
Sensing Area	24" x 24"	60.9 cm x 60.9 cm
Thickness (sensing area, uncompressed)	0.03"	0.09 cm
Thickness (border-cabling side)	0.05"	0.11 cm
Sensing		
Pressure range	0.1–15psi	0.07–10.3N/cm^2
Spatial resolution	0.5''	12.7 mm
Accuracy	±10% full scale	
Sampling frame rate	39 frames/s	
Sensors		
Sensors number	48 x 48 = 2304	
sensor length	12,6875 mm	
sensor area (square)	160,9727 mm^2	
*sensing area (sensor area * sensor number)*	370881 mm^2	

The pressure mat was activated for each posture at the beginning, at middle and at the end, gathering the pressure development for each posture and for each participant (considering all performed postures). The data from the pressure mat (in .CSV files) were processed through the self-developed MatLab® code realized to obtain for each posture:

- Mean, max and min values of pressure distribution
- Map of average pressures
- Contact areas

5.3.2.4 Questionnaires

After each tested posture, participants were asked to fill the “short term questionnaire”: a Body Part Discomfort (BPD) questionnaire where, for each body part it was associate a 5-point scale going from 1= “no discomfort” to 5= “extreme discomfort” (Figure 5-11). From the “short term” questionnaires it was possible to investigate:

- ➢ Discomfort levels according to the posture and cushions
- ➢ Changing of discomfort level over time for each cushion

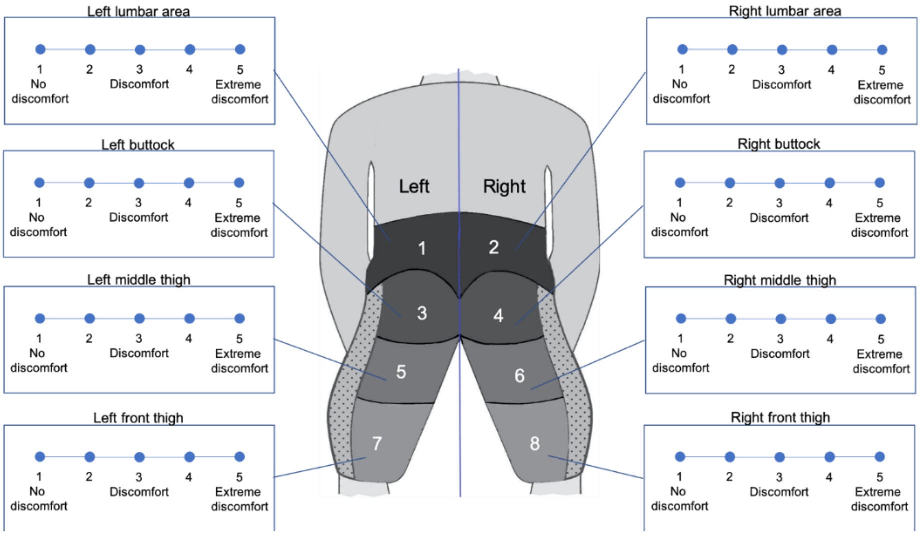

Figure 5-11*: Body Part Discomfort questionnaire*

After sitting one cushion for 42 minutes, participants were asked to rate the "long-term" questionnaire composed by following questions:

1. Overall perceived discomfort (1=No discomfort, 2=Low Discomfort, 5=Discomfort, 7=High Discomfort, 9=Extreme Discomfort)
2. Overall perceived comfort (1=No Comfort, 2=Low Comfort, 5= Comfort, 7=High Comfort, 9=Extreme Comfort)
3. Personal feelings about cushions

☐	Soft	☐	Hard
☐	Cozy	☐	Uncomfortable
☐	Firm	☐	Loose
☐	Adequate	☐	Inadequate
☐	Shaped	☐	Flat
☐	Other: ______________		

Finally, after experiencing both cushions, participants were asked to rate the preferred question and to explain the motivations.

5.3.2.5 Body measurements

The following anthropometric measurements were taken of each participant while standing (or seated for only two measures, as explained below and shown in Figure 5-12):

- Weight (kg) with a weight scale placed in the room.
- Stature height (cm) with a rigid tape meter fixed on the wall.
- Waist width (cm) with a measuring tape at belly-button level.
- Waist circumference (cm) with a measuring tape at belly-button level.
- Seated hip breadth (cm) was measured with a measuring tape at hip level while the participant was seated.
- Hip circumference (cm) at iliac crest using a measuring tape.
- Thigh-length (cm) from the upper part of the femur bone (greater trochanter) to the knee rotula (lateral epicondyle), using a measuring tape.
- Thigh circumference (cm) in the middle of the thigh, using a measuring tape.
- Epicondylar femur width/breadth (cm) was measured at the middle of the thigh while the participant was seated.

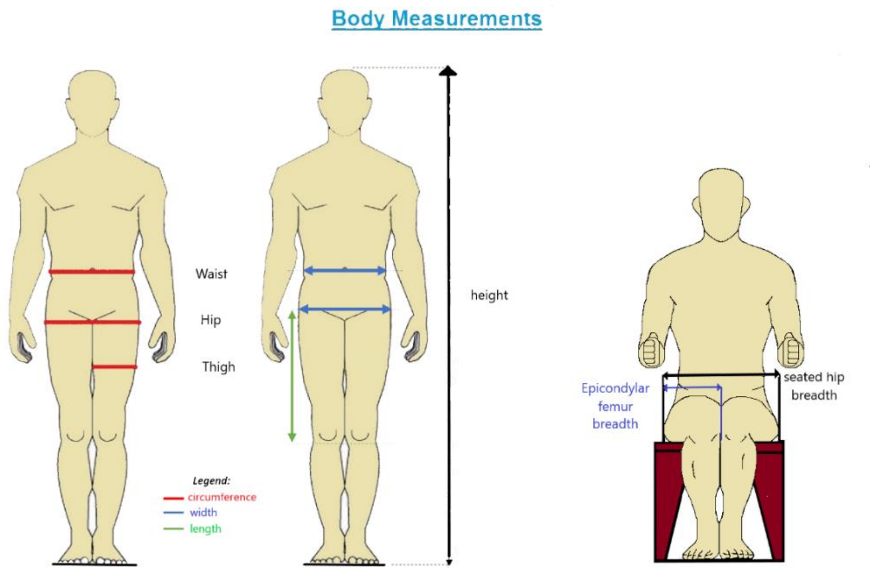

Figure 5-12*: Anthropometric measurements taken on participants' body with measuring tape*

From these measurements, the following indexes were calculated:

BMI (Body Mass Index) = it is calculated as the weight (in kilograms) divided by the square of the stature height (in meters).

WHR (waist-hip ratio) = the relationship between waist circumference and hip circumference: dividing the waist measurement by the hip measurement. A higher WHR indicates a greater accumulation of fat in the abdominal region.

5.3.2.6 Participants

Before conducting experiments, an a priori t-test analysis with GPower software (Faul *et al.*, 2007, 2009; Mayr *et al.*, 2007) was done to determine the sample size N of a test given the desired error probability level α=0.05, the desired power level of 0,8 (defined as 1-β), and with a large effect size ρ=0.5. Results showed that a total sample of N=21 was enough for a confidence interval of 80%. Consequently, 22 (11 males and 11 females) international participants (Chinese, Egyptian, Italian, Colombian, Mexican, Indonesian, Dutch) were recruited to have high variability in weight, height, BMI and WHR. Their anthropometric data are shown in Table 5-3, while the body measurements are in Table 5-4. Also, Figure 5-13 shows the covered range in terms of Height, Weight, BMI and WHR.

Table 5-3: *Anthropometric data of participants (n=22)*

	Average	*Median*	*Standard deviation*	*Max*	*Min*
Age	28.73	27.50	5.55	48.00	24.00
Weight (kg)	64.64	62.50	13.00	95.00	48.00
Height (cm)	169.32	167.00	9.42	193.00	155.00
BMI (Kg/m2)	22.40	22.06	3.05	29.40	16.60
WHR	0.84	0.84	0.06	0.96	0.72

Table 5-4: *Participants' body measurements (n=22)*

		Average	*Median*	*Standard deviation*	*Max*	*Min*
Waist	**Width**	31.14	31.00	3.01	39.00	26.00
	Circumference	80.89	78.65	9.93	105.50	66.00
Hip	**Breadth (seated)**	37.23	37.50	2.52	43.00	32.00
	Circumference	96.17	95.00	6.80	115.00	86.50
Thigh	**Length**	45.83	45.50	4.56	53.00	34.00
	Circumference	48.09	48.15	3.06	52.90	41.50
Epicondylar femur	**Width/breadth**	19.36	19.00	2.00	24.00	16.00

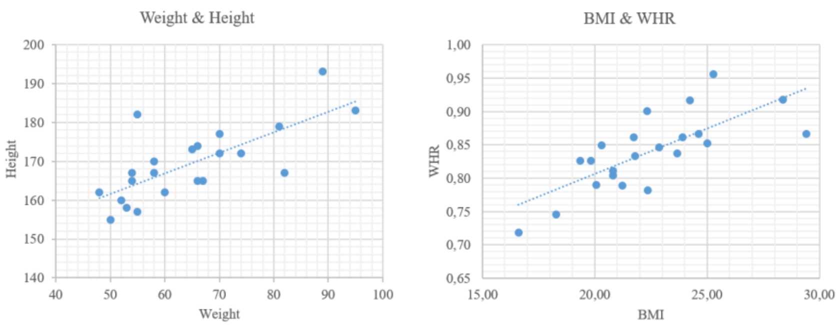

Figure 5-13: *On left: plot of Weight on Height with linear tendency line. On Right: plot of BMI (Body Mass Indexes) on WHR (Waist-Hip Ratio) with linear tendency line.*

5.3.2.7 Experiment protocol

Then, once the participant came to the experiment, the following experiment protocol (Figure 5-14) was performed:

1. The participant was briefed on protocol explaining it was a blinded experiment (2 min).
2. Body measurements were taken (6 min).
3. The participant sat on the planned first cushion assuming for 7 minutes (Helander and Zhang, 1997) each given posture (see para. 5.3.2.8). At the end of each posture, he/she was asked to fill in the *"Short-term-questionnaire"*. Within 7 minutes, the initial 30 seconds were spent for assessing the posture, then 6 minutes on this posture

without changing the body position, and then the last 30 seconds answering the short-term questionnaire. Within these 6 minutes, the pressure-mat recorded pressure distributions three times for 30 seconds (per each posture): at minutes 00:30, 03:15, 6:00 (referring to the timeline of 7 minutes). Meanwhile, photos were taken from all view simultaneously (see para. 0). The last assumed posture was always the desired posture, that is participant could assume their comfortable posture freely during a flight.

4. After 42 minutes on the first cushion (7 minutes x 6 postures = 42 minutes), the participant was asked to fill in the *"Long-term-questionnaire"* (2 min).
5. Break of 5 minutes: the participant went inside the delimited zone (safe area, see Figure 5-10, to distance the participant from the researcher in line with the prevailing COVID-19 regulations). Meanwhile, the pressure mat was placed on the other cushion
6. The second cushion was tested with the same protocol as the first cushion, following the same order of assumed postures.
7. After experiencing both cushions, participant was asked to choose the preferred cushion and to explain the reasons.

The cushion and posture orders were planned for each participant adopting the Latin Square Method to randomize the order keeping the experiments repeatability (Fisher, 1992). The time assumed on each cushion was 44 minutes, supposing that inter-differences were more evident only after 40 minutes (Dangal *et al.*, 2021; Hartung *et al.*, 2004; Mergl, 2006).

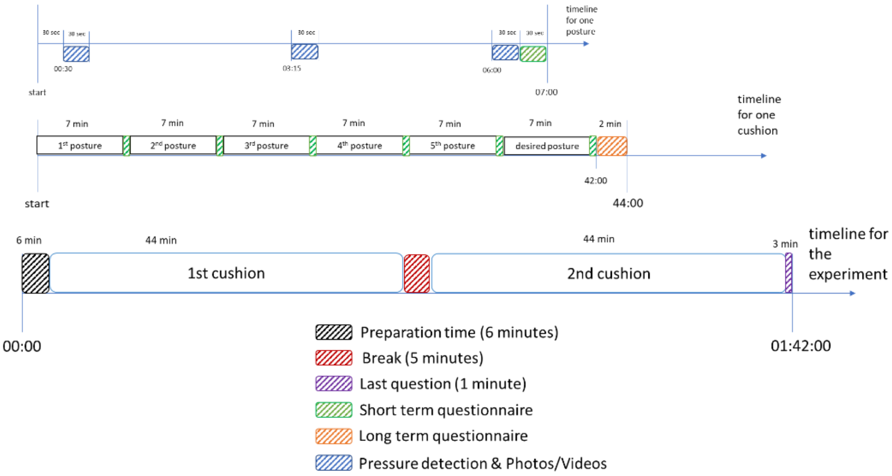

Figure 5-14: *Experiment protocol, time detailed*

5.3.2.8 Postures

A wide monitor was installed in front of the seat, at head level (in order to be readable without bending the neck), to give instructions to participants (see Figure 5-10). The planned postures were based on literature studies and are commonly assumed by passengers (Hiemstra-van Mastrigt, 2015). However, the used aircraft seats had a fixed angle for the backrest, so the slouched/relaxed posture was hard to achieve and was not included in this study. The postures are shown in Table 5-5:

Table 5-5: *Postures assumed by participants*

Upright The participant has to assume the upright posture, angle back-legs around 90° and legs raised at 90° at knee	
Elbow on legs The participant is bended forward placing the elbows on the legs, and both thigh on the seat pan	
Legs crossed The participant has to lay against the backrest and to have leg crossed, with the right leg on the left leg	
Arm on armrest The participant should bend on the right side placing the arm on the armrest	
Legs crossed + arm on armrest Crossing the legs (the left leg on the right leg), the participant should bend on the right side placing the arm on the armrest	
Desired posture The participant can assume his/her comfortable posture freely during a flight	

5.3.2.9 Photo acquisition

Photos were taken from different views with Go-Pro Hero 7 to acquire postural angles through Kinovea® software. Figure 5-10 shows the experiment room configuration and the position of 5 cameras:

- Camera 1: fixed on the tripod to take photos of the participant in front of the meter fixed on the wall to gather participants' height.
- Camera 2 & Camera 4: placed on the lateral sides of the seat group to take the lateral views of the participant's posture. In particular, to acquire hip, knee, and seat-thigh angles, as shown in Figure 5-15. Anatomical joints of shoulders, hip, knee and ankle were considered.

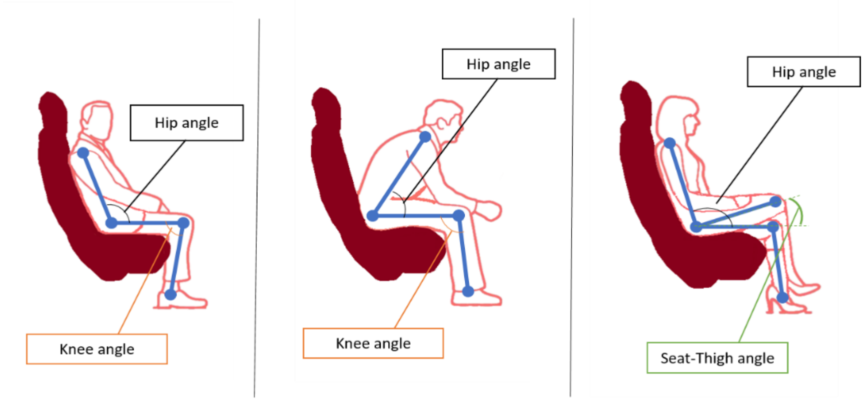

Figure 5-15: *Postural angles acquired with lateral views. Anatomical joints of shoulder, hip, knee and ankle were considered to calculate hip angle, knee angle and seat-thigh angle, respectively*

- Camera 3: placed in front of the monitor to gain the frontal view of the participant's posture, particularly the trunk bending. For the horizontal line, anatomical joints of shoulders and manubrium (upper part of sternum) were considered, while for the vertical line, the manubrium and waist center were considered. The bending on the left was considered with positive angle values, while the bending on the right with negative angle values (as shown in Figure 5-16).

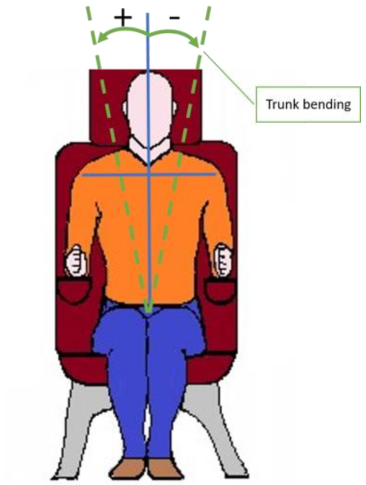

Figure 5-16: *Postural angles acquired on the frontal view. Trunk bending angles were considered.*

- Camera 5: placed on top of the participant to obtain thigh abduction/adduction. The line on the middle of the thigh was considered. The zero-angle value position corresponds to the rest position, with thighs perpendicular to the waist. Angles of thigh adduction were considered negative values, while the abduction ones had positive values (Figure 5-17).

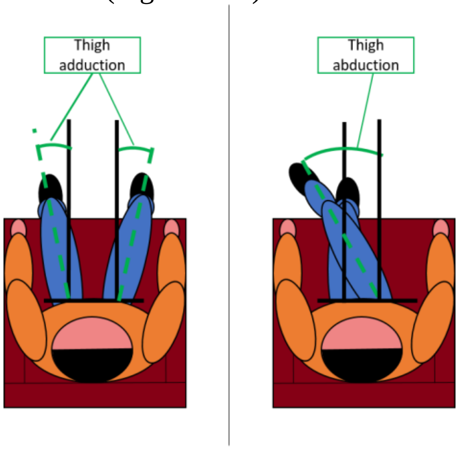

Figure 5-17: *Postural angles acquired from the top view. Thigh abduction/adduction angles were considered.*

5.3.2.10 Statistical analysis and expected outcomes

The statistical analysis approach was adopted in different moments. Before conducting experiments, an a priori t-test analysis with GPower software (Faul *et al.*, 2007, 2009; Mayr *et al.*, 2007) was done to determine the necessary sample size N of a test given the desired error probability level α=0.05, the desired power level of 0,8 (defined as 1-β), and with a large effect size ρ=0.5. Results showed a total sample of N=21 was enough for a confidence interval of 80%. Once performed experiments, statistical differences and analysis of variance were calculated with Wilcoxon test and ANOVA respectively. Also, significant correlations were analyzed with SPSS software. This work aims to study correlations or relationships between the following variables (comparing the cushions):

- (Dis)comfort & Postures
- (Dis)comfort & pressure distribution
- Postures & pressure distribution
- BMI/WHR & contact area
- BMI/WHR & pressure distribution

5.3.3 Results & Discussions

5.3.3.1 "Short-term" questionnaires

From the "short-term" questionnaire data about perceived postural discomfort for each posture and cushion were gathered. Differences among the two cushions were analyzed considering the effects over time and the effects of assumed postures. Figure 5-18 and Figure 5-19 show results of perceived discomfort over time for the flat cushion and shaped cushion, respectively. The histograms represent the discomfort level for each body part and are grouped for each posture, starting with the first assumed posture and ending with the last performed posture. So, the grouped postures refer to an assumed posture generally, without any distinction. The line LBD (Lower Body Discomfort) represents the global perceived discomfort of lower limbs: for each participant, the mean of all body parts was calculated, and the LBD represents the mean of all 22-calculated means. Thus, the LBD was done to compare the discomfort trends of two cushions. Generally, the perceived discomfort for the flat cushion is higher than the shaped cushion. Indeed, the LBD lines are within the range 1.8-2 for the flat cushion and 1.6-1.8 for the shaped cushion. Wilcoxon Sign Rank tests were performed to check significant differences with IBM SPSS Statistics 26. The values considered are the sums of perceived discomfort for each participant and postures. Results showed that there are no significant differences (for $\rho \leq 0.05$) between the flat cushion and shaped cushion. Instead, there are only two significant differences within each cushion: one between Posture 5 and Posture 6 for the flat cushion

(Z=-2.218, ρ=0.027), and the other between Posture 3 and Posture 6 for the shaped cushion (Z=-2.235, ρ=0.025). The absence of significant differences could mean the 7-minutes were not long enough for participants to be aware of differences in perceived discomfort between postures. However, the presence of a significant difference between the last and second-last postures for the flat cushion could mean participants could achieve a less discomfortable posture with their desired posture after 35 minutes of sitting. Instead, the significant difference obtained for the shaped cushion is between the maximum and minimum values of LBD.

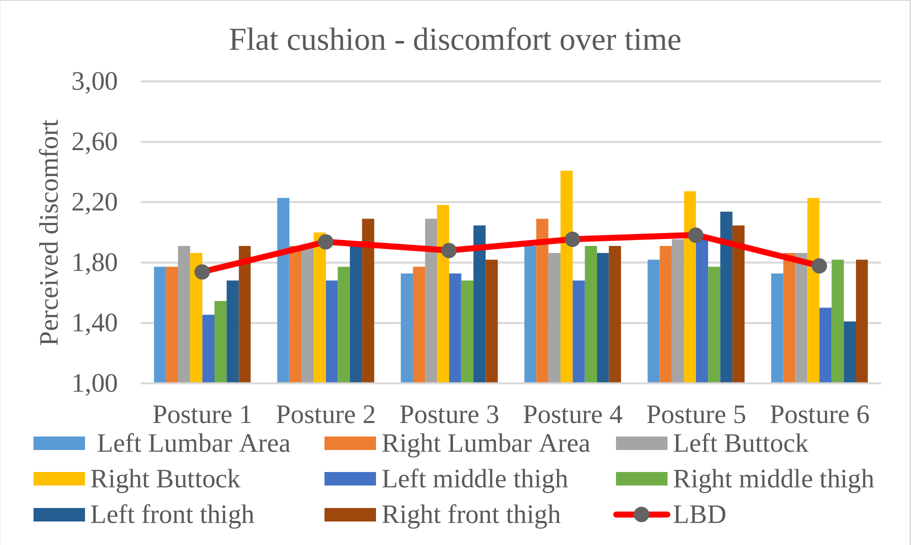

Figure 5-18*: Result from LPD (with 5-point Likert scale) of "short-term" questionnaires - perceived discomfort over time for flat cushion. The line LBD stands for Lower Body Discomfort, the calculated mean of perceived discomfort indexes for each posture.*

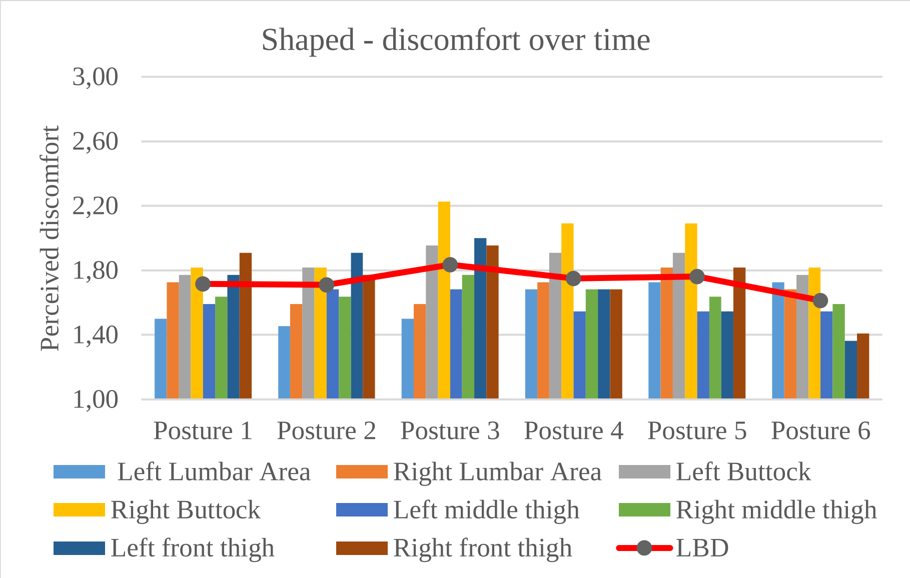

Figure 5-19: *Result from LPD (with 5-point Likert scale) of "short-term" questionnaires - perceived discomfort over time for shaped cushion. The line LBD stands for Lower Body Discomfort, the calculated mean of perceived discomfort indexes for each posture.*

Moreover, these results for each cushion were split according to cushion order. Participants that started with flat cushion rated the shaped cushion with less discomfort. Instead, there are no apparent differences in rating discomfort for participants that started with shaped cushion and ended with the flat one.

Analyzing the perceived discomfort for each assumed posture, Figure 5-20 and Figure 5-21 show results from the BPD questionnaires. The flat cushion scored higher discomfort indexes than the shaped cushion. As before, the Wilcoxon Sign Rank test was performed with IBM SPSS Statistics 26: among the two cushions, there is only one significant difference in "Leg crossed" posture ($Z=-2.811$, $\rho=0.005$). Instead, considering the differences of perceived discomfort within one cushion, Table 5-6 and Table 5-7 report the significant differences for $\rho \leq 0.05$.

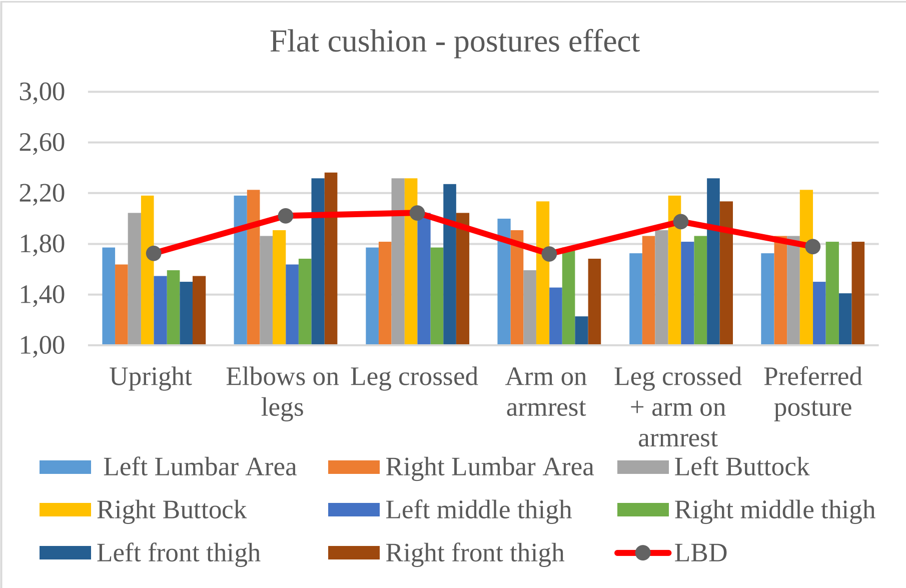

Figure 5-20: *Result from LPD (with 5-point Likert scale) of "short-term" questionnaires - perceived discomfort for each posture while sitting on the flat cushion. The line LBD stands for Lower Body Discomfort, the calculated mean of perceived discomfort indexes for each posture.*

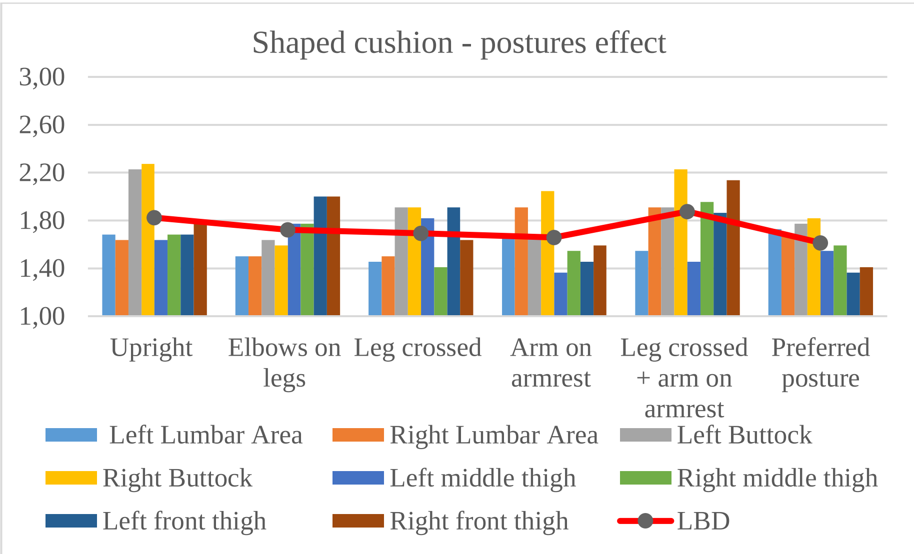

Figure 5-21: *Result from LPD (with 5-point Likert scale) of "short-term" questionnaires - perceived discomfort for each posture while sitting on the shaped cushion. The line LBD stands for Lower Body Discomfort, the calculated mean of perceived discomfort indexes for each posture.*

Table 5-6: *Wilcoxon Sign Rank test calculated for the LBD (Lower Body Discomfort) of Flat cushion. Only significant differences are reported.*

LBD for Flat Cushion	Upright	Arm on armrest	Preferred Posture
Elbows on legs	Z=-2.064, ρ=0.039		Z=-2.347, ρ=0.019
Leg crossed	Z=-2.402, ρ=0.016	Z=-2.218, ρ=0.027	Z=-2.041, ρ=0.041

Table 5-7: *Wilcoxon Sign Rank test calculated for the LBD (Lower Body Discomfort) of Shaped cushion. Only significant differences are reported.*

LBD for Shaped Cushion	Leg Crossed	Arm on armrest	Preferred Posture
Upright			Z=-2.113, ρ=0.035
Leg crossed + arm on armrest	Z=-2.059, ρ=0.039	Z=-2.278, ρ=0.023	

5.3.3.2 "Long-term" questionnaires

The "long-term" questionnaire was rated after experiencing one cushion, that is after 42 minutes of sitting. The Global Discomfort and Global Comfort were rated on a 10-point scale, and results are shown in Figure 5-22. The shaped cushion scored lower perceived discomfort and higher perceived comfort than the flat cushion.

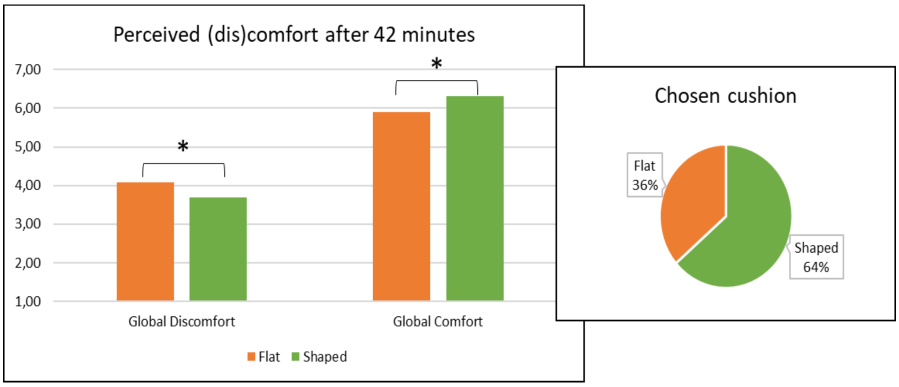

Figure 5-22: *On left: Results from the "long-term" questionnaires regarding the perceived postural discomfort and comfort rated on a 10-point scale. Significant differences are shown with *. On right: results about the chosen cushion.*

Wilcoxon Sign Rank Test was performed with IBM SPSS Statistics 26 to check significant differences between the two cushions, represented in Figure 5-22 with *. In Table 5-8 are shown the significant correlations from

Spearman Correlation analysis; in particular, the global comfort is negatively correlated with the global discomfort meaning that by reducing the discomfort, the perceived comfort could arise per each cushion.

Table 5-8: *Significant Spearman Correlations for subjective data.*

		Global Discomfort Flat	Global Comfort Flat	Global Discomfort Shaped	Global Comfort Shaped
Global Discomfort	Flat	-	-,750**	,762**	
	Shaped	,762**	-,614**	-	-,697**
Global Comfort	Flat	-,750**	-	-,614**	,668**
	Shaped		,668**	-,697**	-

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

As far as the descriptive adjectives, Figure 5-23 and Figure 5-24 show the results for each cushion. The flat cushion appeared firmer than the shaped cushion, while the shaped cushion softer than the flat one.

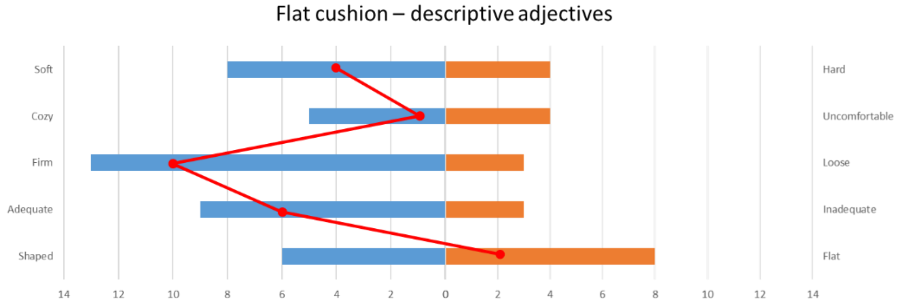

Figure 5-23: *Results from "long-term" questionnaires regarding the descriptive adjectives for the flat cushion.*

Figure 5-24: *Results from "long-term" questionnaires regarding the descriptive adjectives for the shaped cushion.*

5.3.3.3 Preferred cushion in terms of perceived (dis)comfort

After experiencing both cushions, participants were asked to choose their preferred cushion without knowing the difference between them (it was a blind experiment). Indeed, they chose the first or the second cushion tested and explained their reasons. Figure 5-22 shows the results: the majority of participant chose the shaped cushion. The open question's answers were analyzed and categorized into advantages and disadvantages for each cushion. For the shaped cushion, participants felt it softer, more comfortable and more adequate for their body shape. Indeed, they declared that the shape adapted more to their lower body. The disadvantages were more pressure on the front thigh and less firmness. Instead, the flat cushion gave more support, but they felt more pressure on the lower body areas.

5.3.3.4 Objective data: pressure distribution and contact area

The comparison among cushions was evaluated confronting pressure distributions and contact areas by differences: data from the shaped cushion were subtracted with data from the flat one. Negative values of average pressure mean the pressure distribution on the shaped cushion is lower than the flat cushion; positive values of contact area mean the contact area on the shaped cushion is higher than the flat one. Figure 5-25 shows this comparison's results for each assumed posture, demonstrating that the shaped cushion presented less pressure and higher contact area than the flat cushion.

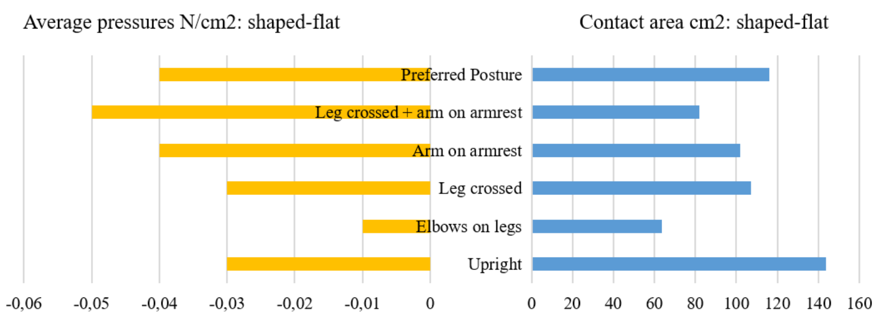

Figure 5-25*: Result from the pressure mat: differences of average pressures and contact areas*

Significant correlations were calculated between objective data (average pressure per each posture) and subjective data (global (dis)comfort rating) with Spearman Correlation coefficients, as shown in Table 5-9. The presence of correlations between pressure distributions and perceived discomfort is aligned with literature studies. Moreover, pressure distributions and contact areas were strongly correlated with gender (p~0,6), indicating that these values were higher for men than women.

Table 5-9: *Significant Spearman Correlations calculated between objective and subjective data for Flat and Shaped cushions (n=22).*

		Average pressure					
		P1	**P2**	**P3**	**P4**	**P5**	**P6**
Global Discomfort	Flat	,770**	,503*	,432*		,656**	
	Shaped			,602**	,805**	,433*	,423*
Global Comfort	Flat	-,627**	-,597**		-,697**	-,556**	
	Shaped	-,433*		-,593**		-,457*	-,566**

5.3.3.5 Postural angles: desired posture

Before comparing pressure distributions, postural angles of desired postures were analyzed, and results are summarized in Figure 5-26. The graph shows the desired posture assumed per each participant, comparing the flat and shaped cushion.

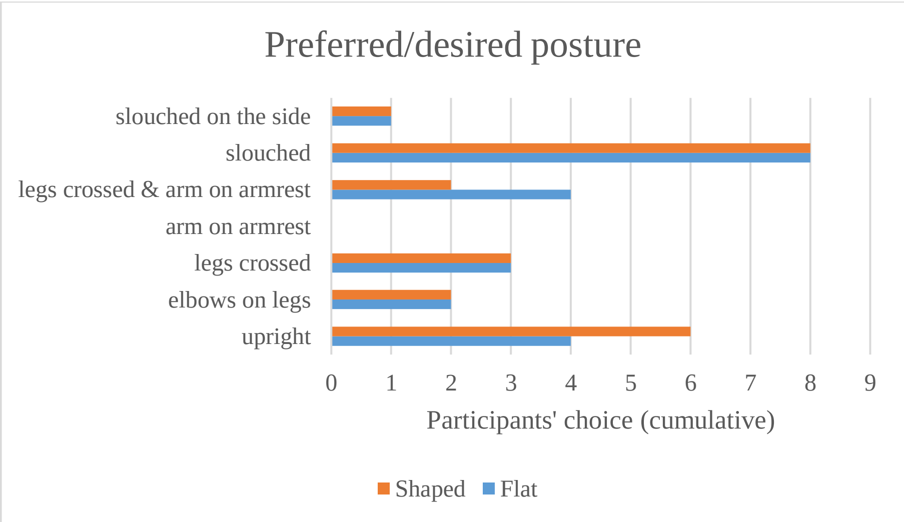

Figure 5-26*: Participants' desired postures for each cushion*

Even though the backrest was fixed, most of the participants tried to assume a slouched posture. Only 4 of them did not assume the same posture on both cushions.

5.3.3.6 Pressure maps

Data acquired from pressure mat were analyzed through a self-developed code on MatLab®. For each participant, 3 acquisitions were made for each posture (at the beginning, in the middle and at the end of the 7-minute slot), obtaining 66 datasets for each posture (3 acquisition/posture x 22 participants) and 462 datasets in total (66 acquisition*participant/posture x 7 posture/participant). Accurate analysis and data alignment were done to reduce the eventual presence of minor errors of mat placing. After this analysis, pressure maps were merged, obtaining the average pressure distribution for each posture and cushion (paragraphs 5.3.3.6.1-5.3.3.7.3). Pressure maps were divided into 6 subareas (see Figure 5-27), as done in previous studies for cars (Kilincsoy *et al.*, 2016; Mergl, 2006; Zenk *et al.*, 2006), and the following data were calculated:

- a_i is the contact area detected in i-subarea, considered through the number of sensors (whose area is 1 cm^2)
- max p_i is the maximum pressure detected in that i-subarea
- $load_i$ is the percentage of load detected in that i-subarea than the overall load detected. Since it was not a direct measure, it was calculated considering the detected pressure and contact area detected in that i-subarea:

$$load_i = \frac{\sum_{j=1}^{n} p_j a_j}{\sum_{j=1}^{N} p_j a_j} \quad [\%]$$

where n=sensors detected in i-subarea; N=sensors detected in all pressure mat

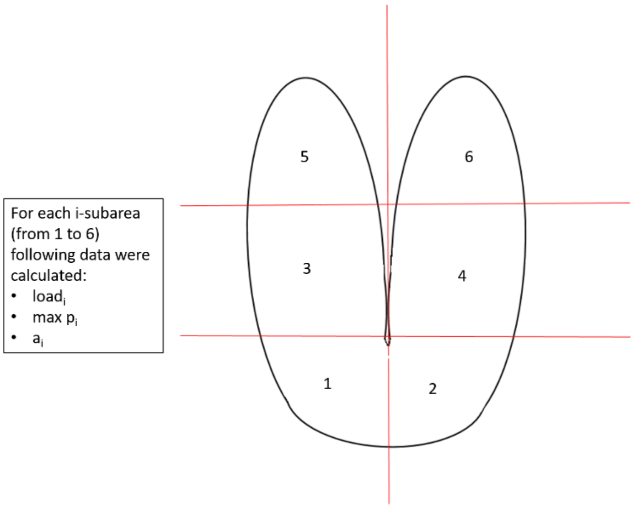

Figure 5-27*: Subdivision in 6 areas where load (in percentage), pressure (N/cm2) and areas (cm2) were calculated*

Also, postural angle acquisition was made with Kinovea® software for each posture, participant and cushion, shown in tables of paragraphs 5.3.3.6.1-5.3.3.7.3, indicating the mean, min and max values (expressed in degree). The angles condition/constraints were always respected for each posture.

5.3.3.6.1 Upright posture

Participants assumed the upright posture, with hip angle around 90°, knee angles around 90°, thighs lying on the seat-pan (so the thigh angles were always 0°), and feet on the floor. During experiments, checking on thigh abductions and trunk bending was done to ensure all participants assumed the same posture, with null values of thighs abduction and trunk bending.

Table 5-10: *Postural angles for upright posture expressed in degree*

Upright			**hip angle**	**Knee angle**		**Thigh angle**		**Thigh abduction**		**trunk bending**
				left	*right*	*left*	*right*	*left*	*right*	
Cushion type	**FLAT**	Mean	108	90,32	90,32	0	0	0	0	0
		Min	90	78	78	0	0	0	0	0
		Max	120	103	103	0	0	0	0	0
	SHAPED	Mean	109,77	93,54	93,54	0	0	0	0	0
		Min	101	72	72	0	0	0	0	0
		Max	125	114	114	0	0	0	0	0

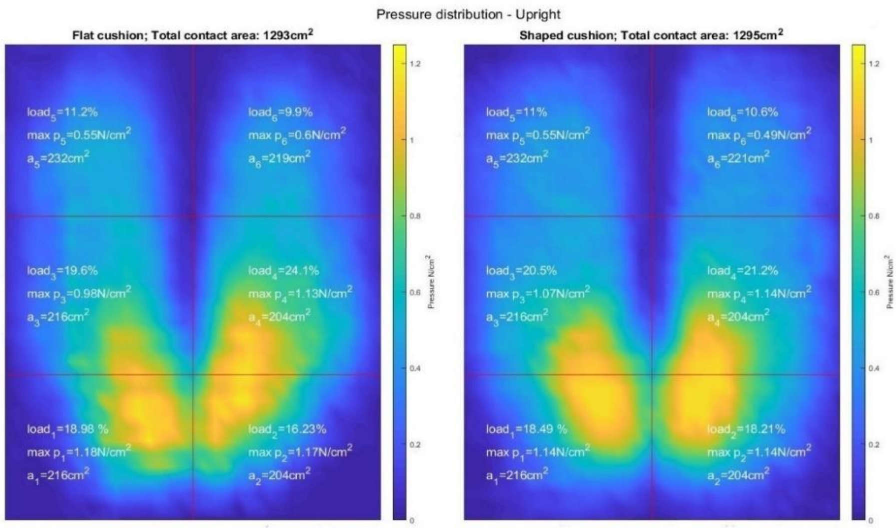

Figure 5-28*: Pressure map distribution for Upright posture (n=22)*

The shaped cushion presented (Figure 5-28) a wider contact area and contours, with a more uniform pressure distribution comparing a_1 with a_2, a_3 with a_4, and a_5 with a_6 on both cushions. The load is more concentrated in middle areas and buttock areas.

5.3.3.7 Elbows on legs posture

Participants bent forward, placing the elbows on thighs (placed without ad/abduction), the angle at knee around 90°, thighs lying on seat-pans.

Table 5-11: *Postural angles for elbows on legs posture expressed in degree*

Elbows on legs			**hip angle**	**Knee angle**		**Thigh angle**		**Thigh abduction**		**trunk bending**
				left	*right*	*left*	*right*	*left*	*right*	
Cushion type	**FLAT**	Mean	50,82	85,36	85,36	0	0	0	0	0
		Min	37	51	51	0	0	0	0	0
		Max	61	105	105	0	0	0	0	0
	SHAPED	Mean	51,62	91,24	91,24	0	0	0	0	0
		Min	37	80	80	0	0	0	0	0
		Max	69	102	102	0	0	0	0	0

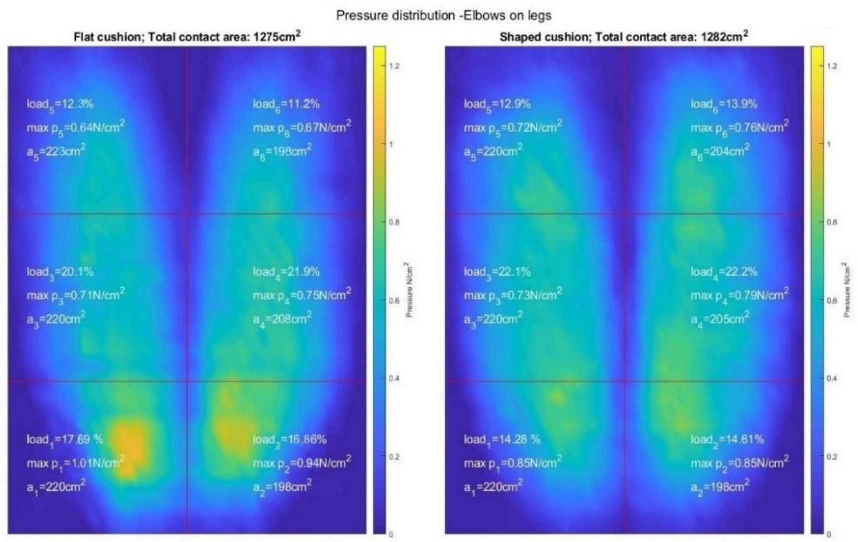

Figure 5-29*: Pressure distribution maps for Elbows on legs posture (n=22)*

The shaped cushion presents a more uniform pressure considering the subareas two by two (Figure 5-29). Moreover, the flat cushion presents peak pressures on buttock areas and only lower load percentages on middle areas than the shaped cushion. Since the center of gravity is forward, the load percentages are lower on the buttocks area and higher in the middle area than in the upright posture.

5.3.3.7.1 Leg crossed (right leg up)

Participants crossed their legs starting from the upright posture, placing the right thigh on the left thigh. Since it was required to respect the seat pitch distance (see Figure 5-10), participants with height ≥179 cm used to adduct the thigh, so the angles were reported with negative values (see Figure 5-17).

Table 5-12: *Postural angles for the leg crossed posture expressed in degree*

Leg crossed (right up)			**hip angle**	**Knee angle**		**Thigh angle**		**Thigh abduction**		**trunk bending**
				left	*right*	*left*	*right*	*left*	*right*	
Cushion type	**FLAT**	Mean	106,14	93,81	89,5	0	22	13,68	19,05	0
		Min	88	77	76	0	15	0	-30	0
		Max	118	112	105	0	47	30	59	0
	SHAPED	Mean	105,67	95,62	89,48	0	18,86	11,33	19,19	0
		Min	88	85	67	0	9	-19	-22	0
		Max	118	112	104	0	31	30	54	0

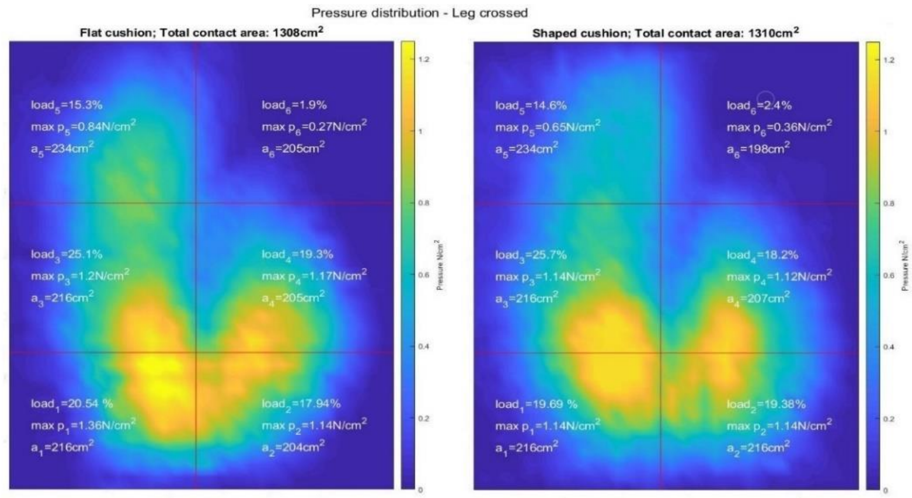

Figure 5-30: *Pressure distribution maps for Leg crossed posture (n=22)*

The shaped cushion presents a more uniform pressure distribution on the buttock area than the flat cushion. The values of load percentages differ from the upright posture since the weight of the right thigh is unloaded on the left thigh.

5.3.3.7.2 Arm on armrest

Starting from the upright posture, participants bent with the trunk on the right side, placing the arm on the armrest; thus, unloading part of the weight on the armrest.

Table 5-13: *Postural angles for the arm on the armrest posture expressed in degree*

Arm on Armrest			**hip angle**	**Knee angle**		**Thigh angle**		**Thigh abduction**		**trunk bending**
				left	*right*	*left*	*right*	*left*	*right*	
Cushion type	**FLAT**	Mean	107,18	92,18	92,18	0	0	0	0	14,81
		Min	93	68	68	0	0	0	0	0
		Max	127	121	121	0	0	0	0	27
	SHAPED	Mean	110,91	93,91	93,91	0	0	0	0	15,41
		Min	100	75	75	0	0	0	0	0
		Max	132	111	111	0	0	0	0	29

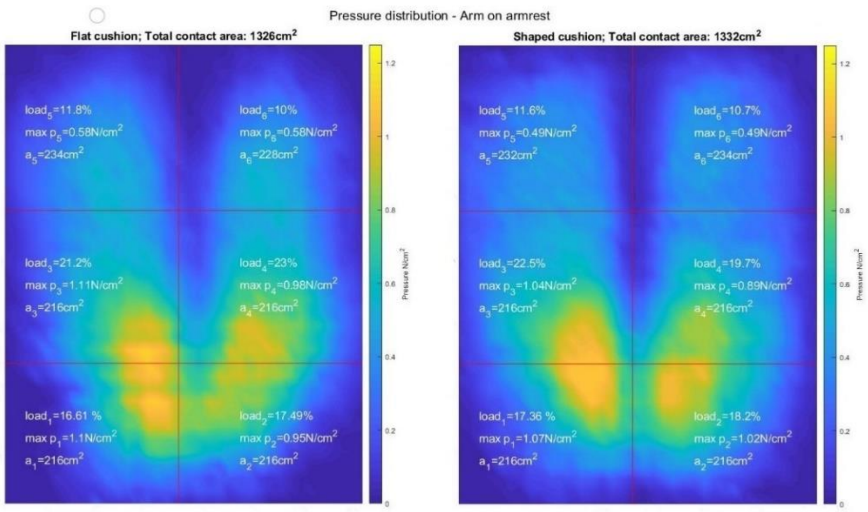

Figure 5-31: *Pressure distribution maps for Arm on armrest posture (n=22)*

The trunk bending is more visible on the flat cushion with the load percentage increased in subarea a_4. On the shaped cushion, there is a decreasing of load percentage in subarea a_4 and increasing in subarea a_3, probably due to the shape (Figure 5-31).

5.3.3.7.3 Leg crossed (left leg up) & arm on armrest

Participants assumed the “arm on armrest” posture again and placed the left thigh on the right thigh. Since it was required to respect the seat pitch distance (see Figure 5-10), participants with height ≥179 cm used to adduct the thigh, so the angles were reported with negative values (see Figure 5-17).

Table 5-14: *Postural angles for the leg crossed & arm on armrest posture expressed in degree*

Leg crossed (left up) & Arm on armrest			**hip angle**	**Knee angle**		**Thigh angle**		**Thigh abduction**		**Trunk**
				left	*right*	*left*	*right*	*left*	*right*	**bending**
Cushion type	**FLAT**	Mean	106,14	83,04	97,68	20,45	0	21,73	14,32	8,59
		Min	75	70	84	11	0	-27	0	0
		Max	117	100	113	32	0	52	35	22
	SHAPED	Mean	110,67	86,67	98,43	19,28	0	21,19	12,24	9,43
		Min	97	73	77	11	0	-23	-14	0
		Max	129	134	120	30	0	48	37	25

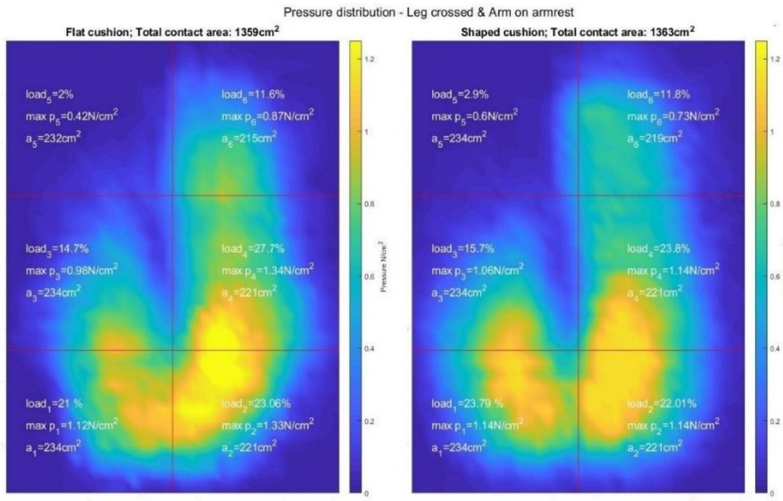

Figure 5-32: *Pressure distribution maps for Leg crossed & Arm on armrest posture (n=22)*

The high values of load percentage are due to the increasing weight on the right side for the trunk bending and the presence of the left thigh. However, the shaped cushion presents likely a more uniform pressure distribution than the flat cushion (Figure 5-32).

5.3.3.8 Correlations

From the previous paper (Fiorillo, Song, Smulders, *et al.*, 2021), only 64% of participants preferred the shaped cushion. Apart from the reasons explained by participants, a further analysis was done in this paper. Spearman's coefficient correlations were calculated with SPSS IBM statistic software between the participant’s choice and the body measurements. Results show strong correlations between the shaped cushion choice and hip circumference (p=0,522*) and weight (p=0,455*). So, the wider the hip circumference or higher the weight, the more comfortable the shaped cushion is. Table 5-15 shows Spearman's coefficient correlations between measurements and data acquired from the pressure mat. BMI and WHR present strong correlations with average pressure distribution and contact areas for both cushions. Also, contact areas of both cushions show correlations with waist, hip and epicondylar femur measurements. Consequently, correlations results confirm findings of literature studies.

Table 5-15: *Spearman's correlation between measurements and data from pressure mat*

P1=Upright P2= Elbows on legs P3= Leg crossed P4= Arm on Armrest P5= P3 & P4 P6= Preferred posture			**Waist**		**Hip**		**Thigh**		**Epicondylar femur width (breadth)**	**Weight (kg)**	**Height (cm)**	**BMI**	**WHR**
			Width	*Circumference*	*Breadth (seated)*	*Circumference*	*Length*	*Circumference*					
Average Pressure	**Flat**	*P1*								,577**	,624**		
		P2	,539**	,693**		,523*		,531*		,722**		,763**	,789**
		P3								,502*	,640**		
		P4	,534*	,636**		,594**				,760**	,549**	,676**	,604**
		P5								,664**	,701**	,429*	
		P6										,518*	,547**
	Shaped	*P1*		,445*						,696**	,646**	,531*	,446*
		P2	,486*	,661**		,503*				,735**		,774**	,766**
		P3								,505*	,494*		
		P4	,457*	,595**		,569**				,816**	,713**	,652**	,518*
		P5								,674**	,722**	,446*	
		P6		,468*				,477*		,585**		,636**	,576**
Contact Area	**Flat**	*P1*	,600**	,787**	,433*	,659**		,461*	,428*	,829**	,457*	,860**	,750**
		P2	,706**	,918**	,503*	,846**	,593**	,499*		,859**	,570**	,793**	,730**
		P3	,626**	,831**	,530*	,741**		,490*	,459*	,854**	,481*	,890**	,710**
		P4	,786**	,914**	,556**	,852**	,430*	,441*	,451*	,919**	,524*	,905**	,765**
		P5	,696**	,843**	,653**	,840**			,573**	,846**		,890**	,663**
		P6	,712**	,724**	,428*	,762**				,706**		,643**	,562**
	Shaped	*P1*	,647**	,843**	,471*	,761**			,480*	,862**	,477*	,840**	,711**
		P2	,681**	,862**		,839**	,509*		,462*	,817**	,573**	,746**	,673**
		P3	,646**	,773**	,622**	,712**			,549**	,807**		,878**	,635**
		P4	,669**	,822**	,607**	,800**	,456*		,575**	,862**	,492*	,848**	,627**
		P5	,782**	,863**	,653**	,866**			,550**	,784**		,843**	,665**
		P6	,561**	,691**		,638**				,593**		,623**	,628**

5.3.3.9 General pressure map distribution

Confronting pressure distributions maps among all postures, the ranges are similar with some differences according to the center gravity position. For instance, when participants bent on the side, the detected pressure on that side was a little higher than the upright position, so the center gravity was closer to that side. Also, passengers could assume different postures during a flight and pressure distributions could change over time. Consequently, an average pressure map distribution was obtained by combining previous pressure maps from all postures, as shown in Figure 5-33. Even in this case, it is clear how the pressure distribution is more uniform on the shaped seat pan.

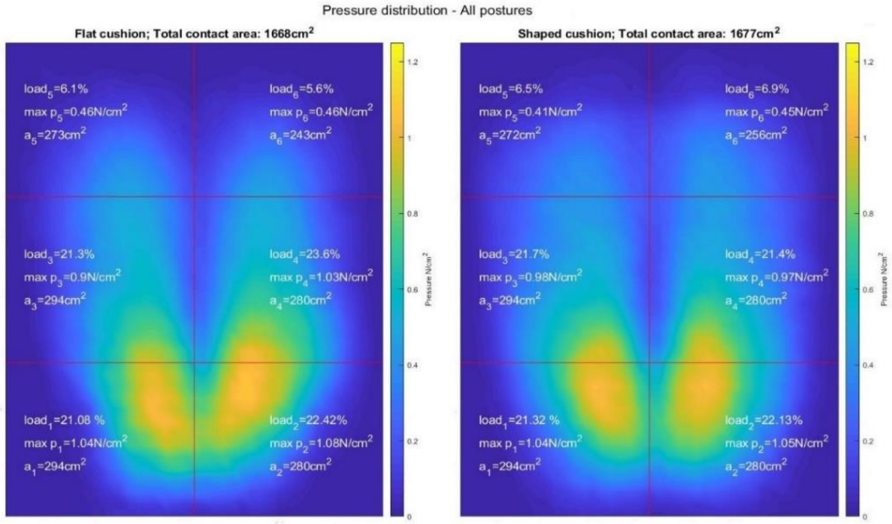

Figure 5-33: *Pressure distribution maps obtained combining all previous postures (n=22)*

5.3.3.10 Comparison between aircraft and car seats

Aircraft and cars are vehicles designed to satisfy the need of users to travel from one location to another one. Aircraft carry passengers during a flight, while cars accommodate drivers and passengers on the road. The different situations/environments generated the need to develop specific seats designed for aircraft and cars. For instance, car seats are generally placed lower, and the taken postures are more slouched. Car seats are also used in a more dynamic environment due to lane changes and turns

Also, people perform different activities. In aircraft, passengers spend their in-flight time somehow, such as sleeping, eating, reading, watching movies, working, constrained to be seated. In cars, instead, drivers perform an active action-driving on seats, moving the legs to brake, accelerate or for gear swift, while passengers can perform any desired action while sitting.

This premise allows comprehend that there are substantial differences between these two vehicles.

Figure 5-34 shows recommended pressure distributions on car seats. Mergl (Mergl, 2006) and Zenk (Zenk *et al.*, 2006) analyzed pressure distributions for drivers, while Kilinsoy (Kilincsoy *et al.*, 2016) for passengers in upright and relaxed postures. or passengers in upright and relaxed postures. These pressure maps present a higher load percentage on the buttock area (a1 and a2) and a lower load percentage on thigh areas (a3, a4, a5 and a6). Thus, the pressure distribution on aircraft seats differs from the one in cars for the presence of several factors. One of them is the difference in position for gravity center since the angle attack for aircraft is 4 degrees and for cars the range is 3-12+ degrees for anti-submarining. Also, the studied postures are different, ignoring differences in seat structure (mainly the frame) and foams.

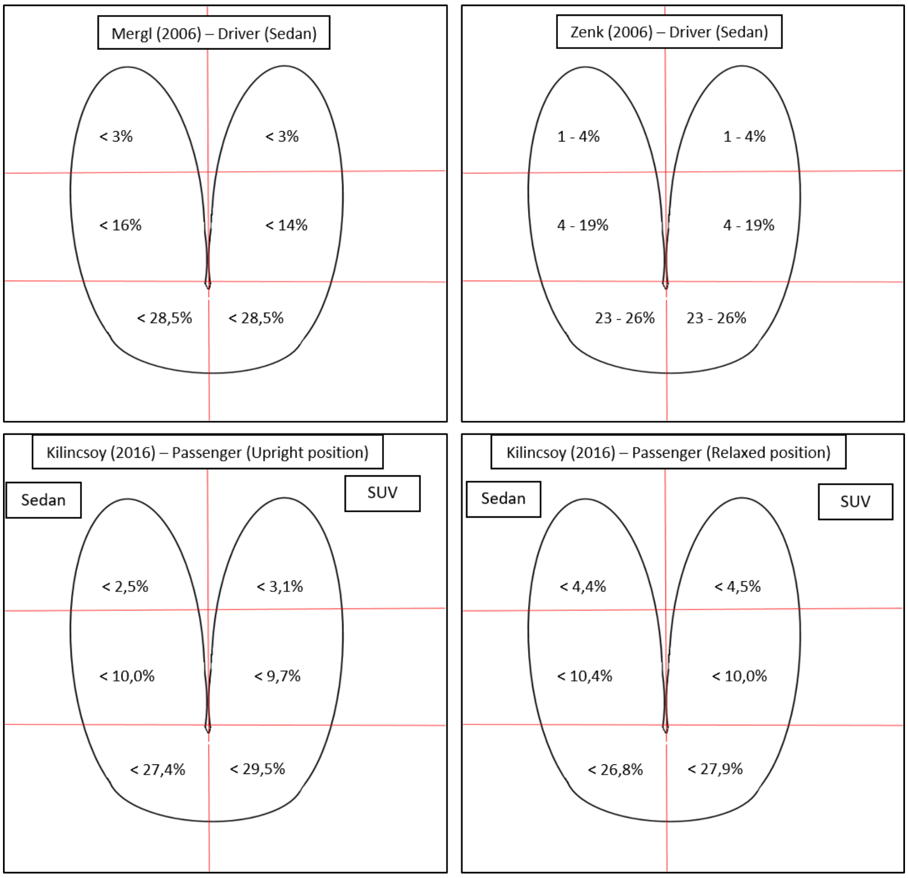

Figure 5-34: *Pressure distribution maps studied on car seats according to Mergl, Zenk and Kilincsoy*

5.3.4 Conclusions

During a journey in future vehicles, passengers could sit for most of the time. So, it is vital to analyze interactions between humans and seats in terms of postural (dis)comfort. For the seat-pan, the postural (dis)comfort could be influenced mainly by two factors: pressure distribution and seat contour. Less pressure distribution at the contact interface between the seat pan and buttock-thigh area could lead to higher perceived comfort or discomfort reduction. Since there are literature studies about the ideal pressure distribution for seat car, experiments were done on aircraft seats. In particular, this work made a comparison between two cushions for the seat pan (flat cushion and shaped cushion) using subjective data from questionnaires and objective data from the pressure mat. Results showed that the shaped cushion could be better than the flat one in terms of postural comfort since pressure distributions were more uniform with low peak pressures and contact areas higher. Statistical analysis with correlations were performed to support subjective and objective results. In particular, results from questionnaires showed that the flat cushion scored higher perceived global discomfort while the shaped higher perceived global comfort. Also, 64% of participants preferred the shaped cushion because it was more comfortable and suitable for the buttock shape. The analysis for comparison was done through the simultaneous use of two acquisition methods: pressure detection with a pressure mat and a postural angles acquisition by photos.

The comparison in terms of pressure distribution maps showed that the shaped cushion always presented a wider contact surface and more uniform pressure distribution, with lower peak pressure. This result is aligned with literature studies that demonstrated a wider contact surface is related to more comfort and lower pressure distribution is related to less discomfort. This aspect could be caught as insight for designers/engineers: increasing contact surface or shaping a seat according to the human body reduces the pressure distribution at the interface that positively influences comfort perceptions.

Moreover, there are no significant differences between postures considering every single cushion. Consequently, a general pressure distribution map for each cushion was figured out, considering that passengers could perform different activities during a journey. From the designer/engineers point of view, this result is translated into this statement: they should consider designing for just one/two postures since the difference are not significant.

Finally, the authors wanted to compare the achieved pressure distribution maps on aircraft seats with those present in literature studies on car seats. The comparison showed that the substantial differences between the two types of seats are reflected in the difference in pressure distribution maps. So, it is recommended to create or search for new guidelines for aircraft seats, separately from those existing in cars, to prevent postural discomfort and health issues during a flight.

However, some limitations should be acknowledged. There are no data about pressure distribution for a slouched posture since the airplane seats were fixed; thus, further pressure maps should be investigated. The seat cushion angle was fixed at 4°; it is recommended to repeat experiments with different seat cushion angle. Also, a table was used to acquire postural angles frontally and simulate the seat pitch distance. It is recommended to repeat experiments with another airplane seat row to simulate an actual condition.

6 PhD dissertation: Discussions & Conclusions

6.1 Discussions

This PhD dissertation aims to be a guideline for future vehicle design and development, showing which methods can be used to measure subjective perceptions of (dis)comfort, considering the influence of external perceptions. By developing the conceptual map, some key concepts were explained, and literature gaps were filled through experiments that adopt both subjective and objective data to gain a complete overview of the design process.

Lets' discuss this from the beginning.

Why focus on future vehicles? Travelling is an everyday necessity and due to technological development designing a comfortable future vehicle is an aspect to prevent. Engineers and Vehicle Manufacturers are always trying to anticipate customer expectations by developing concepts that are fulfilled with the most advanced features to recreate a comfortable environment. Indeed, customers consider "comfort" a quality taken for granted when purchasing a vehicle or a ticket. So, the "comfort and discomfort" are two entities involved in each vehicle design phase, from the concept to the final product.

What are comfort and discomfort? According to Helander and Zhang (Helander and Zhang, 1997; Zhang *et al.*, 1996), discomfort is related to physical characteristics of the environment, including posture, stiffness and fatigue. Comfort is related to luxury, relaxation or the sense of being refreshed; in other words, to a sense of well-being and the aesthetic impression of the product. So, it is essential to reduce discomfort through a correct posture (analyzing postural angles, repetitions of movements, and the time for each assumed posture). And to improve comfort by realizing a comfortable product (that combines ergonomics, aesthetics and first impression) and a relaxing environment (that gives the sense of being refreshed).

How can be (dis)comfort evaluated inside future vehicles? Ergonomics and Human Factors give the basis of (Dis)Comfort assessment (that could be applied in vehicles), ensuring all-important ergonomic requirements and issues are contemplated at an earlies time to accommodate users' needs. The technique consists of "fitting" the human body between environment, users and equipment. The vehicle design process begins with the determination of the context, the size, vehicle type and the number of occupants that the vehicle should accommodate (Vink, 2016). To assure that the required number of occupants can be accommodated, designers must consider the dimensions of drivers and passengers and their posture in the vehicle space. The first step in designing a vehicle is to determine the user populations and their anthropometric and biomechanical characteristics. Then, there is the development of posture-prediction models for vehicle occupants to predict the people's postures and vehicle geometry. Once the final product is defined, the other steps include the optimization of layout, part of the vehicle and another aspect.

Since (dis)comfort perceptions are subjective, as demonstrated in the papers reported in this PhD dissertation, it is recommended to use the combination of two data types to gain better results: subjective data (Ch. 3) and objective data (Ch.4).

Subjective data can be obtained through surveys or questionnaires to allow people to express their feelings. However, creating surveys/questionnaires is not easy as it seems since there are many errors to identify during their design/development (TSE) to minimize them. The survey design process is explained in detail in Ch. 3., also showing examples of suitable scales to evaluate (dis)comfort. Choosing the right level of measurements helps to achieve survey goals'. Also, since a survey is a continuous conversation between the researcher and participant, the cognitive process should be considered (cognitive psychology) to guarantee the validity and consistency of gathered data. The best way to reduce errors is to perform pretesting through expert review, behavior coding, focus groups, cognitive interviewing, usability testing, and so on. In the case of non-response errors, there are some techniques to overcome missing data per non-response errors (MCAR, MAR, MNAR).

Objective data can be detected during human interaction with the object, environment and other people through:

1. **Sensors data analysis:** devices that respond to a physical stimulus (such as heat/thermal perception, light/visual comfort, sound/acoustic comfort, pressure, or vibrations/motion) and transmit a resulting impulse (for measurement or operating a control). In this PhD dissertation, the pressure measurement method on seats is discussed in detail in Ch.5.

2. **Video/photo observations for postural analysis:** achieving postural analysis helps study human behavior, postural comfort and reachability. Postural tracking methods (like the Kinovea® software for photos or the use of ArUco markers for video) are a direct method to acquire postural angles, as reported in this PhD dissertation in Ch.4.
3. **Tools to predict postural (dis)comfort:** literature studies show how to reduce discomfort in a workplace by specific tools that correlate several factors with human fatigue. However, specific tools for vehicle (dis)comfort assessment are required. One of these could be the software CA-Man (see Ch. 4.1), developed by professors Naddeo and Cappetti from the University of Salerno, that associates a comfort index for each postural angle.

Once subjective and objective data is obtained, the next step is to perform statistical analysis, as explained in Ch. 3. Data analysis consists of visualizing and modelling data to highlight information that suggests conclusions and supports decisions. Data analysis has many approaches and facets, which include very different techniques. Choosing the appropriate one per the context could help to present solutions. Also, through correlations, regression analysis and other statistical instruments, it's possible to understand the relationship between subjective and objective data.

Which external factors could influence the data acquisition? Per literature studies and research, three main factors can influence (dis)comfort perceptions: environment, interaction with other people, and interaction with the seat. Leaving out research present in literature studies, which are the literature gaps filled in this PhD dissertation?

Considering the interaction with other people, one aspect to not neglect is the interpersonal distancing, as studied by Hall (1966), Sommer (1962), and Madanipour (2003), or the comfortable community model (Dumur et al., 2004). Indeed, during social interaction, people surround themselves with implicitly defined and organized space to respect. So, which layouts could recreate a comfortable situation in future vehicles? Since there is no research regarding the (dis)comfort and quality of communication while sitting at different angles toward each other in an airplane and the best distances for the seat configuration face-to-face, the following experiments (see Ch. 4) were performed:

1. Towards Comfortable Communication in Future Vehicles

2. Future vehicles: the effect of seat configuration on posture and quality of conversation
3. Design for comfort and social interaction in future vehicles: a study on the leg space between facing-seats configuration

Considering seat rotation, the optimal layout in terms of postural comfort and quality of conversation is the 120° degrees' configuration. When seat rotations are not allowed, the optimal distance for facing seats with a table should be at least 51 cm as the perfect compromise between postural comfort, social interactions and table reachability, satisficing a wide population range. Reducing this distance, feelings of comfort were descending.

Considering seats, among all measurement tools available for (dis)comfort assessment, the pressure distribution mapping is still the most reliable measure of (dis)comfort on seats. However, there were no literature studies about pressure distribution and (dis)comfort on airplane seats. Moreover, only upright and slouched postures had been investigated on car seats. Thus, experiments were performed at TU Delft to investigate the pressure distribution on airplane seats according to 6 different postures. A comparison between 2 seat-pan, a flat cushion and a shaped cushion, was made (Fiorillo, Song, Smulders, *et al.*, 2021). The shaped cushion was designed to follow the buttock-thigh shape of the international population (Iolanda Fiorillo, Yu Song, Peter Vink, 2021). This work compared two cushions for the seat pan (flat cushion and shaped cushion) using subjective data from questionnaires and objective data from the pressure mat. Results showed that the shaped cushion could be better than the flat one in terms of postural comfort since pressure distributions were more uniform with low peak pressures and contact areas higher. Statistical analysis with correlations was performed to support subjective and objective results. The comparison in terms of pressure distribution maps showed that the shaped cushion always presented a wider contact surface and more uniform pressure distribution, with lower peak pressure. This result is aligned with literature studies that demonstrated a wider contact surface is related to more comfort and lower pressure distribution is related to less discomfort. This aspect could be caught as insight for designers/engineers: increasing the contact surface or shaping a seat according to the human body reduces the pressure distribution at the interface that positively influences comfort perceptions.

Moreover, there are no significant differences between postures considering every single cushion. Consequently, each cushion's general pressure distribution map was figured out, considering that passengers could perform different activities during a journey. From the designer/engineers' point of view, this result is translated into this statement: they should consider designing for just one/two postures since the difference are not significant.

Finally, the authors wanted to compare the achieved pressure distribution maps on aircraft seats with those present in literature studies on car seats. The comparison showed that the substantial differences between the two types of seats are reflected in the difference in pressure distribution maps. So, it is recommended to create or search for new guidelines for aircraft seats, separately from those existing in cars, to prevent postural discomfort and health issues during a flight.

In the end, through a deep study of subjective data, objective data and external factors, it is possible to analyze and prevent issues from the earliest stages of vehicle design to the vehicle production.

In my opinion, the best approach to adopt in vehicle design is:

- define the vehicle type
- identify the issues that could come up and choose one/some
- analyze the human body part involved in this issue
- identify the current state of art
- identify the research question/hypothesis to test
- identify the target population
- determine how to gather subjective and objective data
- identify the external factors that could influence the data acquisition
- optimize the data acquisition with trials
- analyze data
- propose solutions

6.2 Conclusions

Recalling the conceptual map of my PhD dissertation (Figure 6-1), the main focus was to give indications on how to analyze the (dis)comfort perceptions in future vehicles. The advantage of subjective data is having people's feedback on (dis)comfort, a concept that they know by personal experience. The disadvantage is that many factors can influence participants' answers, like personal experience and socially desirable responses. Objective data like observations, pressure mat data, and temperature recordings can reveal environmental characteristics. Still, the disadvantage is the uncertainty of what people notice. Combining the two might overcome some disadvantages, as explained through experiments reported in this Ph.D. dissertation. Indeed, the comprehensive study demonstrated that the analysis preferably uses subjective and objective data, always considering the external perceptions that influence interactions between humans and objects (mainly the seat), environment, or people. All this process can determine a future vehicle (dis)comfort assessment.

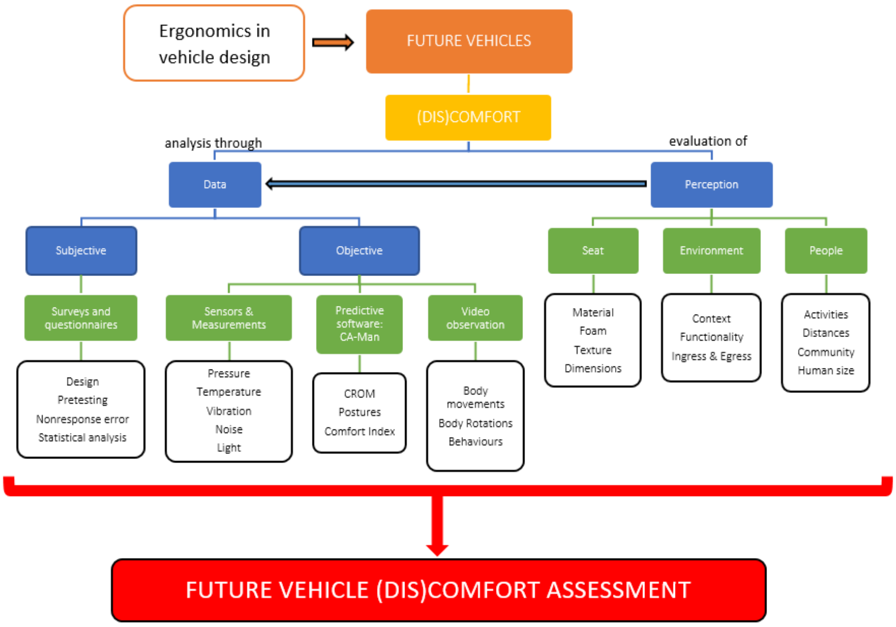

Figure 6-1 *Conceptual map of this PhD dissertation*

The term "future vehicles" refers to anything that transports a person or things (such as a car, a truck, a plane, a bus) and could be developed/designed/improved in future. People expect to travel comfortably with the current innovation in every sector, especially in vehicle design. Consequently, the concepts of comfort and discomfort are intrinsic in vehicle design, where the human-centered design approach is becoming more commonplace.

The subjective data gather personal feelings or feedback from people to comprehend their perceptions and expectations. This Ph.D. thesis shows that the survey is a suitable instrument and that from a sample, it is possible to infer the population by inferential statistics. Primarily questionnaires while using the within-subject design (as often is done in this Ph.D. thesis) show differences between seat cushions and between positions of two persons. While the survey includes a set of questions and the process of collecting, aggregating, and analyzing the responses, the questionnaire consists of any written set of questions. Consequently, the questionnaire represents the constant conversation with people; for this reason, subjective data are collected using the survey (see Ch. 3).

Having only subjective data is insufficient in the vehicle (dis)comfort assessment. Based on data in this Ph.D. thesis, it is advised to gather objective data. Objective data are required for mutual validation with subjective data, explaining the reasons for personal feelings and finding solutions or improvements. In this Ph.D. dissertation, 3 macro-areas for objective data are distinguished: sensors, predictive software (CA-Man), and video/photo observations. One macro-area does not exclude the others so that they can be applied simultaneously.

Since the seat plays a vital role in vehicle (dis)comfort assessment, as it is the primary contact between the vehicle and the person (Ch. 5), examples reported in this Ph.D. dissertation refer mainly to the interaction between humans and the seat and between seated humans with the surrounding environment or people. For these reasons, among all available sensors' technology, in this Ph.D. dissertation, the focus was on pressure distribution since the high correlation with discomfort perception on the seat. In particular, pressure distribution maps could be helpful to create an optimal virtual prototype validated by a physical prototype (Ch. 5). Going from virtual to physical prototype, few interactions and simulations are required to optimize the product comfortably, becoming an advantage for the Time To Market.

Also, the postural analysis in vehicle (dis)comfort assessment can be achieved through the study of video/photo (Ch. 4) or through software that can predict the level of (dis)comfort knowing postural angles (Ch. 4). Thus, the software CA-Man could be very useful (Ch. 4) to estimate comfort and discomfort in an early stage: the digital stage. Digitally, the effect on (dis)comfort can be estimated in different designs without building the prototype.

The combination of all these aspects determines the vehicle (dis)comfort assessment that can be summarized through the 5-W questions, as shown in Figure 6-2.

Future Vehicle (dis)comfort assessment	Who is involved?	Passengers (more related to leisure and relaxation) and drivers (more related to attention and safety)
	What do we need?	Subjective (survey) and objective (sensors, predictive software, video/photo observation) data
	When do we need them?	In all vehicle design phases (concepts, prototype, final product)
	Where do we need them?	In the interaction between human and object/environment/people
	Why do we need them?	To improve comfort and reduce discomfort (as customers expect)

Figure 6-2 *Future Vehicle (dis)comfort assessment explained with the 5-W*

In the end, this Ph.D. dissertation is an example on how perform a future vehicle (dis)comfort assessment. Thus, it could be a guideline for future vehicle design and development, showing how the external factors influence the (dis)comfort. Through in-depth literature studies, literature gaps were filled with experiments that adopt both subjective and objective data to understand the design process. Additionally, many examples of different types of research studying vehicle comfort and discomfort were shown.

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