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INFLUENCE OF LONG-TIME DRIVING ON LOWER LIMBS MUSCULOSKELETAL SYMPTOMS AND PHYSICAL CONTROL

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DEDICATION

This Dissertation is dedicated to my parents

father *Milorad*

and

mother *Slađana*

They gave me invaluable educational opportunities and unselfish love and support.

Ову дисертацију посвећујем својим родитељима

оцу *Милораду*

и

мајци *Слађани*

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RESUMO

A condução profissional envolve a exposição contínua e prolongada, geralmente numa postura estática sentada, apenas com pequenos movimentos nas extremidades superiores ou inferiores do corpo. A exposição ocupacional prolongada, além de desconforto/dor numa determinada parte do corpo, pode desencadear diversos tipos de problemas de saúde. Conduzir em posição estática continuada pode levar a vários distúrbios musculosqueléticos nos membros inferiores, como, por exemplo, doenças vasculares, oedema, cãibras, redução da densidade óssea, entre outros. Além disso, a nocividade dinâmica (por exemplo, vibrações de corpo inteiro) do ambiente pode acelerar o processo de surgimento de uma variedade de outras doenças. Como tal, é essencial estudar os fatores negativos que podem desencadear doenças no condutor. Neste quadro, a tese visa contribuir, analisando a reação física do condutor durante a condução prolongada e determinar se essa exposição tem influência no desempenho da marcha após o exercício dessa atividade.

Este estudo foi realizado com uma amostra de 48 indivíduos. Após análise dos dados, três indivíduos do sexo masculino e um do sexo feminino foram excluídos. Os participantes selecionados estavam na faixa etária de 20 a 40 anos (média de 27.4 ± 4.7 anos). Não foram incluídos na amostra condutores com carta de condução há menos de seis meses, se conduziam mais de duas horas por dia, se foram alvo de uma intervenção cirúrgica ou se sofriam algum tipo de dor nas articulações principais que pudesse influenciar o desempenho durante o processo experimental. Aplicando o Inquérito Nórdico Musculosquelético foi avaliada a prevalência de transtornos musculosqueléticos entre os participantes no ano anterior ao ensaio. O processo de condução foi realizado num simulador de condução durante um total de 120 minutos. Durante o ensaio, foi avaliada a pressão do corpo no assento através de um tapete de pressão posicionado no banco do condutor. Foi também avaliada a postura de condução de cada um dos intervenientes. Durante o ensaio, foi utilizado um questionário para avaliar o desconforto percecionado. Para estabelecer se a condução prolongada influenciava o desempenho dos membros inferiores, foi requerido aos participantes que caminhassem, tanto antes como após o teste de condução.

As posturas de direção preferidas, no caso do tamanho total da amostra, permaneceram sem alterações significativas entre o registro inicial e final do processo de direção. Foram, no entanto, detetadas diferenças relacionadas com o sexo do condutor nas extremidades superiores: os homens adotaram posturas estendidas, enquanto as mulheres preferiram posturas mais fechadas/flexionadas. O valor da pressão na interface condutor / assento aumentou com o tempo. Alguns dos participantes aplicaram 12 kPa de pressão na área das nádegas. A condução prolongada influenciou o conforto dos participantes e a dor corporal foi significativamente maior no final do ensaio. O desempenho da marcha e a pressão plantar foram também influenciados. As mudanças ocorreram na área do hálux, antepé central, medial e retropé central.

Palavras-chave: Distúrbios musculosqueléticos, membros inferiores, condução prolongada, posturas preferenciais de condução, marcha, pressão de interface, pressão plantar.

ABSTRACT

Professional driving involves continuous long-time exposure to the activity of steering a vehicle, often in a static sitting strategy with minor upper or lower extremities movements. Prolonged occupational exposure (in case of professional drives – sitting), besides discomfort/pain in a particular part of the body, might trigger musculoskeletal disorders. Continued static sitting/driving may lead to various lower limbs musculoskeletal disorders such as cardiovascular diseases, lower limbs oedema, cramps muscles, bone density disorder, among others. Furthermore, dynamic harmfulness (for example, whole-body vibrations) in the environment could speed up the process of getting a variety of diseases. As such, the importance of study negative factors that can stimulate illnesses of the driver's body is essential. Therefore, the thesis aimed to provide an insight on physical driver control during long-time driving and to determinate if the time exposure did have an influence on the gait performance.

This study was conducted with a sample population comprising 48 participants. After data analyzing, three male subjects were excluded due to insufficient data quality. Selected participants were in the age range of 20 to 40 years old (with an average of 27.4 ± 4.7 years). As exclusion criteria were considered if drivers had less than six months of driving license, driving more than two hours per day if they had had a surgical intervention or held pain in major joints that may influence performance during the experimental process. The prevalence of the musculoskeletal disorders among the participants was established implementing the standardized Nordic Questionnaire.

Furthermore, the continuous driving process was held out in a driving simulator for 120 minutes. During the drive, applied interface pressure on driver's seat pan and preferred driving postures were assessed. Perceived body discomfort, triggered by the prolonged driving process, was recorded using a modified questionnaire with a six-levels discomfort scale. Moreover, to establish if the prolonged driving influenced the lower limbs performances, participants were performing gait before and after steering the driving simulator.

Preferred driving postures, in case of the total sample size, remained without significant changes between the initial and final recording of the driving process. Gender-based differences occurred in the upper extremities. Male participants adopted more extended postures, while females preferred more closed/flexed driving strategies. Applied IP variables increased over the driving time. For instance, applied average pressure reached 12 kPa under the buttocks area among several participants. The long-time driving influence participants' perceived discomfort increasing it after two hours of the driving process and consequently affected post-steering gait linear kinematics and applied plantar pressure. Changes in the gait variables suggested that participants developed local foot muscles fatigue and generate a risk of forming blisters and skin injuries over time.

Keywords: Musculoskeletal disorders, lower limbs, long-time driving, preferred driving posture, gait, IP, plantar pressure.

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ACRONYMS AND ABBREVIATIONS

2D – Two-dimensional

3D – Three-dimensional

BMI – Body Mass Index

DLT – Direct linear transformation

DPM – Defined Part of the Mat

DTI – Deep Tissue Injury

FEUP – Faculty of Engineering at the University of Porto

IP – Interface Pressure

IT – Ischial Tuberosities

LEFS – Lower Extremity Functional Scale

LLD – Lower Limbs Disorders.

Mid – Middle

MSD – Musculoskeletal Disorders

MS – Musculoskeletal

n.s. – Not significant.

NMQ –Nordic Musculoskeletal Questionnaire

NW – Normal Weight

OW – Overweight

PC – Personal Computer

PDP – Preferred Driving Postures

RM ANOVA – Repetitive Measurements ANOVA

ROP – Roll-over Process

Sm - Small

SPSS – Statistical Package for the Social Sciences

Ta – Tall

UW – Underweight

WBV – Whole-Body Vibration

WHO – World Health Organization

WMSD – Work-related Musculoskeletal Disorders

CHAPTER 1
INTRODUCTION

1 INTRODUCTION

1.1 The problem

Over the decades, with economic development, it was required for faster and more consistent transfer of goods and passengers. The automotive industry starts to manufacture, on large scales, more affordable vehicles in the early beginning of the 20th century. Since today, it can be noticed that many internal/external changes in vehicles have been made. Those improvements are made relating to increase comfort, efficiency, as well as the reliability of the transport. Nonetheless, vehicle design was considered as more important over the ergonomic aspects, leaving the drivers' working environment not well prepared for long-time driving. Different research fields were analyzing and reporting the prevalence of musculoskeletal disorders (MSD) among professional drivers (Messing et al., 2009; Okunribido & Lewis, 2010; Wrona et al., 2015).

The inadequate and non-ergonomic interior design of the driving venue had, consequently, that at least 7.5% of total accidents were reported in the 1977 year (Habsburg & Middendorf, 1977). As a limitation, it could be a lack of manoeuvre space, lack of visual angles or impossibility to perform driving tasks, among others. Perfect interior design does not exist, so it should not be expected to appear in vehicles. The proper starting point is to understand the anthropometric dimensions of drivers and to modify their workplace to a human population as more significant as possible. Even adapting the drivers' working space to the larger society, prolonged awkward postures must be avoided. Those postures can be affected by non-adjustable drivers' steering wheel, seat (by horizontal and vertical distances), or inability to support all body parts (Hanson et al., 2006; Kyung & Nussbaum, 2008).

The driving time is an essential factor in studying a possible consequence caused by prolonged driving exposure. European Union brought a new directive on Jun 2018 (Commission & others, 2003). Bus and lorry drivers can spend driving a vehicle 9 hours per day or in total, 56 hours per week (Commission & others, 2003). In a particular situation, the time spent steering a vehicle could be up to 10 hours (maximum twice per week). What is more, continues driving is up to 4 hours and 30 minutes, after which the drivers must take a break in a total of 45 minutes.

Long-time driving with a static posture of the lower limbs (more than 2 hours (Okunribido & Lewis, 2010)) may cause a variety of consequences such as venous disorders (D'Souza et al., 2005; Łastowiecka-moras, 2017), cardiovascular diseases (Thosar et al., 2015), lower limbs oedema (Belczak et al., 2015; Wrona et al., 2015) the pain after sitting, cramps muscles and the similar (Wrona et al., 2015). The research by Chen et al. (2004), indicates the presence of the knee bone density disorder, as well as cartilage damage of the same after prolonged sitting when driving, is longer than 4 hours per day. The reason of this disorder might be rerepeating the leg movement when driving and other harmful factors as well (straining knee postures with the static position of the left lower limb while driving a vehicle with the automatic gear shift, vibrating floor with the consequence of the whole-body vibrations (WBV), inadequate/restrained space and similar).

Information on the occurrence of bus drivers' MSD and symptoms (Shamsul Bahri M Tamrin et al., 2014) might be found, where it was emphasized that 57% of drivers had symptoms of pain in some parts of the body (the most frequently reported is lower back pain). Furthermore, in the same study (Shamsul Bahri M Tamrin et al., 2014), it can be observed that the percentage of these symptoms of bus drivers' MSD is different in the right lower limb (24%) than in the left lower limb (21%). Sezeto et al. (2007) state that data after five years spent in an awkward posture, i.e., in a prolonged sitting when driving, shows that the pain in the thigh and knee occurs. As a conclusion, they also stated that this is mainly a chronic disease and that more than 50% (both genders) of drivers reported this type of discomfort. Reilly et al. (2000) carried out an analysis of pain prevalence in the driver's knee, where 27.8% of 82 patients reported pain in the knee. The knee pain depends on the period spent while driving. The research conducted by Chen et al. (2004) (within one year) on taxi drivers, showed that the occurrence of pain in the knee was 11%, 17%, 19% and 22% subject to the driving time (≤6; 6 - 8, 8 - 10; and 10≥ hours).

When the driver is seated, his body weight is more than 70% supported by the seat, and his body posture can cause a higher amount of pressure in the ischial tuberosity bone (Kyung et al., 2007). Interface pressure (IP) on the driver's seat is not equally distributed. Based on this assumption, applied pressure under in the ischial tuberosity could be up to 11 times higher (Slayton et al., 2017) than the rest of the buttocks area. In the literature, there are many different opinions about IP on the lower limbs area. Pressure more significant than 8 kPa (in some articles, this threshold was established at 6 kPa or even 4.3 kPa) may cause hamper blood circulation. Having a higher amount of pressure under the mentioned bone can cause discomfort, pain, MSD, or even pressure ulcers in the worst-case scenario (D. M. Brienza et al., 2001; Luboz et al., 2018; Mohanty & Mahapatra, 2014).

The anthropometric factor is essential because an injury caused by pressure differs from person to person (Marras & Kim, 1993). Depending on the interface area during sitting, the sharpness of the bones (sacrum and ischial tuberosity) (Marras & Kim, 1993; Vos et al., 2006), among others. It should be clarifying that people who applied higher areas on the seat report less discomfort in the buttock (Vos et al., 2006). Furthermore, the conclusion cannot be made using one equipment comparable to a pressure mat and measuring only IP (Al-Dirini et al., 2015; Luboz et al., 2018). The problem needs to be assessed using in-depth tissue analysis (D. Brienza et al., 2018; Linder-Ganz et al., 2007).

Additional physical harmfulness such a WBV, exhaust gases coming from the vehicle engine or outside, noise, among others, may play an important role in effecting or even generating MSD (Kirkwood et al., 2011; Łastowiecka-moras, 2017; Thosar et al., 2015). The presence of WBV might lead to functional disorders and changes in the tissues (Ebe & Griffin, 2000; Inagaki et al., 2000; Na et al., 2005) causing lower back pain, spine disorders, shoulder, head, and neck pain (Łastowiecka-moras, 2017), among others. Besides, mental illnesses such as fatigue, tensions, and tiredness might be expected (Thosar et al., 2015).

1.2 Research problem and hypothesis

Dealing with all the negative characteristics that affect professional drivers' lower limbs, whether they are technical or individual ones, it should be emphasized that there is no ideal approach. The static and prolonged sitting analysis is almost impossible to exclude from the process, once it exemplifies the most significant problem for MSD on lower limbs (Kirkwood et al., 2011; Łastowiecka-moras, 2017; Thosar et al., 2015).

In the context of all the harmful attributes that may induce or aggravate the condition of MSD on lower limbs, setting the main goals is essential. With this regard, it is necessary to define a systematic approach to solve all the adverse effects and their elimination or mitigation. Based on the aforementioned negative influences, the main objectives are based on the perceiving of the performances and in the emergence of a possible diagnosis of symptoms in order to characterize MS problems on lower limbs.

In dealing with this scenario, several specific questions are raised:

- Is it possible to identify changes in gait performance after the long-time driving?
- Whether the long-time driving influence applied interface pressure on the drivers' seat pan?
- Do the selected sample size changed initial driving strategies after two hours of steering the driving simulator?

1.3 Thesis design

This doctoral thesis was accomplished within the scope of the Doctoral Program in Occupational Safety and Health, at the Faculty of Engineering of the University of Porto (FEUP), Portugal. The research investigates drivers' performances changes during and after long-time driving.

Structure and organization of this doctoral thesis is the following:

The first chapter is implementing and describing knowledge in a different study area. To obtain crucial information on different study topics, Prisma Statement Methodology was implemented (Moher et al., 2016). In a particular keyword combination, and applying inclusion/exclusion criteria, selected articles were included. The different study topic was following: correlation between IP on the drivers' seat and discomfort, preferred driving postures (PDP), plantar pressure, MSD, and the final was the prevalence of the lower limb MSD among professional drivers.

Furthermore, the second part is aiming to describe the application of the methodology. Equipment, procedure, data acquisition and analysis were defined. The experimental process was held out in in the Laboratory of Traffic Analysis at the Department of Civil Engineering at FEUP, Portugal.

The third part is illustrating results analysis and detailed analysis of the data acquisition during the experimental process. The results are divided into five main sections. The first section in studying obtained anthropometric characteristics of participants. The results were described by the sample size and by main groups (gender, stature, and BMI). Furthermore, the groups were divided into

subgroups (gender) male and female; (stature) small, middle and tall; (BMI) underweight, average weight, and overweight.

Additionally, in the second section was evaluated self-reported MS pain in a particular part of the body (using the Nordic Musculoskeletal Questionnaire). The third section used descriptive statistics to define the preferred interior dimension of the vehicle (before the start of the driving process). The fourth section is investigating applied IP on the drivers' seat pan. The following section was describing PDP and driving strategies during long-time driving. The final section examined the gait performance of the participant comparing it before and after 120 minutes of the driving process.

Chapter three is a discussion of the obtained results. Further comparison of outcomes and previous studies were represented. The discussion is following the results part and its sections and discuss each section separately.

In chapter four, the main thesis conclusion was obtained. Besides, future consideration and study limitation were pointed out.

1.4 Bibliography review

1.4.1 The guidelines of systematic research

The systematic review guidelines followed the standards outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols (PRISMA – P) Statement (Moher et al., 2016). The guidelines were individually repeated for the following topics:

1. IP on the drivers' seat;
2. Preferred driving postures;
3. Plantar pressure and MSD;
4. Prevalence of MSD of lower limbs in professional drivers.

The systematic reviews included the following electronic databases: SCOPUS, Web of Science, Pub Med, Science Direct, Springer, Inspec, and Science Magazine. Furthermore, scientific journal databases were checked: Directory of Open Access Journal (DOAJ), Emerald, IEEE Explore, Ingenta, ACS Journal, and Taylor and Francis.

Based on the nature of technology development, the research was performed, at least, in two phases. The first one settles articles published in the period between 2013 and 2019. The search of the literature was considering only publications written in English, published in journals. The references from the collected articles were screened and included, in this second phase, published articles, thesis, or dissertations, even if before 2013, in pursuance of obtaining relevant outcomes on the current method for assessment results. The process was repeated until the research goals were satisfied (Wohlin, 2014).

Selected articles were analyzed through text and the references (articles published before 2013, as previously stated). The algorithm of a defined search strategy was repeated as long as all the needed information was obtained.

At the end of this research process, through of all databases and journal bases, additional terms can be added apropos achieve the object of the systematic review. The new keywords, from the second phase of the search, were being added to the previously defined keywords, and further research was carried out.

Non-research articles, such as opinion articles, conference abstracts, reports, posters, or papers, were excluded.

After the research process was finished, the selected records were imported and managed by Mendeley software for the de-duplication stage (Zaugg et al., 2011). When it was not possible to automatically export all the selected articles, the alternative was manually collecting all needed information into Microsoft Excel file tables explicitly designed for that purpose. This process required the analysis of the title and abstract of each section. So, to better analyze the selected items, all the information was inserted in the table (see Appendix 5).

Defined groups (parameters and general study characteristics) were determined and, lately, divided (for the article's analysis) into groups. Cochrane Collaboration's Tool (Higgins et al., 2011) was taken as a reference for the defined risk of bias for each article. The range of the topics will be described as "high", "low", and "unclear" (where "unclear" demonstrates non-defined or missing information in order to accomplish the data in need).

Bearing in mind both specific and general study objectives, risk of bias (Higgins et al., 2011) was functional on the study level reflecting all parameters (study objectives, variables, used equipment, applied methodology, defined time of the experiment and assessed procedures) and general characteristics (data sources, used standards, assessment tools following the systematic review specific goals).

1. Correlation between IP on the drivers' seat and discomfort

Published article, with the topic of applied pressure on the drivers' seat and its consequences, were considered. Furthermore, articles with information on pain/discomfort, triggered by prolonged sittings, established by IP measurements, were included.

The research strategy relies on defined keywords, which were divided into four groups. The first group is the major one and was combined with the rest of the sets. The terms in the first group were "interference pressure," "pressure distribution," "pressure measurements", and "contact pressure." The second group had the keywords: "fatigue," "sitting posture," and "comfort." The keywords for the third and fourth group were, "standards" and "comfort model" (for the third group), and "seat" (in the fourth).

A completed list of the combination was the following:

"interface pressure" AND "sitting posture"; "pressure distribution" AND "sitting posture"; "pressure measurement" AND "comfort model"; "contact pressure" AND "sitting posture";

“interface pressure” AND “comfort model”; “pressure distribution” AND “comfort model”; “sitting posture” AND “comfort model”; “sitting posture” AND “comfort”; “interface pressure” AND “seat”; “pressure distribution” AND “seat”; “pressure measurement” AND “seat”; “contact pressure” AND “seat; “pressure distribution” AND “standard”; “pressure measurement” AND “standard”; “contact pressure” AND “standard; “sitting posture” AND “standard”; “sitting posture” AND “fatigue”.

The total number of obtained articles were 9445. Summary of full rejected articles were 9133 (from which were 5948 older than previously defined date; 179 were not written in the English language; 1343 do not satisfy by the described document type; 1650 off-topic, and other criteria rejected 0). After dismissing the duplicates, 312 articles were analyzed. In the end, 73 of items were included in this thesis.

2. Preferred driving postures

The research strategy relies on defined keywords, which were divided into four groups. The first group is the major one and was combined with the rest of the sets. The terms in the first group were “joint angles” and “driving posture”. The second group had the keywords: “driver”, “biomechanics”, “discomfort”, and “comfort”. The keywords for the third and fourth groups were “automotive” and “posture” (for the third group), and “digital human model” and “driving posture”. (in the fourth).

The used keywords combinations were the following:

“joint angles” AND “driver”; “joint angles” AND “automotive”; “joint angles” AND “driver” AND “biomechanics”; “joint angles” AND “driver” AND “discomfort” OR “joint angles” AND “driver” AND “comfort”; “discomfort” AND “posture” AND “driver” OR “comfort” AND “posture” AND “driver”; “driving posture” AND “discomfort” OR “driving posture” AND “comfort”; “driving posture” AND “biomechanics” OR “driving posture” AND “digital human model”.

The total number of obtained articles were 2137. Summary of full rejected articles were 2065 (from which were 1442 older than previously defined date; 17 were not written in the English language; 96 do not satisfy by the described document type; 65 off-topic, and other criteria rejected 443). After dismissing the duplicates, 68 articles were analyzed. In the end, 40 of the items were included in this thesis.

3. Plantar pressure and MSD

The research strategy relies on defined keywords, which were divided into four groups. The first group is the major one and was combined with the rest of the sets. The terms in the first group were “plantar pressure” and “gait”. The second group had the keywords: “threshold”, “disorders”, and “pressure distribution”. The keywords for the third and fourth groups were, “ground reaction forces” (for the third group), and “mapping” (in the fourth).

The used keywords combinations were the following:

“plantar pressure” AND “mapping”; “plantar pressure” AND “gait” AND “threshold”; “plantar pressure” AND “ground reaction forces”; “plantar pressure” AND “pressure distribution” AND “disorders”; “plantar pressure” AND “pressure distribution” AND “threshold”; “plantar pressure” AND “pressure distribution” AND “discomfort”; “plantar pressure” AND “disorders”; “plantar pressure” AND “threshold”; “plantar pressure” AND “discomfort”; “gait” AND “ground reaction forces” AND “discomfort”; “gait” AND “ground reaction forces” AND “disorders”; “gait” AND “ground reaction forces” AND “threshold”.

The total number of obtained articles were 3504. Summary of full rejected articles were 3194 (from which were 2189 older than previously defined date; 13 were not written in the English language; 149 do not satisfy by the described document type; 262 off-topic, and other criteria rejected 581). After dismissing the duplicates, 310 articles were analyzed. In the end, 73 of items were included in this thesis.

4. The prevalence of the lower limbs MSD among professional drivers

The research strategy relies on defined keywords, which were divided into four groups. The first group is the major one and was combined with the rest of the sets. The terms in the first group were “musculoskeletal disorders” and “lower limb”. The second group had the keywords: “driver”; and “occupation”. The keywords for the third and fourth group were, “risk factors” and “disease” (for the third group), and “sitting” (in the fourth).

The used keywords combinations were the following:

“musculoskeletal disorders” AND “lower limb”; “musculoskeletal disorders” AND “lower limb” AND “risk factors”; “musculoskeletal disorders” AND “lower limb” AND “sitting”; “musculoskeletal disorders” AND “lower limb” AND “occupation”; “musculoskeletal disorders” AND “lower limb” AND “driver”; “lower limb” AND “occupation” AND “sitting”; “lower limb” AND “occupation” AND “driver”; “lower limb” AND “risk factors” AND “driver”; “lower limb” AND “disease” AND “sitting”; “lower limb” AND “driver” AND “sitting”.

The total number of obtained articles were 5361. Summary of full rejected articles were 5289 (from which were 3021 older than previously defined date; 69 were not written in the English language; 1236 do not satisfy by the described document type; 346 off-topic, and other criteria rejected 617). After dismissing the duplicates, 72 articles were analyzed. In the end, 29 of items were included in this thesis.

1.5 Definition of comfort and discomfort and designed models

Many different professions require that workers/operators spent their working time in a seated position. The seated position is often static and requires a low level of activity. Determination of a comfortable and healthy working environment may be one of the most critical factors. Relate to this statement; several different scientific fields are cooperating to secure working positions as comfortable as possible. Specifying the terms of comfort and discomfort are still under debate (De Looze et al., 2003).

One of the first definitions of comfort was describing it as harmony between humans (physical and phycological state) and environment (Helander & Zhang, 1997). Richard et al. (1980) described comfort as an individual and subjective feeling of well-being with the direct interaction to a particular situation or environment.

During the years, comfort and discomfort were represented as two extremes/opposites on one scale (De Looze et al., 2003). Concluding, this could be explained as reducing discomfort leading to increase comfort. Still, the absence of discomfort does not necessarily lead to comfort (Cascioli et al., 2016).

Zhang et al. (1996) stated that discomfort is lined with biomechanical factors – reparative movements, awkward postures, adopted body angles, static muscle tension, among others. Comfort, on another side, Zhang et al. (1996) correlate it with the aspect of pleasing. Moreover, in the same study, Zhang et al. (1996) represented comfort/discomfort using cluster analysis (Figure 1).

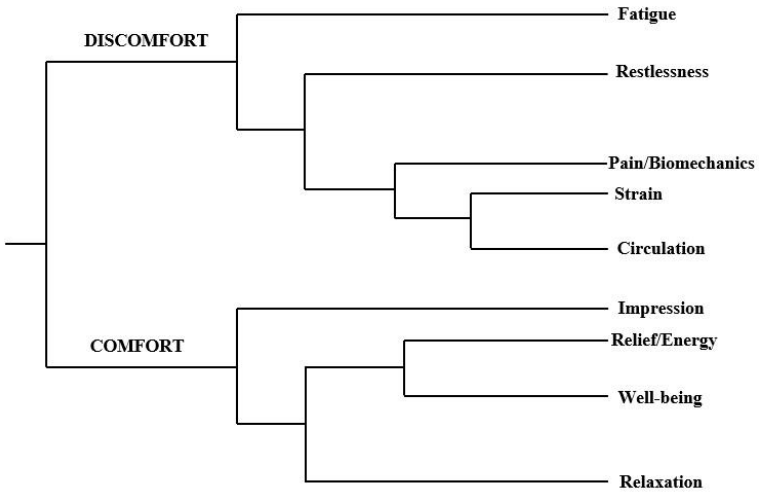


Figure 1. Adapted structure of cluster analysis (Zhang et al., 1996)

Furthermore, Zhang et al. (1996) concluded that the discomfort is increasing with time and fatigue. An individual can reduce its discomfort constrains but does not vitally create comfort. Comfort is represented as psychological well-being and feeling of relaxation.

De Looze et al. (2003) defines comfort as subjective and could be affected by physical and psychological factors. On the other hand, discomfort has been described as an unpleasant response of the human body on the environment, in this case, physical (feeling fatigue, pain, soreness, and similar). Understanding those two terms is essential regarding the determination of a healthy working environment. Moreover, De Looze et al. (2003) created a model and explained the interaction between physical/phycological and working environment and human itself (Figure 2).

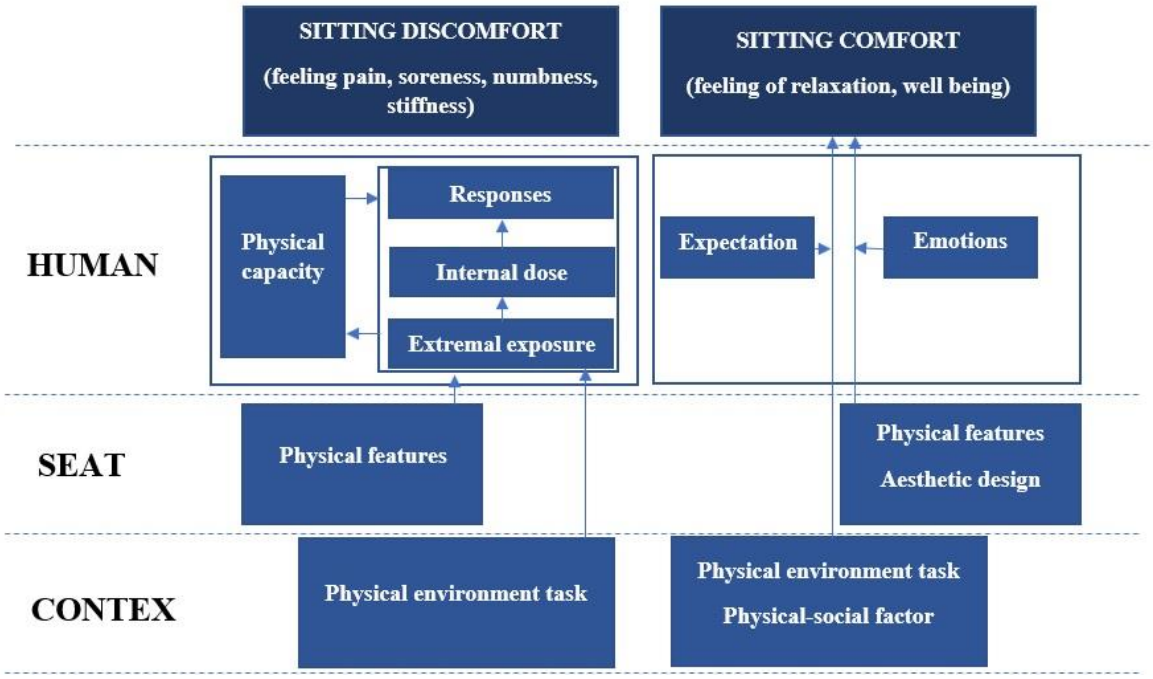


Figure 2. The redrawn theoretical model for sitting comfort/discomfort (De Looze et al., 2003)

The illustrated model (Figure 2) is entire of improvement, considering the base model and thinking of comfort/discomfort as two opposite extremes, and determination two terms as a complex collaboration between operator and working environment. As it is presented in the model, the main factors of positioning two terms are depending primarily on humans and follow by seat character stick and working tasks (De Looze et al., 2003).

To better understand the model (Figure 2) should be divided into two major parts: left (sitting discomfort) and right (sitting comfort). The left side determinates three levels that characterize sitting pain. At the bottom are working tasks, which can require a low or high level of worker activity. Low or high levels of movement can cause fatigue in a particular part of the body (Na et al., 2005). The second level is the seat and its design. Considering the time spent sitting, the seat needs to accommodate all body parts to avoiding discomfort (Carcone & Keir, 2007). Physical human capacity and individual factors are significant in the perception of discomfort (Hiemstra-van Mastrigt et al., 2017; Le et al., 2014). It is defined as the personal human capability to a reaction on long-time sitting exposure. The sitting comfort (the right side of the model) is represented as a subjective reaction on the working environment, seat design, and again, individual expectation of perceived comfort.

The problem of discomfort caused by long-time sitting, which the professional drivers are facing, needs to be observed through the abovementioned model. The work presented by (Hiemstra-van Mastrigt et al., 2017), illustrating a new theoretical model of comfort/discomfort based on De Looze et al. (2003) model. The main goal of this new model is to implement and to predict what can cause body discomfort in prolonged sitting.

The model is constituted in three levels. The first level contains the sale fragments as (De Looze et al., 2003) previously defined models. The second level includes interaction – such as preferred

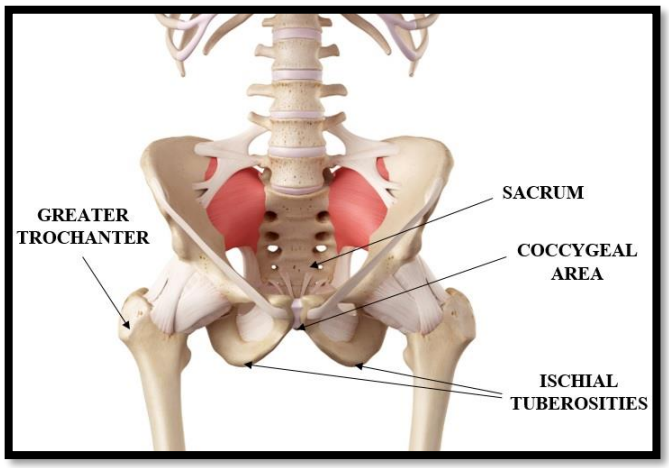
sitting postures, applied pressure on the seat, and task required movements. The final level describes perception as comfortable or discomfort able.

Studying the new concept of the model, to assessing discomfort of professional drivers, vital is to establish a correlation between anthropometric measures of drivers, PDP, and seat dimensions, built material and ergonomic characteristics. Furthermore, it is necessary to measure applied IP on the seat and to compare it with the subjective perception of discomfort. As the final, it is essential to correlate mediating variables and to establish critical values of comfort/discomfort. Regarding the variables, it should be considered drivers activities that can affect driving posture and pressure variables.

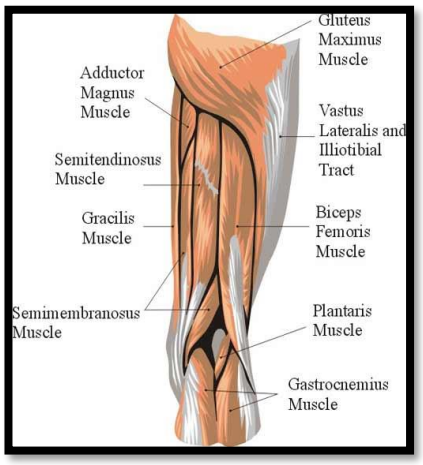
Additionally, comfort should be defined as dynamic or static. Characterization of the dynamic discomfort is described via vibration amplitude transited throughout the drivers' seat (Ebe & Griffin, 2000; S. Y. Kim et al., 2016). Static discomfort considering absence or low magnitude of WBV and having a focus on adopted posture and seat materials. In opposite, the high magnitude of WBV, the discomfort is described as dynamic (Ebe & Griffin, 2000).

1.5.1 Anatomy and anthropometric characteristics

Long-time seated posture may lead to issues with physical health and several MSD in a different part of the body (upper and lower extremities and back, neck, shoulders, among others) (Zemp et al., 2016). During the steering, professional drivers' body is supported by seat cushion by 70% of their total body weight (S. Y. Kim et al., 2016). IP on the driver's seat pan, considering the lower limbs, is upheld by the following bony prominences: ischial tuberosities, sacral coccygeal area, and greater trochanter (Figure 3).



a) Pelvic bone (resource https://www.neuspineinstitute.com/, date 09.12.2019)



b) Thigh posterior muscles and tendons (Romelfanger & Kolich, 2019)

Figure 3. Illustration of pelvic bones and thigh muscles and tendons

Still, the IP is not equally distributed. Regarding that, the pressure may be more significant, under ischial tuberosities, up to 11 times than the rest of the lower limbs area (Slayton et al., 2017) with the covered area of 18% (S J Park & Kim, 1997) of total buttocks/thigh area. The importance is that the seat enables even pressure distribution for the entire lower limbs area.

Gluteus muscle (a muscle between pelvic bony permanency and buttock skin – Figure 3) performs an essential role in prolonged sitting and sense of comfort/discomfort (Moes, 2007). In the case of an upright sitting position (back angle of 90º), the muscle changed position and leaves only subcutaneous adipose tissue between buttocks skin and the ischial tuberosities bone. The increasing angle of the back support, the gluteus muscle takes the bodyweight (Moes, 2007). This suggests that professional drivers, or another profession that requires sitting for a long time, uses more extensive (above 90º) backrest in terms of avoiding local body discomfort.

1.5.2 Pressure distribution and threshold values on the buttocks – thigh area

Different anthropometric characteristics might be essential in the interaction between driving strategies and applied IP. Various human attributes can have a different effect on pressure distribution, applied area, and similar pressure variables. Gender-based differences in pelvic (size and shape) are reported in the literature (Moes, 2007; Vos et al., 2006). Females, in the sitting position, may apply grater covered area due to larger pubic arch, and more significant distance between ischial tuberosities (Vos et al., 2006) comparing to male. Additionally, this can result in better pressure distribution of weight on a seat surface.

A person having a sharper bone (in this case, ischial tuberosities) is more at risk of developing disorders caused by prolonged sitting and applied pressure (Luboz et al., 2018). This finding is supported by Åkerblom et al. (1948), who described a range of the distance between the mean rank of the ischial tuberosities (from 9 to 15 cm), confirming that females had in the average higher range of the values. On the other hand, the structure of the male pelvis usually is narrower with the bones nearly placed (Vos et al., 2006). This has a result of smaller contact areas (comparing with female's anthropometric characteristics) and perhaps greater IP (Vos et al., 2006). The size of the contact area is also associated with the percentage of fat in the buttock area (Moes, 2007), body mass index (BMI) (Vos et al., 2006), stature, and weight of each person, and similar.

Driving tasks, which can require changes of adopted posture, can lead do uneven pressure distribution on the drivers' seat. Moreover, seat-built design regarding building quality might involve asymmetric pressure distribution. Consequently, lymph vessels and blood capillaries will close, or reduce the blood flow, involving several after-effects to the human body such as aches, discomfort, pain, fatigue, and possible MSD (D. M. Brienza et al., 2001; Le et al., 2014; Moes, 2007; J Mark Porter et al., 2003).

Consequently, uneven pressure distribution causing reduce of the total blood flow volume by 1.2% in the lower limb muscle (biceps femoris) in the first 30 minutes of sitting (Le et al., 2014). If the total volume decreases up to 13.4% in the first 60 until 90 minutes, it is possible that a sited person feels discomfort until the 120th minute (Le et al., 2014). As the final consequence of the uniformity

of the pressure distribution on the buttocks/thigh area, tissue ischemia might occur (Bergstrand, 2009; Dharmarajan & Ugalino, 2002; Le et al., 2014).

During the years, many scientists have been discussed about the IP threshold and evaluation of discomfort or tissue injuries (Dharmarajan & Ugalino, 2002). Some researches represented a correlation between higher IP values and discomfort using IP equipment. (Hartung, 2006; C Mergl, 2006). However, the seat pressure measurement has been considered as an objective evaluation of felt discomfort caused by prolonged sitting (Akkarakittichoke & Janwantanakul, 2017; Ciaccia & Sznelwar, 2012; De Looze et al., 2003). Higher pressure under the buttock or back were correlated with higher perceived discomfort (Hartung, 2006). Therefore, the idea was to suggest a single critical value, threshold, above which pressure causes capillary closing and deprivation of oxygen and blood in tissue (Goossens et al., 2005; Hiemstra-van Mastrigt et al., 2017; X. Jin et al., 2009; Moes, 2007; Savonnet et al., 2018).

Initial measures of pressure threshold suggested value of 4.3 kPa (32 mmHg) below which capillary closure does not occur (Jackson et al., 2009; Lewis et al., 2018). This amount of IP on the buttock skin is often used as a critical value of developing deep tissue injuries (DTI) such as pressure ulcers (Defloor & Grypdonck, 2000). Assessment of the IP, during the years, has been improved, and new thresholds have been suggested (Defloor & Grypdonck, 2000; Hartung, 2006; C Mergl, 2006). Other studies have reported that IP, on average, of 4.7 kPa (35 mmHg) (Jackson et al., 2009; Kilincsoy et al., 2016) or 6.3 kPa (47 mmHg) (Defloor & Grypdonck, 2000) may cause tissue ischemia.

The level of applied pressure depends on different factors specific to an individual and the place of the body where the pressure is applied (Defloor & Grypdonck, 2000). Besides this factor, tissue ischemia is in a correlation with applied pressure and its continues exposure (Jackson et al., 2009; Lewis et al., 2018).

If continues pressure exceeds 8 kPa (60 mmHg) with a period of sustained compression above 2 hours, a cellular breakdown is supposed to happen (Lewis et al., 2018). The same effect could be achieved with intermittent pressure up to 25.3 kPa (in the total duration of 4 hours) with a consequence of local cellular chances and damage (Jackson et al., 2009). Besides soft tissue thresholds suggestions, pressure over the bony promenades has different thresholds (Hartung, 2006; Zenk, 2008; Zenk et al., 2012). The blood flow, surface oxygen, thermal clearance, among others, decreased as the severe pressure approached with the value around 13.3 kPa (Goossens, 2007) or 15.2 kPa (Newson & Rolfe, 1982) concluding that the upper limit of the pressure values depends of varies anthropometric characteristics.

Besides, several studies tried to set up a critical singe amount of perceived discomfort caused by prolonged sitting (Levy et al., 2014; Savonnet et al., 2018; J. Smith et al., 2015). It can be found that a pressure bellow 8 kPa does not involve discomfort in the body (Lewis et al., 2018). In some cases, the threshold is in the range from 2.7 kPa until 8.8 kPa (Defloor & Grypdonck, 2000; Hostens et al., 2001; Lewis et al., 2018; Savonnet et al., 2018). The variety of the upper limit value could be affected by the time spent sitting, different seat material, gender, age, stature, among others (Khamis et al., 2018; Zenk et al., 2012).

As was previously stated, the capacity of a tissue to handle or support IP directly depends on the location of applied pressure (Savonnet et al., 2018). Along with, in the table below (Table 1) are illustrated values of maximum pressure, above which subject may perhaps sense discomfort (C Mergl, 2006).

Regarding the presented thresholds in Table 1, the total load on the drivers' seat pan should be supported by buttocks (Ciaccia & Sznelwar, 2012). Additionally, the variable "percentage of load" was only defined by (Hartung, 2006) and (C Mergl, 2006).

Table 1. Pressure threshold under the buttocks/thigh area (adapted by (C Mergl, 2006))

Study	Applied pressure on the lower limb area [kPa]	
	Buttocks	Thighs
Kamijo et al. (1982)	5.8	2.9
Diebschlag et al. (1984)	10-30	2-8
Hartung et al. (2006)	5.1-6.4	<3
Mergl et al. (2006)	<20	<0.7

Regarding the presented thresholds in Table 1, the total load on the drivers' seat pan should be supported by buttocks (Ciaccia & Sznelwar, 2012). Additionally, the variable "percentage of load" was only defined by Hartung et al. (2006) and Mergl et al. (2006).

The lower limb was separated into three areas: buttock, middle thigh, and front of the thigh. For all defined areas, the percentage of load, for both authors, is similar. Among other things, Mergl et al. (2006) included subjective discomfort evaluation to the determinate perception of discomfort for the specified lower limbs are (buttocks: 5.5-6.5 kPa; middle thigh: less than 4 kPa; and front of the thigh: less than 0.2 kPa). Granting that the thresholds are established on subjective evaluation, it should be taken with concern (Savonnet et al., 2018).

1.5.3 Methods of assessing subjective comfort/discomfort

Defining comfort requires phycological variables, correlated with visual perception and individual emotional beliefs (relaxation, well-being, and similar) (De Looze et al., 2003; Hiemstra-van Mastrigt et al., 2017; Thakurta et al., 1995). Recognizing the crucial factors to characterize the comfort and objective measure (pressure distribution on the seat, adopted postures during the time, or electromyography) of evaluating the discomfort may not be able to be applied (De Looze et al., 2003; Hiemstra-van Mastrigt et al., 2017). Establishing something comfortable or not, for example, drivers' seat, involves subjective ranking (Kyung & Nussbaum, 2013; Se Jin Park et al., 2000, 2014). The comfortable seat would require built materials and time spent in sitting position – besides visual appearance (De Looze et al., 2003; Hiemstra-van Mastrigt et al., 2017; Rhimi, 2017).

The main problem of evaluating comfort is the usage of different questionnaires with various required answers and levels of feelings. The not standardizing questionnaire might not lead to a unique opinion about the same seat. What is more, the surveys do not consider the time spent

sitting, the seat (office chair or vehicle seat) design neither the number of participants nor anthropometric characteristics.

The questionnaires could contain several levels and comparing local or total body comfort/discomfort. For example, Kamijo et al. (1982) used a five-level scale to define the feeling of comfort/discomfort assessing fifteen subjects in total. Later, the scale started to be consisted of more than 5 level scale (Lee et al., 1993; Thakurta et al., 1995) considering, again, local or total body perception of comfort/discomfort. The scales level describes the tendency of comfort, starting with the feeling of well-being and up to the final level – feeling pain.

Vergara et al. (2000) and Vink et al. (2004) were assessing office chairs during the long-time sitting, including the same number of participants (equal distribution – three males and three females). Besides objective measurements of comfort/discomfort, there were using the different subjective method of evaluating subjective comfort/discomfort. The subjective evaluation had a different level of expressing the feeling of the chair comfort.

During the years, scales were improving and including diverse and more detailed body parts (Carcone & Keir, 2007; Zenk et al., 2012). One of the most detailed questionnaires/scale was used by Zenk et al. (2012), named the CP50 scale. This scale represents anatomical body parts, further separated into regions, and marked with a number. The scale has its restrictions because it is taking into consideration just body parts that are in contact with the seat. A six-level scale used by (Sammonds et al., 2017; Varela et al., 2019), are applying comfort/discomfort evaluation in two segments. The first segment is choosing a level of comfort/discomfort (with two extreme points: “not uncomfortable” and “extremely uncomfortable”). Following that, participants could describe feeling using a modified Borg scale (Sammonds et al., 2017) for a more detailed comfort/discomfort feeling.

The diversity of questionnaires of perceived comfort/discomfort is illustrated in Table 2.

1.5.4 Association between vehicle seat IP and perceived discomfort

The IP mapping technology is using to measure applied pressure, of a seated person, between the seat interface and subjects’ body (Kilincsoy et al., 2016; Kyung & Nussbaum, 2008; Lewis et al., 2018). Its application is often used as objective measurements in assessing the IP between the mediums, as mentioned above. Moreover, in the combination of subjective perceived comfort/discomfort expressed using a questionnaire with a scale, the IP mapping technology is used to define upper values, after which the local/total body discomfort occurred. This value was represented in many articles as a threshold of applied IP.

Na et al. (2005) experimented with assessing continuous dynamic changes of IP in a total duration of 45 minutes. The study involved 16 male participants (to avoid diversity of anthropometric data). When examining the results, it was assumed that the specified driving period is not long enough to cause any discomfort. Still, the results are showing a tendency to increase the pain over time.

What is more, in parallel with an increment of perceived pain, the average IP variables increased over time as well. Statistical calculations do not support this tendency. Bringing a conclusion without analytical support may be wrong. For expel, Porter et al. (2003) take the lead of an experiment in the total length of 150 minutes, including 18 participants (without mentioning anthropometric characteristics) with the mean age of 40 ±12 years. The participants were surveyed with a seven-point scale of comfort/discomfort (the same scale level – comparing with the previous study).

Additionally, the similarity does not stop there. The authors (Hartung, 2006; C Mergl, 2006; Zenk, 2008) divided the seat (backrest and seat pan) into zones. In summary, Porter et al. (2003) did not find a strong statistical correlation between reported discomfort and applied pressure on the seat pan and drivers' buttocks area.

Long and short exposure of occupational sitting needs to be assessed and determinate time limit after which discomfort appears. Humans' body reaction on total or local body discomfort caused by prolonged sitting, it is still under debate. Many different research articles were using different subjective methods (Gyi & Porter, 1999; Kyung & Nussbaum, 2013; Zenk et al., 2012), populations (many of them did not define the anthropometric characteristics), approaches, among others. Wachsler et al. (1960) concluded no difference in sitting comfort ratings between 5th minute and long-term sittings (up to 4 hours). Mergl et al. (2006) concluded that the time spent steering the driving simulator for 20 minutes is not adequate to establish the discomfort ratings. Gyi et al. (1999) suggested at least 2 hours of the experimental process is needed to assess the body discomfort.

Following this advice, many studies tried to assess driving comfort/discomfort in the mentioned time duration (Inagaki et al., 2000; Le et al., 2014). Porter et al. (2003) lead an experiment and including ten males and ten females who were driving three different cars for 150 minutes. The first recording, using pressure mapping technology, was at the 15th minute and second on 135th minute. The scale (to evaluating subjective comfort/discomfort) was in seven levels, with the two extreme points – "very comfortable" to "very uncomfortable". Although the experiments were held out more than 2 hours, as it was suggested by Gyi et al. (1999), the correlation between body discomfort and the IP was not obtained for all three cars. One of the cars, "car B", had a five out of six significant correlation (reported by the Spearman's correlation) between body discomfort and the IP.

The time spent driving a vehicle may be an essential factor, but not the only one. Investigated PDP reported by Kyung et al. (2010), described that drivers adopt different driving strategies with the class of a different vehicle. Different driving posture (flexed or extended joint angles) may lead to different pressure distribution on the drivers' seat pan and backrest (Kyung & Nussbaum, 2013; Zenk et al., 2012). Oudenhuijzen et al. (2003) examined negative consequences that can result in sitting discomfort in a drivers' vehicle, using two different seats (medium soft and firmed seat). The experiment was held out in a laboratory with a duration of one hour. Subjective comfort was assessed in two phases: using a questionnaire for the total body discomfort and ratings for the local pressure distribution. The correlation between pressure distribution and reported comfort was

established. The pressure was analyzed based on seat areas (the total seat was divided into 32 areas), and it was concluded that equal pressure distribution on the backrest leading to the feeling of comfort. On another side, even pressure distribution on the seat pan does not lead to feelings on comfort (Bubb & Estermann, 2000; Mohanty & Mahapatra, 2014; Oudenhuijzen et al., 2003).

The effect of pressure distribution and local body discomfort was studied by Hartung et al. (2006). The study analyzed pressure distribution in nine different settings, including 48 participants, with a sitting interval of 5 minutes per each set. Subjective comfort was reported using the CP50 scale (includes 17 different body parts that are in contact with the vehicles' seat). The mathematical association was not found between different body parts and IP variables. Furthermore, the correlation was reported for the total body discomfort and the applied pressure on the drivers' seat. The conclusion was that the time spent sitting was not enough to trigger the discomfort. The seats needed to "produce" more IP to cause any discomfort in the short period (C Mergl, 2006).

Nevertheless, Mergl et al. (2006), in his study, used the same subjective and objective method to assess the pressure distribution and pervaded discomfort. The research includes the equal number of gender (ten male and ten female) participants in the age between 20 and 30 years old. Moreover, the participants were testing six different settings of a vehicle seat in the total duration of 180 minutes. The time spent steering the vehicle, in the laboratory condition, were enough to determine a correlation between the reported discomfort and the IP (rankness dependent on the different body part). Several pressure variables (mean and maximum pressure, percentage of load, and pressure gradient) had a various correlation with the body parts of the lower limbs (buttocks, and middle, front, and side thighs).

Another study analyzed IP by zones (Kyung & Nussbaum, 2008) using a visual analogue scale to evaluate overall and local comfort/discomfort for six short driving periods (with the individual duration of 15-20 minutes). This study includes 15 male and 12 female participants with an average stature of 170.7 ±11.7 cm and a weight of 69.1 ±13.1 kg. Correlation between local body discomfort ratings (body parts – left/right buttocks and left/right thigh) and pressure variables (for example, mean pressure, mean pressure ratio, peak pressure, among others) was not statistically significant to be considered (Kyung & Nussbaum, 2008).

Table 2. Correlation between IP variables and perceived comfort/discomfort

Study	N (M/F)	Sample (SD)	Pl.	Time (min)	Pressure variables	Subjective measures of comfort/discomfort	The correlation between a subjective and objective measure
Gyi et al. (1998)	Ex. 1: 14 (7/7) Ex. 2: 12 (6/6)	40.7 (17.9) / 42.86 (11.9) 147.5 – 187.5 n.d. 21.0 (1.95) 193.9 (84) / 154.3 (22) n.d.	Lab. Lab	150 150	Average seat ratio. Maximum pressure value in the defined area. Mean pressure in a defined area. Summary of the cells in the defined area. Ratio maximum – Minimum/maximum in a defined area. Ratio minimum – Second highest pressure/maximum in a defined area. Proportion – "Total"/seat or back total	Local body part discomfort – 7 levels (very comfortable to very uncomfortable)	No correlation coefficient; Reported correlation for average seat ratio: mean lower back pressure and lower back discomfort; buttock discomfort and ischial tuberosities area. Reported correlation for maximum pressure value in the defined area: tall males between buttock discomfort and IT area pressure variables (no correlation coefficient reported).
Porter et al (2003)	18 (8/10)	40.0 (12) n.d. n.d.	Fi	150	Mean pressure (left/right ischial tuberosity, left/right thighs, upper/lower back.) Maximum pressure (left/right ischial tuberosity, left/right thighs, upper/lower back.)	Parts of the body with a 7-point scale (with the two endpoints: very comfortable to very uncomfortable)	Car A: Mean pressure at the right thigh and reported discomfort: r=0.52 (on average for three measurements). Car B: Moderate correlation for 5 out of 6 correlations. Mean pressure at right ischial tuberosities and reported discomfort: r= -0.49 (15th minute). Maximum pressure at the right thigh and reported discomfort: r=0.57 (15th minute) and other measurements at the right thigh and reported discomfort: r=0.47 (on average). Upper back pain and reported discomfort: r=0.61 (135th minute) and upper back pain and reported discomfort: r=0.58 (on average). Car C: No clear mathematical correlation between IP and subjective comfort.
Na et al (2005)	16 (16/0)	25.5 (2.6) 172.8 (5.4) 72.3 (9.8)	Lab	45	Body pressure ratio (sum of body pressures per region divided by sum of body pressures of lumbar and buttocks region). Body pressure change variables: Seat pan – The count of pressure changes, which exceeded 15% of the average total pressure of seatback. Seatback – The count of pressure changes which exceeded 5% of the average total pressure of seat pan	Local body parts – 7 level scale	No correlations were calculated. A tendency of total body discomfort is increasing during the tame. The same conclusion is applied for pressure changes in the drivers' seat.
Zenk et al (2012)	1 (1/0)	42 1.76 83	Lab	0.45	Percentage of the load on the buttocks and the front thighs	Opinion about the discomfort level	Higher values of discomfort were reported in MAX and MIN posture. The IDEAL posture reported a smaller amount of discomfort. MIN posture (front of the thigh: 0.4%, buttocks: 66.5%); IDEAL posture (front of the thigh: 6.4 %, buttocks: 54.0 %); MAX posture (front of the thigh: 10.6 %, buttocks: 47.6 %).
Thakurta et al. (1995)	36 (27/9)	30.4 (9.2) 177.2 (10.7) 75.6 (16.3)	Fi	<120	Pressure distribution on lumbar and ischial and thigh area	Local comfort/discomfort with the 10-point scale	It was reported a strong correlation between pressure distribution and local comfort. A mathematical correlation was not provided.

Study	N (M/F)	Sample (SD)	Pl.	Time (min)	Pressure variables	Subjective measures of comfort/discomfort	The correlation between a subjective and objective measure
Merlg (2006)	20 (10/10)	20-30 179.0 (7) / 166.0 (5) 65 (12)	Lab	180	Percentage of load, mean/maximum and gradient of pressure for the right/left buttocks, right/left middle thighs, right/left front thighs and side thighs	Body Map (17 body parts) with a CP50 scale (with six levels of discomfort)	Correlation of local subjective discomfort and IP variables on the seat pan, fort the following areas: Buttock: Quadric correlation: percentage of load, and mean pressure. Linear correlation: maximum pressure, and pressure gradient. Middle of the thigh. Linear correlation: percentage of load, mean pressure, maximum pressure, and pressure gradient. Front of the thigh. Linear correlation: percentage of load, mean pressure, maximum pressure, and pressure gradient. Side of thighs Linear correlation: percentage of load, and maximum pressure. The correlation of IP ratings and perceived discomfort of the lower limbs is not presented for the sample size. It is considered, depending on the lower limb area, in the range from 15% to 50% of the sample size.
Hartung (2005)	48 (n.d./n.d.)	18-29 179-182 72-76	Lab	45	Maximum pressure, mean pressure, and percentage of load for the right/left buttocks, right/left middle thighs, right/left front thighs and side thighs	Body Map (17 body parts) with a CP50 scale (with six levels of discomfort)	Correlation between total body pressure and pervaded discomfort. No mathematical correlation between body parts and discomfort ratings.
Kyung et al. (2008)	27 (12/15)	20-35 170.7 (11.7) 69.1 (13.1)	Lab	6x20	Local (left/right thighs, left/right buttocks, and upper/lower back): Mean pressure, mean pressure ratio, peak pressure, peak pressure ratio, contact area, contact area ratio. Overall (sum of the local body parts): Mean pressure, mean pressure ratio, peak pressure, peak pressure ratio, contact area, contact area ratio.	Visual Analogue Scale – with the range from “no pain” to “extreme pain.”	A significant correlation between contact area ratio and overall comfort and discomfort ratings. A significant correlation between the left thigh with a whole-body comfort rating. For the rest variables and regions, no correlation was found.
	28 (12/15)	20-35 170.7 (11.7) 69.1 (13.1)	Fi.	6x20		Visual Analogue Scale – with the range from “no pain” to “extreme pain.”	A significant correlation between buttock left/right, ration for the buttocks left/right, the ratio for lower/upper back, and overall comfort and discomfort ratings. A significant correlation between the left/right thigh, left/right buttock, upper back, the ratio of the lower back, and with the whole-body comfort rating. For the rest variables and regions, no correlation was found.
Kyung et al. (2013)	11 (n.d./n.d.)	71.4 (8.6) 168.2 (11.7) 73.5 (22.0)	Lab / Fi	6 x 20	6 local body parts with the 10 levels of comfort/discomfort Whole-body comfort/discomfort ratings (ranged from 0 to 100)	Mean contact area and ratio, mean pressure and ratio, mean peak pressure and ratio for the following body parts left/right thigh, left/right buttock, and lower/upper back	In total, 22 out of 36 variables were statistically significant correlated (from low to moderate).
	11 (6/5)	21.8 (3.2) 168.9 (11.2) 67.9 (11.1)	Lab / Fi	6 x 20			

Study	N (M/F)	Sample (SD)	Pl.	Time (min)	Pressure variables	Subjective measures of comfort/discomfort	The correlation between a subjective and objective measure
Milivojevich et al. (2000)	12 (6/6)	n.d. / n.d. 158-188 / 152-183 59-104 / 5-82	Lab.	n.d.	Mean pressure for the ischial tuberosities, thigh, and lumbar area. Total contact area (activated sensing elements)	Subjectively defined comfort/discomfort	Subjective discomfort is in correlation with pressure distribution.
Inagaki et al. (2000)	7 (7/0)	26-37 n.d. n.d.	Lab.	180	Pressure distribution	The five-point scale of comfort/discomfort	The relation between pressure distribution and comfort.
Jin et al (2009)	8 (6/2)	28.4 (4.6) 169.4 (10.2) 68.6 (9.0)	Lab.	100	Load, contact pressure, contact area, and centre of load.	Whole-body discomfort ratings (from 0 until -4; where 0 represents “no feelings” and -4 “extreme discomfort”) and local body parts: left/right thigh, left/right hip, left/right upper back, and left/right lumbar.	A strong correlation between perceived discomfort and total load and pressure of the whole seatback. A moderate mathematical correlation between perceived discomfort and pressure on the left thigh and upper back, and pressure ratio at the buttock.
Le et al (2014)	12 (6/6)	33.0 (13.4) 169.8 (9.5) 69.2 (13.2)	Lab.	120	Seat pan distribution – “The pressure point percentages referred to the proportion of points on the mat .6.4 kPa relative to the amount of area contacted”. Pan oscillators – “postural shifts in the seat over the 2-h period.”	Visual Analogue Scale – with the range from “no pain” to “extreme pain.”	Mathematical correlations did not support discomfort ratings. Considering the lower limbs: Taller subjects (>171 cm) reported discomfort in the hip and knee. Lighter subjects (<58 kg) reported discomfort in the buttocks area. Upper leg discomfort was reported by heavier subjects (>71 kg).

Lab. -Laboratory, Fi- Field, n.d. – Not Defined, N – Number of participants (male/female), Pl – Place, M/F – Male/Female, SD – Standard Deviation.

1.5.5 Anthropometric characteristics and seat IP variables

Apart from the ergonomic aspects (seat design, manoeuvre space, and similar), the time spent steering a vehicle, tasks, and anthropometric categories (such as stature, weight, age, gender, body mass index, percentage of subcutaneous fat, among others) may have a significant impact on applied pressure variables (Chester et al., 2002; Le et al., 2014; Na et al., 2005). It is essential that the vehicle design is following anthropometric requirements for driving venue, as well as seat model, with support the physical size of the driver and to provide a comfortable working environment (Gyi & Porter, 1999; Kyung & Nussbaum, 2013; Mohanty & Mahapatra, 2014; Zemp et al., 2015).

An individual having different anthropometric attributes may have experienced differently discomfort ratings (Le et al., 2014). The percentage of tissue fat and the distance between ischial tuberosities appears to be an essential factor (Le et al., 2014; Moes, 2007) considering the IP between subject and seat. Additionally, this may be the difference between the gender, knowing that the females tend to have a higher percentage of fat in the lower limbs area and the more significant distance between the bony prominence in the pelvic area (Gyi & Porter, 1999; Sember, 1994). Furthermore, males having narrower pelvis (a shorter distance between the ischial tuberosities and a tighter pubic arch) could result in a smaller loading area on a seat (Vos et al., 2006). They are having a higher mass and lesser loading area results (Åkerblom, 1948; Marras & Kim, 1993), on average, approximately 2.1 kPa higher pressure than females (Moes, 2007).

Additionally, gender-based differences could be found in a chair with armrest (Vos et al., 2006). Vos et al. (2006) referring that females were loading less pressure (to a limited extent) on the seat pan than males, in case of using the armrest. On the other side, males had a lesser pressure load on the seat pan, increasing the backrest angle (Vos et al., 2006). Gyi et al. (1999) performed an experiment in the total duration of two and a half hours and included seven males and seven females. Their study has shown that the hip breadth was the best predictor for the mean IP on a vehicle seat and adding that thinner people had higher and more constant pressure under the ischial tuberosities and sacrum. A newer study has shown (J. Park et al., 2013) that the sitting pressure ratio (for the 17 different body parts) does not have any mathematical correlation with the gender characteristics.

Hostens et al. (2001) analyzed BMI (kg/m^2) with a pressure variable for four types of agricultural seats. His study includes ten males with an average weight of 67.9 ±8.9kg and stature 174.9 ±6.8 cm. The participants were testing the seat, seating on it 2 minutes per each with a break of 2 minutes. To conclude, objective measurements (referring to the IP) and BMI had almost a linear correlation with the mean pressure distribution. Additionally, peak pressure did not correlate with BMI. According to Jackson et al. (2009), the same findings, concerning BMI and peak pressure, has been shown. Jackson et al. (2009) experimented with five different seats, including and 35 participants with a height of less than 180 cm, in a total length of 150 minutes.

What is more, anthropometric characteristics such as stature and body mass did not have a mathematical relationship with the peak pressure. Furthermore, Vos et al. (2006) testing 12 office chairs found a correlation between the applied contact area and BMI. Participants with a higher value of BMI are covering a greater area on the seat. This statement has been shown by Paul et al. (2012). Besides various anthropometric variables, the BMI demonstrated for three different cars from moderate until strong correlation with covered area. What is more, body mass has the same tendency for more pressure variables such as total force for the various seat pars (Paul et al., 2012).

Recent research by Kyung et al. (2013) included two groups based on the age differences (the old group had more than 60 years, while the young group was in the range between 20 and 30 years old). After examination of the variables for the obtained by six driving sessions, demonstrated the pressure variables (mean contact area) have a higher value at the right buttock. Previously mentioned could be caused by different sitting strategies preferred by the older group. Lack of visual ability may lead to asymmetric posture and to create a nonequal pressure distribution (Kyung & Nussbaum, 2013). The younger driver tends to have higher hip joint degrees, which can cause higher pressure on the backrest of a vehicle seat.

Stature, as an anthropometric variable, has been reported as one of the most critical factors to influence sitting posture (Hiemstra-van Mastrigt et al., 2017; Kyung & Nussbaum, 2013) and IP distribution (Vincent et al., 2012; Vos et al., 2006) (pointing that the pressure is in correlation with the stature – higher people applying more weight pressure). Taller people tend to sit with a more open stance (extended joint angles –shoulder, elbow, and hip) (Le et al., 2014). As often reported, upper leg discomfort might be an adopted position of prolonged sitting (Le et al., 2014). In the case of smaller diving venue, knee and hip angle might be more flexed and could cause different sitting strategies and lead to uneven pressure distribution (Le et al., 2014) causing a reduced amount of blood flow in the lower limbs. Kyung et al. (2008) found that the contact area at the right thigh and upper back is larger for tall participants (>175 cm) than for the rest two groups (small <164 cm, and medium 165≤175 cm). Le et al. (2014) concluded that the lighter people (with a weight of less than 68 kg) reported more discomfort in the buttocks area. As they refer (Le et al. 2014), a reason could be of the lower oxygenation in the biceps femoris (lower limb) muscles causing a lack of blood flow of 2.1% form 90^{th} until 120^{th} minute. Additionally, less weight is a lesser percentage of fat under the bony prominence in the buttock region.

1.5.6 Correlation between the IP and sitting posture

Besides a personal factor that might affect the driving posture and applied pressure on the seat pan, researchers were trying to establish a correlation between PDP and IP on the vehicles' seat (Carcone & Keir, 2007; Vink, 2004; Xu et al., 2012). Xu et al. (2012) used low-cost pressure mapping technology (in total, 64 pressure sensing points) developed an algorithm to assess and define sitting strategies based on IP on the seat. Based on the binary results, the algorithm can classify the adapted human sitting posture into nine groups, with an accuracy of 82.3%.

The drivers tend to move and to change the posture with a feeling of discomfort (Hiemstra-van Mastrigt et al., 2017; Na et al., 2005). Under the time progression of the driving, the drivers happen to adopt new positions regarding reducing body discomfort in a particular part of the body (Li et al., 2017; Vink & Hallbeck, 2012). Changing the torso angle, pressure on the seat pan (buttock-knee length), and lumbar/backpressure increases (Vos et al., 2006). This statement has been proved along with research done by Na et al. (2005). Moreover, it was shown that the driving period influenced trunk, hip, and knee angles growth. Variables used for the IP measurement were in correlation with the joint angle changes (Na et al., 2005).

Preferred interior dimensions of the driver's seat, adjusting backrest angle, horizontal and vertical distances, increase or decrease IP on the seat. H. Chen at al. (2013) in their study, used office chairs and included nine participants with a stature of 167.7 ±9.2 cm and a weight of 56.8 ±14.3 kg. Increasing the backrest angle, the centre of the pressure applied on the seat pan is decreasing due to the centre of the pressure is moving towards the seat backrest (H. Chen et al., 2013). This report is not supported by J. Park et al. (2013). In his study participate forty drivers with the stature range from 150 cm to 181 cm. PDP and the IP (presented in the 17 different regions of the seat) had no significant correlation.

1.6 Driving postures and body discomfort caused by long-time driving

Driver working environment requires adequate ergonomic adaptation but always considering the drivers' tasks and the most important the satisfy majority anthropometric need (Naddeo et al., 2015). Hence, several scientific research (J. Park et al., 2016; Se Jin Park et al., 1999; Tilley & others, 2001) are collecting driver's anthropometric data concerning developing and adopt the working environment to a driver. Besides anthropometric attributes, several factors need to be a concern, such as driving venue (Jeong & Park, 2017; Reed et al., 2000; Vogt et al., 2005), horizontal and vertical seat distances (Hanson et al., 2006) as well as the driving wheel adjustment (S. Jin et al., 2018), among others. Nevertheless, vehicle designers are using, and sill improves tool recommended by Society of Automotive Engineers (SEA) (Hanson et al., 2006; Kyung et al., 2007; Se Jin Park et al., 2014) where the parameters such as a seat and eye position, possible modifications, and similar, respecting development a suitable vehicle interior to the majority population.

Still, taking into consideration truck drivers' tasks it might require awkward sitting during a long-time driving (Hussain, 2004). Besides negative factors (for example, WBV) (Serrano-Fernández et al., 2019) adopting impropriate/awkward driving posture during prolonged driving will cause pain/discomfort in a particular part of the body. Steering vehicle in such a condition must require balance muscle activities of the lower and upper limbs (Schmidt et al., 2015), while the trunk, head as well as upper extremities, must be supported by comfortable seat (Harrison et al., 2000; J Mark Porter & Gyi, 1998).

J. Smith et al. (2015), in their investigation, include twelve participants and examined two different driving postures and compared. The experiment was held out in the laboratory condition steering

the driving simulator in the total length of 60 minutes. As the outcomes indicated, the prolonged driving influenced total body comfort and pain boosted with the time, considering the total body. Two different driving strategies, standard and lifted (J. Smith et al., 2015), has shown significantly higher discomfort reported in the right ankle for the high driving posture. The mathematically considerable difference between the time spent driving, and driving postures were not obtained (J. Smith et al., 2015). Another laboratory research showed the influence of the adopted postures and long-time driving (Sammonds et al., 2017). After 140 minutes of the steering the driving simulator, in laboratory conditions, it was shown that overall discomfort was continuously progressing with the time. Spending long-time in the small venue will directly cause body discomfort (Li et al., 2017) no matter of adopted driving posture (Sammonds et al., 2017; J. Smith et al., 2015).

Subjects with different anthropometric attributes, suggesting the variance in the stature, were assessed by several studies (Hanson et al., 2006; Jeong & Park, 2017; Peng et al., 2015, 2018). Kyung et al. (2009) investigated participants with different statute, defining three groups (small <165 cm, middle ≥ 165 ≤ 175 cm, and tall > 175 cm). The research included 38 participants of different ages and stature. The study Kyung et al. (2009) concluded that participants with different stature had different driving angles. Moreover, it was shown that older and younger participants adopted different driving strategies. Furthermore, Hanson et al. (2006) assessed two different stature group (smaller than 170 cm, and taller than 190 cm) in the total duration of 20 minutes. The time spent steering a vehicle did not influence the preferred driving posture, nor between the stature groups. As the outcomes indicated, the difference was obtained by the left and right side (caused by the driving task) (Hanson et al., 2006). Additionality, comparison between two different demography participants (French and Chinese) was paralleled in the study done by Peng et al. (2018). In total, 61 participants, divided into three stature groups (with height average dimensions: short 158.2 ±4.1 cm, average 171.5 ±3.2 cm, and tall 184.6 ±6.2 cm). Assessing the PDP it was concluded that shorter participants adopted more reclaimed trunk angles than the two groups (average and taller classified participants).

Moreover, focusing on the BMI and its influence on the joints range of motion were assessed and analyzed by Park et al. (2010). It was shown that participants with higher BMI had a significantly smaller range of motion in some of the main joint angles (for example, knee flexion and extension) than normal-weight subjects. What is more, in the investigation done by Jeong et al. (2017) was shown that participants with higher BMI, primarily classified as obesity, were adopting more substantial horizontal and vertical interior adjustment comparting to normal-weight subjects.

Table 3 is representing the preferred three-dimensional (3D) main joint angles (focusing only on the left side of the body) of drivers. Moreover, the table is an adopted version form several articles (Lourenço & Ackermann, 2015; Schmidt et al., 2014).

Table 3. 3D driver's joint angles (an adapted and updated version of (Schmidt et al., 2014))

			Flexion / Extension of main joint angles (°)				
Study	Participants number	Groups	Ankle	Knee	Hip	Shoulder	Elbow
Porter et al. (1998)	55	M/F	80-130	99-138	90-115	19-75	86-164
Park et al. (2000)	43	M/F	100.8±8.6	133.7±8.5	117.4±7.7	19.5±6.4	113.0±14.0
Hanson et al. (2006)	38	M/F	97±5.5*	125±9.3*	100±4.4*	39 ±15*	128±16*
Kyung et al. (2009)	38	G1 S	82-88*	84-91*	79-87*	1-29*	85-120*
		G2 S	92-123*	118-129*	107-118*	32-58*	146-165*
		G1 SUV	94-130*	95-105*	84-87*	2-11*	84-116*
		G2 SUV	108-116*	135-138*	119-126*	38-59*	121-160*
Park et al. (1999)	36	M/F	103±6.87	132.7±6.90	115.8±6.52	19.2±5.55	111.5±11.4
Andreoni et al. (2002)	8	M/F	N.A.	140±10	93±6	32±10	115±10
Vogt et al. (2005)	15	M/F	103	119	99	22	127
Schmidt et al. (2015)	40	M/F	N.A.	N.A.	N.A.	N.A.	95-120
Peng et al. (2017)	61	Re	N.A.	95-123	80-102	N.A.	
		De	N.A.	82-112	73-96	N.A.	110-168
		Fi	N.A.	114-147	93-114	N.A.	
Park et al. (2015)	20	W1	123.0±14.3	106. 5±5.4	117.7±3.2	N.A.	131.5±1.8
		W2	111.2±23.8	111.2±23.8	108.8 ±5.6	N.A.	117.0±14.9
		W3	122.4±6.2	122.4±6.2	104.8±2.1	N.A.	126.9±24.9
Oudenhuijzen et al. (2004)	11	M	N.A.	111.5	N.A.	N.A.	N.A.

* - Left side of the body; M/F – Male / Female; G – group; S – sedan; Re – driving postures at rest; De – beginning, Fe – end; W – weight; N. A. – Not Available

Proposed angles (represented in Table 3) do differ between the researchers. There might be several reasons for this problem. Besides different anthropometric or demography characteristics (Andreoni et al., 2002; J. Park et al., 2014; Se Jin Park et al., 2000), duration time may pay an essential role in the determination of preferred or comfortable driving postures. Porter et al. (1998) dedicated that at least 2 hours in needed to establish if the comfort/discomfort is obtained in the human body. Moreover, Schmidt et al. (2014) in systematic review proposed several vital points be followed, for the easiest posture assessment. Schmidt et al. (2014) proposed at least 30 minutes of the driving process, standardized driving working environment, determination of 3D joint angles, among others. Importance of the standardized driving venue is that some of the vehicles do not have adjustable horizontal/vertical distances of the seat or driving wheel position. Additionally, as it was shown in Kyung et al. (2010), the driver adopts different driving strategies for the different vehicle class.

1.7 Gait performances and potential problems among professional drivers

Professional drivers' daily activity often does not include many tasks out of the vehicles' internal working environment. Nevertheless, this assumption does not refer to all of the driving professions. Considering the truck drivers, it might involve additional working effort outside the vehicle (entering/opening/closing the truck trailer, and similar) (Sekkay et al., 2018; Spielholz et al., 2008). This action requires gait performances on the different ground levels, which directly demand additional muscles activities, especially after long-time driving (Mickle et al., 2011; C. K. Smith & Williams, 2014; Spielholz et al., 2008).

Besides long-time driving, WBV might be one of the negative factors that contributed to the postural stability (Oullier et al., 2009). This effect was studied by Oullier et al. (2009) on twelve

bulldozer operators and twelve non-drives and assessed their postural stability after driving. Furthermore, the conclusion was that postural stability was disturbed by prolonged WBV exposure.

Human postural stability and walking involve complex systems such as musculoskeletal, neurological, vestibular and the somatosensory, visual, among others (Chiu & Wang, 2007; Eils et al., 2002). Additionally, disturbing one of the mentioned systems, human gait performances might interrupt and caused falls (Mickle et al., 2009; Taylor et al., 2013), slips (Barrett et al., 2010), and similar. Moreover, the gait is formed from several gait periods and tasks, as well as from events and phases. Figure 4 is illustrating the right lower limb gait cycle, starting from the initial recoding up to 100% of the gait cycle (new initial contact). The percentage of the walking cycle confronts each of the events.

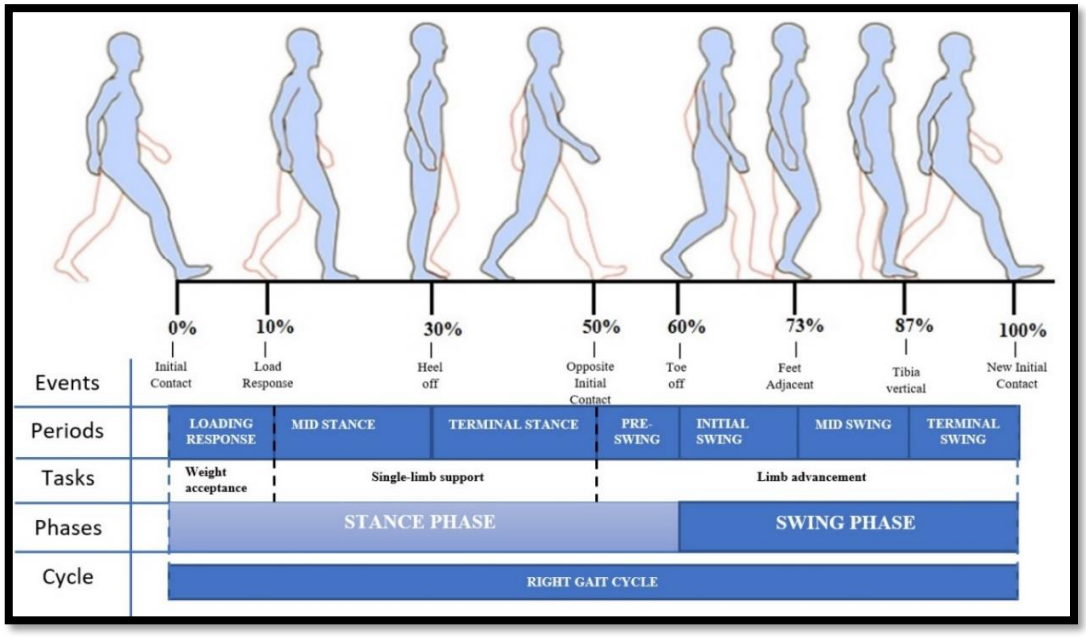


Figure 4. Phases of the right lower limb gait cycle (an adapted version from (Neuman, 2010))

During gait performances, human body involves primary body segments characterized by their angular and linear kinematics, kinetics, different temporal characteristics, among others (Fryzowicz et al., 2018; Slijepcevic et al., 2017). Classification of the gait between the different ages and determination it as a normal walk performance, contains variables such as spatiotemporal (Burnfield et al., 2004; Franklin et al., 2015; Kirkwood et al., 2011; Segal et al., 2004; Van Deursen, 2004), ground reaction force (C. Chen et al., 2007; Muniz & Nadal, 2009; Soares et al., 2016), the centre of pressure (Soares et al., 2016; Sole et al., 2017), distribution of the plantar pressure (Nagel et al., 2008; Rosenbaum et al., 1994), angular and linear kinematics of the lower limbs (Hajduk et al., 2016; Pietraszewski et al., 2012), and similar, are still under the debate (Fryzowicz et al., 2018).

The gait performance does differ between the barefoot and in-shoes walking (Segal et al., 2004). This disparity might involve various gait parameter, especially gait velocity (Bohannon et al., 2011; Burnfield et al., 2004; Segal et al., 2004). Moreover, in-shoes higher or slower gait velocity might have disembogued outcomes such as ground reaction force (Allet et al., 2008), applied plantar pressure (Deschamps et al., 2013; Segal et al., 2004), among others, than walking barefoot (Burnfield et al., 2004; Segal et al., 2004).

Öberg et al. (1993), in their study, tried to examine basic gait parameters and to determinate three levels of gait velocity for healthy subjects. The study included an age range from 10 to 79 years old participants. The examination was held out in a laboratory, controlled, conditions including 233 subjects (from which were 116 male and 117 female). On the lower gait speed, including both genders, the range was from 83.1 cm/s to 93.5 cm/s, where older participants (more than 50 years old) were having lower values. The normal speed was considered between 108.6 cm/s to 135.1 cm/s, while fast gait was classified between 141.8 – 184.3 cm/s (Öberg et al., 1993). Again, the same happened on the walking speed (older participants were having slower values than younger subjects). Furthermore, in a descriptive meta-analysis, Bohannon et al. (2011) have collected multiple studies and compared normal gait speed. The data included 231111 subjects of different ages. Normal gait speed was again proffered to vary between the ages, where the fastest, normal, speed was determined between 137.9 cm/s to 148.8 cm/s for the age between the 40 and 49 years old. After examination results obtained on comfortable self-selected speed by a young woman (with age on average 21 years old) (Fryzowicz et al., 2018), it was concluded that the speed (137 ± 0.11 m/s) were higher for the same age than the outcomes represented by Öberg et al. (1993). Represented values of the normal walking speed (Bohannon et al., 2011) are higher than the research done by Öberg et al. (1993). One of the possible reasons might be that participants tend to walk faster in-shoes than where are barefoot (Bohannon et al., 2011; Franklin et al., 2015; Segal et al., 2004). Increasing gait velocity have an impact on the human MS system increasing an impact on the total body, as well as rising ground reaction forces (C. Chen et al., 2007), linearly increasing interface plantar pressure at the specific foot region (Segal et al., 2004), and beside dynamics also have on gait kinematics (Fryzowicz et al., 2018) performances.

Higher walking speed involves additional muscle working effort in the lower limbs (rear and front thigh, buttock, biceps femoris, among others) (Chung & Wang, 2010; Fryzowicz et al., 2018; Pataky et al., 2008) and as the speed increases, more energy is needed to support the walk. Moreover, the speed between 123 and 125 cm/s are the most energy-efficient (Fryzowicz et al., 2018). Besides, the viscoelastic behaviour of the muscles/tissues are reacting differently at the higher speed (the tissue stiffness increases parallel with the gait velocity) (Xiong et al., 2011). To determinate if the performed gait might be classified as “normal” more spatiotemporal variables are needed (Eils et al., 2002; Fryzowicz et al., 2018). Barefoot walking will influence another parameter; in this case, the frequency of steps (cadence), where subjects will motivate more steps walking without shoes or with flexible footwear (Franklin et al., 2015). Hollman et al. (2011) represented mean values for the spatiotemporal variable (cadence) where the average was different for the male (102 ± 8 steps/min) and female (113 ± 20 steps/min) participants. On average female participants tend to walk faster, applying more cadence (Hollman et al., 2011) and having more

considerable step length concerning keep walking speed similar to the male population (Fryzowicz et al., 2018).

Decreasing specific spatiotemporal variables is corresponding to the risk of falls (Butterworth et al., 2015; Kirkwood et al., 2011; Mickle et al., 2010). Taking into consideration reducing the swing phase (for 10 %) is positively correlated with the risk of falls (Hollman et al., 2011). Furthermore, participants with lower gait velocity longed stance phase or decreasing step length, less mobility, movement or plantarflexion deformity in the ankle, reduction in ground reaction forces, among others, are classified as potential as a subject with the risk of falls (Eils et al., 2002; Ma et al., 2018; Neri et al., 2017). The fact is that the risk of falls is increasing with age, where older participants are more determined to fall (Mickle et al., 2010). Pointing out that professional drivers pretend to conditionally at risk for slips, trips, and falls after prolonged driving (performing walk on the same or different ground levels) (Spielholz et al., 2008). Moreover, the risk of falls is associated with different MS symptoms (Kirkwood et al., 2011).

During the gait, the foot contributes as one of the essential parts of the lower limbs, and regarding it, disturbance of the normal plantarflexion/dorsiflexion may contribute to different applied pressure (Höhne et al., 2009; Merker et al., 2018; Xiong et al., 2011) or might be linked with risk of falls and slips (Nagel et al., 2008), and similar.

Starting from the initial contact and finishing with the push-off phase, the pressure does not equally distribute on the plantar area (Putti et al., 2008). Analyzing that, it is necessary to divide the plantar area to primary four (rearfoot, mid-foot, forefoot, and fingers) (Cavanagh et al., 1987) or more regions (the majority of articles divided foot into ten regions) (Liu et al., 2005; Nurse & Nigg, 2001). Besides, dividing into the region, it is easier to understand the interface plantar pressure distribution and to assess and discover possible abnormalities during the gait cycle (Höhne et al., 2009; Nagel et al., 2008). Influence of the gait velocity on the plantar region was done by several studies (Burnfield et al., 2004; Segal et al., 2004).

Burnfield et al. (2004) in their study compared the difference between three different gait velocities and plantar pressure distribution on the plantar, walking barefoot and in-shoes. The study included evenly delivered genders, in total, twenty healthy participants. As the barefoot walking speed increased, it influenced the rearfoot, central forefoot, and the fingers (hallux and other fingers) area rising the applied pressure (Burnfield et al., 2004). Furthermore, the pressure under the lateral midfoot area was negatively associated with the gait velocity. In the research done by Segal et al. (2004) had a similar conclusion, while the data acquired with footwear. The results indicated that the linear pressure increased under the rearfoot and hallux area as the gait speed increased (Segal et al., 2004) for twenty-two subjects. The outcomes showed the lateral mid-foot pressure decreasing wearing shoes while walking (Segal et al., 2004). Parallelly, the pressure under the hallux area was smaller for the barefoot walking, while the rearfoot is obtained higher pressure values comparing to pressure in-shoes (Burnfield et al., 2004; Segal et al., 2004).

Nevertheless, the correlation between pressure distribution and gait speed, having different opinions (Chung & Wang, 2010). The progress of the plantar pressure distribution during the roll-over process (ROP) can be influenced by participants BMI (Butterworth et al., 2015), foot pain

(Burns et al., 2005; Sullivan et al., 2015), low physical activity level (Riddiford-Harland et al., 2015), impropriate muscle activities (Höhne et al., 2009), among others.

Classifying subject by the BMI, it has shown different walking strategies that directly influenced the distribution of the plantar pressure (Xiong et al., 2011) as one of the reasons might be linked with subjects' flat feet (Butterworth et al., 2015), which are often present among overweight people. This type of foot is more pain-sensitive (Xiong et al., 2011) and in a case of heel pain (or another foot part) might interrupt the pressure distribution (Sullivan et al., 2015). Moreover, these walking strategies among overweight subjects may cause higher pressure under the foot and directly affect gait balance (Wu & Madigan, 2014). Performing gait at the higher gait velocity might reduce pressure at the push-off stage (Chung & Wang, 2010; Eils et al., 2002; Riddiford-Harland et al., 2015) for the hallux area and transmit it to the forefoot (first and second metatarsal head) (Riddiford-Harland et al., 2015). This way, the subject is trying to prevent the overloading of the fingers area (Neri et al., 2017).

What is more, various vigorous types are associated with different plantar pressure values, where was pointed out that participants with low activity level are highly associated with higher pressure (Riddiford-Harland et al., 2015). Uncomfortable plantar pressure values, for example, under the rearfoot, will change affect the distribution during the ROP applying lesser under the posterolateral heel, and lower maximum values at the initial contact (Liu et al., 2005; Riddiford-Harland et al., 2015). Also, it might modify foot biomechanics, and in the case of older people might emphasize the gait performances and possible lead to the risk of falls (Ma et al., 2018). Importance of determining the pressure threshold of the foot and the plantar area was shown by Xiong et al. (2011). The study (Xiong et al., 2011) aimed to represent the maximum values of the local pressure and feeling of pain, including twenty participants (gender equally distributed). Plantar pressure thresholds were not the same for male and female participants. It was established that male participants were more resistant and could handle higher pressure values under the foot area. Regarding it, established thresholds were the highest under the rearfoot (where the average values for female were 566 kPa and for male 616 kPa) and followed by medial forefoot (for female 415 kPa and male 427 kPa), central and lateral forefoot (Xiong et al., 2011). The smallest threshold values were obtained for the mid-food, where the medial had the lowest threshold (217 kPa for female and 206 for male) (Xiong et al., 2011).

With maintaining the balance and control during the walk, the human foot is a complex multitude of muscles (in total 19), six bones and thirty-three joints (Figure 5). Gait angular kinematics and dynamics during the cycle, does not depend only on the foot muscles or joints, but also from calf muscle which contributes to the foot flexing motion (Chiu & Wang, 2007).

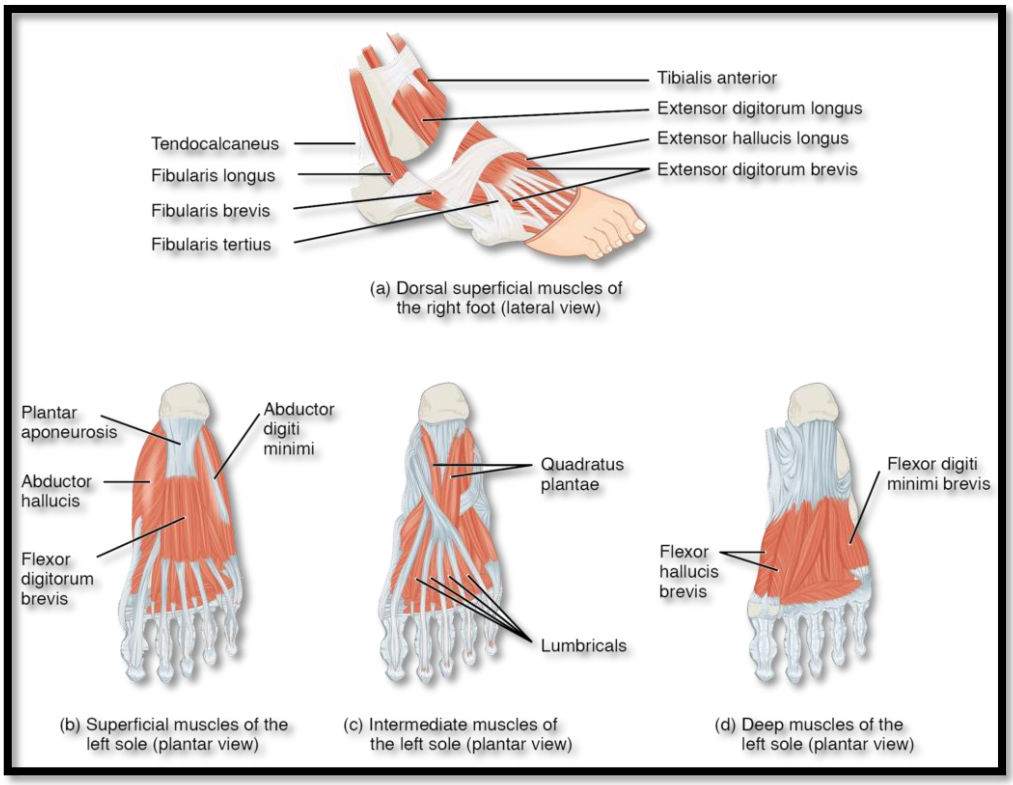


Figure 5 The muscles of the human feet (Human Anatomy and Physiology Lab, n.d.)

Reducing force at the late stance or push-off phase might be correlated to a decreased soleus muscle reflects activity (Eils et al., 2002). Applying lesser pressure during the final stage (push-off) does not necessarily refer to reduced muscle activities of the lower limbs. Sullivan et al. (2015), in their research, reported the same effect with the participants who reported tension in the plantar fascia. More indications were referred to an adopted walking strategy were participants were applying lesser pressure under the hallux, and medial forefoot area concerning reducing pain and tensions appeared in the plantar fascia (Sullivan et al., 2015). Further possibilities of reducing plantar pressure and transferring into another foot region were described by muscle fatigue (do Carmo Aprigio et al., 2020; Nagel et al., 2008) or intrinsic foot muscle atrophy (Höhne et al., 2009).

The imbalance between the flexor and extensors muscle, caused by the intrinsic foot muscle atrophy, will directly result in the hallux and metatarsal heads deformity after a certain amount of time (Höhne et al., 2009). Additionally, this problem will further prolong to decrease of muscle thickness in the local plantar regions, especially under the metatarsals head (Höhne et al., 2009). Transmission of the pressure under the hallux to the central forefoot area might be caused by local muscles fatigue placed in the foot (Nagel et al., 2008; Voloshin, 2000). The inability of the flexor muscles to perform the basic routine will have for the abovementioned consequence problem (Nagel et al., 2008). This failure will occur at the late phase of the stance or at the push-off phase, where the central forefoot will lead with the function instead of the fingers (Nagel et al., 2008). Overloading the metatarsal head will lead to future failures or injuries (Höhne et al., 2009; Nagel et al., 2008).

1.8 Prevalence of lower limbs MSD among professional drivers

While operating a task, workers' bodies may be in awkward positions, which might cause a great variety of illnesses, known as work-related musculoskeletal disorders (WMSD) (Okunribido & Lewis, 2010; Szeto & Lam, 2007). Long-time occupational standing/sitting, climbing up, carrying a heavy non-ergonomic burden (both in short and in the long-distance), or kneeling may cause a variety of risk factors linked to MSD of workers' lower limbs (Okunribido & Lewis, 2010). In other words, WMSDs are illnesses of muscles, bones, tendons, nerves, joints, and body circulation system caused after long time work exposure in a combination of physical harmfulness (in the working environment) and awkward (often static) posture (Mozafari et al., 2015; Sekkay et al., 2018). The disorders are in the complex interaction between human perception (of pain/discomfort of the affected area) or individual characteristics (both physical and psychological) with destructiveness (again, physical and mental) in the working environment (Messing et al., 2008; Sekkay et al., 2018; Shamsul Bahri M Tamrin et al., 2014). A psychosocial work environment increases muscle tension, which might direct influence in the reduction of blood flow with a consequence of the higher perception of discomfort/pain at the loaded area (Shamsul Bahri M Tamrin et al., 2014).

Epidemiological studies established three groups of risks: 1st) Physical risks – repetitive movements, awkward static postures, exposure to physical harmfulness (WBVs), and manual holding on non-ergonomic materials. 2nd) Organization attributes – high level of physical activity. 3rd) Individual factors – different anthropometric characteristics and quality of the lifestyle (Mozafari et al., 2015; Sekkay et al., 2018; Tissot et al., 2005).

Professional drivers, after a long uncooperative driving position and required movements by the working process, the most frequent disorders occur in the lower back, neck, and upper extremities pain (Madhan, 2015; Shamsul Bahri M Tamrin et al., 2014). Analysis objective methods for body posture and perceived body discomfort, may be beneficial to the designing of a corresponding seat, which has to meet basic standards, relating to support of soft tissue, pelvis, back and lower limbs of the driver, and so that it, when sitting, does not cause discomfort.

WBV, non-ergonomic working environment, anthropometric factors (for instance age, worker gender, height and weight, BMI, health status), as well long-time sitting and processes required by the workplace may endanger and consequently increase the risk of MSD (Madhan, 2015; Szeto & Lam, 2007; Shamsul Bahri M Tamrin et al., 2014). Data on the prevalence of bus drivers' MSD and corresponding symptoms could be found in Tamrin et al. (2014) research, where it was emphasized that 57% of drivers had symptoms of pain in some parts of the body. Tamrin et al. (2014) indicated that the percentage of these symptoms of bus drivers' MSD is different in the right lower limb (24%) than in the left lower limb (21%). The obtained information might depend on various considerations, one of which is vehicle manoeuvring, i.e., the use of an automatic transmission.

Long-time driving with a static posture of the lower limbs (more than 2 hours (Okunribido & Lewis, 2010)) possibly will cause a variety of consequences such as venous disorders (D'Souza et

al., 2005; Łastowiecka-moras, 2017), cardiovascular diseases (Thosar et al., 2015), lower limbs oedema (Belczak et al., 2015; Wrona et al., 2015), local or total discomfort, cramps muscles, among others (Wrona et al., 2015).

Furthermore, the excessive use of the lower limbs may perhaps trigger injuries in the drivers' lower limbs (feet/ankle, knee, and hip). Professional bus drivers spend many years, driving from 9 to 10 hours per day (Commission & others, 2003), in a similar driving posture with, in fact, the same repetitive movements, both on lower and upper extremities; the consequences of their excessive use are expected. A possible condition of the lower limbs after an acute injury and excessive consumption is shown in the paper (Okunribido & Lewis, 2010), and Table 4.

Table 4. Lower limb disorders conditions that have been associated with occupational populations (Okunribido & Lewis, 2010)

Variable	LLD conditions according to the regions of the lower extremity		
	Hip/thigh	Knee / lower leg	Ankle/foot
Overuse Injuries	Osteoarthritis (OA) Piriformis syndrome Trochanteritis Hamstring strains Sacroiliac pain	Beat knee/Hyperkeratosis Bursitis Meniscal lesions Osteoarthritis (OA) Patellofemoral pain syndrome Pre-patellar tendonitis Shin splints Infra-patellar tendonitis Stress fractures	Achilles tendonitis Blisters Foot corns Hallux valgus (bunions) Hammertoes Pes traverse planus Plantar fasciitis Sprained ankle Stress fractures Varicose veins Venous disorders
Acute Injuries		Meniscal tear	Ankle fractures Metatarsal fractures

LLD – lower limbs disorders.

Potential disorders (illustrated in Table 4) that awkward body posture during a long-time drive may prompt MSD in the region of the hip, knee, and ankle/foot (Hussain, 2004; Mansfield & Marshall, 2001) caused by overuse injuries. As an example, the pain in the knee of the taxi drivers was mentioned, as a subjective testing method, NMQ was applied, and the obtained data were crossed with the time spent driving (J. Chen et al., 2004).

Individual characteristics and gender differences of drivers are some of the critical elements of MSD of lower limbs. It should also be emphasized that the presence of both genders as professional bus drivers was about the same in the first 5 years of work experience, but then the difference is much more significant (Messing et al., 2009; Szeto & Lam, 2007; Shamsul Bahri M Tamrin et al., 2014; Wrona et al., 2015).

Grace et al. (2007) state that data after 5 years spent in an awkward posture, i.e., in a prolonged sitting when steering a vehicle, demonstrated that the discomfort in the thigh and knee occurs. To conclude, they also confirmed that this is practically a chronic disease, concerning that more than 50% (both genders) of drivers reported this type of pain.

Messing et al. (2009) compared gender differences in the prevalence of body discomfort in the past 12 months. The occurrence of pain in the knee is higher in male (9.8%) than in female (7.3%) population, whereas in female, discomfort in the hips, feet, and ankles is on average more excellent for 1.5% (Messing et al., 2009; Okunribido & Lewis, 2010). Reilly et al. (2000) illustrated an analysis of pain prevalence in the driver's knee, where 27.8% (in total, 82 participants) reported pain in the knee. Outputs represented by Chen et al. (2004) are illustrating that the prevalence of knee pain depends on the length of the driving exposure. The research was held out in the total duration of one year, including 1242 taxi drivers, and showed that the occurrence of knee pain was 11%, 17%, 19%, and 22%, corresponding to the driving time (≤6; 6 - 8, 8 - 10; and 10≥ hours).

Still, postural oedema is connected with the static and prolonged sitting, which is expected with professional drivers, where the driver spends several hours a day driving (up to 10 hours, referred by (Commission & others, 2003)), and it affects the appearance of swelling and deformation of the joints (De Looze et al., 2003). Studies researching MS injuries on professional drivers report lower limb disorders, the majority of them, knee disorders (J. Chen et al., 2004; Szeto & Lam, 2007). Nevertheless, it should be noted that the relation of discomfort occurred in the knee to the length of driving is significant (J. Chen et al., 2004). The research led by Chen et al. (2004) indicates the presence of the knee bone density disorder, as well as cartilage damage of the same after long-time sitting/driving, is longer than 4 hours/day. The reason of this disorder might be rerepeating the lower limb movement, and other harmful issues as well (straining knee postures with the static position of the left lower limb while driving a vehicle with the automatic gear shift, vibrating floor with the consequence of the WBVs, inadequate/restrained space, prolonged body load on the seat, and similar).

Besides the before illustrated list of disorders of the lower limb (see Table 4), it also needs to be observed a Lower Extremity Functional Scale (LEFS) whose research was conducted by Negahban et al. (2014). At the LEFS (Negahban et al., 2014) the categories of MSD of lower limbs such as degenerative joint disease, muscle strain, bursitis, ligament sprain, patellofemoral pain syndrome, tendonitis, meniscal injury, ligament, and meniscal injury, plantar fasciitis or heel pain, and nonspecific sprain/strain. The mentioned LEFS is a reliable, consistent, and vital tool for introducing and determining the functionality of the lower extremities, and as such, the presented MSD of lower limbs may be considered.

The results of the lower limb MSD occurrence in professional drivers have been obtained through subjective methods (questionnaire) (Table 5). Also, neither the laboratory research nor the one carried out in practice, of the aforesaid lower limb disorders, have been studied enough.

Considering the physical, individual and organizational factors that might interact and cause a disorder, WMSD has the highest injury prevalence rate among professional truck drivers. In second place are the injuries caused by slips, trips and falls (C. K. Smith & Williams, 2014). It has also been noted, by the same authors, that in the United States of America, professional truck drivers have one of the highest rates of work-related injuries and illnesses. The interesting thing is slides, trips, and falls (from the same or higher level) happened next to a truck in which the driver

operates. This conclusion could bring a discussion amount of the consequence that can lead to this health problem and carry a high level of medical costs.

Falls from elevation and WMSD had the most senior medical price, comparing to the rest type of injuries. Additionally, those injuries/disorders were causing more work abstinence than the rest. Spielholz et al. (2008) pointed the problem of falls, trips, and falls are one of the top two most severe issues in the truck industries (considering injuries and illnesses) and represented 54% of the damages over time.

Table 5. Prevalence of MSD of the lower limbs among professional drivers

Author	Country	Questionnaire type	Standardized	Pain/Discomfort occurred in the past year	Vehicle type	Number of participants	Lower limb prevalence (%)				Fundamental findings
							Hip/thigh	Knee	Lower leg	Ankle/foot	
Tamrin et al. (2014)	Malaysia	An English version of the Nordic Questionnaire translated to the Malay language.	S.	N.S.	Commercial Bus	1181	19.9	27.5	N.D.	28.9	WMSD in the lower limbs were reported in a total of 896 commercial bus drivers. Factors such as individual components, adopted posture, WBVs, seat characteristics, and psychological state can influence the prevalence of the disorders.
Reilly et al. (2000)	England	A questionnaire designed for assessing the prevalence of osteoarthritis in the knee.	N.S.	N.S.	Bus	82	N.D.	27.8	N.D.	N.D.	The prevalence of knee osteoarthritis among bus drivers was higher than the works which require prolonged sitting. This conclusion is not statistically supported.
Yasobant et al. (2015)	India	Assessment of MSD was using the following questionnaires: Quick Exposure Check (QEC), Rapid Entire Body Assessment (REBA), Rapid Upper Limb Assessment (RULA) and Nordic Musculoskeletal Questionnaire (NMQ).	S.	One year	Bus	280	N.D.	6	N.D.	4	Non-ergonomic driving venues and prolonged static posture were associated with the prevalence of MSD. Drivers with fewer physical activities were classified as a group with a higher probability of developing MSD.
Chen et al. (2004)	China	A Chinese version of the Nordic musculoskeletal questionnaire	In process	One year	Car/Taxi	1242	N.D.	11 17 19 22	N.D.	N.D.	A strong significant correlation between the time spent driving, and the occurrence of the knee pain abound professional taxi drivers. The assessed period was the following: lesser or equal to 6, >6 through 8, >8 through 10, and >10 hours.

Author	Country	Questionnaire type	Standardized	Pain/Discomfort occurred in the past year	Vehicle type	Number of participants	Lower limb prevalence (%)				Fundamental findings
							Hip/thigh	Knee	Lower leg	Ankle/foot	
Szeto et al. (2007)	Hong Kong - China	An adopted questionnaire from a Chinese version of the Standardized Nordic Questionnaire	N.S.	One year	Bus	481	35		18	17	The discomfort that occurred in the thigh/knee is was the most in the bus driver population aged between 45 and 49 years old (40.6 %). The prevalence happened more in females (49.4%) than males (33.4%) driving population. What is more, drivers with the working experience between 11 and 15 years had the most thigh/knee pain (41.9%) than the rest drivers. Medical help, regarding the pain or discomfort, felt in the thigh/knee area, were caused by 83.1% by driving period and tasks.
Tamrin et al. (2007)	Malaysia	An English version of the Nordic Questionnaire translated to the Malay language.	N.S.	One year	Bus	760	22.2	29.3	29.1	N.D.	The conclusions were based on the prevalence of MSD in the lower back. It was assumed that the working condition, adapted driving posture, and perception of WBV are associated with the lower back pain,
Senthanara et al. (2018)	Canada	Standardized Nordic Questionnaire		One year	Truck	107	N.D.	N.D.		41	Determinants such as fatigue, a healthy working environment and culture, and high-risk tasks were found to be in positive association with the prevalence of MSD and felt pain/discomfort over the last year.
Akinpelu et al. (2011)	Nigeria	Standardized Nordic questionnaire	S.	One year	Bus	159	8.8	27	N.D.	11.9	The prevalence of MSD is in correlation with working experience. In other words, the drivers with the most experience of driving having a higher chance of developing MSD over time.

Author	Country	Questionnaire type	Standardized	Pain/Discomfort occurred in the past year	Vehicle type	Number of participants	Lower limb prevalence (%)				Fundamental findings
							Hip/thigh	Knee	Lower leg	Ankle/foot	
Sekkaya et al. (2018)	Canada	Québec Social and Health Survey of 1998 (ESSQ98) based on Nordic Questionnaire - to establish the prevalence of MSD and individual factors; and Québec Survey on Working and Employment Conditions and Occupational Health and Safety (EQCOTESST) - exposure to each physical risk factor	N.S.	One year	Truck	123	8.9	7.3	3.3	5.7	The prevalence of MSD was higher at long-haul drivers than the short-haul drivers - from 1.5 to 4 times higher. The higher incidence was more significant either for the last twelve months and for the past seven days.
Mansfield et al. (2001)	England	Modified self-administered questionnaire form the Nordic Questionnaire of MSD and questionnaire for assessing vibration injuries to the hand/arm and whole body	N.S.	One year	Car	41	12	10	7	7	Most participants reported discomfort/pain in the back area (lower and upper). The hand discomfort was more distributed with drivers than co-drivers. While co-drivers more reported knee pain and the pain of the rest area of the lower limbs happened with the driver's population.
Hussain (2004)	England	Using a combination of two questionnaires - modified version of the Nordic questionnaire and the General Health Questionnaire (GHQ12).	N.S.	One year	Truck	461	8	39	N.D.	13	Reported discomfort was the highest for the following body areas: lower back, shoulders, neck and wrist/hand areas. The reported discomfort/pain was not associated with the age of participants, not with the length of working experience.

Author	Country	Questionnaire type	Standardized	Pain/Discomfort occurred in the past year	Vehicle type	Number of participants	Lower limb prevalence (%)				Fundamental findings
							Hip/thigh	Knee	Lower leg	Ankle/foot	
Mozafari et al. (2014)	Iran	Modified Nordic Questionnaire (SNQ) for detection of MSDs in office workers and drivers - Iranian version	S.	One year	Truck	181	5.8	19.1	N.D.	4	The highest reported knee prevalence was among truck drivers' next characteristics: Age between 35 and 50 years old, normal weight (BMI between 25-30 kg/cm2), and work duration less than ten years. The prevalence of WMSD was higher among professional drivers than with office workers.
Mehta et al. (2019)	India	Self-administered questionnaire incorporated with Modified Nordic questionnaire and Numeric pain rating scale	N.S.	One year	Truck	78	N.D.	53.3	N.D.	N.D.	Among Indian truck drivers, the prevalence of the knee pain was the second-highest reported, after the lower back pain. The reason for the thigh/knee prevalence is referring to a dynamic discomfort (caused by WBVs), ages, number of driving per day/week, driving posture, and the time to rest and its duration.
Kim et al. (2016)	United States of America	Standard Nordic Questionnaire	S.	One year	Truck	96	N.D.	42	26.1	31.9	WBV correlates with the prevalence of MSD among the drivers.

S – Standardized, N.S. – Not Standardized. N.D. – Not Defined.

1.9 Thesis objectives

1.9.1 General objectives

The main goal raised by present thesis is ascertaining changes of the gait performances caused by long-time driving and providing insights on possible musculoskeletal symptoms occurring on drivers' lower limbs.

1.9.2 Specific goals

Specific objectives are the following:

I. Determine whether the long-time driving triggers local or total body discomfort.
II. Identify changes in preferred driving postures during the steering period.
III. Identify if preferred driving strategies are in correlation with perceived body discomfort.
IV. Determine whether the possible adverse outcomes might occur in the lower limbs' regions caused by different interface pressure values.
V. Establish if applied interface pressure is in correlation with perceived body discomfort.
VI. Ascertain whether the prolonged occupational driving has on the linear gait kinematics and applied plantar pressure.
VII. Investigate whether changes in the gait pattern can be associated with spatiotemporal characteristics of people with developed risk of falls.

2 MATERIALS AND METHODS

2.1 Informed consent and ethical matters

A printed version of Informed Consent (see Appendix 1) was provided to every participant. In that document, information regarding the study pertinence is given, as well as protocol rationale, including possible risks, provoked discomfort, or benefits as a consequence of acting on the project. It was also explained that the participants could drop out of the trial at any time, not having to provide any reason for that matter, and no further consequence would occur. Participants could ask for any additional information regarding any aspect that was not clear to them. By signing the Informed Consent, the participants were choosing to voluntarily participate in the project and agreeing to share their personal information. Despite that, the participants could not decide to be part of the experiment and could leave at any time; in that case, their data would be excluded without any undesirable outcomes.

This research protocol was analyzed and approved by the Ethics Committee of the University of Porto, Portugal, and registered under the number PARACER No84/CEUP/2019 (see Appendix 2).

2.2 Sample selection

The sample was recruited from FEUP students and employees population in Portugal. The target was any participant aged between 20 and 40 years old, meeting the following inclusion criteria:

- To have a driving license;
- Do not drive, continuously, more than two hours per day;
- Not having had any surgical intervention on lower limbs;
- Not having had a history of MSD in the lower limbs;
- Do not feel pain in the main joints (hip, knee, and ankle) in a lower limb that can cause any kind of inability to walk (either barefoot or shod);

Participants with an inability to perform regular barefoot or shod walk, without unusual behaviour and assistance, nor steer a driving simulator in a demanding virtual environment, were excluded from the research.

In total, 48 subjects volunteered and agreed to participate in the study, of which were 25 male and 23 female applicants. While analyzing the data of the conducted experiment, four participants needed to be excluded due to insufficient data quality.

2.3 Equipment

2.3.1 Scale (Seca)

A portable mechanical scale with a maximum capacity of 220 kg (with the graduation of 50 gr) and vertical measurements of the stature was used to assess the participant's weight and body height. The height measure range is from 60 cm until 200 cm.

2.3.2 Anthropometer

Anthropometer is used to get body dimensions in order to define a sample's characteristics. This apparatus is equipped with plastic needles, which allows precise measures. The measuring range is up to 200 cm, with a maximum fold length of 217 cm. The instrument weight is 150 gr.

2.3.3 Markers

The markers were specifically designed for the experiment. The total diameter of each one is 2 cm, and the fabric is a reflective, white material whose purpose was to contrast and be visible on the images.

2.3.4 Plantar pressure mat (Tekscan®)

Walkway Pressure Assessment Systems (Tekscan®, United States of America, model MatScan Sensor 3150) was used to assess gait plantar pressure and linear kinematics (Figure 6). The pressure mat is made of four sensing elements, which have to be calibrated (using Tekscan® software – Walkway 7.02) before each experiment, with the accurate participant's weight. The overall dimension of the pressure mat is 180.6x50.8 cm, with the matrix dimensions 174.4x36.9 cm, and a total number of 9152 pressure-sensing points.

MatScan was connected with two VersaTeks (two-port hub systems): one to connect A and B, and another for C and D. VersaTek represents the link between the mat and the PC and its powered by an adapter. The MatScan and the two-port hubs are connected with CAT5E cables. Also, port hubs are linked to the PC using USB type-2 cables (Figure 7).

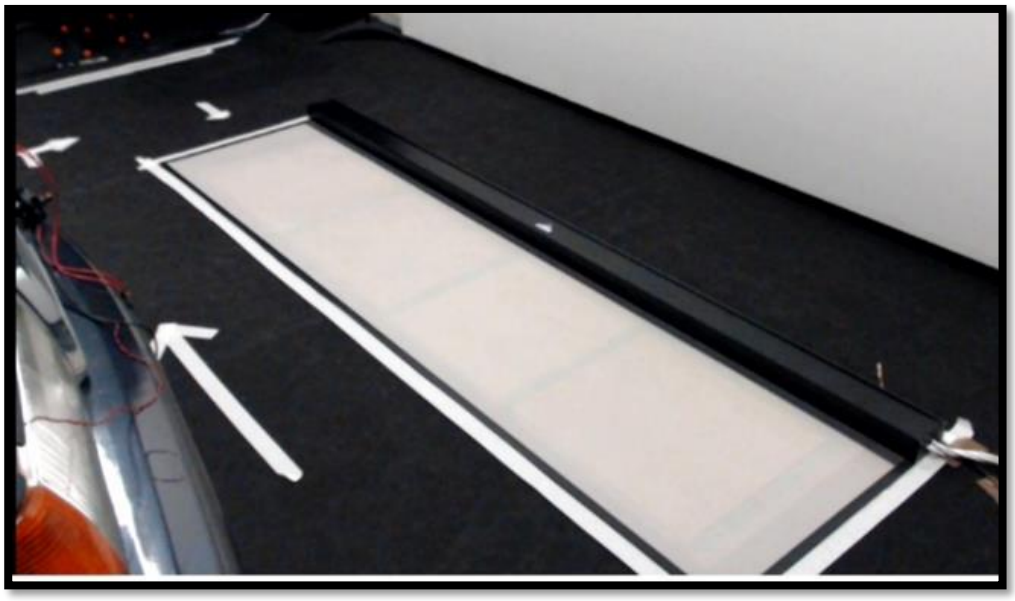
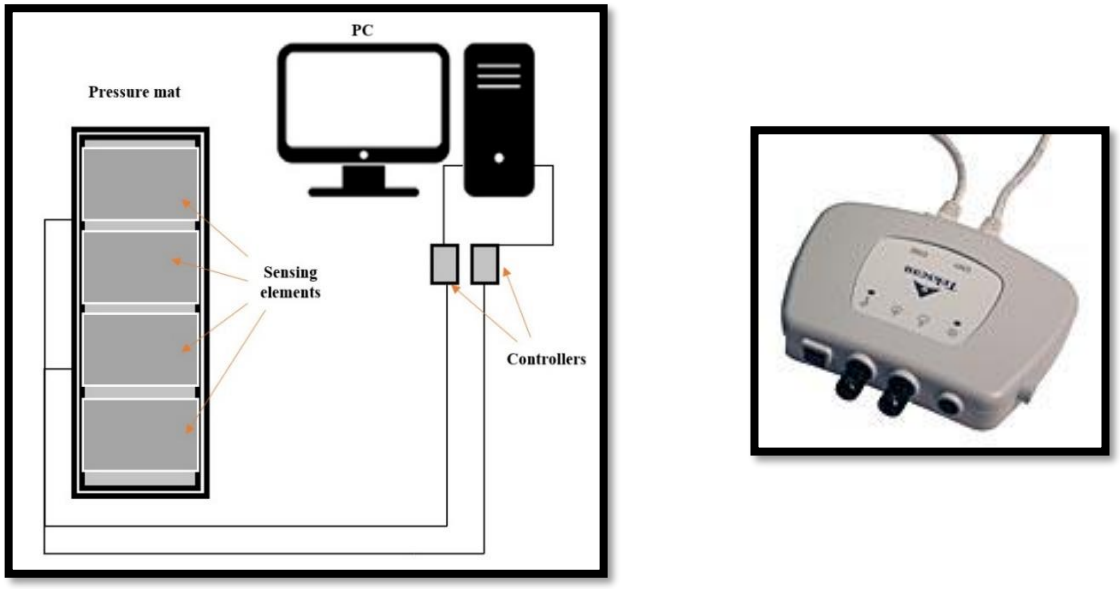


Figure 6. Plantar pressure mat (Tekscan®)



a) Scheme of connection b) Controller

Figure 7. Illustration of the equipment connection

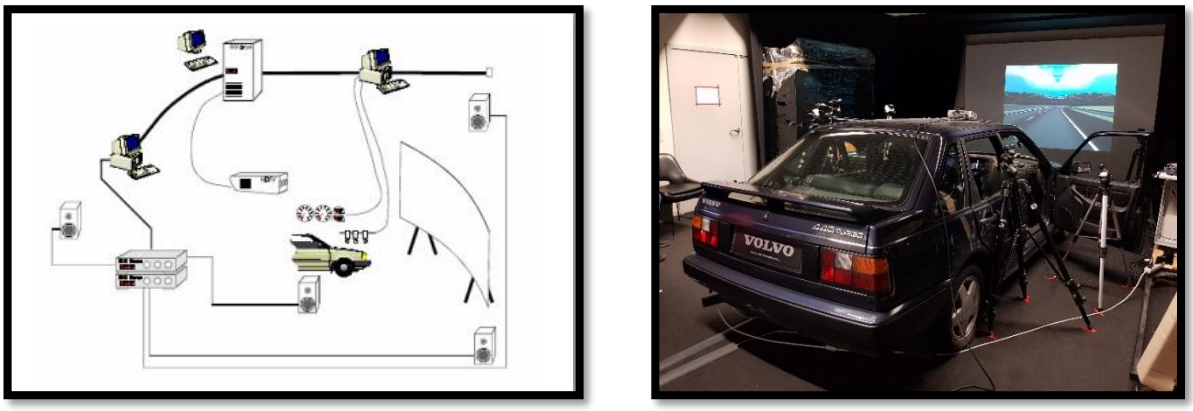
2.3.5 Driving simulator (“DriS”)

Through collaboration between two institutions – Faculty of Engineering of the University of Porto (FEUP) and Polytechnic of Porto – School of Engineering (ISEP), a driving simulator named “DriS” (J Miguel Leitão et al., 1999) was developed. The DriS is a modified vehicle (A 1994 Volvo v440 turbo – real vehicle) installed with a steering wheel, pedals, ignition key, and other

technical elements that support the driving simulator. All of the previously mentioned parts were specifically developed for DriS.

Image fabrication and synthesis are reproduced with personal computer “SGI Onyx Engine 2” launched on the Linux operative system. The two soundbars (“Sound Blaster AWE32” from Creative Labs) and the cockpit are supported with a personal computer (PC) with Windows 98 operative system. Altogether the equipment is connected to a local area network and reconnected to “Switch D - link 1010G HUB” (Figure 8) (J Miguel Leitão et al., 1999).

Virtual reality simulations are launched and supported with three PCs placed in control room number one (Figure 8). Video images are reproduced on a flat-screen by the Barco 801s RGB projector (60 frames per second with pixels resolution of 1280x1025 in three colour system – RGB). The loudspeakers are placed in the experimental workspace (two outside the vehicle – in front, and two inside the driving simulator – behind the driver seat), and volume is controlled by the amplifiers placed in control room number two. The operator can control variables such as the type of driving simulation (road, for instance), and physical factors such as noise and vibration.



a) Scheme of driving simulator connection (J Miguel Leitão et al., 1999)

b) The driving simulator

Figure 8. The driving simulator

2.3.6 Camera (Logitech C920)

In order to record the participants’ PDP during the long-time driving, the Logitech C920 web-camera (Logitech, United States of America) was selected (Figure 9). This equipment can record a video in full HD resolution (up to 1920 x 1080 pixels), with an automatic focus on moving or static subject in 30 fps, which is adequate for the analysis to be performed. It supports the USB type 2.0 connection, which connects them to PCs.



Figure 9. Logitech C920 camera

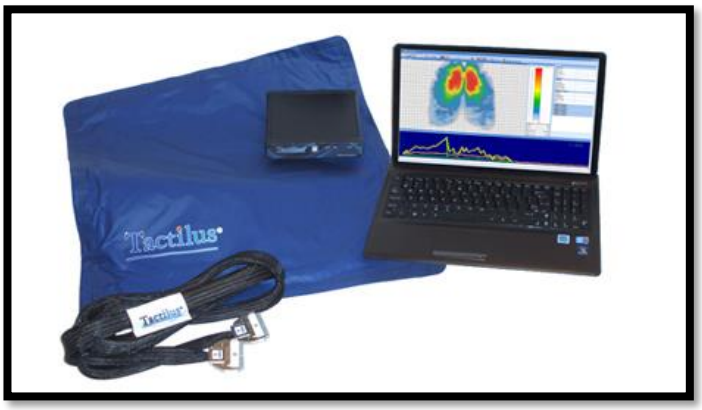
2.3.7 Seat pan pressure mat (Tactilus®)

IP was measured using Tactilus® (Tactilus®, United States of America), real-time surface pressure mapping technology. Total sensing points are 1024 in a grid of 32x32. The pressure point size is 1.5x1.5cm, and the overall contact area is 2304 cm^2 (48x48 cm), being the thickness of the mat 7 mm (approximately) (Figure 10).

This real-time mapping technology allows insight regarding the applied pressure and represents it into a 2D or 3D map, providing values for each sensor separately. Furthermore, temperature changes on the surface of the sensors do not influence the reliability of the obtained results. The frequency range of the data provided by the mat can be adjusted according to the user needs, in frames per second.



a) Pressure mat on the seat pan



b) Illustration of the pressure map (Tactilus (2019, December 20) https://www.sensorprod.com/tactilus.php)

Figure 10. Pressure mapping technology (Tactilus®)

2.3.8 Additional materials

In addition to the objective measurements, the health status for each participant was also determined in two phases. The first phase assessed the health status (related to the musculoskeletal conditions) in the year previous to the experiment until the week before it, through the Standardized Nordic Questionnaire.

The discomfort felt at the time of the experiment was assessed through the modified Discomfort Scale, adapted from ISO 2631-1 (Vibration, 1997), which was held within the initial record (first five minutes of driving), and every 40 minutes until the end of the experiment (2-hour protocol).

2.3.9 Standardized Nordic Questionnaire

The prevalence of MSD among participants was assessed using an adapted version of Standardized Nordic Musculoskeletal Questionnaires (NMQ) (Kuorinka et al., 1987). The sample size appeared to have a diverse of demographically associated contributors (majority Portuguese, followed by Italians, Brazilians, Bolivian, French, Iranian, Spanish, Indian, Polish, Lebanese, and Romanian). Apropos it, the questionnaire had two validated versions for Portuguese (adapted from (Kuorinka et al., 1987)) and English speakers (see Appendix 3 and 4).

Besides the necessary information of anthropometric characteristics, born year, gender and others, the questions: “What equipment do you use?” and “How many years and months have you been doing your present type of work?” were directly referring on type of vehicle they operate and period of possessing the driving license.

The main part of the questionnaire describes nine regions of the body (neck, shoulder, upper back, elbow, lower back, wrists/hands, hips/thighs, knees, ankles/feet) and amount of discomfort/pain in the past twelve months (mild, moderate, intense and unbearable).

2.3.10 Discomfort scale

This study implements a modified discomfort scale defined in ISO 2631-1 (Vibration, 1997) standard. The scale is initially in the English language, but since Portuguese volunteers were participating, it was translated into Portuguese. The scale (Figure 11) was placed on a drivers’ visible location and was used as a reference to answer the questionnaire. Amount of discomfort/pain was verbally described choosing one of the following levels:

1. Not Uncomfortable
2. A little Uncomfortable
3. Fairly Uncomfortable
4. Uncomfortable
5. Very Uncomfortable
6. Extremely Uncomfortable

If participants would have reported “extremely uncomfortable” – corresponding to the sixth level, the experimental process was rebutted. The principal researcher noted reported discomfort.

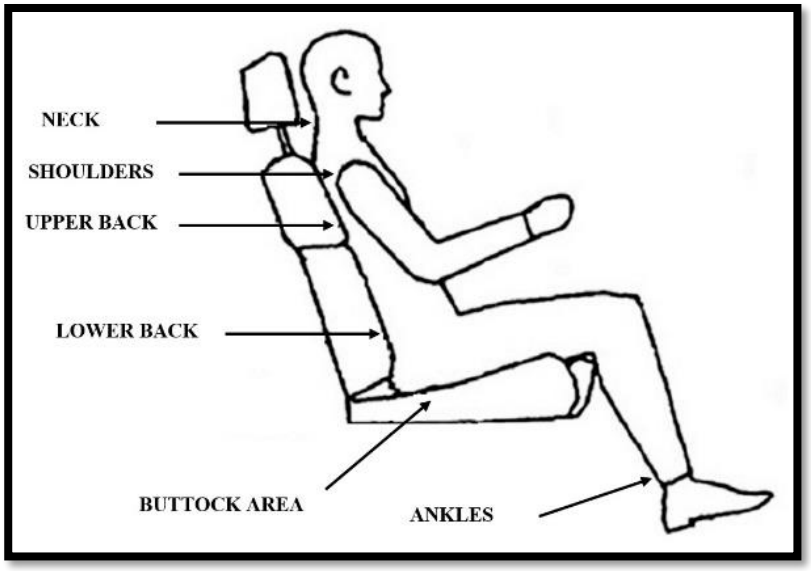


Figure 11. Discomfort scale

2.4 Experimental protocol

2.4.1 Laboratory setup

The experimental protocol was launched in the Laboratory of Traffic Analysis at the Department of Civil Engineering at the Faculty of Engineering of the University of Porto, Portugal. In the central position of the laboratory rests a driving simulator, the DriS (João Miguel Leitão et al., 1997) (Figure 12).

The laboratory occupies a total area of 75 m^2 and has two control rooms (number one and two) and one experimental room (with a surface area of 50 m^2) (Figure 12). The experimental room is covered with a black opaque curtain (thus blocking any additional light or outside noise) and equipped with a driving simulator. The simulator is facing a flat-screen dimension of 3.2x2.4 m. The virtual reality images are reproduced by a video projector placed above the vehicle. The Space was equipped with six cameras and tripods, two pressure mapping technologies, and PCs. After exploring appropriate angles for recording driving postures, tripods and cameras were placed to corresponding positions.

Along with that, two pressure mats were used. One of them was placed on the vehicles’ seat pan – to record applied body pressure on the driver's seat, and another one was placed in front of the vehicle – for the gait analysis). Figure 12 shows the complete display of the experimental environment. In order to correct unwanted movement/displacement of the equipment, every

placement was marked and secured, as shown in Figure 13. The cameras were connected to the former mentioned PCs.

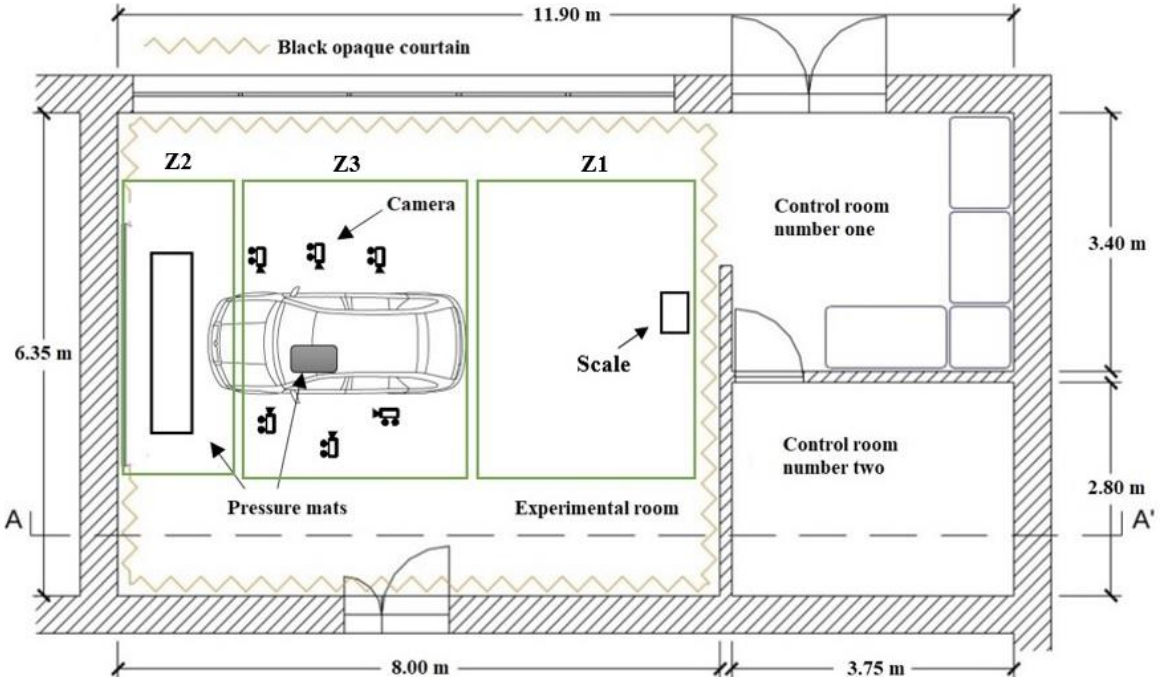


Figure 12. Laboratory setup. Z1 – zone one; Z2 – zone two; Z3 – zone three (adapted by (João Miguel Leitão et al., 1997))



Figure 13. Laboratory setup

2.4.2 Equipment calibration

Camera calibration

The camera calibration was done individually at least 30 minutes before each experiment. In the case of equipment's minor or major movement/displacement, the calibration had to be repeated. Cameras were placed on a tripod and marked in case of potential movement (knowing that creating a 3D model requires at least two cameras placed from 60^0 until 120^0 from each). Calibration was completed using cube inside the vehicle (dimensions 20.00 x 20.00 x 20.00 cm) (Figure 14). Throughout any trial, the sound was not recorded.



Figure 14. Calibration cube

Plantar pressure mat calibration

The pressure mat for gait analysis had to be calibrated using the precise weight of each subject before the trial. Plant static and dynamic applied pressure were recorded with the sampling rate of 100 Hz, with the pressure range from 1 to 850kPa.

Seat pan mat calibration

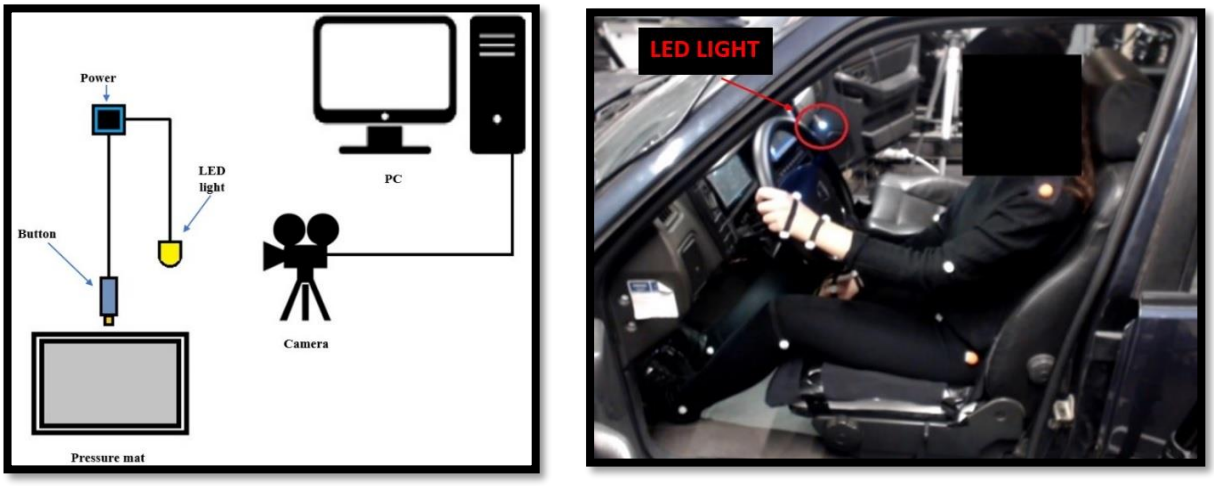
Calibration has factory settings, with a pressure range from 0 until 34.7 kPa, including an error under 3%. During the experiment, the data was collected in 30 fps. Before each trial, Tactilus® was placed on the drivers' seat and secured of possible displacement. Afterwards, the mat was connected to a PC using a USB type 2 connector.

Defining the trial start

Knowing beforehand that each equipment has its own measurement time, it was essential to define a standard and simultaneous event from which the data acquisition can be considered and synchronized. Therefore, before each data recording, this process was carried out by the subjects themselves. Firstly, the pressure mat was activated by pressing a button on Tactilus®. That action

triggered LED light, which appeared in all frames of the cameras. The first frame in which the light has appeared was considered for synchronization between the pressure mat and the cameras. Both types of equipment (pressure mat and cameras) were recorded in the same framerate, which was set on 30 fps.

The laboratory was arranged in the function of the experiment and was categorized by the zones illustrated in Figure 15.



a) Schematic illustration of camera calibration synchronization

b) Example of the LED light appears in a frame

Figure 15. Cameras synchronization

2.4.3 Introducing the participants with the experiment and scheduling

The experiment was held three times per day – at 10 am, at 3 pm and 6 pm. The total duration of each trial was 140 minutes. Schedules were arranged at least one week before the subjects' contribution. Potential risk, time duration, methodology, tasks, and the main goal of the study was presented to each participant separately.

2.4.4 Preferred interior dimensions

The drivers preferred interior adjustment was regulated before every trial for each participant independently. Based on SAE J1100 (SAE J1100, 2002), the correction could be made on horizontal points (the distance between the heel and hip point – in the range from 80.0 cm until 98.0 cm) and in the backrest angle. Horizontal and vertical distances for the steering wheel could not be corrected, so they stayed the same for all participants. Table 6 illustrates the minimum and maximum distances that can be adjusted.

The diver seat is made of leather with seat pan length of 48.0 cm and wide 52.0 cm along with the above-mentioned adjustments.

Table 6. Preferred driving interior dimensions based on the SAE J11 standard (Hanson et al., 2006)

	Interior dimensions	Min	Max
Horizontal	Steering wheel to heel point - L11 [cm]	34.0	34.0
	Hip point to heel point - L53 [cm]	80.0	98.0
	Hip point to the steering wheel [cm]	46.0	64.0
Vertical	Steering wheel to heel point - H17 [cm]	62.5	62.5
	Hip point to heel point - H30 [cm]	26.0	26.0
	Hip point to the steering wheel [cm]	36.0	36.0
	Seat cushion length [cm]	48.0	48.0
	Backrest angle [°]	N.D.	N.D.

N.D. Not Defined; Min – minimum; Max – maximum

2.4.5 Main phases of the experimental protocol

The experimental protocol was formed into the following phases:

- Phase I: Preparation of subjects, anthropometric measurements and NMQ;
- Phase II: Gait performance – before the long-time driving;
- Phase III: Steering the driving simulator;
- Phase IV: Gait performance – after the long-time driving.

2.4.5.1 Phase I: Preparation of subjects, anthropometric measurements, and NMQ

Stature and body height

Appropriate clothing was prepared to ensure that the participant's clothing did not affect the collected data. Clothes that could interfere with the mat sensors placed on the drivers' seat pan or cover joint angles were considered unacceptable. The control room number two was adapted corresponding to participants prepared for the experimental process. After the subjects had prepared, weight measurements were done (Grieco & Masali, 1971). Lastly, reflective markers were placed on previously defined body places. While the subject was standing on the mechanical scale, they were asked to adopt a natural unstretched position with the head held straight and the heels touching each other regarding measuring participant's stature (from the floor to the top of the head) using the scale.

Other anthropometric measurements

For a precise 3D reconstruction of drivers' body posture, the body segments must be correctly assessed. The subject was measured using an anthropometer, and the accuracy of 0.1 cm will be sufficient. Measured body dimensions (Grieco & Masali, 1971) are the following:

- arm span (from fingertip to fingertip with the arms extended to opposite side);
- shoulder width (from the right to the left acromion);
- hip height (measured from the floor to the great trochanter);
- knee height (from the floor to apical lateral epicondyle);
- hip width (from left to right anterior superior iliac spine);
- ankle height (from the floor until lateral malleolus on the lower leg);
- foot size (from the heel bone to the toe end).

As taking dimensions of arm span could be difficult, it was done by two operators simultaneously. The subject was required to stand up straight with shoulders relaxed and arms spread. Knee and ankle joints needed to be on the same vertical-align, while feet were facing straight (with 5 cm between them).

For further comparison and detailed analysis between the subjects, they were divided into the following groups:

- Stature (short < 165 cm, middle ≥165≤175 cm and tall >175 cm) (for Health Statistics (US), 1994),
- Body Mass Index (BMI) (malnourished < 18.5, normal ≥18.5≤24.9, and overweight ≥25) (Nuttall, 2015)
- Gender (male and female)

Definition of the joint angles using reflective markers

For a more straightforward observation of the changes of the adopted/preferred driving postures, eight reflective markers were positioned on anatomical landmarks corresponding to major joints (Figure 16). Only the left side of the driver's body was considered in this study. Therefore, markers were placed on the joints, according to the landmarks that follow. For that, glue tape was used, with wrist joint exception, where the attachment was using an elastic tape.

- lateral metatarsal head (foot);
- lateral and medial malleolus (ankle);
- lateral and medial epicondyle of the femur (knee);
- great trochanter (hip);
- right and left acromion (shoulder);
- lateral epicondyle of the humerus;
- radial styloid process and heal of the ulna (wrist);
- head of the 2^{nd} and 5^{th} metacarpus.

These markers were used to calculate joint angles according to the scheme illustrated in Figure 16 of the angles' definition, where can also be observed in the driving venue.



Figure 16. Definition of main joint angles (3D Flexion/Extension)

2.4.5.2 Phase II: Gait performance – before long-time driving

As previously mentioned, to collect data with high accuracy, the pressure mat for gait analysis was calibrated for each participant separately. Within Tekscan® software (Walkway version 7.02), the subjects' weight was entered. Straight after, they were asked to step with both feet (barefoot) on the first sensing element (Figure 7). The calibration itself requires a few seconds, while the software gives information about the calibration status. In case of an error, the same process had to be repeated; if not, the calibration could be continued for the remaining three sensing elements.

The participant was introduced with the walking path, which had a total length of seven meters. Furthermore, normal walk performance was required with self-selected speed, and without any unusual behaviour. The gait started with the subject being behind the marked start line, and on the sound sing, "You can walk", they have begun performing the gait. In the case of failing to record the data, the same method was repeated until three recordings were obtained. Gait kinematics and plantar pressure were recorded using Walkway software. The data were noted with a secret code, randomly defined for each participant separately.

2.4.5.3 Phase III: Steering the driving simulator

The virtual environment was set to imitate a highway with a defined road, vehicles movement, and behaviours' in both directions. Besides response to the virtual environment, which gives a feeling of real driving, the undesirable harmfulness (such as vibrations or possible acute injuries caused by a traffic accident or similar) were excluded.

In advance of the data acquisition, approximately five minutes were given to the participants for adaptation to the new environment. As soon as they were ready, the initial recording was completed. The frequency of data collection was every 40 minutes (5^{th}, 40^{th}, 80^{th}, and 120^{th}) with a duration of six seconds. PDP, IP on the drivers' seat pan, and reported the discomfort of anatomical parts caused by prolonged driving were collected.

2.4.5.4 Phase IV: Gait performance – after a long-time driving

After completing the two hours of steering the driving simulator, the participants were asked to stop the driving and to prepare for the final phase. Subsequently, the second phase method was repeated; only, in this case, the equipment (mat pressure) calibration was not obligatory.

With the realization of the tasks, data acquisition was accomplished. The raw data were kept in two different mobile hard drives. Subsequently, the preparation for the next trial was done, including laboratory preparation and equipment calibration.

2.5 Data analysis

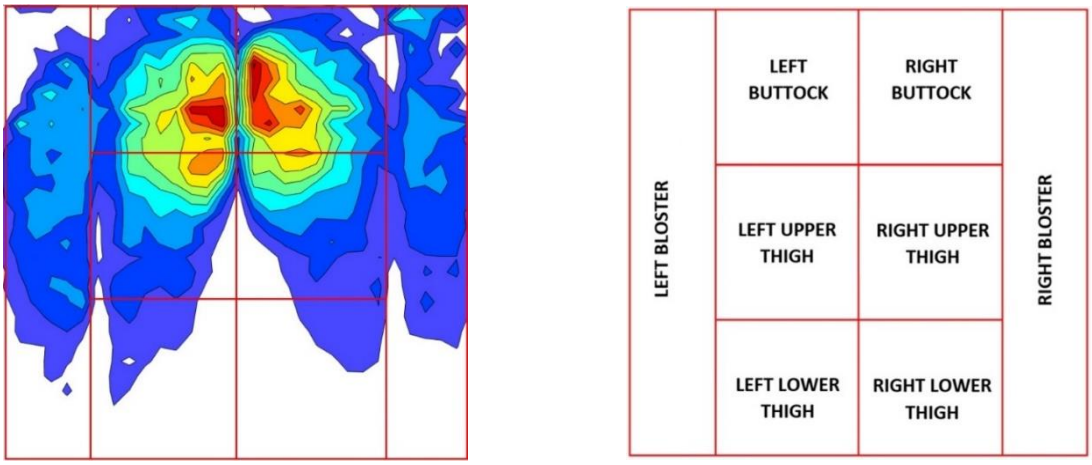
2.5.1 Adopted driving postures

Digital human models (DHM) were manually created using the software named SkillSpector® (version 1.3.2. – made by Video4Coach, Odense, Denmark). The 3D model was formed linking reflective markers, placed on the subject's body, frame by frame in the video sequences. The software used previously synchronized images, for all cameras included, and a created replica of drivers' posture presented in a 3D environment. Direct linear transformation (DLT) was precisely linked with the previously defined calibration, and it was used to calculate coordinates consequently to create the model. The left side of the driving posture was analyzed considering the flexion/extension of the main joint angles (ankle, knee, hip, shoulder, elbow, and wrist).

2.5.2 Seat pan IP

IP on the drivers' seat pan was recorded using Tactilus 8.1 software made by Tactilus®. The softer gives insight into the real-time pressure map presented in two-dimensional (2D) and 3D technology.

Furthermore, the pressure mat matrix was divided into eight zones (Figure 17) and analyzed for every dependent variable separately.



a) Pressure mat on the seat pan b) Illustration of the pressure map

Figure 17. IP presented into zones (C Mergl, 2006)

Table 7 illustrates the division of the variables into groups and subgroups. The effect of long-time driving was further analyzed and compared.

Table 7. Seat IP variables

Group	Variables by zones
Peak pressure [kPa]	
	Right/Left Bolster [kPa]
	Right/Left Buttock [kPa]
	Right/Left Upper thigh [kPa]
	Right/Left Lower thigh [kPa]
	Total Area [kPa]
Average pressure [kPa]	
	Right/Left Bolster [kPa]
	Right/Left Buttock [kPa]
	Right/Left Upper thigh [kPa]
	Right/Left Lower thigh [kPa]
	Total Area [kPa]
Average contact area [cm^2]	
	Right/Left Bolster [cm^2]
	Right/Left Buttock [cm^2]
	Right/Left Upper thigh [cm^2]
	Right/Left Lower thigh [cm^2]
	Total Area [cm^2]

2.5.3 Gait linear kinematics

Barefoot pressure and linear kinematic data were recorded using Walkway software (version 7.02). After defining each footprint of the gait, the obtained linear kinematic data were automatically calculated with the software. The next step was to export the data into an Excel 2016 (Microsoft Corporation) file. This process was repeated individually for each gait cycle. The variables obtained by the software are presented in Table 8.

Table 8. Gait linear kinematics variables

Variable	Unite
Cadence	[steps/min]
Gait Time	[sec]
Gait Distance	[cm]
Gait Velocity	[cm/sec]
Maximum Force - Left Leg	[N]
Maximum Force - Right Leg	[N]
Maximum Force - Difference	[N]
Impulse - Left Leg	[N*sec]
Impulse - Right Leg	[N*sec]
Impulse - Difference	[N*sec]
Stance Time - Right Leg	[sec]
Total Double Support Time - Right Leg	[sec]
Maximum Force Difference	[kg]
Maximum Peak Pressure Difference	[kPa]

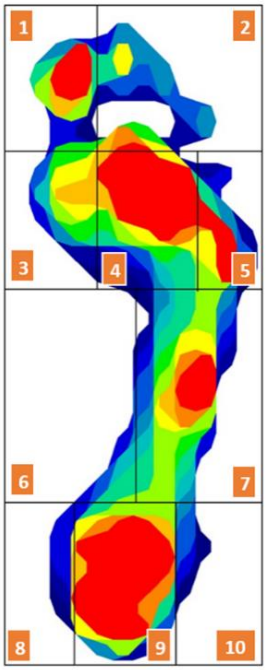
2.5.4 Barefoot plantar pressure

Applied barefoot pressure, before and after long-time driving, was firstly recorded by Walkway software and afterwards assessed by a MATLAB® R2017b (Mathworks Inc., Natick, MA) routine. The routine was developed in the LABIOMEP laboratory at the Faculty of Sports at the University of Porto[1], Portugal. In order to understand how plantar pressure was changing, the foot was divided into ten zones (see Figure 18).

Each zone was automatically chosen and defined by a software routine, and in the case of a non-proper selection, the zones could be adjusted.

The MATLAB® routine was used to evaluate the applied plantar pressure of the right footprint provoked before/after the steering of the driving simulator. Considering the full gait cycle (staring with heel contact – right foot), both plantar pressures induced by the right foot were analyzed. The same method was practiced on every gait cycle. Table 9 is illustrating included variables for the barefoot plantar applied area, average pressure as well as maximum pressure during the gait cycle.

[1] Developed by Professor Leandro Machado.



Fingers
1. Hallux
2. Other fingers

Forefoot
3. Medial forefoot
4. Central forefoot
5. Lateral forefoot

Mid-foot
6. Medial mid-foot
7. Lateral mid-foot

Rearfoot
8. Medial rearfoot
9. Central rearfoot
10. Lateral rearfoot

Figure 18. Definition of the foot regions

Table 9. Definition of plantar regions variables

Foot region	Mean peak pressure [kPa]	Average pressure [kPa]	Contact Area [cm^2]	Contact Area / Total foot area [cm^2]
Total foot	*	*	*	*
Fingers				
Hallux	*	*	*	*
Other fingers	*	*	*	*
Forefoot				
Medial forefoot	*	*	*	*
Central forefoot	*	*	*	*
Lateral forefoot	*	*	*	*
Mid-foot				
Medial mid-foot	*	*	*	*
Lateral mid-foot	*	*	*	*
Rearfoot				
Medial rearfoot	*	*	*	*
Central rearfoot	*	*	*	*
Lateral rearfoot	*	*	*	*
Contralateral	*	*	*	*

* - Included

In addition, the followings independent variables were added:

- Maximum pressure at initial contact (1st peak);
- Maximum pressure at midstance;
- Maximum pressure at push-off (2nd peak);
- Difference between gait velocity (after and before the driving process)

The abovementioned variables also referred to the analysis of right foot pressure.

2.6 Statistical analysis

The acquired data were statistically investigated using the SPSS® statistical software v.23 produced by IBM (New York, USA).

Concerning the total sample size (forty-four participants included), the Shapiro-Wilk's test was used to resolve if the data has (not)normal distribution. Besides the sample size, the test was used to establish if the data based on the previously defined groups needed to be assessed by nonparametric/parametric analysis.

A statistically significant difference was considered at α – value higher than 0.05 (or $p<0.05$). Quantitative data were represented as the mean value per individual and ± standard deviation (SD).

To define if there were a statistically significant difference between the groups, One Way ANOVA was performed for normally distributed data with the post hock Tukey's test. In the case of the not normal distribution, nonparametric Kruskal-Wallis H test was used. Further, the variance was established by the Mann-Whitney U test taking into consideration the Bonferroni adjustment.

Independent Sample T-test or Mann-Whitney U test was used to establish the difference between two subgroups (for example, gender group) in driving postures or applied IP on the drivers' seat.

What is more, Spearman's correlation was used to establish if there were a correlation between the anatomical parts or areas during the steering of the driving simulator. For the IP placed on the drivers' seat pan, the defined anatomical zones were compared for each time of the recording (at 5^{th}, 40^{th}, 80^{th}, and 120^{th} minute). The same method was applied for the adopted driving postures. Moreover, the preferred interior dimensions were correlated with the driving postures using the Spearman's correlation.

PDP, IP on the drivers' seat, and plantar pressure (before and after steering the driving simulator) were assessed using Repetitive Measures ANOVA was applied with the post hock Tukey's test (considering Wilks' Lambda factor). The data obtained inside the driving simulator was recognized as a four-time factor (for each of the data recording). In the case of the barefoot plantar pressure, a two-time factor was treated.

As a consequence of the long-time driving affected the driver's posture, IP, and reported discomfort, the acquired were further used to create a new group based on the mentioned parameters. Per each recording, the parameters mentioned above were used as a reference to create new groups. The groups were created using hierarchical clustering procedures. Firstly, Ward's cluster method was selected with the interval based on Euclidean distance. The transformation values were standardized in the range from -1 to 1. Further, the number of clusters was defined by visual classification (with the fixed number of three clusters per recording).

Before the experimental process and according to the proposed objectives, weight and other anthropometric data had to be collected, as well as the adopted angles regarding each participant's PDP.

Determination if spatiotemporal variables and barefoot plantar pressure variables do differ between two gait periods Paired Sample T-test or Wilcoxon Signed Rank Test was utilized (depending on the data distribution for each variable separately). To definitive statistical difference between the gender-based classification, Independent Sample T-test or Mann-Whitney U test was used, while Stature and BMI subgroups were tested using One Way ANOVA (Tukey's post hock test) and for nonparametric data Kruskal-Wallis H test.

CHAPTER 2
RESULTS

3 RESULTS

3.1 Anthropometric characterization of the sample size

The participants' anthropometric characteristics collected during the experimental process are illustrated in Table 10. The table contains a descriptive illustration of the mean anthropometric outcomes with the standard deviation. Moreover, the statistically significant differences between the gender are displayed as well, where the p-values were defined at 0.05.

Table 10. Anthropometric characteristics of participants (mean and ± standard deviation)

Anthropometric characteristics	Total (n=44)	Female (n=22)	Male (n=22)	*p-value gender diff.*
Age [years]	27.4 ±4.7	28.2 ±5.1	26.6 ±4.2	*n.s.*
Weight [kg]	68.4 ±14.4	60.8 ±7.2	76.0 ±16.0	***<0.001***
Body height [cm]	170.4 ±8.2	164.4 ±5.2	176.4 ±6.1	***<0.001***
Sitting height [cm]	73.6 ±4.9	70.3 ±3.4	76.9 ±3.8	***<0.001***
Arm span [cm]	167.7 ±9.7	160.3 ±4.8	175.2 ±7.4	***<0.001***
Shoulder width [cm]	36.2 ±4.2	34.3 ±2.8	38.1 ±4.6	***<0.001***
Hip height [cm]	96.8 ±6.0	94.1 ±4.2	99.5 ±6.4	***0.002***
Knee height [cm]	48.2 ±2.8	47.1 ±2.6	49.2 ±2.7	***0.014***
Buttock-knee length [cm]	48.6 ±5.2	47.0 ±4.7	50.3 ±5.2	***0.033***
Anterior superior iliac [cm]	26.9 ±2.5	25.7 ±2.1	28.0 ±2.5	***0.002***
Ankle height [cm]	6.8 ±0.8	6.5 ±0.8	7.2 ±0.7	***0.001***
Foot size [cm]	25.4 ±1.6	24.3 ±1.0	26.5 ±1.5	***<0.001***
BMI [kg/m^2]	23.5 ±4.0	22.6 ±3.4	24.3 ±4.4	*n.s.*

The significant difference is considered at p<0.05; p – values between the subject differences; n.s. – not significant; n – number of participants; ± Standard Deviation; BMI – body mass index.

From Table 10 can be presumed that the gender-based differences were occurred in most of the anthropometric attributes, except the BMI and age of male and female participants. Moreover, male participants were statistically dominant in all anthropometric measurements.

The population was further separated into two groups (Stature and BMI) and six subgroups (Small, Middle and Tall for stature; Underweight, Normal and Overweight for BMI), shown in Table 11. The total number of each subgroup was not evenly spread, except the gender-based classification. The majority of the participants were middle stature (categorization reported (for Health Statistics (US), 1994)) and average weight (classification was done by Nuttall et al. (Nuttall, 2015)). The smaller number of subjects was with the categorization of small stature and underweight.

Table 11 is illustrating differences in the anthropometric characteristics between the stature subgroups, and as well as BMI subgroups. The acquired data on the stature groups would seem to suggest that the statistical variations take place in several anthropometric variables (Table 11). The expected differences were in the total body and sitting height and buttocks-knee length, which is essential to diverse for further analysis between the groups. On the other hand, BMI is not statistically considerably different between the stature groups. According to statistics, it is important to mention that anterior superior iliac and weight is statistically diverse between the BMI groups.

Table 11. Participant characteristics of the Stature and BMI groups (mean and ± standard deviation)

	Stature				BMI			
Participant characteristics	Small (n=8)	Middle (n=20)	Tall (n=16)	*p*	Underweight (n=3)	Normal weight (n=32)	Overweight (n=9)	*p*
Age [years]	29.3 ±6.5	26.7 ±4.0	27.4 ±4.6	*n.s.*	28.3 ±1.5	27.0 ±4.2	28.6 ±6.9	*n.s.*
Weight [kg]	63.1 ±9.1	64.1 ±10.1	76.3 ±18.1	***0.029***	54.4 ±5.3	64.6 ±9.0	86.4 ±17.6	***<0.001***
Body height [cm]	159.8 ±3.4	169.4 ±2.4	177.0 ±8.7	***<0.001***	175.0 ±7.2	170.2 ±7.9	169.8 ±10.4	*n.s.*
Sitting height [cm]	68.6 ±2.5	73.9 ±5.1	75.7 ±3.9	***0.002***	76.7 ±4.0	73.3 ±4.9	73.7 ±5.4	*n.s.*
Arm span [cm]	157.8 ±5.1	165.8 ±4.4	175.1 ±10.9	***<0.001***	168.8 ±4.5	167.0 ±9.8	169.9 ±11.1	*n.s.*
Shoulder width [cm]	35.3 ±1.8	35.2 ±3.7	37.8 ±5.2	*n.s.*	30.8 ±4.2	36.0 ±4.0	38.6 ±3.2	***0.016***
Hip height [cm]	91.2 ±2.6	95.5 ±5.0	101.3 ±5.4	***<0.001***	98.3 ±9.6	96.9 ±5.9	96.1 ±5.8	*n.s.*
Knee height [cm]	47.0 ±2.9	47.4 ±2.1	49.8 ±3.1	***0.016***	49.7 ±2.1	47.9 ±2.7	48.7 ±3.5	*n.s.*
Buttock-knee length [cm]	44.2 ±3.6	48.1 ±5.5	51.6 ±3.6	***0.002***	48.7 ±7.8	49.0 ±5.4	47.4 ±3.8	*n.s.*
Anterior superior iliac [cm]	26.3 ±2.0	26.5 ±2.5	27.6 ±2.9	*n.s.*	24.2 ±0.8	26.5 ±2.3	29.2 ±2.4	***0.002***
Ankle height [cm]	6.5 ±0.8	6.9 ±0.8	7.0 ±0.9	*n.s.*	6.8 ±0.3	6.8 ±0.9	7.1 ±0.7	*n.s.*
Foot size [cm]	24.0 ±1.3	25.0 ±1.0	26.6 ±1.7	***<0.001***	26.5 ±0.9	25.1 ±1.6	25.9 ±1.9	*n.s.*
BMI [kg/m^2]	24.8 ±4.1	22.3 ±3.3	24.2 ±4.6	*n.s.*	17.7 ±0.3	22.2 ±1.8	29.7 ±3.3	***<0.001***

The significant difference is considered at p<0.05; p – values between the subject differences; n.s. – not significant; n – number of participants; ± Standard Deviation; BMI – body mass index.

3.2 Nordic questionnaire

3.2.1 Driving experience / Driving per day

Participants driving experience were collected using the Nordic Questionnaire (see Appendix 3 and 4). Collected data, referred to the driving experience and driving per week, is shown in Table 12. Moreover, the driving experience is represented in months. Table 12 displays, besides descriptive statistics, the considerable statistical difference between the main groups.

Table 12. Participants driving experience and amount of driving hours per day (mean and ± standard deviation)

Groups		Driving experience (months)	Driving per week (hours)
Total		89.8 ±56.0	4.5 ±4.0
Gender			
	Female	90.4 ±59.7	3.6 ±3.7
	Male	89.1 ±53.4	5.4 ±4.2
	p-value gender diff.	*n.s.*	*n.s.*
Stature			
	Small	83.36 ±62.6	2.5 ±2.7
	Middle	83.9 ±49.8	4.3 ±3.7
	Tall	104.2 ±61.0	6.7 ±4.5
	p-value stature diff.	*n.s.*	*n.s.*
BMI			
	Underweight	113.0 ±14.8	6.7 ±3.5
	Normal weight	81.3 ±46.8	4.4 ±4.2
	Overweight	112.0 ±85.3	4.2 ±3.9
	p-value BMI diff.	*n.s.*	*n.s.*

The significant difference is considered at p<0.05; p – values between the subject differences; n.s. – not significant; ± Standard Deviation; BMI – body mass index.

Statistically significant differences between the subgroups did not exist. On average, participants were having driving experience of 89.8 ±56.0 months and driving 4.5 ±4.0 hours per week.

3.2.2 Symptoms of MSD in the past twelve months

The prevalence of musculoskeletal pain/discomfort for the nine anatomical regions was examined using the Nordic questionnaire (see Appendix 3 and 4). Exanimating the total sample size, the most reported discomfort was in the lower back (61.4%), followed by complaints in the lower limbs – thighs, knees, and ankles/feet – (18.2%, 34.1%, 22.7%).

Compering gender and prevalence of the pain (felt in the lower limbs in the past twelve months), it could be concluded that the females suffered more discomfort in both knees and feet than males. The same assumption is related to the neck pain (female reported more significant pain for 9.1%) and wrist/hand pain (3.0% grater pain reported by females).

Besides gender, there was a difference in the stature group. Middle participants (body high from 166 until 174cm) experienced more pain in nearly all anatomical regions, except upper back (slightly higher pain for tall participants than small and middle group) and knee (equal percentage for the small and middle group). Moreover, the descriptive percentage of the prevalence of MSD during the past 12 months is illustrated in Table 13.

Table 13. Prevalence of MSD in the past 12 months

Body part		Total	Gender		Stature			BMI		
			Fe	Ma	Sm	Mid	Ta	UW	NW	OW
Neck [%]		27.3	36.4	18.2	36.4	20.0	30.8	33.3	31.3	11.1
Upper limbs										
Shoulder [%]										
	Left	13.6	13.6	13.6	18.2	15.0	7.7	66.7	6.3	22.2
	Right	18.2	18.2	18.2	9.1	30.0	7.7	0.0	25.0	0.0
	Both	18.2	18.2	18.2	9.1	20.0	23.1	33.3	21.9	0.0
Elbow [%]										
	Left	2.3	4.5	0.0	0.0	5.0	0.0	0.0	3.1	0.0
	Right	2.3	4.5	0.0	0.0	5.0	0.0	0.0	3.1	0.0
	Both	4.5	4.5	4.5	0.0	10.0	0.0	0.0	3.1	11.1
Wrist/Hand [%]										
	Left	4.5	4.5	4.5	9.1	0.0	7.7	0.0	6.3	0.0
	Right	18.2	27.3	9.1	0.0	35.0	7.7	33.3	21.9	0.0
	Both	9.1	9.1	9.1	9.1	15.0	0.0	0.0	9.4	11.1
Back										
Upper back [%]		31.8	27.3	36.4	27.3	25.0	46.2	33.3	40.6	0.0
Lower back [%]		61.4	63.6	59.1	54.5	60.0	69.2	66.7	71.9	22.2
Lower Limbs										
One or both hips/thighs [%]		18.2	18.2	18.2	9.1	20.0	23.1	0.0	21.9	11.1
One or both knees [%]		34.1	45.5	22.7	63.6	35.0	7.7	33.3	34.4	33.3
One or both ankles/feet [%]		22.7	27.3	18.2	27.3	25.0	15.4	33.3	18.8	33.3

Fe- Female; Ma -Male; Sm – Small; Mid -Middle; Ta- Tall; UW-Underweight; NW-normal weight; OW- Overweight; BMI – body mass index.

Furthermore, data indicated a higher prevalence of pain in all anatomical regions for the normal-weight subjects. The main reason could be the higher number of participants classified as having a normal weight, based on WHO classification (Nuttall, 2015).

Based on the *Spearman's* correlation coefficient, the assumption is that there was a moderate correlation between neck pain and lower back pain (r_s=0.486, p<0.01) and hips/thighs and wrists/hands pain (r_s=0.437, p<0.01). The rest correlation has no or weak relationship.

3.2.3 Symptoms of MSD in the past seven days

The incidence of pain/discomfort in the past seven days continue the same tendency as for the past twelve months, but with the less rate of occurrence (back pain – 43.2%; upper limbs – 13.6% and lower limbs with 27.3%).

With the symptoms in the past seven days, considering gender, males reported more pain for the majority part of the body but shoulder and hips/thighs regions (the percentage is equal). The stature group, middle height participants, are still the dominant group registered by the questionnaire. What is more, the normal weight population has a higher prevalence of pain.

Table 14 is illustrating the prevalence of MSD in the past seven days.

Table 14. Prevalence of MSD in the past seven days

Body part		Total	Gender		Stature			BMI		
			Fe	Ma	Sm	Mid	Ta	UW	NW	OW
Neck [%]		11.4	9.1	13.6	9.1	5.0	23.1	0.0	12.5	11.1
Upper limbs										
Shoulder [%]										
	Left	11.4	9.1	13.6	9.1	15.0	7.7	66.7	3.1	22.2
	Right	11.4	13.6	9.1	9.1	15.0	7.7	0.0	15.6	0.0
	Both	4.5	4.5	4.5	0.0	5.0	7.7	0.0	6.3	0.0
Elbow [%]										
	Left	2.3	0.0	4.5	0.0	0.0	7.7	0.0	0.0	11.1
	Right	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Both	4.5	4.5	4.5	0.0	10.0	0.0	0.0	3.1	11.1
Wrist/Hand [%]										
	Left	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Right	4.5	4.5	4.5	0.0	5.0	7.7	33.3	3.1	0.0
	Both	2.3	0.0	4.5	0.0	5.0	0.0	0.0	0.0	11.1
Back										
Upper back [%]		18.2	13.6	22.7	9.1	20.0	23.1	0.0	25.0	0.0
Lower back [%]		25.0	22.7	27.3	18.2	25.0	30.8	33.3	28.1	11.1
Lower Limbs										
One or both hips/thighs [%]		9.1	9.1	9.1	0.0	10.0	15.4	0.0	9.4	11.1
One or both knees [%]		9.1	4.5	13.6	9.1	10.0	7.7	33.3	6.3	11.1
One or both ankles/feet [%]		9.1	4.5	13.6	9.1	5.0	15.4	0.0	6.3	22.2

Fe- Female, Ma -Male, Sm – Small, Mid -Middle, Ta- Tall, UW-Underweight, NW-normal weight, OW- Overweight; BMI – Body Mass Index.

A strong correlation was found with elbow and shoulder pain (r_s=0.612, p<0.01) conducted with the *Spearman's* test.

3.2.4 Absence of work caused by MS pain

Besides the higher prevalence of the (upper and lower) back pain in the past twelve months, lower limb MS pain caused a higher rate (it total 13.6%) of absence the work or driving. What is more,

female participants reported a higher prevalence of the lower limbs pain, with the consequence of the driving absence, than the male participant. Assessing the groups by height, the individuals of medium height were those who had the highest absenteeism due to pain in the lower limbs.

Additionally, normal weight participants were more absent from driving, then the remaining two BMI subgroups. Upper extremities did not cause the absence of work/drive in the past 12 months. The statistical analyses showed that the distractive between the groups did not occur.

The prevalence of the pain/discomfort felt in the past 12 months that caused driving absence is shown in Table 15.

Table 15. Absence of work caused by MS pain

Body part	Total	Gender		Stature			BMI		
		Fe	Ma	Sm	Mid	Ta	UW	NW	OW
Back									
Upper back [%]	2.3	4.5	0.0	0.0	5.0	0.0	0.0	3.1	0.0
Lower back [%]	6.8	4.5	9.1	0.0	10.0	7.7	33.3	6.3	0.0
Lower Limbs									
One or both hips/thighs [%]	4.5	9.1	0.0	0.0	10.0	0.0	0.0	6.3	0.0
One or both knees [%]	6.8	9.1	4.5	9.1	10.0	0.0	33.3	6.3	0.0
One or both ankles/feet [%]	2.3	4.5	0.0	0.0	5.0	0.0	0.0	3.1	0.0

Fe- Female, Ma -Male, Sm – Small, Mid -Middle, Ta- Tall, UW-Underweight, NW-normal weight, OW- Overweight; BMI – Body Mass Index.

3.3 Preferred interior dimensions

Table 16 is representing the mean and standard deviation of all horizontal and vertical distances that could or not be adjusted before starting the driving session. The illustrated values are describing the sample size. The horizontal distance between the hip to heel and hip to steering wheel points are mutually dependent (Table 16). The reason is that the steering wheel could not be adjusted nor in the horizontal or vertical direction. Adjusting hip to heel distance will directly influence hip to steer wheel distance since the steering wheel position could not be modified.

Gender-based differences in the selecting interior dimensions vary between the male and female populations. Horizontal distances (hip point to heel point, as well as hip point to steering wheel point) were statistically significantly different ($Z=-4.386$, $p<0.01$, $p<0.05$). Seats' backrest adjustment has differed as well for both genders ($p<0.01$, $p<0.05$).

Favoured adjustments for the seats' backrest were different between the stature group (small, middle, and tall) ($p<0.001$, $p<0.05$). Taking into consideration the stature group, the difference between the subject has occurred between tall, small, and middle participants (tall and middle: $p<0.001$, $p<0.05$; and tall and small: $p<0.002$, $p<0.05$). Between the subjects, variations were not found in the BMI groups ($p=0.578$, $p<0.05$).

Horizontal distances, defined as L53 and as hip to the steering wheel (Table 16), are considerably unlike for the stature group ($p=0.04$, $p<0.05$). Applying the Bonferroni adjustment, the only difference was found between the tall and small participants ($p=0.003$, $p<0.05$). The difference between the BMI groups did not take place.

Table 16. Participants' preferred interior dimensions (values are represented as mean and ± standard deviation – an adapted version of (Hanson et al., 2006))

Distance	Dis	Total	Gender		
			Female	Male	*p*
Horizontal	L11 [mm]	340	340	340	*n.s.*
	L53 [mm]	**913.4 ±44.1**	**884.5 ±30.2**	**942.3 ±36.5**	***<0.001***
	HPSW [mm]	**573.4 ±44.1**	**544.5 ±30.2**	**602.3 ±36.5**	***<0.001***
Vertical	H17 [mm]	625	625	625	*n.s.*
	H30 [mm]	260	260	260	*n.s.*
	HPDW [mm]	360	360	360	*n.s.*
	SCL [mm]	480	480	480	*n.s.*
	BA [°]	**111.1 ±3.6**	**109.0 ±2.6**	**113.2 ±3.3**	***<0.001***

The significant difference is considered at p<0.05; p – values between the subject differences; n.s. – not significant; Dis. – Distance; ± Standard Deviation; L11- Horizontal distance from steering wheel to heel point; L53 - Horizontal distance from hip point to heel point; HPSW - Horizontal distance from hip point to the steering wheel; H17 – Vertical distance from steering wheel to heel point; H30 - Vertical distance from hip point to heel point; HPDW - Vertical distance from hip point to the steering wheel; SCL - Seat cushion length; BA - Backrest angle.

Table 17 is showing the mean and standard deviation of preferred interior adjustment of the seat horizontal and vertical distances referred for the stature and BMI groups.

Table 17 Preferred interior dimensions of the participants classified in the stature and BMI groups (mean and ± standard deviation)

Dis.	Dis	Stature				BMI			
		Small	Middle	Tall	*p*	UW	NW	OW	*p*
Horizontal	L11 [mm]	340	340	340	*n.s.*	340	340	340	*n.s.*
	L53 [mm]	**887.5±30.1**	**900.5±27.6**	**942.5±52.1**	***0.004***	**920.0±52.9**	**910.0±44.1**	**923.3±45.3**	*n.s.*
	HPSW [mm]	**547.5±30.1**	**560.5±27.6**	**602.5±52.1**	***0.004***	**580.0±52.9**	**570.0±44.1**	**583.3±45.3**	*n.s.*
Vertical	H17 [mm]	625	625	625	*n.s.*	625	625	625	*n.s.*
	H30 [mm]	260	260	260	*n.s.*	260	260	260	*n.s.*
	HPDW [mm]	360	360	360	*n.s.*	360	360	360	*n.s.*
	SCL [mm]	480	480	480	*n.s.*	480	480	480	*n.s.*
	BA [°]	**109.1±1.8**	**109.7±3.1**	**113.9±3.3**	***<0.001***	**113.2±3.78**	**111.0±3.4**	**110.7±4.4**	*n.s.*

The significant difference is considered at p<0.05; p – values between the subject differences; n.s. – not significant; ± Standard Deviation; Dis. – Distance; BMI – body mass index; UW – underweight; NW – Normal Weight; OW – Ower Weight; L11- Horizontal distance from steering wheel to heel point; L53 - Horizontal distance from hip point to heel point; HPSW - Horizontal distance from hip point to the steering wheel; H17 – Vertical distance from steering wheel to heel point; H30 - Vertical distance from hip point to heel point; HPDW - Vertical distance from hip point to the steering wheel; SCL - Seat cushion length; BA - Backrest angle.

3.4 Reported discomfort during steering the driving simulator

Figure 19 illustrated the reported discomfort during long-time driving. The graph starts at value 1, which characterizes the "not uncomfortable" level described in the questionnaire (ISO 2631 -1). The dots represent the average values of the reported discomfort. On the horizontal axis are placed body parts and the time of the reported discomfort. The discomfort ratings are in the range from 1 to 6 (where 6 represented the maximum discomforts defined as "Extremely Uncomfortable"). In Figure 19 are depicted as single maximum and minimum values, as well as the mean values of the

sample size. The mean value was calculated as the sum of overall discomfort (per recording) and divided by the total number of considered participants.

It could be seen that after eightieth minutes, anatomical parts such as shoulders, lower back, and buttocks had reported the highest single discomfort (5^{th} level – very uncomfortable). One participant reported lower back pain as "a little uncomfortable" at the initial recording. What is more, lower back pain had the highest discomfort values equating it with the rest body parts. Total body discomfort has been significantly influenced by long-time driving ($p<0.001$, which is substantial at $p<0.05$). Considering the period of two hours, second and third recoding (which refers to the 40^{th} and 80^{th} minute) had a significant difference regarding the entire body ($p<0.001$). The last minutes of driving had no considerable variation of body discomfort for almost all anatomical parts, except for the lower back pain which was higher than at 80^{th} minute ($Z=-2.530$, $p=0.011$, $p<0.05$). Additionally, the participants continued to have a high rate of discomfort ($r_s>0.900$) at the end of the driving period.

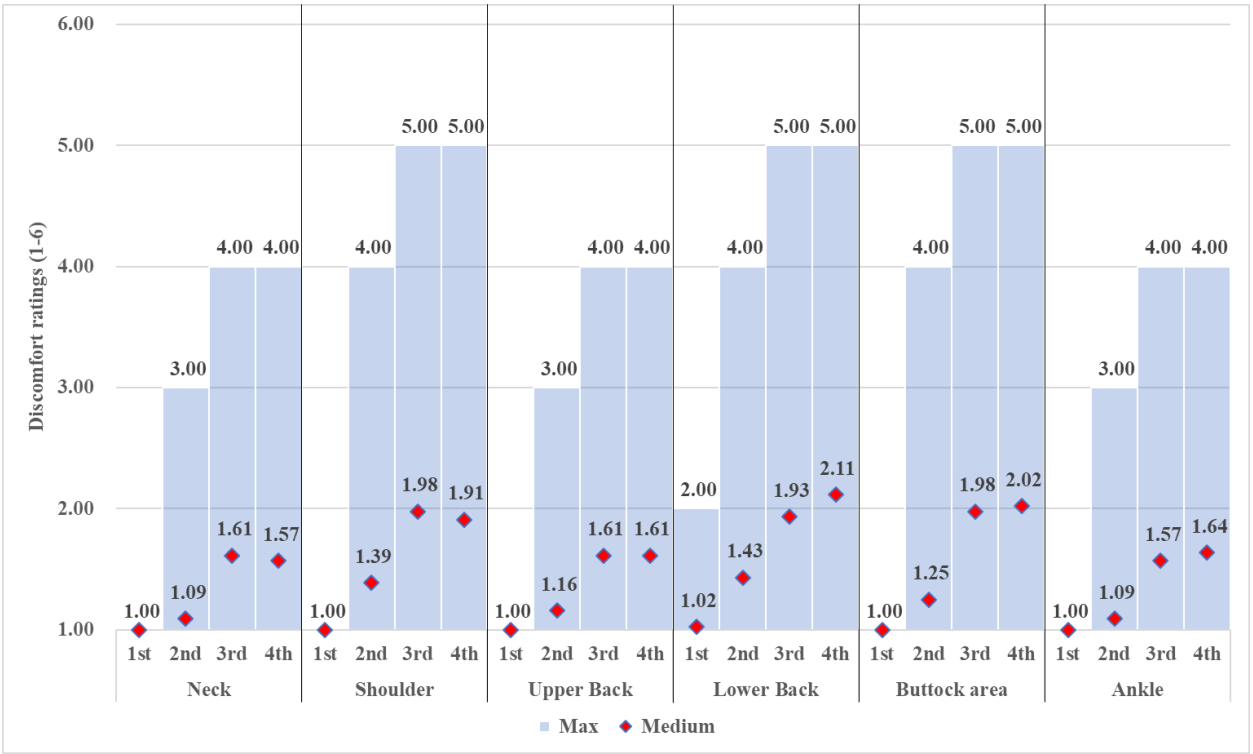


Figure 19. Reported pain/discomfort during steering the driving simulator

Table 18 is representing values of the reported discomfort in a specific part of the body during steering the driving simulator.

A Mann-Whitney test indicated that differences in the lower back pain were higher for males than for females, with the p values less than 0.05 ($p<0.05$) during two hours of driving the simulator. Reported pain/discomfort in the buttocks was statistically different from studying the BMI subgroups. Taking into consideration the Bonferroni adjustment, the difference exists between

normal weight and obesity participants at 80th (Z=-3.324, p<0.01, p<0.017) and 120th (Z=-0.971, p<0.01, p<0.017) minute of the driving.

Table 18 Reported body discomfort by subgroups

Body part	Minute	Gender		Stature			BMI		
		Female	Male	Small	Middle	Tall	UW	NW	OW
Neck	5th	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0
	40th	1.1±0.4	1.1±0.4	1.3±0.7	1.0±0.0	1.1±0.5	1.0±0.0	1.1±0.4	1.2±0.7
	80th	1.7±0.8	1.5±0.7	1.9±1.0	1.6±0.7	1.6±0.8	1.3±0.6	1.6±0.8	1.8±1.0
	120th	1.6±0.7	1.5±0.7	1.8±0.7	1.5±0.6	1.6±0.8	1.3±0.6	1.5±0.6	1.8±1.0
Shoulder	5th	1.0±0.1	1.0±0.1	1.0±0.1	1.0±0.1	1.0±0.1	1.0±0.1	1.0±0.1	1.0±0.1
	40th	1.5±1.0	1.2±0.6	1.5±0.9	1.2±0.5	1.6±1.0	1.0±0.0	1.5±0.9	1.2±0.7
	80th	2.2±1.1	1.8±0.9	2.1±1.0	1.7±0.7	2.3±1.3	2.0±1.0	2.0±1.1	1.8±1.0
	120th	2.0±1.1	1.8±0.9	2.1±1.0	1.7±0.7	2.1±1.3	2.0±1.0	1.9±1.0	1.8±1.0
Upper back	5th	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0
	40th	1.1±0.4	1.2±0.6	1.0±0.0	1.2±0.6	1.2±0.5	1.0±0.0	1.2±0.6	1.0±0.0
	80th	1.6±0.8	1.6±0.8	1.5±0.5	1.7±0.9	1.6±0.8	1.3±0.6	1.7±0.9	1.4±0.5
	120th	1.6±0.8	1.6±0.8	1.5±0.5	1.7±0.9	1.6±0.8	1.3±0.6	1.7±0.9	1.4±0.5
Lower back	5th	1.0±0.0	1.1±0.3	1.0±0.0	1.0±0.0	1.1±0.3	1.1±0.3	1.0±0.0	1.0±0.0
	40th	1.2±0.6	1.7±1.0	1.3±0.7	1.4±0.7	1.6±1.0	2.7±1.5	1.4±0.8	1.2±0.7
	80th	1.5±0.7	2.3±1.2	1.8±0.7	1.8±1.0	2.2±1.3	3.0±1.0	1.9±1.1	1.8±1.0
	120th	1.7±1.0	2.5±1.5	2.0±1.3	2.0±1.2	2.4±1.6	3.7±1.5	2.0±1.3	1.9±1.3
Buttock area	5th	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0
	40th	1.3±0.8	1.2±0.8	1.4±1.1	1.3±0.6	1.2±0.8	2.7±1.5	1.0±0.2	1.6±1.1
	80th	2.0±1.0	2.0±1.2	1.9±1.0	2.2±1.1	1.8±1.2	3.3±1.5	1.6±0.8	2.9±1.1
	120th	1.9±1.0	2.1±1.4	1.9±1.0	2.2±1.3	1.9±1.1	2.7±1.2	1.6±0.8	3.3±1.3
Ankles	5th	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0	1.0±0.0
	40th	1.1±0.4	1.1±0.4	1.3±0.7	1.0±0.0	1.1±0.5	1.0±0.0	1.1±0.4	1.2±0.7
	80th	1.5±0.7	1.6±0.8	1.8±0.7	1.5±0.6	1.6±0.9	1.3±0.6	1.5±0.6	2.0±1.0
	120th	1.6±0.9	1.6±0.9	1.9±1.0	1.5±0.8	1.7±1.0	1.3±0.6	1.5±0.8	2.1±1.2

± Standard Deviation; BMI – body mass index; UW – Underweight; NW – Normal weight; OW – Overweight.

3.5 IP of the drivers' seat pan

The IP variables, and its changes of mean values during the long-time driving, are shown in Table 19. The presented values are referring to the total seat pan area – an area that was covered with the mat pressure mapping technology. It is essential to underscore that the maximum, mean, and minimal values of the pressure-dependent variables were represented using the SPSS software. The mean results were calculated for each recorded sequence (for 5th, 40th, 80th, and 120th minute) in the total length defined in the methodology part. Moreover, Table 19 contains statistical data on the group's differences.

Since the initial recording, male participants were applying higher average pressure on the seat pan total area comparing female participants. Gender-based differences have occurred at the 3rd recoding (related to 80th minute of the driving) where the male had a considerably higher peak pressure at the seat interface. Overall IP was different at the initial recording for the stature group as well (smaller participants were applying lesser average pressure than middle and tall subjects). Additionally, at the final recording, the peak pressure was dissimilar for the stature group as well (middle applicants were applying the highest peak pressure than the two remaining groups). Analyzing the applied pressure by BMI subgroups, it was noted that underweight participants were having superior peak pressure (at the 5th and 80th minute) than the normal weight and overweight

subjects. Furthermore, normal weight participants were having statistically smaller average pressure on the total seat pant area than two BMI subgroups

Table 19. Peak and average pressure of the total seat pan (mean and ± standard deviation)

		Peak pressure [kPa]				Average pressure [kPa]			
		5th	40th	80th	120th	5th	40th	80th	120th
Total	Min	10.4	13.9	16.1	12.6	2.9	2.9	4.1	3.8
	Max	34.7	34.7	34.7	34.7	6.2	6.7	7.6	8.6
	Mean	20.9 ±8.1	24.9 ±7.2	27.6 ±6.5	28.5 ±6.6	4.4 ±0.8	5.3 ±0.9	5.6 ±1.0	5.8 ±1.1
Gender									
Female	Mean	19.8 ±8.4	23.1 ±7.7	25.6 ±6.7	27.1 ±6.0	4.0 ±0.8	4.8 ±0.9	5.1 ±8.0	5.3 ±0.9
Male	Mean	22.0 ±7.9	26.6 ±6.3	29.5 ±5.7	29.9 ±6.9	4.8 ±0.6	5.8 ±0.5	6.2 ±0.8	6.3 ±1.1
p-value gender diff.		*n.s.*	*n.s.*	***0.028***	*n.s.*	***<0.001***	***<0.001***	***<0.001***	***0.002***
Stature									
Small	Mean	17.7 ±7.1	22.0 ±7.1	22.9 ±5.1	25.0 ±6.2	3.7 ±0.8	4.7 ±0.8	5.0 ±0.8	5.2 ±0.9
Middle	Mean	21.6 ±9.0	26.2 ±8.0	29.3 ±6.6	31.0 ±5.3	4.4 ±0.7	5.3 ±0.7	5.6 ±1.0	6.0 ±1.0
Tall	Mean	21.7 ±7.5	24.5 ±6.1	27.7 ±6.1	27.8 ±7.3	4.7 ±0.7	5.6 ±1.0	5.9 ±0.9	5.9 ±1.2
p-value stature diff.		*n.s.*	*n.s.*	*n.s.*	***0.042***	***0.007***	*n.s.*	*n.s.*	*n.s.*
BMI									
Underweight	Mean	31.3 ±5.8	34.0 ±1.3	34.6 ±0.1	32.6 ±3.6	4.4 ±0.3	5.6 ±0.3	6.1 ±0.6	6.0 ±0.8
Normal weight	Mean	20.1 ±8.2	24.0 ±7.4	27.2 ±6.6	28.6 ±6.8	4.2 ±0.8	5.1 ±0.9	5.4 ±0.9	5.6 ±1.0
Overweight	Mean	20.5 ±6.9	24.7 ±5.4	26.5 ±6.1	26.8 ±6.4	4.8 ±0.8	5.9 ±0.8	6.4 ±0.8	6.6 ±1.2
p-value BMI diff.		***0.045***	*n.s.*	***0.038***	*n.s.*	*n.s.*	*n.s.*	***0.006***	*n.s.*

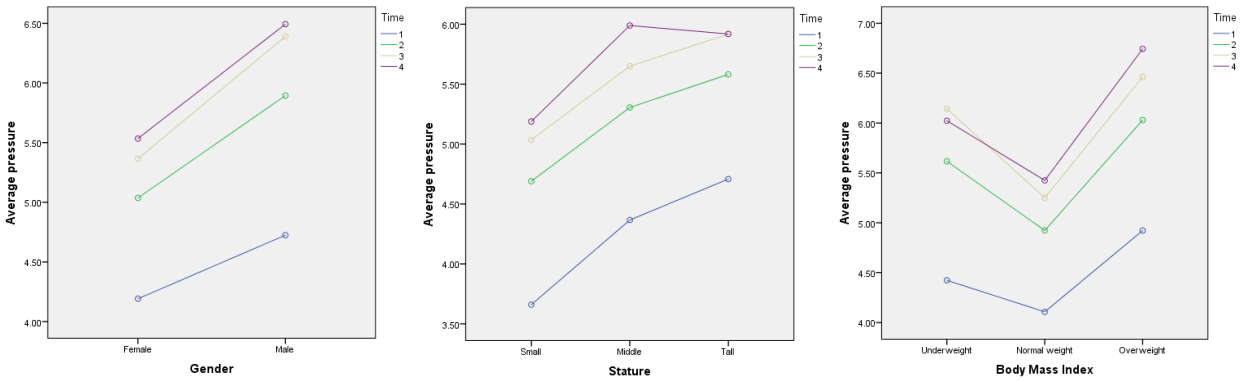
Min – Minimum; Max – Maximum; diff. – Difference; BMI – Body Mass Index, ± - Standard deviation; statistically significant differences were considered at p<0.05; p – values between the subject differences; n.s. – Not Significant.

3.5.1 Changes of the average and peak pressure along with the long-time driving

Nonparametric Friedman's test was used to evaluate the time effect on the peak pressure during the steering of the driving simulator. The test has shown that the time, at the previously defined recording periods, had a significant influence on the peak pressure growth (Chi-Square value of 46.395, which was significant, p<0.001). At the 3rd recording (equals to the 80th minute), 25% of the participants have reached the maximum peak pressure that the mat IP technology can record (34.7 kPa).

Furthermore, Repetitive measures ANOVA (RM ANOVA) has indicated that the average pressure had a significant effect of the time spent in driving between the initial and final recording (Wilks' Lambda = 0.221, F (3,41) = 48.198, p <0.001). Bearing in mind that some researches (Defloor & Grypdonck, 2000) defined the threshold of the IP at 6 kPa, in this study, 25% of the total number of participants has reached this threshold after forty minutes of steering the driving simulator. The percentage (the population with the 6 kPa of applied pressure – considering the total area) has been raised at 50% after the 80th minute and continued until the final recording (120th minute).

Figure 20 illustrates the average pressure of a total seat pan area for each group separately. On the horizontal axis are represented groups, while on the vertical axis values of the average pressure. The dots connected with lines are illustrating a period of the time recording (blue– 5th minute, green – 40th minute, yellow – 80th minute, and purple – 120th minute of the driving process).



a) Gender group b) Stature group c) BMI group

Figure 20. Comparison of the average IP on the total seat pan area by groups

Multivariate test (reading Wilks' Lambda impact) has indicated that the time impact pressure variable (average pressure) of the gender during the long-time driving (Wilks' Lambda = 0.212, F (3,40) = 49.614, p <0.001). What is more, the between-subjects' effect reported the same – statistically significant difference between the male and female (p<0.001). Using the same method to analyze the time effect on the pressure variable, the reminding two groups (stature and BMI) reported the time effect on the average pressure variables (both groups reported p<0.001). The between-subjects' effect (small, middle, and tall participants) differed between the time (p=0.031), as well as the BMI group (p=0.14).

The time effect on the peak pressure affected the sample size, including groups as well (gender, stature, and BMI) with a statistically significant variation (p<0.001). On the other hand, the between-subjects' effect did not appear between each group separately (gender p=0.087, stature p=0.126, and BMI p=0.071; p<0.05).

3.5.2 Total contact area

The contact area between the subjects' lower limbs and the vehicles seat pan, was calculated as the average value of the activated sensing cells during each recording. Table 20 displays an average value of the contact area for the total number of participants, as well as for each group separately. What is more, the statistically significant difference between the groups was emphasized.

Statistically significant differences in the applied contact area did exist between the BMI groups throughout 120 minutes of steering the driving simulator (p<0.001; p<0.005). The post hoc Turkey's analysis showed that the difference between the underweight, normal weight and overweight existed during first forty minutes of the driving, after which the difference between two groups (underweight and normal weight) stop to happen (at 80th minute p=0.062, and 120th minute p=0.111; p<0.05).

Table 20. Contact area applied to the drivers' seat pan

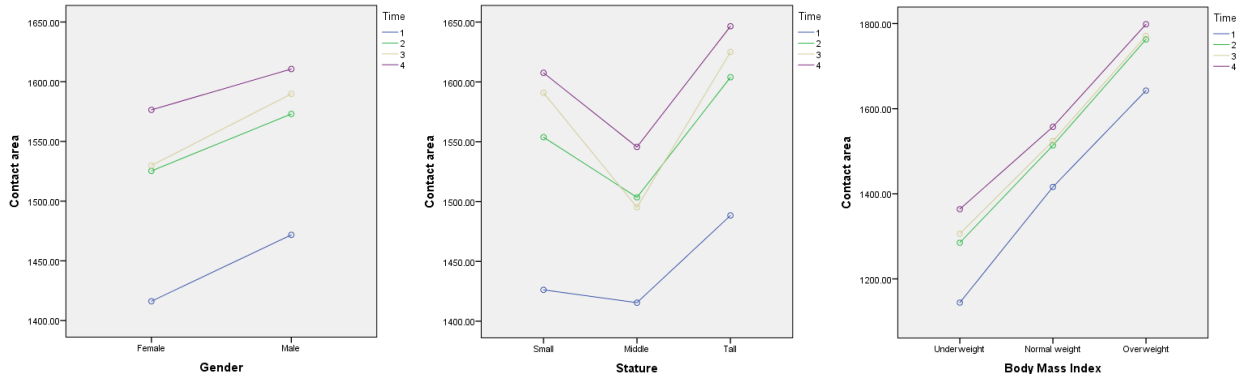
Group		Contact area [cm^2]			
		5th	40th	80th	120th
Total	Min	935.9	1113.9	1125.2	1136.8
	Max	1876.6	1975.2	2023.7	2050.2
	Mean	1443.0 ±196.8	1549.1 ±194.4	1559.8 ±193.6	1593.5 ±191.0
Gender					
Female	Mean	1416.1 ±148.6	1525.3 ±157.4	1529.8 ±160.2	1576.4 ±143.8
Male	Mean	1471.7 ±235.8	1573.0 ±226.8	1589.8 ±221.8	1610.6 ±231.0
p-value gender diff.		*n.s.*	*n.s.*	*n.s.*	*n.s.*
Stature					
Small	Mean	1426.2 ±162.9	1553.8 ±142.6	1590.9 ±139.5	1607.6 ±149.3
Middle	Mean	1415.5 ±208.4	1503.5 ±204.7	1495.3 ±200.6	1545.6 ±203.7
Tall	Mean	1488.3 ±200.8	1603.8 ±199.6	1624.9 ±191.7	1646.4 ±188.2
p-value stature diff.		*n.s.*	*n.s.*	*n.s.*	*n.s.*
BMI					
Underweight	Mean	1144.3 ±184.6	1285.0 ±154.3	1306.3 ±133.6	1363.9 ±207.1
Normal weight	Mean	1416.1 ±149.9	1513.8 ±149.1	1524.2 ±146	1557.4 ±138.9
Overweight	Mean	1642.6 ±177.5	1762.8 ±169.1	1771.0 ±186.9	1798.6 ±195.6
p-value BMI diff.		***<0.001***	***<0.001***	***<0.001***	***<0.001***

Min – Minimum; Max – Maximum; diff. – Difference; BMI – Body Mass Index, ± - Standard deviation; statistically significant differences were considered at p<0.05; p – values between the subject differences; n.s. – Not Significant.

3.5.2.1 The time effect on the total contact area

As for the earlier defined pressure variables (peak and average pressure), it was presumed that the time had a significant mathematical effect on the seat pan and the drivers' lower limbs contact area (Wilks' Lambda = 0.334, F (3,41) = 27.254, p <0.001).

Figure 21 explains the contact area of a total seat pan area for each group separately. On the horizontal axis are represented groups, while on the vertical axis values of the contact area. The dots connected with lines are illustrating a period of the time recording (blue– 5th minute, green – 40th minute, yellow – 80th minute, and purple – 120th minute of the driving process).



a) Gender b) Stature c) BMI

Figure 21. Comparison of groups' applied contact area on the drivers' seat pan

The time had a statistically significant effect on gender (Wilks' Lambda = 0.331, F (3,40) = 26.950, p <0.001), stature (Wilks' Lambda = 0.343, F (3,39) = 24.859, p <0.001), and BMI (Wilks' Lambda = 0.461, F (3,39) = 15.230, p <0.001) groups. Furthermore, the between-subject' effect has shown different results. Examining gender and stature groups between-subjects' effect, the

mathematical correlation did not prove a divergence. On the other hand, the test of between-subject' effect demonstrated the difference between the underweight, normal weight, and overweight participants during the recorded sequences ($p<0.001$, $p<0.05$).

3.5.2.2 Statistical differences between the recording time for the total number of participants

To determine the difference between recording sequences six combinations were used for each pressure variable (5^{th} and 40^{th} minute, 5^{th} and 80^{th} minute, 5^{th} and 120^{th} minute; 40^{th} and 80^{th} minute, 40^{th} and 120^{th} minute; and 80^{th} and 120^{th} minute).

The average pressure showed a statistically significant difference for each pair of the commination (*p* values were the same for every single combination, $p<0.001$, $p<0.05$). The same statistical test (Partied Sample T-test) demonstrated results for the contact area (*p* values were the same for every single combination, $p<0.001$, $p<0.05$).

Peak pressure has indicated different results for the last combination (between the 80^{th} and 120^{th} minute – $p= 0.111$; $p<0.05$) and referring that the null hypothesis has been accepted (no difference between the two time periods). The remainder sequences showed a statistically significant difference between two time periods (*p* values were the same for every single combination, $p<0.001$, $p<0.05$).

3.5.3 Correlation between pressure variables during the long-time driving

To establish a mathematical correlation between the IP variables, the bivariate correlations (Pearson and Spearman) were applied. Since the peak pressure had the non-normal distribution, the Spearman's correlation was used to establish the relationship between the peak and average IP and the contact area, as well as the correlation between the peak pressure values during the four recoding sequences.

Table 21 is presenting the correlation between the two pressure variables – average and peak pressure, and their correlation between the time sequences. A correlation between the prior variables with the contact area is not significant and was excluded from the table.

As can be noticed for Table 21, peak and average pressure were showing a strong correlation between the time sequences. It could be concluded that participants with higher pressure (peak or average) in the first 5 minutes of the driving process were continuing to have higher values in three reminding time sequences.

Table 21. Correlation between pressure variables and recording time

		Peak pressure [kPa]				Average pressure [kPa]			
		5th	40th	80th	120th	5th	40th	80th	120th
Peak pressure (kPa)	5th	1.000							
	40th	**0.724****	1.000						
	80th	**0.625****	**0.806****	1.000					
	120th	**0.511****	**0.665****	**0.660****	1.000				
Average pressure (kPa)	5th	**0.553****	0.430**	0.352*	0.320*	1.000			
	40th	0.403**	**0.526****	0.404**	0.373*	**0.793****	1.000		
	80th	*n.s.*	0.482**	**0.556****	0.377*	0.531**	**0.715****	1.000	
	120th	*n.s.*	**0.510****	0.467**	**0.628****	0.465**	**0.617****	**0.767****	1.000

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant

Table 22 displays result obtained using Pearson's correlation between the contact area itself and the recording times.

Table 22. Correlation between seat pan contact area and recording time

		Contact area [cm^2]			
		5th	40th	80th	120th
Contact area [cm^2]	5th	1.000			
	40th	**0.893****	1.000		
	80th	**0.836****	**0.940****	1.000	
	120th	**0.842****	**0.934****	**0.933****	1.000

**Correlation is significant at the 0.001 level.

The results from Table 22 are proving a strong positive correlation between the contact area for the four-time recordings (the correlation was significant at the level $p<0.001$).

3.5.3.1 Correlation between the IP variables and anthropometric characteristics

Correlation between the IP variables and obtained anthropometric characteristics are illustrated in Tables 23. It should be noted that for the normally distributed variables were applied *Pearson's* correlation, and in case of non-linear distribution, the nonparametric *Spearman's* method was used.

After correlation with the data, it was concluded that the peak pressure did not have any statistically significant correlation.

In Table 23 are illustrated only statistically strong or considerable correlations between the average pressure and anthropometric attributes. What is more, the substantial correlation above 0.5 was bolded. A strong positive correlation was reported between the average pressure and subjects' weight and stature, among others.

Table 23. Correlation between average pressure and anthropometric attributes

	Average pressure [kPa]			
Anthropometric characteristics/Minute	5th	40th	80th	120th
Weight [kg]	0.475**	**0.515****	**0.526****	0.460**
Body height [cm]	**0.567****	**0.576****	0.473**	0.459**
Shoulder width [cm]	0.388**	**0.581****	**0.513****	0.444**
Hip height [cm]	0.355*	0.454**	0.358*	0.384*
Knee height [cm]	**0.521****	0.478**	0.318*	*n.s.*
Anterior superior iliac [cm]	0.355*	0.400**	0.484**	0.415**

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant

Table 24 shows the correlation between the anthropometric characteristics and the seat pan covered area during the long-time driving. Spearman's correlations have demonstrated a strong significant correlation between the participant's weight, anterior superior iliac, and the contact area. Subjects with the greater distance between the anterior superior iliac or with the higher weight values were covering larger contact area.

Table 24. Correlation between the contact area and anthropometric attributes

	Contact area [cm^2]			
Anthropometric attributes /Minute	5th	40th	80th	120th
Weight [kg]	**0.682****	**0.753****	**0.745****	**0.691****
Anterior superior iliac [cm]	**0.589****	**0.619****	**0.600****	**0.553****

**Correlation is significant at the 0.001 level.

3.5.3.2 Correlation between IP variables and preferred interior dimensions

To define a correlation between IP variables and preferred interior dimensions of the driving simulator, the nonparametric Spearman's test was used. After applying the test, the mathematical correlation between the dependent variables is displayed in Table 25. As it is represented in the aforementioned table, the correlation was established among average pressure and dependent interior dimensions. A significant association above 0.5 ($p<0.05$) was bolded.

Table 25. Mathematical association between average pressure and horizontal distances of the driving venue

	Average pressure [kPa]			
Interior dimensions/Minute	5th	40th	80th	120th
Hip point to heel point [mm]	**0.564****	**0.523****	0.440**	0.409**
Hip point to steering wheel [mm]	**0.564****	**0.523****	0.440**	0.409**
Backrest angle [°]	*n.s.*	0.299*	0.313*	*n.s.*

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant

Results obtained using the Spearman's correlation indicated that there was a moderate positive association between horizontal dependent variables (hip to heel point, and hip to steering wheel point) and average pressure on the total area at 5th and 40th minute of recording (r_s=0.564, $p<0.001$, and r_s=0.523, $p<0.001$). The moderate statistically significant correlation reminded until the end of the driving process, but with the r_s value less than 0.5 (see Table 25). The preferred backrest

angle had a weak correlation between the 40th (r_s=0.299, p<0.05) and the 80th minute (r_s=0.313, p<0.05).

3.5.3.3 Correlation between IP variables and reported discomfort

The IP variables and reported body discomfort were separately correlated using the statistics methods (parametric Pearson's test and nonparametric Spearman's test) – depending on the data distribution. The tests were performed separately for each time sequence (5th, 40th, 80th, and 120th minute). The IP variables (average pressure and peak pressure) did not show a significant mathematical correlation between reported body discomfort and applied pressure. The total seat pan contact area indicated a weak negative association between lower back pain and the contact area at 40th minute (r_s=-0.299, p<0.05). What is more, the discomfort occurred in the ankle and 80th minute and the contact area (the same time considered) reported a weak positive correlation (r_s=0.355, p<0.05).

3.5.4 IP variables represented by zones

Tables 26, 27, and 28 represents an overview of IP variables (using mean values with standard deviation) during the long-time steering of the driving simulator. The tables included, besides the descriptive statistics of the sample size, gender, stature, and BMI groups. The results of subjects-based differences can be found in the table for each group separately.

The results represented in tables 26, 27 and 28 are showing unequal average pressure distribution among groups. Average pressure, under the right buttock, has reached 6 kPa for 25% of the sample size at the initial recording. The percentage of participants with a higher value than 6 kPa were among 50% of the gender population (male at 40th – 8 kPa, and 80th – 8.4 kPa; female at 40th – 6.5 kPa, and at 80th – 7.1 kPa) from 40th until the 80th minute. The final recording, even 75% of female participants have reached 6.3 kPa, while 50% of males reached above 5 kPa.

On the other hand, the 95 percentiles illustrated different average pressure distribution under the right buttock. The first two recording sequences (at 5th and 40th minute) 5% of the female population had more significant pressure than 11.7 kPa (at 5th minute) and 14 kPa (at 40th minute) while 5% males population had enormous pressure at initial recording more than 9 kPa, and 12.2 kPa (at 40th minute). During the 80th and 120th minutes, the 5% pressure distribution was higher among male participants. At 80th minute, 5% of female participants were having more than 11.4 kPa more pressure, while 5% of male participants had average pressure more than 13.8 kPa under the right buttocks. During the final recording, 5% of the female population was having average grater pressure than 12.8 kPa, although 5% of the male population had more than 15.9 kPa under the right buttocks.

Table 26. Description of applied average IP by zones (mean and ± standard deviation)

Side	DPM	Minute	Total [kPa]	Gender [kPa]			Stature [kPa]				BMI [kPa]			
				Female	Male	*p*	Small	Middle	Tall	*p*	Underweight	Normal Weight	Overweight	*p*
Right	Bolster	5th	2.1 ± 0.9	1.8 ±0.7	2.5 ±0.9	***0.011***	1.9 ±1.0	2.0 ±0.7	2.5 ±1.0	*n.s.*	1.2 ±0.4	2.0 ±0.7	3.0 ±1.0	***<0.001***
		40th	2.8 ± 1.1	2.3 ±0.8	3.2 ±1.2	***0.006***	2.6 ±1.0	2.5 ±0.9	3.2 ±1.3	*n.s.*	1.6 ±0.1	2.5 ±0.8	4.0 ±1.0	***<0.001***
		80th	2.9 ± 1.2	2.4 ±0.9	3.4 ±1.3	***0.004***	2.8 ±1.2	2.6 ±1.1	3.4 ±1.3	*n.s.*	2.0 ±0.3	2.6 ±0.8	4.4 ±1.5	***0.001***
		120th	3.2 ± 1.3	2.7 ±0.9	3.6 ±1.6	***0.027***	2.9 ±1.2	3.0 ±1.3	3.5 ±1.5	*n.s.*	1.9 ±0.4	2.9 ±1.0	4.6 ±1.6	***0.006***
	Buttock	5th	5.7 ± 2.0	5.5 ±2.0	5.9 ±2.0	*n.s.*	4.8 ±1.1	5.9 ±2.0	5.9 ±2.0	*n.s.*	7.7 ±1.6	5.2 ±1.7	6.6 ±2.6	***0.045***
		40th	7.2 ± 2.5	6.9 ±2.4	7.5 ±2.7	*n.s.*	6.7 ±1.2	7.2 ±2.9	7.5 ±2.7	*n.s.*	10.4 ±2.4	6.6 ±2.1	8.4 ±3.0	***0.011***
		80th	7.7 ± 2.8	7.1 ±2.1	8.2 ±3.3	*n.s.*	7.5 ±1.7	7.4 ±3.0	8.1 ±3.0	*n.s.*	12.0 ±2.8	6.9 ±2.4	8.9 ±2.7	***0.002***
		120th	7.9 ± 3.0	7.5 ±2.1	8.3 ±3.7	*n.s.*	7.8 ±1.7	7.6 ±2.9	8.4 ±3.7	*n.s.*	12.2 ±3.8	7.2 ±2.5	9.0 ±3.4	***0.008***
	Upper thigh	5th	5.2 ± 2.1	4.5 ±1.6	6.0 ±2.3	***0.017***	3.3 ±1.2	5.6 ±2.5	5.6 ±1.4	***0.016***	3.2 ±2.0	5.2 ±2.2	6.0 ±1.7	*n.s.*
		40th	6.6 ± 2.6	5.6 ±2.0	7.7 ±2.7	***0.006***	4.6 ±1.8	7.1 ±3.0	7.1 ±1.8	*n.s.*	4.5 ±2.4	6.4 ±2.4	8.1 ±2.6	*n.s.*
		80th	7.1 ± 2.9	6.0 ±2.0	8.2 ±3.2	***0.007***	5.3 ±1.6	7.6 ±3.5	7.4 ±2.1	***0.043***	4.9 ±2.7	6.7 ±2.6	9.1 ±3.1	***0.032***
		120th	7.3 ± 3.0	6.2 ±2.4	8.5 ±3.2	***0.009***	5.5 ±2.0	8.0 ±3.9	7.4 ±1.7	*n.s.*	5.0 ±2.8	7.0 ±2.9	9.3 ±3.1	***0.047***
	Lower thigh	5th	0.9 ± 0.6	1.0 ±0.5	0.9 ±0.7	*n.s.*	1.4 ±0.6	0.8 ±0.6	0.9 ±0.5	*n.s.*	0.3 ±0.3	0.9 ±0.6	1.4 ±0.7	***0.035***
		40th	1.2 ± 0.7	1.3 ±0.7	1.2 ±0.8	*n.s.*	1.7 ±0.8	1.1 ±0.7	1.2 ±0.7	*n.s.*	0.5 ±0.6	1.1 ±0.6	1.9 ±0.7	***0.003***
		80th	1.3 ± 0.9	1.3 ±0.7	1.3 ±1.0	*n.s.*	1.8 ±0.6	1.2 ±1.0	1.2 ±0.7	*n.s.*	0.5 ±0.5	1.1 ±0.6	2.2 ±1.1	***0.002***
		120th	1.3 ± 0.9	1.4 ±0.7	1.3 ±1.0	*n.s.*	1.8 ±0.6	1.3 ±1.0	1.1 ±0.8	*n.s.*	0.6 ±0.5	1.1 ±0.6	2.4 ±1.2	***0.002***
Left	Bolster	5th	1.6 ± 1.0	1.3 ±0.7	1.8 ±1.1	*n.s.*	1.5 ±0.9	1.3 ±0.8	1.9 ±1.1	*n.s.*	0.3 ±0.2	1.5 ±0.7	2.3 ±1.3	***0.005***
		40th	2.2 ± 1.3	1.8 ±0.9	2.5 ±1.6	*n.s.*	2.1 ±1.1	1.7 ±1.0	2.8 ±1.6	*n.s.*	0.4 ±0.4	2.0 ±1.0	3.4 ±1.5	***0.002***
		80th	2.2 ± 1.4	1.9 ±1.0	2.6 ±1.7	*n.s.*	2.4 ±1.1	1.7 ±1.2	2.9 ±1.5	***0.019***	0.5 ±0.4	2.0 ±1.0	3.7 ±1.8	***0.001***
		120th	2.4 ± 1.5	2.2 ±1.0	2.7 ±1.8	*n.s.*	2.7 ±1.5	2.0 ±1.3	2.8 ±1.8	*n.s.*	0.5 ±0.5	2.2 ±1.0	4.0 ±2.1	***0.003***
	Buttock	5th	4.9 ± 1.6	4.7 ±1.3	5.0 ±1.9	*n.s.*	4.8 ±0.9	4.5 ±1.6	5.3 ±1.9	*n.s.*	5.4 ±2.6	4.7 ±1.5	5.4 ±1.8	*n.s.*
		40th	6.4 ± 2.3	6.3 ±2.1	6.5 ±2.6	*n.s.*	6.7 ±1.5	6.2 ±2.5	6.4 ±2.5	*n.s.*	8.8 ±2.3	6.0 ±2.2	7.1 ±2.2	*n.s.*
		80th	7.1 ± 2.7	7.1 ±2.2	7.2 ±3.2	*n.s.*	7.7 ±1.9	6.8 ±2.8	7.3 ±3.0	*n.s.*	9.1 ±2.5	6.8 ±2.7	7.8 ±2.7	*n.s.*
		120th	7.5 ± 3.1	7.7 ±2.5	7.4 ±3.6	*n.s.*	7.9 ±1.9	7.5 ±3.1	7.4 ±3.6	*n.s.*	9.4 ±3.0	7.2 ±3.0	7.9 ±3.2	*n.s.*
	Upper thigh	5th	5.1 ± 2.0	4.1 ±1.5	6.0 ±2.0	***0.001***	3.5 ±2.0	5.0 ±1.8	5.9 ±1.8	***0.017***	3.8 ±1.4	5.0 ±2.1	5.8 ±1.7	*n.s.*
		40th	6.8 ± 2.5	5.5 ±1.9	8.0 ±2.4	***<0.001***	5.0 ±2.6	6.8 ±2.6	7.6 ±2.0	*n.s.*	5.6 ±1.8	6.6 ±2.5	7.7 ±2.8	*n.s.*
		80th	7.3 ± 2.8	6.1 ±2.3	8.5 ±2.7	***0.003***	4.9 ±1.5	7.5 ±3.1	8.3 ±2.1	***0.013***	6.2 ±1.9	7.2 ±2.9	8.2 ±2.6	*n.s.*
		120th	7.8 ± 3.2	6.5 ±2.6	9.1 ±3.3	***0.009***	4.9 ±1.9	8.6 ±3.5	8.4 ±2.6	***0.012***	6.0 ±1.5	7.7 ±3.2	8.9 ±3.5	*n.s.*
	Lower thigh	5th	0.8 ± 0.7	0.6 ±0.5	1.1 ±0.9	*n.s.*	0.4 ±0.4	0.9 ±0.8	0.9 ±0.7	*n.s.*	0.6 ±0.7	0.7 ±0.6	1.4 ±0.9	*n.s.*
		40th	1.0 ± 0.9	0.7 ±0.5	1.3 ±1.0	***0.049***	0.7 ±0.6	1.1 ±1.1	1.1 ±0.7	*n.s.*	0.3 ±0.1	0.9 ±0.7	1.7 ±1.1	***0.017***
		80th	1.0 ± 1.0	0.8 ±0.7	1.3 ±1.2	*n.s.*	0.6 ±0.6	1.2 ±1.3	1.1 ±0.6	*n.s.*	0.3 ±0.1	0.9 ±0.7	1.8 ±1.5	***0.013***
		120th	1.2 ± 1.0	0.9 ±0.7	1.5 ±1.3	*n.s.*	0.6 ±0.4	1.3 ±1.3	1.3 ±0.8	*n.s.*	0.7 ±0.5	1.0 ±0.8	1.9 ±1.7	*n.s.*

DPM – Defined Part of the Mat; BMI – Body Mass Index; n.s. -Not significant; ± - Standard deviation; p – the statistical difference between the groups; statistically significant differences were considered at $p<0.05$.

Table 27. Description of applied peak IP by zones (mean and ± standard deviation)

Side	DPM	Minute	Total	Gender [kPa]			Stature [kPa]				BMI [kPa]			
				Female	Male	*p*	Small	Middle	Tall	*p*	UW	NW	OW	*p*
Right	Bolster	5th	9.1 ±3.1	9.2 ±4.0	9.0 ±2.1	*n.s.*	9.6 ±3.6	8.6 ±3.7	9.4 ±2.0	*n.s.*	6.1 ±0.2	8.8 ±3.2	11.2 ±2.2	***0.001***
		40th	10.9 ±3.6	10.5 ±4.2	11.4 ±2.9	*n.s.*	12.2 ±5.6	9.6 ±2.9	12.0 ±2.6	*n.s.*	8.1 ±0.2	10.2 ±3.3	14.4 ±2.8	***0.001***
		80th	11.6 ±5.2	10.1 ±5.1	13.1 ±5.0	***0.014***	12.7 ±7.1	9.8 ±3.3	13.3 ±5.7	*n.s.*	9.3 ±0.9	10.7 ±5.2	15.5 ±4.1	***0.008***
		120th	12.3 ±4.9	11.7 ±5.6	12.9 ±4.1	*n.s.*	13.6 ±7.6	11.2 ±4.1	13.1 ±4.2	*n.s.*	9.1 ±1.3	11.6 ±4.7	15.9 ±4.6	***0.020***
	Buttock	5th	16.2 ±7.6	15.1 ±7.8	17.4 ±7.5	*n.s.*	11.1 ±2.3	17.5 ±8.6	17.2 ±7.3	***0.002***	28.1 ±11.3	15.5 ±6.5	14.8 ±7.8	*n.s.*
		40th	19.7 ±7.6	17.7 ±7.6	21.6 ±7.2	***0.023***	14.7 ±3.0	20.6 ±7.9	21.0 ±8.2	*n.s.*	29.5 ±8.9	19.1 ±7.1	18.4 ±7.4	*n.s.*
		80th	20.1 ±7.0	18.2 ±6.2	21.9 ±7.5	*n.s.*	16.7 ±4.0	20.5 ±7.0	21.3 ±8.0	*n.s.*	29.8 ±8.5	19.3 ±6.5	19.5 ±6.7	*n.s.*
		120th	21.2 ±7.5	19.1 ±6.0	23.3 ±8.4	*n.s.*	17.4 ±4.8	21.3 ±7.2	22.9 ±8.6	*n.s.*	30.0 ±8.1	20.9 ±7.0	19.2 ±8.0	*n.s.*
	Upper thigh	5th	14.7 ±7.7	14.3 ±8.9	15.1 ±6.5	*n.s.*	8.3 ±3.0	16.6 ±8.5	15.5 ±6.9	***0.005***	16.4 ±7.7	15.1 ±8.3	12.6 ±5.7	*n.s.*
		40th	17.9 ±7.8	16.7 ±8.3	19.0 ±7.4	*n.s.*	11.5 ±3.9	19.8 ±8.5	18.7 ±7.0	***0.007***	21.5 ±12.7	17.8 ±7.4	16.9 ±8.4	*n.s.*
		80th	18.4 ±7.4	16.4 ±7.4	20.4 ±7.0	***0.037***	12.7 ±3.9	20.8 ±8.5	18.3 ±5.8	***0.026***	20.0 ±7.7	18.1 ±7.3	18.8 ±8.7	*n.s.*
		120th	19.8 ±8.0	17.3 ±7.6	22.3 ±7.6	***0.025***	13.4 ±4.8	22.5 ±9.0	19.6 ±6.1	***0.027***	22.7 ±8.0	19.7 ±8.1	19.1 ±8.4	*n.s.*
	Lower thigh	5th	4.5 ±1.7	4.3 ±1.5	4.6 ±1.9	*n.s.*	5.3 ± 1.4	4.3 ±2.1	4.3 ±1.3	*n.s.*	2.8 ±0.4	4.3 ±1.7	5.4 ±1.7	*n.s.*
		40th	5.4 ±2.1	5.1 ±1.8	5.7 ±2.4	*n.s.*	6.2 ±1.8	5.2 ±2.5	5.2 ±1.7	*n.s.*	3.0 ±1.5	5.2 ±1.9	7.0 ±2.1	***0.005***
		80th	5.7 ±2.7	5.3 ±1.8	6.0 ±3.4	*n.s.*	6.3 ±1.4	5.7 ±3.6	5.3 ±1.7	*n.s.*	3.3 ±0.6	5.2 ±1.8	8.3 ±4.0	***0.005***
		120th	5.9 ±2.9	5.5 ±1.6	6.2 ±3.8	*n.s.*	6.4 ±0.9	6.3 ±3.9	5.0 ±1.8	*n.s.*	4.4 ±1.3	5.3 ±1.8	8.5 ±4.7	***0.014***
Left	Bolster	5th	10.4 ±4.9	9.8 ±4.0	10.9 ±5.7	*n.s.*	10.9 ±4.4	9.7 ±4.8	11.0 ±5.5	*n.s.*	3.6 ±3.0	9.8 ±3.9	14.5 ±5.7	***0.002***
		40th	12.0 ±6.0	10.7 ±4.5	13.3 ±7.1	***0.021***	12.9 ±5.7	10.6 ±6.2	13.4 ±5.9	*n.s.*	4.9 ±3.6	11.4 ±5.6	16.4 ±5.5	***0.004***
		80th	12.6 ±6.9	11.2 ±5.5	14.0 ±8.0	*n.s.*	13.9 ±5.5	10.1 ±6.6	15.0 ±7.3	***0.027***	6.0 ±2.5	12.0 ±6.9	16.8 ±5.9	***0.005***
		120th	13.4 ±8.1	13.2 ±7.8	13.5 ±8.6	*n.s.*	17.6 ±11.0	11.7 ±6.9	13.3 ±7.7	*n.s.*	4.8 ±3.4	12.5 ±7.4	19.3 ±8.5	***0.003***
	Buttock	5th	15.4 ±6.6	14.6 ±5.7	16.2 ±7.4	*n.s.*	14.0 ±3.1	14.6 ±6.3	17.2 ±8.0	*n.s.*	21.0 ±11.3	15.1 ±6.6	14.7 ±4.3	*n.s.*
		40th	19.6 ±8.0	18.7 ±7.4	20.5 ±8.6	*n.s.*	17.7 ±4.6	20.3 ± 9.2	19.7 ±8.0	*n.s.*	29.4 ±9.2	18.9 ±7.6	18.8 ±7.8	*n.s.*
		80th	22.6 ±8.8	21.7 ±7.5	23.5 ±10.0	*n.s.*	20.2 ±6.4	23.0 ±9.4	23.4 ±9.2	*n.s.*	30.4 ±7.5	22.6 ±8.7	19.9 ±8.7	*n.s.*
		120th	22.2 ±8.8	22.5 ±7.8	21.8 ±9.9	*n.s.*	20.0 ±6.6	24.0 ±9.7	20.9 ±8.7	*n.s.*	28.9 ±10.1	22.9 ±8.7	17.2 ±7.5	*n.s.*
	Upper thigh	5th	13.9 ±7.2	12.5 ±6.8	15.3 ±7.5	*n.s.*	11.4 ±9.3	14.0 ±6.8	15.0 ±6.7	*n.s.*	18.7 ±9.6	14.1 ±7.6	11.6 ±3.9	*n.s.*
		40th	18.1 ±8.1	15.9 ±8.0	20.3 ±7.8	*n.s.*	13.7 ±8.7	19.3 ±7.7	18.8 ±8.0	*n.s.*	26.5 ±12.4	18.0 ±7.8	15.6 ±6.7	*n.s.*
		80th	20.9 ±8.9	19.1 ±8.7	22.8 ±9.0	*n.s.*	12.9 ±4.1	23.2 ±8.6	22.1 ±9.2	*n.s.*	29.1 ±9.5	21.4 ±9.3	16.7 ±5.1	*n.s.*
		120th	22.5 ±9.5	20.6 ±8.9	24.3 ±9.9	*n.s.*	13.1 ±5.4	25.8 ±8.6	22.9 ±9.5	***0.006***	25.2 ±9.8	23.0 ±9.6	19.6 ±9.4	*n.s.*
	Lower thigh	5th	4.5 ±2.4	3.6 ±1.8	5.3 ±2.6	***0.018***	2.7 ±1.5	4.8 ±2.6	5.0 ±2.0	*n.s.*	3.8 ±2.3	4.1 ±2.2	6.0 ±2.6	*n.s.*
		40th	5.4 ±2.8	4.4 ±2.0	6.3 ±3.1	***0.017***	3.6 ±1.7	5.5 ±3.2	6.0 ±2.4	*n.s.*	3.0 ±0.4	5.1 ±2.6	7.2 ±3.1	***0.038***
		80th	5.5 ±2.8	4.7 ±2.1	6.2 ±3.3	*n.s.*	4.0 ±1.6	5.8 ±3.6	5.7 ±2.1	*n.s.*	3.3 ±0.5	5.0 ±2.2	7.8 ±3.9	***0.025***
		120th	5.7 ±3.2	4.7 ±1.9	6.7 ±3.9	*n.s.*	4.0 ±1.6	6.2 ±4.0	5.9 ±2.4	*n.s.*	3.7 ±1.1	5.2 ±2.2	8.2 ±4.9	*n.s.*

DPM – Defined Part of the Mat; BMI – Body Mass Index; n.s. -Not significant; UN- underweight; NW – normal weight; OW – overweight; ± - Standard deviation; statistically significant differences were considered at $p<0.05$; p – the statistical difference between the groups.

Table 28. Description of applied contact area by zones (mean and ± standard deviation)

Side	DPM	Minute	Total [cm^2]	Gender [cm^2]			Stature [cm^2]				BMI [cm^2]			
				Female	Male	*p*	Small	Middle	Tall	*p*	UW	NW	OW	*p*
Right	Bolster	5th	318.8 ±57.5	305.1 ±50.0	332.5 ±62.3	*n.s.*	304.6 ±69.1	307.3 ±52.2	340.2 ±55.1	*n.s.*	271.7 ±91.5	309.9 ±49.7	366.2 ±49.2	***0.009***
		40th	344.8 ±50.5	338.8 ±43.5	350.9 ±57.0	*n.s.*	335.4 ±52.6	339.4 ±46.7	356.4 ±55.0	*n.s.*	323.7 ±35.3	334.3 ±48.8	389.6 ±35.8	***0.008***
		80th	345.7 ±47.2	333.7 ±46.2	357.7 ±46.1	*n.s.*	338.9 ±40.6	334.8 ±49.5	362.9 ±44.9	*n.s.*	326.4 ±10.0	337.3 ±44.3	382.3 ±49.1	***0.027***
		120th	352.9 ±48.0	344.7 ±40.5	361.0 ±54.2	*n.s.*	342.8 ±56.8	345.0 ±42.6	367.7 ±49.3	*n.s.*	335.4 ±31.0	345.0 ±46.9	386.6 ±44.3	*n.s.*
	Buttock	5th	200.0 ±31.0	207.7 ±19.0	192.3 ±38.5	*n.s.*	211.6 ±12.2	199.7 ±30.6	194.6 ±37.3	*n.s.*	212.4 ±11.4	195.4 ±33.1	212.1 ±24.2	*n.s.*
		40th	201.4 ±35.0	209.5 ±24.7	193.4 ±42.0	*n.s.*	215.8 ±12.2	199.0 ±36.9	197.4 ±39.7	*n.s.*	217.4 ±4.8	196.5 ±37.8	213.8 ±25.8	*n.s.*
		80th	201.4 ±32.9	208.3 ±24.6	194.5 ±38.9	*n.s.*	215.2 ±13.0	198.3 ±36.1	198.4 ±35.4	*n.s.*	213.2 ±10.5	197.2 ±34.3	212.7 ±31.0	*n.s.*
		120th	202.1 ±33.3	209.3 ±23.3	194.8 ±40.2	*n.s.*	217.1 ±9.4	199.3 ±36.0	198.1 ±36.7	*n.s.*	213.9 ±11.1	198.5 ±33.0	210.8 ±39.0	*n.s.*
	Upper thigh	5th	204.4 ±21.5	198.1 ±16.3	210.7 ±24.5	***0.003***	193.7 ±21.2	202.4 ±24.2	212.3 ±15.7	*n.s.*	162.7 ±34.8	204.3 ±17.6	218.8 ±10.2	***0.004***
		40th	212.3 ±15.7	206.3 ±14.7	218.3 ±14.6	***0.002***	204.3 ±17.1	209.8 ±17.5	219.5 ±9.2	*n.s.*	189.0 ±20.3	211.3 ±14.8	223.7 ±3.9	***0.002***
		80th	213.2 ±13.7	208.2 ±14.1	218.3 ± 11.4	***0.009***	209.3 ±15.5	210.4 ±15.4	218.8 ±8.3	*n.s.*	196.4 ±13.7	211.7 ±13.4	224.5 ±1.6	***0.002***
		120th	214.3 ±13.5	209.0 ±14.5	219.6 ± 10.4	***0.004***	210.3 ± 16.9	211.3 ±15.2	220.1 ±6.7	*n.s.*	200.0 ±13.0	212.8 ±13.8	224.5 ±1.5	***0.001***
	Lower thigh	5th	119.0 ±46.0	128.2 ±37.2	109.7 ±52.6	*n.s.*	153.3 ± 35.8	111.9 ±47.1	110.7 ±43.4	*n.s.*	66.0 ±55.4	116.0 ±42.4	147.5 ±40.1	***0.019***
		40th	138.7 ±45.0	141.7 ±38.6	135.6 ±51.4	*n.s.*	160.2 ±33.4	129.5 ±49.3	139.4 ±43.1	*n.s.*	72.5 ±62.1	134.5 ±38.9	175.5 ±28.6	***0.001***
		80th	141.1 ±50.0	147.3 ±42.4	134.8 ±57.0	*n.s.*	173.6 ±33.6	129.8 ±52.4	138.9 ±49.3	*n.s.*	71.7 ±58.7	133.9 ±42.1	189.5 ±32.9	***<0.001***
		120th	144.7 ±48.1	151.4 ±44.9	137.9 ±51.3	*n.s.*	179.6 ±35.1	133.8 ±50.8	140.8 ±44.4	*n.s.*	76.5 ±53.6	137.3 ±37.1	193.6 ±41.9	***<0.001***
Left	Bolster	5th	191.3 ±76.1	180.3 ±52.8	202.2 ±94.0	*n.s.*	188.5 ±57.4	177.9 ±82.1	209.4 ±77.1	*n.s.*	47.6 ±48.5	191.7 ±58.9	237.9 ±83.4	***<0.001***
		40th	222.5 ±85.2	205.3 ±58.9	239.6 ±103.7	*n.s.*	223.5 ±61.6	195.1 ±82.4	256.2 ±90.6	*n.s.*	71.5 ±46.1	215.3 ±68.0	298.4 ±72.9	***<0.001***
		80th	223.3 ±86.1	204.7 ±61.6	242.0 ±103.2	*n.s.*	234.7 ±60.5	188.1 ±82.3	261.6 ±87.5	***0.032***	84.0 ±41.7	217.1 ±72.2	292.0 ±80.4	***<0.001***
		120th	233.4 ±83.5	221.3 ±65.1	245.6 ±98.7	*n.s.*	241.7 ±67.1	208.8 ±78.4	260.0 ±92.3	*n.s.*	89.1 ±59.1	225.5 ±65.6	309.6 ±73.1	***<0.001***
	Buttock	5th	188.7 ±33.8	194.5 ±24.0	182.8 ±41.2	*n.s.*	205.7 ±15.6	183.8 ±35.1	186.2 ±37.6	*n.s.*	178.1 ±22.4	184.9 ±35.0	205.6 ±29.2	***0.042***
		40th	194.8 ±38.2	202.1 ±28.6	187.4 ± 45.4	*n.s.*	214.6 ±10.5	190.5 ±41.5	190.2 ±41.1	*n.s.*	201.9 ±3.5	189.3 ±41.9	211.8 ±23.8	***0.042***
		80th	195.4 ±35.8	202.9 ±25.9	188.0 ±42.9	*n.s.*	213.2 ±15.3	190.5 ±39.5	192.7 ±37.2	*n.s.*	199.7 ±5.3	191.1 ±37.9	209.2 ±32.2	*n.s.*
		120th	196.5 ±37.7	204.9 ±24.9	188.1 ±46.2	*n.s.*	216.1 ±10.8	192.0 ±40.7	192.4 ±40.9	*n.s.*	199.0 ±6.1	193.0 ±38.5	208.3 ±41.0	***0.025***
	Upper thigh	5th	212.0 ±19.1	205.3 ±22.3	218.7 ±12.4	***0.002***	196.5 ±28.4	212.3 ±18.1	219.3 ±8.5	***0.047***	208.1 ±2.3	210.1 ±21.4	220.0 ±10.0	*n.s.*
		40th	217.7 ±13.7	214.4 ±14.6	221.1 ±12.2	***0.001***	209.6 ±20.3	217.1 ±14.6	222.6 ±3.9	*n.s.*	218.9 ±2.5	216.6 ±15.4	221.6 ±8.1	*n.s.*
		80th	219.5 ±12.1	216.2 ±15.6	222.8 ±5.5	***0.004***	211.1 ±21.3	219.3 ±10.6	223.9 ±1.7	***0.018***	219.1 ±2.5	218.4 ±13.9	223.5 ±3.8	*n.s.*
		120th	219.6 ±11.7	216.8 ±15.0	222.4 ±6.2	*n.s.*	210.1 ±20.1	220.2 ±9.9	223.6 ±3.6	***0.021***	221.0 ±5.0	218.4 ±13.3	223.5 ±4.1	*n.s.*
	Lower thigh	5th	96.6 ±55.4	80.7 ±52.1	112.6 ±55.1	*n.s.*	57.2 ±41.3	104.3 ±63.7	106.7 ±42.8	*n.s.*	63.2 ±38.8	89.2 ±53.0	134.2 ±54.9	*n.s.*
		40th	112.6 ±57.0	99.1 ±54.5	126.1 ±57.4	*n.s.*	85.1 ±55.0	118.1 ±67.5	119.5 ±40.4	*n.s.*	61.8 ±21.2	107.1 ±54.5	149.2 ±56.8	***0.037***
		80th	114.3 ±54.9	100.4 ±53.2	128.3 ±54.2	*n.s.*	91.4 ±52.5	114.0 ±65.7	126.2 ±38.3	*n.s.*	71.1 ±21.0	109.1 ±52.8	147.5 ±56.9	*n.s.*
		120th	125.9 ±60.9	113.9 ±65.8	137.9 ±54.4	*n.s.*	87.7 ±45.2	127.8 ±71.7	142.7 ±45.6	*n.s.*	109.0 ±58.7	120.2 ±62.5	152.1 ±53.8	*n.s.*

DPM – Defined Part of the Mat; BMI – Body Mass Index; n.s. -Not significant; UN- underweight; NW – normal weight; OW – overweight; ± - Standard deviation; statistically significant differences were considered at $p<0.05$; p – the statistical difference between the groups.

The average pressure under the right buttock for the stature and BMI groups were not equally distributed as well. Average pressure under the right buttocks (taking into consideration the stature group) 25% of participants were having higher average pressure more than 6 kPa after the initial recording. Following, the percentage of participants higher than 6 kPa increased. Moreover, even 75% of small participants (stature group) were having more significant average pressure under the right buttocks, while 50% of middle and tall participants had more than the mentioned value of average pressure. The same percentage was kept for the tall participants at the final recording, although 75% of small and middle participants had superior pressure than the previously established threshold.

On the other hand, the BMI group reported different prevalence of the average pressure. A smaller amount of 5% of underweight participants was having lesser pressure than 6 kPa after the initial recording. While normal weight (25% of total sample size) and overweight (50% of total sample size) were having grater pressure than declared. In the final record, 95% of the underweight population had a pressure greater than 8.9 kPa, while 50% of the normal weight population had an average pressure greater than 6.9 kPa. On the other hand, 75% of the overweight population had a pressure greater than 7.7 kPa of pressure under the buttocks after 120 minutes in the driving simulator.

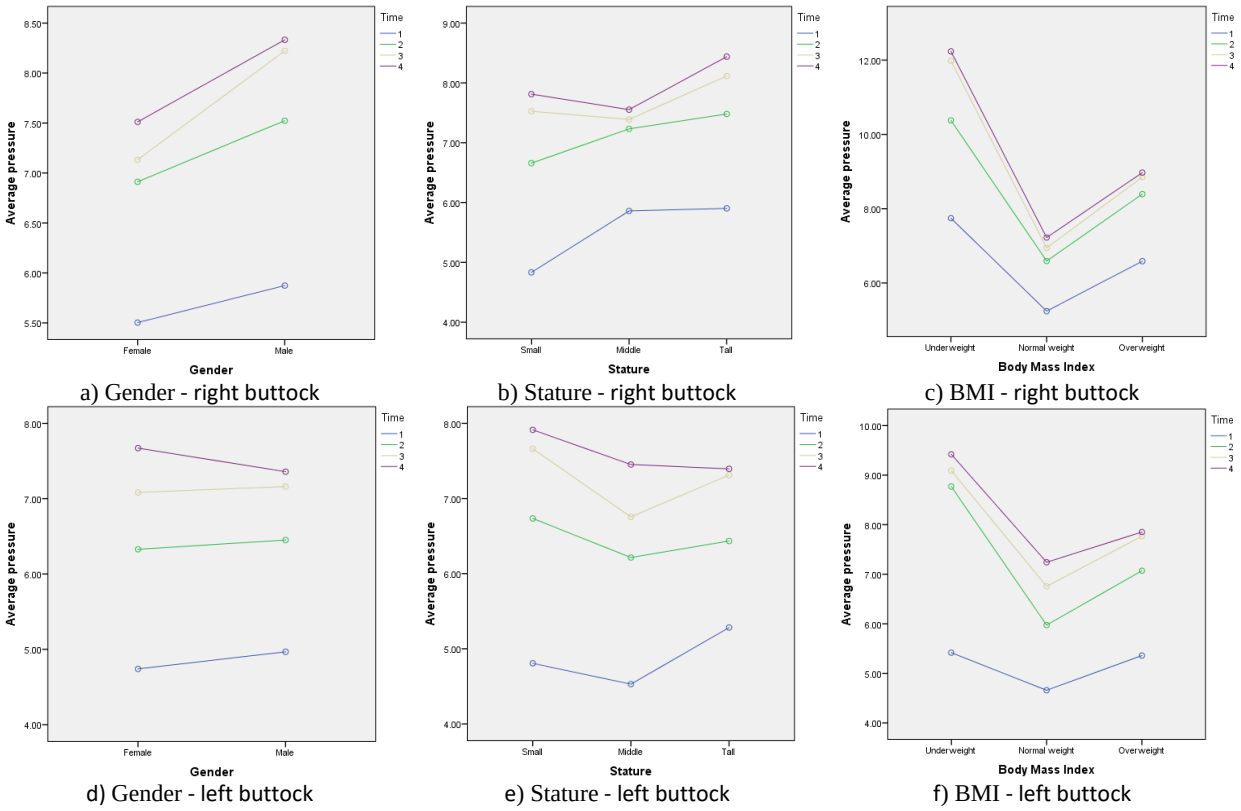
Taking into consideration the left buttocks the threshold value of the average pressure was reached during the initial recording – more than 10% for females and more than 25% of the male were having a higher pressure than the previously defined threshold value. During the 80^{th} and 120^{th} minute, more female participants were having more considerable pressure under the right buttocks than male participants (at 80^{th} minute – 75% female participants and 50% male participants; at 120^{th} minute – the same percentage frequency). The value of the average pressure for the 95 percentiles for the gender group was 7.5 kPa for females and 8.3 kPa for male participants. At the final recording, 5% of female participants were having a higher pressure than 12.7 kPa, while male participants were having greater than 12.9 kPa under the left buttocks area. Regarding the stature group, the difference in percentiles was obtained in the final recording. Pressure under the left buttocks higher for 95% small participants than 6.7 kPa, even though 50% of middle and tall participants were having grater pressure than 7.3 kPa at the same recording time.

What is more, the BMI group showed similar results with the underweight group as the small stature group. After the 40^{th} minute, 95% of participants had higher pressure than 6.2 kPa, while 50% of normal weight (6.0 kPa) and underweight (7.2 kPa) were having average greater pressure under the left buttocks. During the final recording, the same percentage was kept for underweight and normal weight population, as long as 75% of the overweight population had greater pressure than 6.4 kPa.

3.5.5 Changes of the average pressure distribution through the represented seat pan zones during the driving time

To determine the effect of the long-time driving on the distribution of average pressure, RM ANOVA was used. The multivariate test, considering the Wilks' Lambda, has shown that the time had a statistically significant effect of time on the average pressure distributed through the zones (defined in chapter 3.5.2) with $p<0.001$ (correlation is significant at the 0.05 level).

The figures 22, 23, and 24 are representing the visual differences of average pressures on the left/right buttocks, left/right upper thigh, and left/right lower thigh area during 120 minutes of the drive.



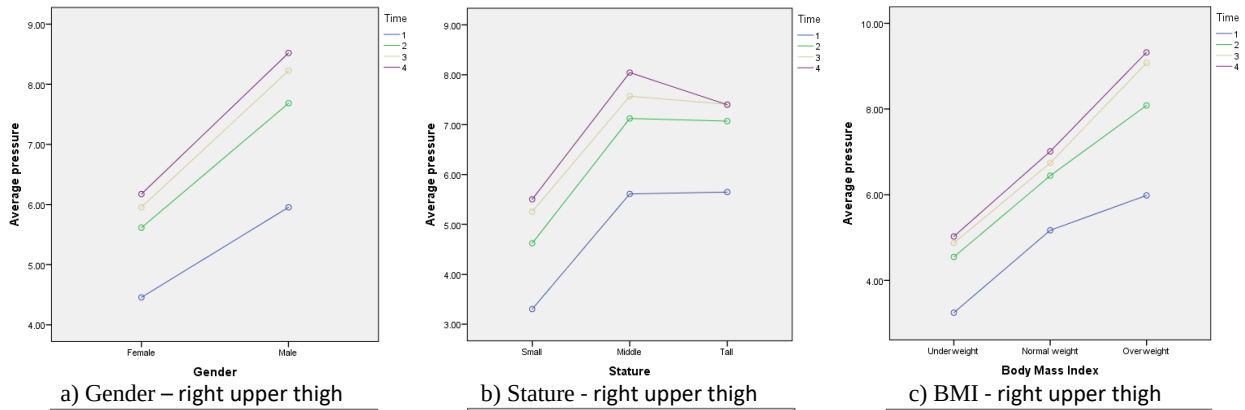
a) Gender - right buttock b) Stature - right buttock c) BMI - right buttock

d) Gender - left buttock e) Stature - left buttock f) BMI - left buttock

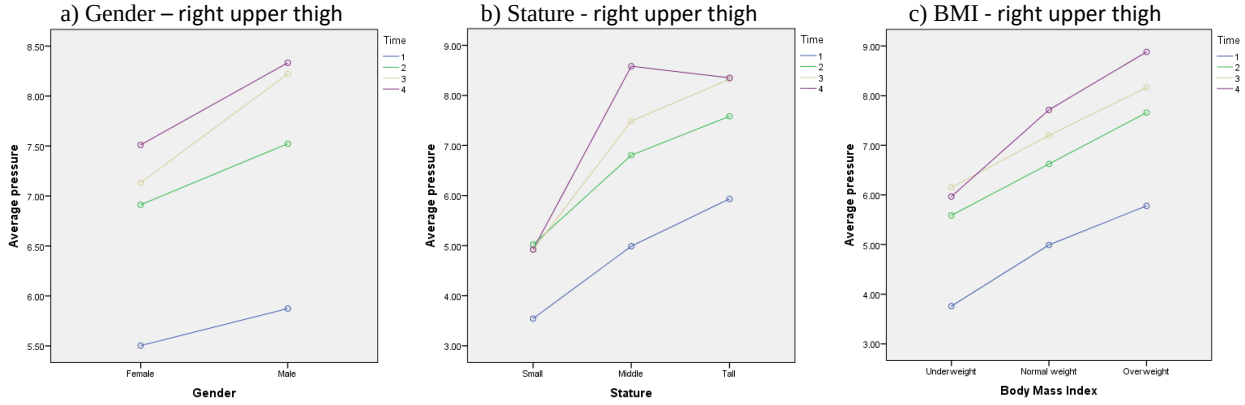
Figure 22. Changes in average pressure on the right and left buttocks area

Further statistical analysis (using Tukey's post hock analysis) it was conducted the test of between-subjects effect. The test has shown that the gender-based differences were affected and statistically significantly different at the right bolster ($p=0.006$, $p<0.05$), under the right upper thigh ($p=0.006$, $p<0.05$), left upper thigh ($p=0.006$, $p<0.05$), and under the left lower thigh ($p=0.006$, $p<0.05$).

Also, the average pressure defined by the stature group reported the statistically significant difference between the time sequences ($p<0.001$, $p<0.005$). Taking into consideration the test of between-subjects effects, the only statistically significant variation was reported under the left upper thigh ($p=0.002$, $p<0.05$). Additionally, smaller participants were reporting lesser average pressure values than the middle ($p=0.036$, $p<0.05$) and tall ($p=0.010$, $p<0.05$) participants.

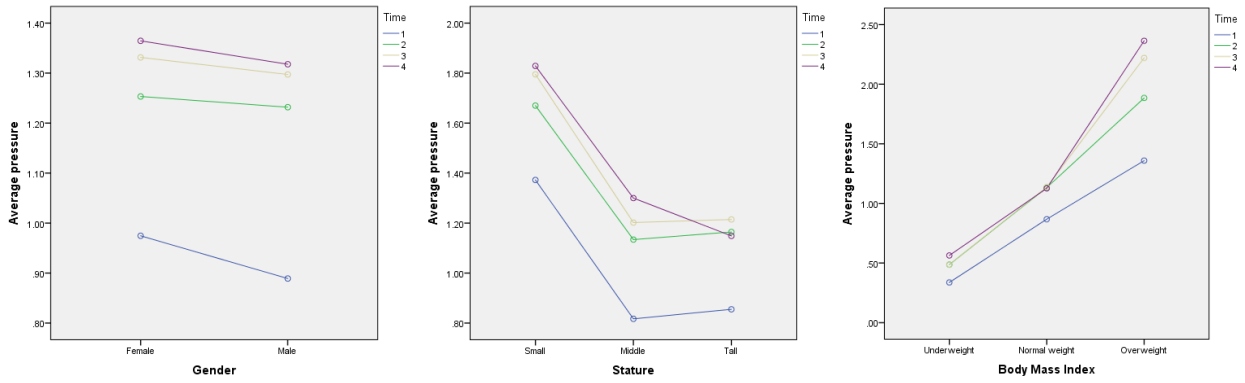


a) Gender – right upper thigh b) Stature - right upper thigh c) BMI - right upper thigh

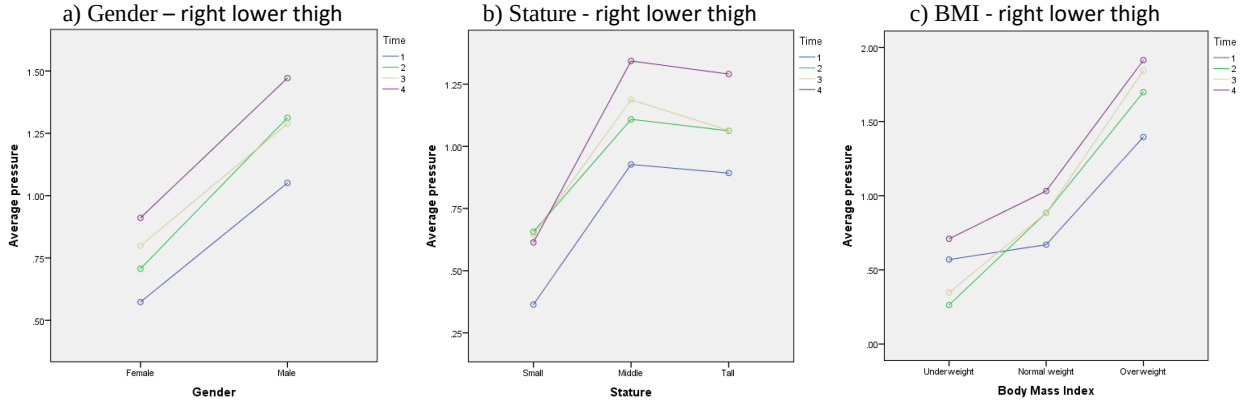


d) Gender - left upper thigh e) Stature - left upper thigh f) BMI - left upper thigh

Figure 23. Changes in average pressure on the right and left upper thigh area



a) Gender – right lower thigh b) Stature - right lower thigh c) BMI - right lower thigh



d) Gender - left lower thigh e) Stature - left lower thigh f) BMI - left lower thigh

Figure 24. Changes in average pressure on the right and left lower thigh area

Issue related between the time spends driving and applied average pressure on the driver's seat pan, the RM ANOVA test shown for the BMI group slightly different results than the rest. The

time involved changes in the average pressure at the almost all zones, expect the pressure under the left lower thigh ($p=0.144$, $p<0.05$). Additionally, the test of between-subject effect reported a statistically significant difference between the BMI groups.

3.5.6 Correlation between IP (by zones) and anthropometric variables

Mathematical association between IP variables (defined by zones) and participants' anthropometric attributes were correlated using Pearson's or Spearman's test (depending on data distribution). Tables 29 and 30 were compared to applied average pressure on the drivers' seat pan (by each zone separately) and obtained anthropometric measurements. In both tables, values above 0.5 were bolded regarding more comfortable notice stronger correlations.

Participants with the more extensive distances between anterior superior iliac bones and with a more considerable amount of body weight were applying higher average pressure on the seat pan bolsters. This correlation has been shown as strongly associated with both dependent variables (Table 29).

Table 29. Correlation between applied average IP of the seat pan zones and anthropometric attributes

Anthropometric attributes /Minute	Right Bolster				Left Bolster			
	5^{th}	40^{th}	80^{th}	120^{th}	5^{th}	40^{th}	80^{th}	120^{th}
Weight [kg]	**0.764****	**0.822****	**0.841****	**0.780****	**0.640****	**0.671****	**0.671****	**0.615****
Body height [cm]	0.435**	0.323*	0.335*	0.349*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
Anterior superior iliac [cm]	**0.633****	**0.710****	**0.682****	**0.652****	**0.532****	**0.553****	**0.592****	**0.547****

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant.

Additionally, weight is moderately correlated with higher pressure values under the left and right upper thigh (Table 30). Additionally, weight is moderately correlated with higher pressure values under the left and right upper thigh (Table 30). The same association is represented by more extensive distances between anterior superior iliac bones. Hip height and arms span were moderately correlated with a more considerable amount of the average pressure under the left upper thigh.

Left lower thigh were reporting higher average pressure values with participants with more kilograms (the statistically significant correlation was registered for the whole four recordings in rage from 0.372 to 0.544, $p<0.001$).

Participants with higher knee height were moderately associated with higher average pressure under the right buttocks (considering 120 minutes of steering the driving simulator in the range from 0.307 until 0.485, $p<0.001$) while under the left buttocks did not have any statistically significant correlation.

Hip height and arms span were moderately correlated with a more significant amount of the average pressure under the left upper thigh.

Left lower thigh were reporting higher average pressure values with participants with more kilograms (the statistically significant correlation was registered for the whole four recordings in rage from 0.372 to 0.544, $p<0.001$).

Participants with greater knee height were moderately associated with higher average pressure under the right buttocks (considering 120 minutes of steering the driving simulator in the range from 0.307 until 0.485, $p<0.001$) while under the left buttocks did not have any statistically significant correlation.

Table 30. Association between applied average IP under the upper thighs and anthropometric variables

	Right upper thigh				Left upper thigh			
Anthropometric attributes /Minute	5th	40th	80th	120th	5th	40th	80th	120th
WE	0.412**	0.488**	**0.507****	**0.501****	**0.546****	**0.566****	**0.542****	0.487**
BH [cm]	0.353*	0.381*	*n.s.*	0.323*	**0.519****	**0.582****	**0.533****	0.453**
SH [cm]	0.302*	0.305*	*n.s.*	0.311*	0.413**	0.415**	0.313*	*n.s.*
AS [cm]	*n.s.*	0.361*	0.298*	0.298*	0.476**	**0.581****	**0.511****	0.435**
HH [cm]	*n.s.*	*n.s.*	*n.s.*	*n.s.*	0.397**	**0.509****	**0.525****	0.478**
BK [cm]	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	0.397**	0.439**	0.416**
ASI [cm]	0.352*	0.393**	0.435**	0.361*	0.451**	0.437**	0.449**	0.359*

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant., WE – weight, BE – body height; SH - Sitting height, AS - Arm span; HH - Hip height; BK - Buttock-knee length; ASI - Anterior superior iliac.

Table 31 describes the mathematical correlation between peak pressure and seat pans' bolsters. Table 31 can be seen that the participants with more kilograms and more considerable distances between anterior superior iliac bones were applying higher values of peak pressure on extreme horizontal seat pans' areas.

Table 31. Correlation between applied average IP under the bolsters and anthropometric variables

	Right Bolster				Left Bolster			
Anthropometric attributes /Minute	5th	40th	80th	120th	5th	40th	80th	120th
Weight [kg]	**0.503****	**0.624****	**0.684****	**0.676****	0.341*	**0.575****	**0.584****	**0.499****
Anterior superior iliac [cm]	*n.s.*	0.369*	0.451**	0.378*	0.460**	**0.622****	**0.527****	**0.526****

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant.

Table 32 clarifies the mathematical association among the applied contact area and seat pans' bolsters. As it was concluded for the dependent pressure variables (average pressure and peak pressure), it can be seen (Table 32) that the participants with more kilograms and more considerable distances between anterior superior iliac bones were applying more contact area on seat pans' bolsters.

Table 32. Correlation between contact area under the bolsters and anthropometric variables

Anthropometric attributes /Minute	Right Bolster				Left Bolster			
	5th	40th	80th	120th	5th	40th	80th	120th
Weight [kg]	**0.666****	**0.617****	**0.643****	**0.649****	**0.519****	**0.610****	**0.648****	**0.631****
Anterior superior iliac [cm]	**0.583****	**0.557****	**0.607****	**0.559****	0.383*	**0.521****	**0.546****	**0.534****

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level.

Table 33 is showing a correlation between the contact area and some of the anthropometric attributes. A strong, statistically relevant correlation was found between people with more kilograms and higher values of the contact area under the left and right upper thighs.

On the other hand, people with higher stature and more full anterior superior iliac bones had a moderate correlation with applied contact area under the upper thighs. Additionally, higher values of body weight were having affecting the left lower thigh contact area (considering four recording sequences the values were in the range from 0.309 until 0.532, $p<0.001$).

Table 33. The link between the contact area and some of the anthropometric attributes

Anthropometric attributes /Minute	Right upper thigh				Left upper thigh			
	5th	40th	80th	120th	5th	40th	80th	120th
Body height [cm]	0.337*	0.364*	*n.s.*	0.332*	0.458**	0.439**	0.395**	*n.s.*
Weight [kg]	**0.674****	**0.751****	**0.716****	**0.759****	**0.637****	**0.619****	**0.632****	**0.462****
Anterior superior iliac [cm]	**0.531****	**0.585****	**0.536****	**0.554****	**0.591****	**0.547****	**0.535****	0.327*

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant.

3.5.7 Correlation between IP (by zones) and reported discomfort

To establish a mathematical relationship between IP variables and reported discomfort during steering the driving simulator it was separately applied the test for normal (Pearson's test) and not normal (Spearman's test) data distribution. Recorded dependent pressure variables and reported discomfort were correlated for each time (at 5th, 40th, 80th, and 120th minute) sequences separately. Analyzed results did not show a strong, statistically significant correlation between the variables.

During the 40th minute of the driving process, a weak positive interrelationship between upper back discomfort and left upper thigh area was reported (r_s=0.335, $p<0.05$). Weak negative correlations were reported at 80th minute between shoulder pain and right upper thigh (r_s=-0.375, $p<0.05$) and at 120th-minute shoulder discomfort was again weak associated with right upper thigh (r_s=-0.333, $p<0.05$).

Only one positive moderate correlation was obtained among neck pain and left buttocks area (r_s=0.415, $p<0.001$) at the 80th minute of the driving.

3.5.8 Correlation between IP (by zones) and preferred interior dimensions

To determine a mathematical relationship between IP variables and preferred interior dimensions, nonparametric Spearman's test was applied. The dependent pressure variables (for every time sequence) were correlated with preferred backrest angles and horizontal and vertical distances inside the vehicle. Analyzed results did not indicate a strong, statistically significant correlation between the before mentioned variables.

A moderate positive correlation was obtained between horizontal distances (hip to heel, and hip to steering wheel points) and contact area at the upper left thigh (r_s=0.407, p<0.001). Correlating average pressure with the preferred interior dimensions showed a more moderate correlation than the contact area. Positive mathematical association between average pressure at the left buttocks (at the initial recording) and hip to heel (as well as hip to the steering wheel) were obtained (r_s=0.425, p<0.001). Average pressure under the left upper thigh and preferred horizontal distances illustrated moderate positive correlation at the initial recording (r_s=0.468, p<0.001), following at 40th (r_s=0.473, p<0.001) and at 80th (r_s=0.422, p<0.001) minute.

3.6 Preferred driving postures during

PDP, and the changes of 3D angles flexion/extensions during long-time driving, are illustrated in Figure 25. In Figure 25 are represented values for minimum, maximum, and average adopted angles during two hours of steering the driving simulator. The represented results are referring to the total sample size. For a more straightforward observation, Figure 25 is divided into six parts, where each part was representing changes of adopted driving angles during the recording time sequences (at 5th, 40th, 80th, and 120th minute).

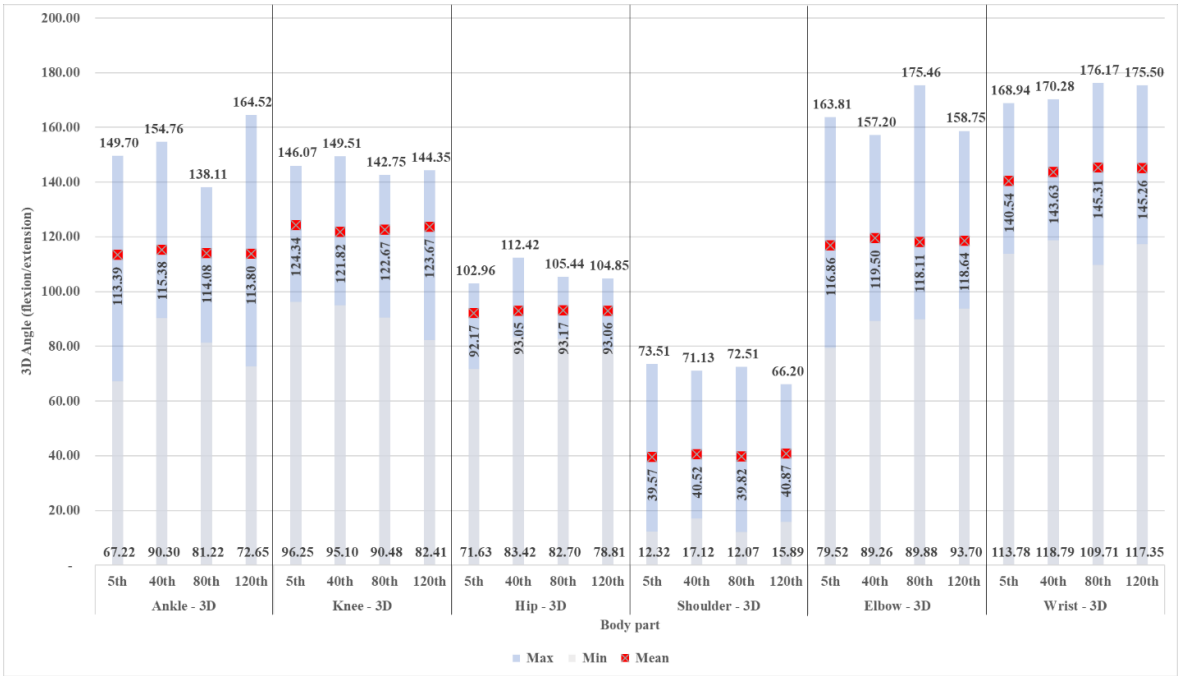


Figure 25. Drivers' joint angles (Flexion/Extension) during long-time driving

To define if the long-time driving affected PDP, it was performed the nonparametric Friedman's test or parametric RM ANOVA test, depending on the data distribution. Both tests were considering the sample size, and, in this case, the between-subject effect was not applied. The results indicated that the time did not have a statistically significant effect on the PDP.

Changes of main joint angles, by each group (gender, stature, and BMI) are illustrated in Table 34. The results are representing a mean value (with the standard deviation) per each recording. Moreover, next to groups are placed p ($p<0.05$) which was obtained using either parametric Independent t-test or nonparametric Mann-Whitney U test.

As Table 34 demonstrated, the statically significant difference was not obtained in the lower limbs among the gender group. The only considerable change has occurred in the upper limb main joint angles (precisely in the shoulder – $p=0.013$, $p<0.05$; and elbow $p=0.004$, $p<0.05$) at the final recording. After 120 minutes of steering the driving simulator, the male population tended to adopt more extended upper limb angles (more open posture) than the female population.

The stature group differs in the preferred ankle joint angle at the 40^{th} minute of the driving. Reminding joint angles and the time sequences did not show any statistically significant differences.

What is more, the BMI group did not vary in the adopted driving postures during the long-time driving.

Table 34. Preferred driving joint angles represented by groups

		Gender			Stature				BMI			
		Female	Male		Small	Middle	Tall		UW	NW	OW	
Joint angle	Min.	Mean [˚]	Mean [˚]	*p*	Mean [˚]	Mean [˚]	Mean [˚]	*p*	Mean [˚]	Mean [˚]	Mean [˚]	*p*
Ankle	5th	114.5 ±13.5	112.3 ±16.7	*n.s.*	111.9 ±14.8	115.2 ±17.3	111.9 ±12.0	*n.s*	114.4 ±8.5	111.5 ±16.4	119.9 ±9.8	*n.s.*
	40th	119.0 ±14.3	111.8 ±12.7	*n.s.*	120.6 ±15.4	117.0 ±12.6	108.5 ±12.8	***0.027***	115.7 ±15.7	113.1 ±13.6	123.3 ±13.1	*n.s*
	80th	116.3 ±13.4	111.8 ±12.2	*n.s.*	111.2 ±14.2	117.8 ±12.6	110.9 ±11.5	*n.s*	118.6 ±13.7	112.9 ±13.5	116.7 ±11.1	*n.s*
	120th	117.7 ±15.4	109.9 ±14.0	*n.s.*	116.3 ±19.7	114.0 ±16.0	111.4 ±8.7	*n.s*	114.3 ±10.6	112.7 ±15.3	117.7 ±16.6	*n.s*
Knee	5th	124.9 ±11.0	123.8 ±11.0	*n.s.*	122.6 ±10.7	126.6 ±9.8	122.3 ±12.7	*n.s*	123.6 ±7.1	124.0 ±11.9	125.9 ±8.4	*n.s*
	40th	120.7 ±15.2	123.0 ±10.6	*n.s.*	115.8 ±16.8	126.1 ±11.1	120.3 ±10.3	*n.s*	123.4 ±4.5	120.9 ±13.5	124.7 ±13.6	*n.s*
	80th	119.4 ±15.6	125.9 ±8.6	*n.s.*	116.0 ±15.1	124.9 ±12.4	125.0 ±10.2	*n.s*	124.9 ±1.7	121.7 ±13.2	125.4 ±13.9	*n.s*
	120th	120.3 ±16.3	126.9 ±8.4	*n.s.*	119.8 ±11.8	123.2 ±16.5	127.7 ±6.9	*n.s*	128.7 ±2.4	122.7 ±14.6	125.3 ±10.1	*n.s*
Hip	5th	93.1 ±6.3	91.3 ±6.3	*n.s.*	94.6 ±5.6	92.2 ±5.5	90.0 ±7.6	*n.s*	88.8 ±3.2	92.2 ±6.9	93.1 ±4.9	*n.s*
	40th	93.0 ±5.8	93.1 ±6.3	*n.s.*	93.7 ±6.1	93.7 ±6.8	91.4 ±4.7	*n.s*	87.4 ±1.4	93.1 ±6.2	94.6 ±5.6	*n.s*
	80th	93.4 ±5.8	92.9 ±6.0	*n.s.*	95.2 ±6.0	93.3 ±5.7	91.3 ±5.9	*n.s*	89.8 ±1.4	92.9 ±5.9	95.1 ±6.4	*n.s*
	120th	93.8 ±7.3	92.3 ±5.4	*n.s.*	97.0 ±6.0	92.0 ±6.8	91.4 ±5.0	*n.s*	89.4 ±3.1	93.0 ±6.9	94.4 ±4.8	*n.s*
Shoulder	5th	41.1 ±13.2	38.0 ±9.0	*n.s.*	40.2 ±15.0	40.7 ±9.7	37.3 ±10.5	*n.s*	45.5 ±4.7	39.2 ±10.5	39.0 ±15.2	*n.s*
	40th	40.8 ±14.2	40.0 ±11.3	*n.s.*	40.2 ±16.0	39.1 ±12.7	43.0 ±9.9	*n.s*	46.3 ±5.5	40.5 ±13.6	38.7 ±11.4	*n.s*
	80th	37.7 ±13.8	41.9 ±14.4	*n.s.*	37.4 ±14.8	37.5 ±12.3	45.5 ±15.6	*n.s*	32.0 ±8.3	40.8 ±14.1	38.8 ±15.9	*n.s*
	120th	36.4 ±12.7	45.4 ±10.1	***0.013***	32.6 ±13.3	40.4 ±10.0	48.5 ±10.3	*n.s*	50.9 ±13.9	40.5 ±12.7	38.9 ±9.4	*n.s*
Elbow	5th	116.0 ±19.3	117.7 ±14.3	*n.s.*	116.3 ±21.5	114.4 ±15.0	121.1 ±15.6	*n.s*	118.7 ±7.0	116.4 ±15.1	117.7 ±24.8	*n.s*
	40th	116.6 ±16.0	122.4 ±15.7	*n.s.*	116.6 ±14.5	116.1 ±16.0	127.2 ±15.4	*n.s*	122.0 ±7.6	119.8 ±16.0	117.7 ±18.8	*n.s*
	80th	113.7 ±17.5	122.5 ±20.7	*n.s.*	114.5 ±17.8	113.1 ±15.3	128.8 ±23.3	*n.s*	106.2 ±1.7	118.4 ±19.0	121.2 ±23.8	*n.s*
	120th	112.1 ±15.0	125.2 ±15.0	***0.004***	109.0 ±13.6	115.3 ±13.1	132.1 ±14.8	*n.s*	125.9 ±11.7	118.4 ±16.8	117.1 ±16.1	*n.s*
Wrist	5th	142.0 ±15.1	139.1 ±13.2	*n.s.*	138.0 ±14.8	145.9 ±13.4	134.4 ±12.3	*n.s*	151.1 ±10.5	141.7 ±13.1	133.0 ±16.2	*n.s*
	40th	144.6 ±13.0	142.7 ±11.4	*n.s.*	147.6 ±11.8	145.2 ±13.5	138.0 ±8.4	*n.s*	144.8 ±10.1	143.6 ±12.1	143.3 ±14.0	*n.s*
	80th	144.2 ±16.8	146.5 ±14.2	*n.s.*	141.9 ±18.6	146.7 ±14.9	146.0 ±14.0	*n.s*	141.4 ±14.9	148.2 ±15.7	136.4 ±11.8	*n.s*
	120th	143.9 ±12.5	146.6 ±12.5	*n.s.*	142.0 ±12.0	150.1 ±13.3	140.6 ±9.0	*n.s*	149.3 ±13.7	145.6 ±13.2	142.9 ±9.9	*n.s*

Min. – Minute; p – the statistical difference between the groups; n.s. – Not significant; correlation is significant at the 0.05 level; ± – Standard deviation; UW – Underweight; NW – Normal weight; OW – Overweight.

3.6.1 Correlation between driving angles

Defining a mathematical correlation between the preferred joint angles during the long-time driving the bivariate correlations (Pearson's and Spearman's) were used.

Table 35 is introducing the correlation between the two lower limb joint angles – knee and hip, and their correlation between the time sequences. A correlation between the beforementioned variables and ankle did not occur, and it was excluded for Table 35.

A strong positive correlation was reported (Table 35) for preferred knee angles between 40th and 80th (rs=0.738, p<0.001) and as well as 80th and 120th (rs=0.724, p<0.001) minute of driving. Participants adopted posture kept the knee angles after the 40th minute until the end of the driving process.

Taking into consideration preferred hip angles, participants were showing a strong positive association between the initial recording and the final recording (r_s=0.659, p<0.001).

Table 35. Correlation between knee and hip during the long-time driving

Joint angle		Knee				Hip			
	Min.	5th	40th	80th	120th	5th	40th	80th	120th
Knee	5th	1.000							
	40th	0.494**	1.000						
	80th	**0.527****	**0.738****	1.000					
	120th	0.461**	**0.670****	**0.724****	1.000				
Hip	5th	**0.642****	n.s.	n.s.	0.299*	1.000			
	40th	0.380*	0.475**	0.404**	0.383*	**0.632****	1.000		
	80th	0.335*	n.s.	0.360*	n.s.	**0.611****	**0.542****	1.000	
	120th	n.s.	n.s.	n.s.	0.419**	**0.659****	**0.631****	**0.687****	1.000

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant.

Table 36 is illustrating the relationship between the shoulder and elbow joint angles during the long-time driving. What is more, correlations between joint angles are represented as well.

As it might be seen from table 36, a moderate positive correlation between shoulder joint angles during the long-time driving happened (with the r_s rage from 0.519 until 0.569, p<0.001). A strong positive correlation was reported for the elbow joint angle during 120 minutes of driving (with the r_s rage from 0.666 until 0.691, p<0.001).

The first forty minutes of driving has a strong association between shoulder and elbow angles. Participants with the grater joint angles continue to adopt more extensive joint angles after eight minutes and continue until the end of the driving process (the very strong relationship was in the range among 0.812 and 0.876, p<0.001).

Table 36. Correlation between shoulder and elbow during the long-time driving

Joint angle		Shoulder				Elbow			
	Min.	5th	40th	80th	120th	5th	40th	80th	120th
Shoulder	5th	1.000							
	40th	**0.519****	1.000						
	80th	0.372*	**0.525****	1.000					
	120th	0.308*	**0.535****	**0.569****	1.000				
Elbow	5th	**0.766****	0.489**	**0.590****	0.397**	1.000			
	40th	0.375*	**0.760****	**0.522****	**0.505****	**0.666****	1.000		
	80th	*n.s.*	0.449**	**0.876****	0.459**	**0.651****	**0.670****	1.000	
	120th	*n.s.*	0.419**	**0.566****	**0.812****	**0.532****	**0.675****	**0.691****	1.000

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant.

3.6.2 Correlation between preferred driving postures and anthropometric attributes

Correlation between participant's anthropometric characteristics and PDP (for each time recoding) were performed using bivariate parametric and nonparametric tests (Pearson's and Spearman's).

The results have shown a moderate negative relationship along with adopted hip angles, at initial recording, and knee height (r_s=-0.429, p<0.001). Furthermore, participants with higher stature, sitting height, and arms span showed a moderate positive correlation with larger shoulder angles (shoulder r_s=0.443; sitting height r_s=0.446; arm span r_s=0.416; p<0.001).

3.6.3 Correlation between preferred driving postures and seat adjustments

Spearman's correlation was used to determine the effect of preferred vehicle interior dimensions on driving postures. The correlation was applied for every joint angle for each recording time separate. The results have shown that a positive correlation was established between horizontal points (hip to heel, and hip to the steering wheel) and larger shoulder (r_s=0.406, p<0.001) and elbow (r_s=0.578, p<0.001) angles at the end of the driving period. Additionally, chosen seat backrest angles were influencing participants to adopt greater joint angles (shoulder r_s=0.412, and elbow r_s=0.585; p<0.001) at the 120th minute.

3.6.4 Correlation between preferred driving postures and reported discomfort

Association between adopted driving postures and reported discomfort were analyzed by nonparametric (Spearman's) test using SPSS®. The findings did not indicate any statistically significant correlation between the beforementioned dependent variables.

3.6.5 Correlation between preferred driving postures and seat pan IP

Applied IP by the total seat pan area

The mathematical correlation was performed considering the IP of the total area and chosen joint angle for each time sequence. If a correlation existed between the different time sequences (analyzing the IP and adopted driving strategies), the correlation was not considered.

During the initial recording (correspond for the 5th minute) a moderate negative correlation was established among participants with lower hip joint angles and higher peak pressure of the total seat pan area (r_s=-0.430, p<0.001). What is more, applied average pressure on the total seat pan and hip angles reported a moderate negative association between two dependent variables. At the final recording, participants with the lower hip joint angles, again, were having higher applied peak pressure on the seat pan (the correlation was moderate, where r_s=-0.425, p<0.001).

The initial recording showed a positive mathematical correlation between participants with knee extension and higher total contact is on the driver's seat pan (r_s=0.401, p<0.001).

Applied IP divided by zones

To establish a mathematical correlation between the lower limbs' areas and PDP, the nonparametric Spearman's, and parametric Pearson's test was performed. The correlation was performed between each lower limb area and the main joint angle separately (taking into consideration search time recording separately, as same as with the total area).

A moderate positive association was settled among preferred driving angles and applied IP for each lower limbs' zones. The correlation was between extended angles and higher values of IP under the left lower thigh (rs=0.485, p<0.001) during the 80th minute. The correlation was indicated at the final recording as well (r_s=0.478, p<0.001).

A moderate negative correlation was established between greater values of applied peak IP and flexed knee angles (*rs*=-0.414, p<0.001). The same tendency was shown among higher peak IP and flexed hip angles (*rs*=-0.450, p<0.001). Furthermore, participants with hip flexed joint angles were applying higher pressure under the left buttock area (the association was moderate and negative, r_s=-0.489, p<0.001). At the second recording, the correlation was established between hip extended joint angles and huger values on peak pressure under the left upper thigh (r_s=0.409, p<0.001).

During the long-time driving, participants with more open knee angles were covering the higher area under the left lower thigh. The association between two dependent variables during the time has a moderate and strong correlation. At the initial recording the association is moderate (r_s=0.473, p<0.001), following, the second recoding reported strong correlation (r_s=0.652, p<0.001), while the third (r_s=0.522, p<0.001) and fourth (r_s=0.539, p<0.001) recording reported again moderate positive correlation. Additionally, hip joint angles illustrated similar mathematical correlation. Participants with more extension in the hip angle were covering higher are under the left lower thigh. The correlation was weak (r_s=0.393, p<0.001) at the 5th minute, but at the 40th minute the association was positive and moderate (r_s=0.561, p<0.001), following 80th (r_s=0.335,

p<0.001) and 120th (r_s=0.435, p<0.001) minute reported correlation between two dependent variables. Moreover, higher hip angles had a moderate positive correlation with the higher area under the left upper thigh (r_s=0.405, p<0.001) at the final recording.

3.7 Evolution of sitting strategies during long-time driving

Determination of PDP during long-time driving was grouped using a hierarchical clustering method. Each period defines three subgroups founded on its similarities/dissimilarities based on the adopted joint angle and pressure distribution on the driver's seat pan.

Table 37 displays the number of the participants belong to the cluster subgroups, starting from the initial and follow by the rest time recording. For more straightforward observation and analysis, different driving strategies were represented by participants attribute (gender, stature, BMI).

Table 37. Description of clusters datasets by subgroups

			Gender		Stature			BMI		
Time	Cl. No.	Total	Female	Male	Small	Middle	Tall	Underweight	Normal Weight	Overweight
5th										
	Cluster 1	14	9	5	5	3	6	0	10	4
	Cluster 2	22	12	10	3	12	7	3	18	1
	Cluster 3	8	1	7	0	5	3	0	4	4
40th										
	Cluster 4	12	3	9	1	7	4	0	7	5
	Cluster 5	18	8	10	3	8	7	2	13	3
	Cluster 6	14	11	3	4	5	5	1	12	1
80th										
	Cluster 7	9	4	5	0	5	4	0	8	1
	Cluster 8	20	14	6	6	11	3	3	15	2
	Cluster 9	15	4	11	2	4	9	0	9	6
120th										
	Cluster 10	18	2	16	0	8	10	0	14	4
	Cluster 11	5	3	2	1	3	1	2	3	0
	Cluster 12	21	17	4	7	9	5	1	15	5

Cl. No. – Cluster Number, BMI – Body Mass Index

Table 38 is describing adopted driving angles separated into four different time sequences. Each of the series is characterized by three subgroups created by Wards' method.

The clusters were composed of 14 dependent variables (main joint angles and average pressure distribution of the seat pan zones – previously defined in the method part). Created clusters at the initial recording were defined as following: cluster 2 were having smaller lower limbs main joint angles (ankle, knee, and hip) than the rest two clusters, while the adopted angles of the upper extremities have varied only in the wrist angle between the clusters (participants represented by the second cluster were positioning hand on the driving wheel with the smaller writ angle than the first and third cluster). The clusters number 1, 2, and 3 were not having statistically significant difference considering applied pressure under the left and right buttock. The rest are on the lower limbs (left/right side of the upper/lower thigh and left and right bolster of the seat pan) One Way ANOVA reported statistically substantial variation among the subgroups.

The second recording (corresponding to 40th minute of the drive period) is having more equally distributed of cluster datasets compared to the initial recording. The difference of the driving strategies is mirrored in the knee, hip, and elbow joint angles between the 4th, 5th, and 6th cluster. Flexed lower limbs, as well as elbow, angles were defined by 6th cluster, while the 4th and 5th were represented by more extend/open joint angles. On the other hand, the statistically significant difference between the groups (at the 40th minute) was reported for the area of all lower limb except the left bolster where the difference was not significant. It should be noted that the cluster 5 is having the highest average pressure under the left and right buttocks, while left and upper thigh was showed that cluster number 4 registered with the more excellent value than the cluster 5 and 6.

Table 38. Description of preferred driving angles by clusters

		Joint angel					
Time	Cluster No.	Ankle	Knee	Hip	Shoulder	Elbow	Wrist
5th							
	Cluster 1	118.9 ± 7.6	131.4 ± 7.7	95.5 ± 5.6	39.5 ± 15.0	120.7 ± 22.4	129.9 ± 12.9
	Cluster 2	106.2 ± 14.4	118.5 ± 9.5	89.8 ± 6.6	39.2 ± 8.8	112.9 ± 11.7	146.1 ± 11.5
	Cluster 3	123.4 ± 17.9	128.1 ± 11.2	92.8 ± 3.6	40.6 ± 11.3	121.0 ± 17.1	143.8 ± 13.3
	p - difference	***0.003***	***0.001***	***0.024***	*n.s.*	*n.s.*	***0.001***
40th							
	Cluster 4	108.4 ± 12.3	126.1 ± 11.5	95.2 ± 7.1	39.5 ± 14.0	122.1 ± 17.2	138.8 ± 13.3
	Cluster 5	118.0 ± 12.5	129.3 ± 8.5	94.7 ± 4.2	44.7 ± 10.4	125.8 ± 13.8	142.2 ± 12.1
	Cluster 6	117.9 ± 15.6	108.5 ± 8.0	89.0 ± 5.2	36.0 ± 13.3	109.2 ± 13.0	149.6 ± 9.1
	p - difference	*n.s.*	***<0.001***	***0.006***	*n.s.*	***0.009***	*n.s.*
80th							
	Cluster 7	101.9 ± 9.7	121.4 ± 17.6	99.2 ± 4.9	30.1 ± 12.5	109.5 ± 8.9	148.2 ± 8.7
	Cluster 8	121.6 ± 10.9	125.4 ± 8.4	92.7 ± 5.4	42.3 ± 15.1	121.2 ± 24.4	141.4 ± 18.8
	Cluster 9	111.4 ± 10.6	119.9 ± 14.6	90.2 ± 4.5	42.3 ± 11.5	119.2 ± 15.5	148.8 ± 12.8
	p - difference	***<0.001***	*n.s.*	***<0.001***	*n.s.*	*n.s.*	*n.s.*
120th							
	Cluster 10	108.0 ± 14.3	127.1 ± 11.9	92.8 ± 5.7	46.0 ± 9.1	126.2 ± 14.9	146.7 ± 13.5
	Cluster 11	111.6 ± 8.6	127.3 ± 10.1	88.9 ± 6.1	60.2 ± 4.3	133.3 ± 17.2	156.1 ± 16.0
	Cluster 12	119.3 ± 15.5	119.9 ± 14.3	94.3 ± 6.8	31.9 ± 6.8	108.7 ± 10.4	141.5 ± 8.9
	p - difference	*n.s.*	*n.s.*	*n.s.*	***<0.001***	***<0.001***	***0.046***

Cluster No. – Cluster number, ± – Standard deviation, correlation is significant at the 0.05 level, n.s. – Not significant; p – the statistical difference between the groups.

District subgroups were identified with a slight difference in the driving strategies at the 80th minute of the driving process. The three clusters (7th, 8th, and 9th) were termed as all clusters before (at initial and second recording). One Way ANOVA indicated that in the majority of the joint angles did not exit any significant differences among the cluster. The difference was shown in the angle and hip joint angle, where the cluster 7 were having an extent angle in the hip and flexed ankle angle than the 8th and 9th cluster.

The final recording occurred at the 120th minute, and driving posture was classified into three clusters, as the earlier time sequences. The One Way ANOVA has shown that the defined driving postures, taking into consideration the lower limbs angles, did not differ between the cluster at the beforementioned driving time. Besides, preferred joint angles of the upper limbs were different among the clusters (10th, 11th, and 12th), where cluster 11 adopted extend shoulder, elbow, and wrist angles. Moreover, average pressure under the left and right buttocks prompted not

statistically different as well as the right lower thigh, although the remaining lower limbs areas were statistically significantly different between the clusters at the final recording.

Average pressure distribution on the driver's seat pan is illustrated in Table 39. Table 39 detailed average pressure distribution for each cluster separately and as well as for each time sequences.

Table 39. Description of applied average pressure by clusters

		Right				Left			
Time	Cluster	Bolster	Buttock	Upper thigh	Lower thigh	Bolster	Buttock	Upper thigh	Lower thigh
5th									
	Cluster 1	2.2 ± 0.9	5.8 ± 2.4	4.1 ± 1.6	1.1 ± 0.6	1.7 ± 0.9	5.1 ± 1.2	4.1 ± 1.7	0.8 ± 0.5
	Cluster 2	1.8 ± 0.7	6.0 ± 1.6	4.9 ± 1.7	0.6 ± 0.4	1.2 ± 0.6	5.1 ± 1.5	4.9 ± 1.9	0.4 ± 0.4
	Cluster 3	2.9 ± 0.9	4.6 ± 2.1	8.0 ± 1.7	1.5 ± 0.6	2.3 ± 1.4	3.8 ± 2.3	7.3 ± 0.8	1.9 ± 0.7
	p - difference	***0.008***	*n.s.*	***<0.001***	***<0.001***	***0.003***	*n.s.*	***<0.001***	***<0.001***
40th									
	Cluster 4	3.5 ± 1.0	5.7 ± 2.4	9.1 ± 2.2	2.0 ± 0.5	2.8 ± 1.7	4.7 ± 2.2	9.0 ± 2.3	2.0 ± 0.9
	Cluster 5	2.8 ± 1.0	8.8 ± 2.3	5.6 ± 2.2	0.9 ± 0.6	2.1 ± 1.1	8.0 ± 1.6	5.9 ± 1.8	0.8 ± 0.5
	Cluster 6	2.2 ± 0.8	6.4 ± 1.9	6.0 ± 1.9	1.1 ± 0.6	1.7 ± 1.1	5.8 ± 1.8	6.0 ± 2.4	0.4 ± 0.3
	p - difference	***0.004***	***0.001***	***<0.001***	***<0.001***	*n.s.*	***<0.001***	***0.001***	***<0.001***
80th									
	Cluster 7	3.0 ± 0.6	5.1 ± 2.0	9.2 ± 3.1	1.6 ± 0.3	1.7 ± 1.0	3.9 ± 2.2	8.3 ± 2.3	1.7 ± 0.8
	Cluster 8	2.1 ± 0.7	8.0 ± 2.9	5.2 ± 1.8	1.0 ± 0.6	1.4 ± 0.7	7.7 ± 2.2	5.4 ± 1.6	0.5 ± 0.3
	Cluster 9	4.0 ± 1.3	8.7 ± 2.1	8.3 ± 2.3	1.6 ± 1.2	3.6 ± 1.3	8.3 ± 2.2	9.3 ± 2.6	1.4 ± 1.3
	p - difference	***<0.001***	***0.004***	***<0.001***	*n.s.*	***<0.001***	***<0.001***	***<0.001***	***0.002***
120th									
	Cluster 10	3.8 ± 1.5	7.4 ± 3.3	9.7 ± 2.6	1.6 ± 1.1	3.0 ± 1.8	6.5 ± 3.4	10.4 ± 3.2	1.8 ± 1.3
	Cluster 11	1.6 ± 0.4	10.0 ± 4.4	3.9 ± 1.7	0.9 ± 0.8	0.9 ± 0.6	10.0 ± 1.9	4.6 ± 0.9	0.7 ± 0.6
	Cluster 12	2.9 ± 1.0	7.9 ± 2.2	6.2 ± 2.0	1.2 ± 0.7	2.3 ± 1.2	7.8 ± 2.6	6.4 ± 1.8	0.8 ± 0.6
	p - difference	***0.002***	*n.s.*	***<0.001***	*n.s.*	***0.016***	*n.s.*	***<0.001***	***0.003***

± - Standard deviation; p – the statistical difference between groups; correlation is significant at the 0.05 level; n.s. – Not significant.

3.8 Assessment of the gait variables between two different time cycles

In this section it was assessed gait spatiotemporal characteristics of the right lower limb, walking symmetry (including performances of both legs), and as well as applied plantar pressure and covered area during the walking performances. The obtained data were analyzed, compared, and examined by parametric and nonparametric statistical tests in the SPSS software. The two timelines were defined – before entering into the driving simulator (at the very beginning of the experimental process) and after a long-time driving (120 minutes of the driving procedure).

3.8.1 Gait Spatiotemporal parameters before and after long-time driving

Table 40 is proving results obtained by performances of the right lower limb during the previously defined time cycles. The outcomes are referring to spatiotemporal (time and distances) performed before and after steering the driving simulator and its relations. The connection between the two-time sequences as well as the difference between the subgroups is represented in tables 40 and 41).

Nevertheless, the statistically significant difference between the subjects did not occur. Table 40 is including mean outcomes with standard deviation achieved by SPSS® software for more accessible, straightforward analysis.

Table 40. Description of the linear gait kinematics before and after long-time driving

	Gait Time [s]		Gait Distance [cm]		Gait Velocity [cm/s]		Cadence [steps/min]	
	Before	After	Before	After	Before	After	Before	After
Total	1.5 ± 0.3	1.4 ± 0.3	132.5 ± 13.9	134.2 ± 12.6	93.5 ± 12.6	96.9 ± 15.3	102.2 ± 8.1	105.4 ± 9.9
Gender								
Female	1.5 ± 0.3	1.4 ± 0.3	134.6 ± 13.8	135.8 ± 11.8	93.3 ± 13.5	97.6 ± 18.5	103.9 ± 8.6	107.7 ± 11.4
Male	1.4 ± 0.3	1.4 ± 0.2	130.4 ± 14.0	132.6 ± 13.4	93.8 ± 12.0	96.2 ± 11.7	100.5 ± 7.4	103.0 ± 7.9
p value	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
Stature								
Small	1.5 ± 0.3	1.5 ± 0.4	130.9 ± 15.4	132.1 ± 15.2	89.5 ± 13.0	92.6 ± 17.3	100.6 ± 7.5	103.8 ± 7.9
Middle	1.4 ± 0.2	1.4 ± 0.3	135.2 ± 12.8	134.5 ± 10.8	96.6 ± 12.6	99.3 ± 14.6	104.5 ± 7.5	106.9 ± 10.2
Tall	1.4 ± 0.3	1.4 ± 0.3	130.0 ± 14.9	134.8 ± 14.0	91.6 ± 12.3	96.2 ± 15.6	100.1 ± 8.9	104.3 ± 10.9
p value	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
BMI								
UW	1.5 ± 0.3	1.5 ± 0.2	131.6 ± 19.6	137.1 ± 13.0	89.9 ± 6.0	91.7 ± 4.8	108.2 ± 7.9	110.9 ± 4.9
NW	1.4 ± 0.2	1.4 ± 0.3	133.3 ± 14.6	135.3 ± 12.6	95.8 ± 13.1	99.3 ± 16.1	102.5 ± 8.4	106.0 ± 10.7
OW	1.5 ±0.2	1.5 ± 0.3	130.1 ± 10.3	129.2 ± 12.6	86.6 ± 10.0	90.4 ± 12.9	99.0 ± 6.1	101.3 ± 7.2
p value	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*

± – Standard deviation; p – the statistical difference between groups; n.s. – not significant; correlation is significant at the 0.05 level.

Prolonged driving has influenced participants walking speed after two hours of steering the driving simulator. Gait velocity has increased for 3.6% considering the sample size, which has been shown as substantial ($t(43) = -2.883$, $p=0.006$) comparing the period between entering in the vehicle and finishing the driving process. What is more, gait velocity influenced that participants waling cadence increase ($t(43) = -2.542$, $p=0.015$) after the driving process for 3.1%.

Further, linear kinematics variables obtained by the performance of the right lower limb are illustrated in Table 41. Besides the descriptive illustration, mean values, standard deviation, and statistical variations between the subjects are represented for each variable (including the main groups). Moreover, the terminal double support time is represented using two decimals, comparting with the reset variables. For more straightforward observed of obtained differences, to represent the outcomes, two decimals were used.

Parametric Paired Sample t-test reported statistically significant changes in the total double support time $t(43) = 2.103$, $p=0.041$), taking into consideration the total number of the participants. Moreover, participants classified in the groups represented in Table 41, did not report any differences between the groups. The only difference has occurred in the step length were male participants were having lager step length of the right lower limb compared with the female after the long-time driving. Descriptive statistics, standard deviation, and between-subjects' differences for the gait cycle are illustrated in Table 41.

Table 41. Description of the gait cycle before and after long-time driving

	Gait cycle time [s]		Stance Time [s]		Double Support Time [s]		Step Length [cm]	
	Before	After	Before	After	Before	After	Before	After
Total	1.1 ± 0.4	1.1 ± 0.3	0.77 ± 0.07	0.75 ± 0.08	0.33 ± 0.06	0.32 ± 0.07	55.2 ± 5.2	56.0 ± 7.6
Gender								
Female	1.2 ± 0.1	1.1 ± 0.4	0.76 ± 0.08	0.73 ± 0.09	0.33 ± 0.06	0.32 ± 0.07	54.2 ± 6.0	54.1 ± 7.2
Male	1.0 ± 0.5	1.1 ± 0.3	0.78 ± 0.07	0.76 ± 0.07	0.33 ± 0.06	0.32 ± 0.07	56.2 ± 4.2	57.9 ± 7.6
p value	*n.s.*	*n.s.*	*n.s.*	***0.014***	*n.s.*	*n.s.*	*n.s.*	***0.031***
Stature								
Small	1.2 ± 0.1	1.2 ± 0.1	0.44 ±0.37	0.43 ±0.26	0.35 ±0.51	0.33 ±0.62	53.8 ± 4.1	53.5 ± 6.3
Middle	1.1 ± 0.4	1.1 ± 0.4	0.42 ±0.43	0.43 ±0.38	0.32 ±0.57	0.31 ±0.58	55.8 ± 6.3	56.5 ± 7.8
Tall	1.1 ± 0.4	1.1 ± 0.3	0.45 ±0.37	0.44 ±0.39	0.34 ± 0.64	0.32 ±0.83	55.2 ± 4.2	56.6 ± 8.2
p value	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
BMI								
UW	1.1 ± 0.1	1.1 ± 0.1	0.40 ±0.49	0.39 ±0.49	0.33 ±0.30	0.30 ±0.35	54.6 ± 12.1	58.6 ± 21.4
NW	1.1 ± 0.4	1.1 ± 0.4	0.44 ±0.41	0.43 ±0.36	0.32 ±0.56	0.31 ±0.73	55.7 ± 5.0	55.7 ± 5.9
OW	1.2 ± 0.1	1.2 ± 0.1	0.42 ±0.30	0.44 ±0.26	0.38 ±0.60	0.34 ±0.47	53.4 ± 2.5	56.34 ± 7.7
p value	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*

± – Standard deviation; p – the statistical difference between groups; n.s. – not significant; correlation is significant at the 0.05 level.

3.8.2 Effect of prolonged driving on gait symmetry

To determinate how long-time driving influenced the participant's gait symmetry, applied force and gait impulse were examined. Findings obtained by applied force during the walking performances, considering both lower limb and its differences, are illustrated in Table 42. Beside mean values, the standard deviation and between the subject's differences are included in Table 42.

To definitive if statistically significant changes were obtained between two different time sequences, considering each lower limb separately, Wilcoxon's nonparametric test was used. The test outcomes have indicated that variations between pre and post applied forces were not mathematically considerable.

Table 42. The applied force of both lower limbs during pre- and post-steering gait

	Force [N] - Left Leg		Force [N] - Right Leg		Force [N] - Difference	
	Before	After	Before	After	Before	After
Total	714.1 ± 177.2	718.9 ± 162.0	717.8 ± 150.6	722.2 ± 174.9	3.6 ± 74.7	3.2 ± 81.1
Gender						
Female	624.6 ± 93.8	635.2 ± 106.9	638.1 ± 81.1	631.1 ± 91.7	13.5 ± 71.6	-4.2 ± 79.0
Male	803.7 ± 196.8	802.6 ± 166.3	797.5 ± 162.9	813.2 ± 192.0	-6.3 ± 78.2	10.6 ± 84.3
p-value	***0.001***	***<0.001***	***<0.001***	***<0.001***	*n.s.*	*n.s.*
Stature						
Small	651.9 ± 110.5	689.2 ± 119.1	675.2 ± 95.0	691.5 ± 100.5	23.3 ± 35.2	2.3 ± 68.8
Middle	656.9 ± 129.1	652.6 ± 132.9	679.0 ± 121.0	671.9 ± 130.6	22.1 ± 78.4	19.3 ± 67.6
Tall	816.8 ± 213.6	816.8 ± 172.3	787.5 ± 184.7	800.4 ± 225.8	-29.3 ± 76.3	-16.4 ± 100.5
p-value	***0.031***	***0.014***	*n.s.*	*n.s.*	*n.s.*	*n.s.*
BMI						
UW	566.7 ± 66.2	565.4 ± 70.1	627.3 ± 71.8	601.9 ± 89.2	60.6 ± 10.7	36.5 ± 44.5
NW	669.1 ± 116.6	684.5 ± 121.9	671.8 ± 89.5	671.5 ± 110.6	2.6 ± 73.7	-13.0 ± 78.4
OW	923.4 ± 222.7	892.6 ± 186.5	911.5 ± 189.2	942.2 ± 211.9	-11.9 ± 86.3	49.7 ± 84.6
p-value	***0.001***	***0.002***	***0.001***	***0.001***	*n.s.*	*n.s.*

± – Standard deviation; p – the statistical difference between groups; BMI – Body mass index; n.s. – not significant; correlation is significant at the 0.05 level.

Nevertheless, groups-based differences have been obtained. Male participants were applying greater force under the left and right lower limbs, considering before and after the long-time driving. It has been shown that taller participants were applying higher force under the left lower

limbs (for both timelines) for participants classified into the stature groups. Overweight participants had higher force values under both lower limbs than the underweight and normal weight subjects.

Obtained results on the applied force per second (impulse) for left lower limb, right lower limb, and their difference (values obtained by right limb minus values obtained by left lower limb) are illustrated in Table 43. The table includes descriptive statistics and its standard deviation for the sample size and each subgroup separately. Moreover, it was represented the p-values for the group differences. It should be noted that the statistically significant difference between the groups was bolded.

Table 43. The impulse of both lower limbs during pre- and post-steering gait

	Impulse [Ns] - Left Leg		Impulse [Ns] - Right Leg		Impulse [Ns] - Difference	
	Before	After	Before	After	Before	After
Total	377.43 ± 118.44	371.03 ± 103.99	393.21 ± 109.91	380.40 ± 120.89	15.78 ± 45.29	9.38 ± 51.01
Gender						
Female	321.57 ± 72.47	322.77 ± 66.40	338.71 ± 61.82	322.56 ± 63.30	17.14 ± 47.83	-0.21 ± 47.19
Male	433.29 ± 130.14	419.28 ± 113.38	447.71 ± 121.20	438.25 ± 137.51	14.42 ± 43.69	18.97 ± 53.93
p-value	***0.001***	***0.003***	***<0.001***	***0.001***	*n.s.*	*n.s.*
Stature						
Small	354.49 ± 86.83	357.54 ± 60.90	369.37 ± 71.22	359.76 ± 56.67	14.88 ± 32.66	2.22 ± 24.97
Middle	333.53 ± 70.92	331.19 ± 78.44	356.46 ± 67.67	344.73 ± 73.80	22.93 ± 53.12	13.54 ± 45.84
Tall	443.79 ± 150.93	427.57 ± 125.90	451.07 ± 144.17	435.32 ± 168.40	7.28 ± 40.78	7.75 ± 66.74
p value	*n.s.*	***0.049***	***0.041***	*n.s.*	*n.s.*	*n.s.*
BMI						
UW	294.65 ± 32.98	275.97 ± 38.73	329.21 ± 45.94	297.30 ± 44.28	34.56 ± 13.98	21.33 ± 14.22
NW	346.63 ± 78.82	350.03 ± 78.09	362.58 ± 71.92	347.33 ± 78.71	15.96 ± 44.57	-2.70 ± 47.12
OW	514.57 ± 153.43	477.35 ± 127.48	523.45 ± 141.36	525.70 ± 152.78	8.89 ± 55.60	48.36 ± 54.65
p value	***0.004***	***0.006***	***0.002***	***0.001***	*n.s.*	***0.023***

± – Standard deviation; BMI – body mass index; p – the statistical difference between groups; n.s. – not significant; correlation is significant at the 0.05 level.

Long-time driving influenced the right lower limb and caused lesser force per second of the driving process ($Z= -2.019$, $p<0.43$). Moreover, male participants were having grater values of the impulse variable under both lower limbs compared to female participants. The same results were achieved for the overweight participants equating with the two remaining BMI groups. Additionally, it has been shown that the difference between the right and left applied force per second were higher for walking after the post driving process. The taller subject had significantly higher values under the left leg for the gait performed after the driving process, than the rest stature subgroups. Additionally, the divergence of applied force per second under the right foot has not been considered as mathematically significant.

3.8.3 The influence of gait velocity on the linear kinematics variables

Correlation between the gait velocity and spatiotemporal variables are shown in Table 44. Values above ±0.5 are bolded. A strong positive correlation (Table 44) was obtained among gait velocity and cadence. Increasing the walking speed was followed by increasing the performed steps per minute (cadence). Moreover, walking speed had an opposite effect on the gait time and cycle, as

expected. Participants higher gait velocity, after the driving process, caused lesser stance and double support time. While the step length of the right lower limb was in a coordinate with the walking speed.

Table 44. Correlation between gait velocity and spatiotemporal variables for pre- and post-steering gait

	Period	Cadence [steps/min]	Gait time [s]	Gait Cycle Time [s]	Stance time [s]	DST [s]	Step Length [cm]
Gait Velocity [cm/s]	Before	**.713****	**-.751****	**-.547****	*n.s.*	-.373*	**.655****
	After	**.737****	**-.852****	**-.677****	-.402**	**-.661****	**.524****

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant; DST –double support time.

Furthermore, the differences between the performed gait velocity before and after long-time driving were calculated. The results indicated that 25% of participants reduced the gait velocity after the prolonged steering the driving simulator. The results are shown in Table 45.

Table 45. Defining participants with reduced gait velocity after the long-time driving

Percentiles	5	10	25	50	75	90	95
Gait velocity - difference [cm/s]	-9.6	-6.4	-1.3	2.6	7.5	15.4	18.2

Eleven participants, equal to 25% of the sample size, have significantly reduced (t (10) = 3.640; p= 0.005, p<0.005) the gait velocity comparing before and after gait performances. Anthropometric attributes of the group mentioned above are illustrated in tables 46 and 47. Moreover, the tables are showing the groups-based differences and descriptive statistics with the standard deviation for the eleven participants and its classification for each subgroup separately. The number of selected participants does not belong to the underweight category.

Table 46. Description of participants anthropometric attributes (with reduced post-steering gait velocity) – by sample size and gender classification

		Gender		
Anthropometric characteristics	Total (n=11)	Female (n=6)	Male (n=5)	*p*
Age [years]	28.5 ± 5.1	27.7 ± 5.1	29.4 ± 5.5	*n.s.*
Weight [kg]	68.1 ± 17.9	60.5 ± 8.0	77.1 ± 23.1	*n.s.*
Body height [cm]	171.8 ± 8.6	166.3 ± 4.4	178.3 ± 8.1	***0.012***
Sitting height [cm]	73.4 ± 5.3	70.6 ± 4.5	76.9 ± 4.1	***0.040***
Arm span [cm]	169.3 ± 10.5	161.8 ± 4.0	178.2 ± 8.6	***0.002***
Shoulder width [cm]	37.4 ± 3.3	35.0 ± 1.9	40.2 ± 1.9	***0.007***
Hip height [cm]	98.3 ± 5.5	95.8 ± 4.7	101.4 ± 5.2	*n.s.*
Knee height [cm]	49.5 ± 2.7	49.5 ± 2.7	49.6 ± 2.9	*n.s.*
Buttock-knee length [cm]	48.8 ± 6.3	46.3 ± 7.2	51.8 ± 3.7	*n.s.*
Anterior superior iliac [cm]	26.4 ± 2.4	25.3 ± 2.4	27.8 ± 1.8	*n.s.*
Ankle height [cm]	6.8 ± 1.0	6.7 ± 0.8	6.9 ± 1.2	*n.s.*
Foot size [cm]	25.5 ± 2.3	24.1 ± 1.6	27.2 ± 1.8	***0.014***

± – Standard deviation; n – number; p – the statistical difference between groups; n.s. – not significant, correlation is significant at the 0.05 level.

Differences between both sexes are in seated height and the extension of the arm and shoulder. The difference between the foot size should be mentioned as well. The same mathematical noteworthy difference appears in the stature group, considering the same body attributes as in the gender group. Furthermore, there was no variation between normal weight and overweight participants.

Table 47. Description of participants anthropometric attributes (with reduced post-steering gait velocity) – by stature and BMI classification

	Stature				BMI		
Anthropometric characteristics	Small (n=1)	Middle (n=6)	Tall (n=4)	*p*	NW (n=9)	OW (n=2)	*p*
Age [years]	30	26.8 ± 5.0	30.5 ± 5.7	*n.s.*	27.7 ± 4.9	32.0 ± 5.7	*n.s.*
Weight [kg]	54.3	60.6 ± 7.9	82.7 ± 22.5	*n.s.*	62.8 ± 10.4	91.8 ± 31.0	*n.s.*
Body height [cm]	158.7	167.7 ± 2.3	181.1 ± 6.0	***0.001***	171.2 ± 8.6	174.1 ± 11.9	*n.s.*
Sitting height [cm]	66.2	71.2 ± 4.0	78.6 ± 1.9	***0.011***	72.8 ± 5.2	76.1 ± 6.2	*n.s.*
Arm span [cm]	156	164.7 ± 4.9	179.5 ± 9.3	***0.014***	168.7 ± 10.0	172.0 ± 17.0	*n.s.*
Shoulder width [cm]	35	35.5 ± 2.3	40.8 ± 1.7	***0.025***	37.0 ± 2.9	39.0 ± 5.7	*n.s.*
Hip height [cm]	92.5	96.5 ± 4.4	102.5 ± 5.3	*n.s.*	98.4 ± 5.9	98.0 ± 5.7	*n.s.*
Knee height [cm]	52	48.5 ± 2.7	50.5 ± 2.4	*n.s.*	49.2 ± 2.7	51.0 ± 2.8	*n.s.*
Buttock-knee length [cm]	40.5	48.0 ± 6.8	52.0 ± 4.2	*n.s.*	49.2 ± 6.9	47.0 ± 2.8	*n.s.*
Anterior superior iliac [cm]	23	25.9 ± 2.2	28.0 ± 2.0	*n.s.*	25.9 ± 2.1	28.5 ± 3.5	*n.s.*
Ankle height [cm]	7	6.4 ± 1.0	7.4 ± 0.8	*n.s.*	6.8 ± 1.1	7.0 ± 0.0	*n.s.*
Foot size [cm]	21.5	24.7 ± 1.0	27.8 ± 1.5	***0.003***	25.1 ± 2.2	27.5 ± 2.1	*n.s.*

± - Standard deviation; n – number; BMI – body mass index; p – the statistical difference between groups; n.s. – not significant; correlation is significant at the 0.05 level.

Decreasing gait velocity was leading to reducing the number of steps per minute and step length. Moreover, the walking slower was having as a consequence to increase the gait cycle time and the total double support and stance time of the right foot (Table 48).

Table 48. Correlation between gait velocity and spatiotemporal variables – for the participants with gait velocity reduction

	Period	Cadence [steps/min]	Gait time [s]	Gait Cycle Time [s]	Stance Time [s]	DST [s]	Step Length [cm]
Gait Velocity [cm/s]	Before	**.711***	**-.773****	**-.687***	n.s.	n.s.	**.811****
	After	**.743****	**-.870****	**-.841****	-.780**	**-.715***	**.764****

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant; DST – double support time.

3.8.4 Plantar pressure distribution

Average plantar pressure distribution from active frames during the ROP

The plantar pressure distribution represented in the ten plantar areas during the ROP is illustrated in Figure 26. The results are representing the sample size with the average pressure from active frames for each plantar area before and after long-time driving. Both gait performances, referring to pre and post driving process, are obtained on the participant's self-selected comfortable speed.

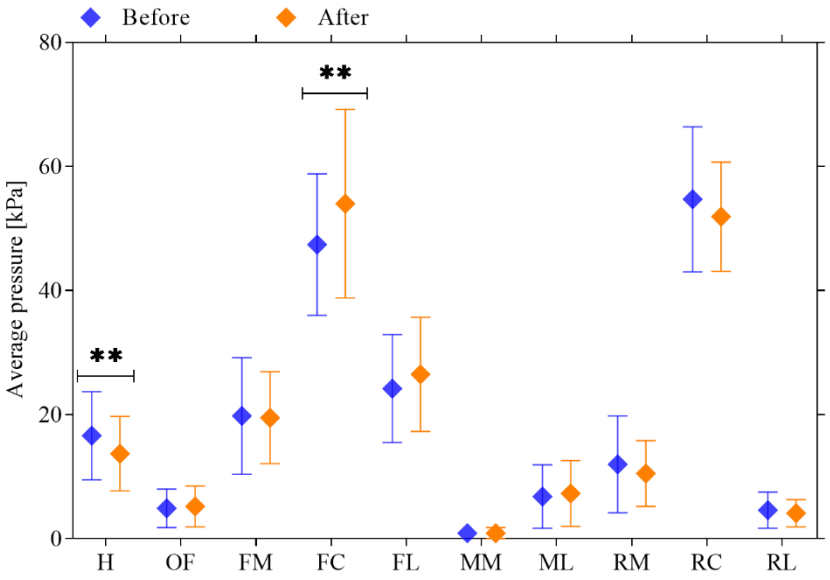


Figure 26. Illustration of average plantar pressure before and after steering the driving simulator. H – hallux; OF – Other fingers; FM – Forefoot medial; FC – Forefoot central; FL – Forefoot lateral; MM - Mid-foot medial; ML – Mid-foot lateral; RM – Rearfoot medial; RC – Rearfoot central; RL – Rearfoot lateral; ** – correlation is significant at the 0.001 level.

Furthermore, Table 49 is showing the average pressure for the total foot and as well as for each foot region separately. Besides the descriptive and standard deviation statistics, the table contains significant differences for the previously defined groups. The statistically considerable variations are displayed and bolded.

It was observed that the gender-based differences did not occur for the average pressure during the ROP. Middle participants were applying considerably lesser average pressure than taller participants after the driving process. Moreover, the average pressure before the driving process took place, under the medial forefoot area, lesser for the taller subject comparing the medial and small participants. Nevertheless, overweight participants were dominating over the total foot average pressure as well as for the specific plantar regions than the underweight and normal eight participants, for both periods. The substantial variations have occurred in the forefoot (central and lateral) and mod-foot (medial and lateral) areas.

Table 49. Average plantar pressure with pre- and post-steering gait (mean and ± standard deviation)

	Gender				Stature				BMI			
	Total	Female	Male	*p*	Small	Middle	Tall	*p*	Underweight	Normal weight	Overweight	*p*
Total foot [kPa]												
Before	17.1 ± 8.5	17.1 ± 8.5	16.1 ± 3.0	*n.s.*	16.3 ± 2.0	16.9 ± 9.0	16.3 ± 3.4	*n.s.*	13.1 ± 1.8	16.5 ± 7.1	18.1 ± 3.1	***0.022***
After	15.3 ± 2.2	15.3 ± 2.2	16.0 ± 3.2	*n.s.*	16.4 ± 2.0	14.9 ± 2.4	16.1 ± 3.5	*n.s.*	12.9 ± 2.1	15.2 ± 2.1	18.1 ± 3.4	***0.002***
Contralateral [kPa]												
Before	4.1 ± 1.2	4.1 ± 1.2	3.8 ± 1.3	*n.s.*	4.6 ± 1.4	3.8 ± 1.3	3.7 ± 1.0	*n.s.*	4.4 ± 1.0	3.8 ± 1.3	4.4 ± 1.1	*n.s.*
After	4.1 ± 1.3	4.1 ± 1.3	4.4 ± 1.8	*n.s.*	4.3 ± 1.4	4.2 ± 1.9	4.2 ± 1.3	*n.s.*	3.6 ± 0.9	3.9 ± 1.5	5.4 ± 1.5	***0.038***
Hallux [kPa]												
Before	16.6 ± 7.1	16.6 ± 7.1	15.5 ± 9.4	*n.s.*	19.2 ± 6.1	15.9 ± 8.4	13.5 ± 9.1	*n.s.*	15.8 ± 2.6	15.6 ± 8.1	17.7 ± 10.3	*n.s.*
After	13.7 ± 6.0	13.7 ± 6.0	11.7 ± 6.7	*n.s.*	15.7 ± 6.2	13.0 ± 7.1	9.7 ± 3.8	*n.s.*	10.9 ± 5.6	13.3 ± 6.7	11.3 ± 5.4	*n.s.*
Other fingers [kPa]												
Before	4.9 ± 3.1	4.9 ± 3.1	5.6 ± 3.1	*n.s.*	5.1 ± 2.9	4.6 ± 3.2	6.4 ± 3.0	*n.s.*	3.2 ± 0.9	4.9 ± 3.0	7.0 ± 3.4	*n.s.*
After	5.2 ± 3.3	5.2 ± 3.3	5.3 ± 3.1	*n.s.*	5.5 ± 3.2	4.7 ± 3.6	5.9 ± 2.5	***0.040***	4.0 ± 2.0	5.2 ± 3.3	5.8 ± 3.2	*n.s.*
Forefoot - medial [kPa]												
Before	19.8 ± 9.4	19.8 ± 9.4	18.9 ± 8.5	*n.s.*	19.1 ± 10.5	21.6 ± 7.1	16.1 ± 9.4	***0.044***	21.4 ± 6.4	18.0 ± 7.5	23.4 ± 12.8	*n.s.*
After	19.5 ± 7.4	19.5 ± 7.4	18.9 ± 7.9	*n.s.*	20.3 ± 9.3	20.7 ± 5.4	16.0 ± 8.4	*n.s.*	14.5 ± 3.6	18.6 ± 6.3	23.1 ± 11.1	*n.s.*
Forefoot - central [kPa]												
Before	47.4 ± 11.4	47.4 ± 11.4	54.2 ± 15.0	*n.s.*	50.8 ± 12.4	47.9 ± 11.6	55.2 ± 17.0	*n.s.*	45.2 ± 9.3	48.1 ± 12.4	62.3 ± 13.7	***0.013***
After	54.0 ± 15.2	54.0 ± 15.2	58.4 ± 13.4	*n.s.*	58.1 ± 14.2	54.0 ± 15.0	58.0 ± 14.0	*n.s.*	52.2 ± 12.5	53.6 ± 13.6	66.8 ± 13.6	***0.040***
Forefoot - lateral [kPa]												
Before	24.2 ± 8.7	24.2 ± 8.7	33.1 ± 22.1	*n.s.*	26.1 ± 10.6	23.4 ± 8.5	38.8 ± 26.1	*n.s.*	14.9 ± 2.4	25.5 ± 11.6	44.5 ± 26.0	***0.002***
After	26.5 ± 9.2	26.5 ± 9.2	35.0 ± 19.8	*n.s.*	28.0 ± 9.8	26.7 ± 8.8	39.4 ± 24.1	*n.s.*	20.3 ± 3.5	27.9 ± 10.6	44.4 ± 25.0	***0.016***
Mid-foot - medial [kPa]												
Before	0.9 ± 0.9	0.9 ± 0.9	1.4 ± 2.0	*n.s.*	1.0 ± 0.9	0.8 ± 1.0	1.9 ± 2.4	*n.s.*	0.0 ± 0.0	1.2 ± 1.6	1.3 ± 1.5	***0.031***
After	0.9 ± 0.9	0.9 ± 0.9	1.4 ± 2.0	*n.s.*	0.9 ± 0.9	0.8 ± 0.9	1.9 ± 2.5	*n.s.*	0.0 ± 0.0	1.1 ± 1.2	1.7 ± 2.6	***0.018***
Mid-foot - lateral area [kPa]												
Before	6.8 ± 5.1	6.8 ± 5.1	8.1 ± 7.1	*n.s.*	7.7 ± 4.5	6.5 ± 6.2	8.9 ± 7.2	*n.s.*	0.7 ± 0.3	7.0 ± 5.8	11.4 ± 5.8	***0.004***
After	7.3 ± 5.3	7.3 ± 5.3	8.7 ± 6.8	*n.s.*	8.3 ± 6.7	7.2 ± 4.7	9.1 ± 7.6	*n.s.*	1.6 ± 1.5	7.3 ± 5.4	12.7 ± 6.5	***0.005***
Rearfoot - medial [kPa]												
Before	12.0 ± 7.8	12.0 ± 7.8	11.1 ± 5.9	*n.s.*	13.5 ± 9.6	10.3 ± 4.8	11.7 ± 6.9	*n.s.*	9.3 ± 1.3	12.1 ± 7.5	10.3 ± 5.2	*n.s.*
After	10.5 ± 5.3	10.5 ± 5.3	10.8 ± 5.9	*n.s.*	11.2 ± 5.8	10.5 ± 3.8	10.4 ± 7.6	*n.s.*	7.5 ± 2.6	11.1 ± 6.0	10.2 ± 4.3	*n.s.*
Rearfoot - central [kPa]												
Before	54.7 ± 11.7	54.7 ± 11.7	51.0 ± 11.4	*n.s.*	58.4 ± 12.7	53.1 ± 11.5	47.7 ± 8.8	*n.s.*	45.9 ± 6.9	53.1 ± 12.0	54.0 ± 11.2	*n.s.*
After	51.9 ± 8.8	51.9 ± 8.8	49.8 ± 10.5	*n.s.*	56.3 ± 6.2	49.3 ± 9.8	48.7 ± 10.6	*n.s.*	46.0 ± 7.4	50.3 ± 9.8	54.4 ± 9.3	*n.s.*
Rearfoot - lateral [kPa]												
Before	4.6 ± 2.9	4.6 ± 2.9	4.0 ± 2.1	*n.s.*	5.3 ± 3.4	4.6 ± 2.4	3.1 ± 1.4	*n.s.*	2.9 ± 1.8	4.6 ± 2.9	3.8 ± 0.9	*n.s.*
After	4.1 ± 2.2	4.1 ± 2.2	4.0 ± 1.7	*n.s.*	4.8 ± 2.4	4.0 ± 1.8	3.5 ± 1.6	*n.s.*	4.4 ± 2.3	3.9 ± 1.9	4.6 ± 2.2	*n.s.*

± - Standard deviation, BMI – body mass index, *p* – the statistical difference between groups, n.s. – not significant, correlation is significant at the 0.05 level

The statistically significant change did not appear among the participants during the assessment of the average plantar pressure from active frames provided by the data routine. The outcomes obtained by sample size, average pressure under the hallux area decreased (mathematical correlation obtained by nonparametric Wilcoxon's test was Z = -3.443, p<0.001) with the post-steering walk. Moreover, the average pressure under the central forefoot area increased (the correlation was t (43) = -5.108, p<0.001). The reminding plantar areas did have slight changes, but they were not statistically significant (Figure 26).

Mean peak plantar pressure distribution from active frames during the ROP

Mean values with a standard deviation of the mean peak plantar pressure distribution for the foot regions during the ROP are illustrated in Figure 27. Through visual examination could be seen that the dominant mean peak pressure is obtained in the plantar central zones (rearfoot and forefoot) and hallux area. Moreover, the figure contains the mean peak pressure achieved pre and post the driving process.

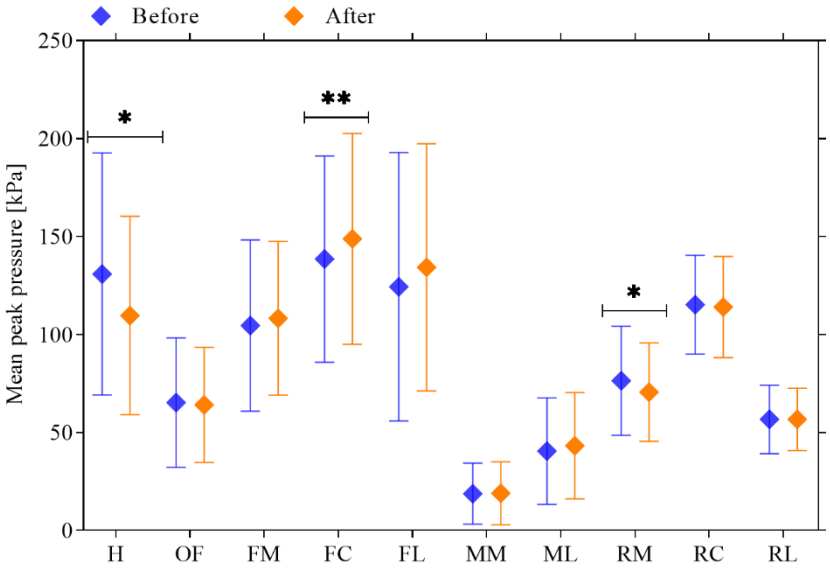


Figure 27. Illustration of the mean peak plantar pressure with pre- and post-steering gait. H – hallux; OF – Other fingers; FM – Forefoot medial; FC – Forefoot central; FL – Forefoot lateral; MM - Mid-foot medial; ML – Mid-foot lateral; RM – Rearfoot medial; RC – Rearfoot central; RL – Rearfoot lateral; * correlation is significant at the 0.05 level; ** – correlation is significant at the 0.001 level.

Further description of the maximum pressure, considering the total foot and as well as the precisely defined regions, are shown in Table 50. Moreover, the table contains the mean peak values of the gait cycles with the standard deviation for the overall number of participants and its groups' classification (by gender, stature, and BMI). Additionally, the variations between each subgroup are obtained and numerically displayed if there were the mathematically considerable differences.

Table 50. Plantar mean peak pressure before and after long-time driving (mean and ± standard deviation)

	Gender				Stature				BMI			
	Total	Female	Male	*p*	Small	Middle	Tall	*p*	Underweight	Normal weight	Overweight	*p*
Total foot [kPa]												
Before	258.0 ±44.0	281.3 ± 36.3	288.8 ± 51.2	*n.s.*	289.5 ± 34.0	276.4 ± 45.4	294.5 ± 49.8	*n.s.*	223.2 ± 3.8	289.2 ± 38.3	290.9 ± 56.6	***0.038***
After	281.5 ±45.6	285.8 ± 46.3	277.2 ± 45.6	*n.s.*	301.4 ± 46.2	271.2 ± 47.3	280.5 ± 39.9	*n.s.*	205.4 ± 33.3	287.4 ± 36.6	285.8 ± 58.3	***0.008***
Contralateral [kPa]												
Before	86.4 ± 25.9	91.8 ± 27.7	81.0 ± 23.4	*n.s.*	100.8 ± 30.8	82.8 ± 25.9	79.7 ± 17.1	*n.s.*	76.9 ± 17.7	86.2 ± 28.3	90.2 ± 19.4	*n.s.*
After	94.6 ±30.9	94.4 ± 23.6	94.9 ± 37.5	*n.s.*	98.7 ± 21.0	95.8 ± 36.7	89.5 ± 29.8	*n.s.*	76.6 ± 16.5	90.4 ± 28.4	115.9 ± 35.3	***0.039***
Hallux [kPa]												
Before	130.9 ± 61.7	127.8 ± 61.0	134.1 ± 63.8	*n.s.*	146.7 ± 58.8	122.9 ± 69.7	129.9 ± 52.4	*n.s.*	117.5 ± 36.5	134.7 ± 64.2	122.1 ± 62.8	*n.s.*
After	109.7 ± 50.6	112.4 ± 54.1	106.9 ± 48.0	*n.s.*	129.8 ± 53.2	103.5 ± 51.9	102.2 ± 45.5	*n.s.*	80.1 ± 24.4	117.2 ± 51.0	92.7 ± 51.4	*n.s.*
Other fingers [kPa]												
Before	65.3 ± 33.0	62.2 ± 36.1	68.4 ± 30.1	*n.s.*	68.5 ± 32.5	56.1 ± 34.4	76.9 ± 29.2	*n.s.*	42.8 ± 1.5	63.2 ± 34.5	80.5 ± 27.7	*n.s.*
After	64.1 ± 29.4	63.2 ± 33.3	65.1 ± 25.8	*n.s.*	67.2 ± 31.3	57.9 ± 34.5	71.3 ± 16.7	*n.s.*	51.7 ± 15.5	63.9 ± 32.1	69.1 ± 22.8	*n.s.*
Forefoot - medial [kPa]												
Before	104.6 ± 43.7	108.0 ± 49.2	101.2 ± 38.4	*n.s.*	98.6 ± 43.2	114.4 ± 43.8	94.6 ± 44.3	*n.s.*	102.0 ± 46.4	102.8 ± 45.9	111.9 ± 38.5	*n.s.*
After	108.3 ± 39.2	111.1 ± 40.8	105.5 ± 38.2	*n.s.*	109.4 ± 43.8	114.7 ± 35.9	97.5 ± 40.7	*n.s.*	74.3 ± 15.5	107.3 ± 40.9	123.1 ± 32.0	*n.s.*
Forefoot - central [kPa]												
Before	138.5 ± 52.6	133.8 ± 53.1	143.2 ± 52.8	*n.s.*	135.7 ± 49.3	135.3 ± 55.8	145.8 ± 53.5	*n.s.*	97.5 ± 20.6	138.9 ± 54.1	150.9 ± 50.8	*n.s.*
After	148.8 ± 53.8	146.9 ± 59.8	150.6 ± 48.3	*n.s.*	152.4 ± 52.1	146.6 ± 63.2	149.0 ± 41.9	*n.s.*	113.9 ± 35.8	150.0 ± 58.5	156.0 ± 37.6	*n.s.*
Forefoot - lateral [kPa]												
Before	124.4 ± 68.5	113.3 ± 44.5	135.5 ± 85.8	*n.s.*	113.9 ± 43.4	106.6 ± 46.2	160.5 ± 99.1	*n.s.*	61.7 ± 10.2	117.9 ± 59.7	168.3 ± 86.8	***0.009***
After	134.3 ± 63.1	127.4 ± 51.5	141.1 ± 73.4	*n.s.*	126.8 ± 47.2	124.4 ± 57.7	155.8 ± 80.1	*n.s.*	78.4 ± 16.3	130.2 ± 60.1	167.6 ± 69.5	***0.049***
Mid-foot - medial [kPa]												
Before	18.8 ± 15.6	17.6 ± 12.3	20.0 ± 18.5	*n.s.*	20.2 ± 12.7	15.4 ± 13.8	23.0 ± 19.9	*n.s.*	0.9 ± 1.3	19.0 ± 16.4	24.0 ± 11.0	***0.017***
After	19.0 ± 16.1	18.0 ± 11.7	19.9 ± 19.8	*n.s.*	21.2 ± 11.8	14.8 ± 13.1	23.4 ± 22.2	*n.s.*	0.6 ± 0.8	19.4 ± 14.7	23.7 ± 20.3	***0.015***
Mid-foot - lateral area [kPa]												
Before	40.5 ± 27.2	33.8 ± 15.1	47.2 ± 34.5	*n.s.*	39.0 ± 13.4	33.2 ± 22.1	53.0 ± 38.2	*n.s.*	11.9 ± 4.9	35.8 ± 22.3	66.8 ± 29.2	***0.002***
After	43.3 ± 27.1	35.8 ± 15.0	50.7 ± 34.0	*n.s.*	38.1 ± 17.3	39.1 ± 19.2	54.0 ± 40.2	*n.s.*	18.3 ± 10.6	37.7 ± 20.6	71.2 ± 32.0	***0.003***
Rearfoot - medial [kPa]												
Before	76.4 ± 27.8	79.9 ± 25.8	72.8 ± 29.9	*n.s.*	87.2 ± 29.3	75.5 ± 23.6	68.5 ± 31.5	*n.s.*	67.3 ± 13.6	77.7 ± 29.3	74.9 ± 27.3	*n.s.*
After	70.6 ± 25.1	71.4 ± 20.7	69.8 ± 29.3	*n.s.*	74.3 ± 20.8	71.4 ± 18.9	66.1 ± 36.0	*n.s.*	60.0 ± 8.9	71.7 ± 26.2	70.2 ± 25.6	*n.s.*
Rearfoot - central [kPa]												
Before	115.2 ± 25.2	117.5 ± 24.1	112.8 ± 26.7	*n.s.*	122.5 ± 27.1	117.1 ± 25.0	106.0 ± 23.0	*n.s.*	104.3 ± 25.1	116.1 ± 23.6	115.6 ± 32.4	*n.s.*
After	114.1 ± 25.8	118.5 ± 25.6	109.8 ± 25.9	*n.s.*	128.1 ± 29.1	110.4 ± 19.4	107.9 ± 29.0	*n.s.*	104.4 ± 19.6	113.4 ± 24.1	119.8 ± 34.0	*n.s.*
Rearfoot - lateral [kPa]												
Before	56.7 ± 17.5	55.1 ± 19.1	58.3 ± 16.1	*n.s.*	60.5 ± 22.8	57.8 ± 17.6	51.8 ± 11.4	*n.s.*	37.7 ± 11.3	57.8 ± 19.0	59.2 ± 8.1	*n.s.*
After	56.7 ± 15.9	54.1 ± 16.8	59.4 ± 14.9	*n.s.*	62.4 ± 15.3	53.2 ± 17.4	57.3 ± 13.6	*n.s.*	53.3 ± 3.4	53.4 ± 15.3	69.5 ± 14.6	***0.021***

± - Standard deviation, BMI – body mass index, n.s. – not significant, p- value for groups differences, correlation is significant at the 0.05 level

Applying the parametric and nonparametric test in the SPSS software, to establish the considerable mathematical differences between the subgroups, has shown that the gender-based nor stature-based differences have not occurred. On another side, the overweight participants were dominant in the lateral areas (forefoot, mid-foot, and rearfoot). Moreover, the underweight participants were applying lesser maximum pressure than the rest two BMI groups, considering the total plantar area.

Besides the visual observation and noticeable difference of the maximum pressure under the hallux area, nonparametric Wilcoxon's test has shown the statistically significant difference between the gait performed in a different time ($Z=-2.556$, $p<0.011$). Which referees that participants were applying lesser pressure under the hallux area after 120 minutes of the steering the driving simulator. Moreover, the same test demonstrated the considerable mathematical differences between two pressure variables under the central forefoot area. It was shown that post-driving gait performances were resulting in the higher pressure under the central forefoot area ($Z=-3.676$, $p<0.001$) than the pre-driving walk. In the rearfoot, precisely medial area, it was noted that the maximum pressure has decreased after the prolonged driving ($Z=-2.147$, $p<0.032$).

Maximum pressure of the right foot during the ROP

Applied maximum pressure of the total foot, represented in gait phases, during the ROP is illustrated in Table 51. The table shows the maximum pressure of the loading response, mid-stance, and push off and give a statistical comparison between the subgroups.

Table 51 Maximum pressure of the right foot during the gait cycle

		Loading response [kPa]		Mid-stance [kPa]		Push off [kPa]	
	Subgroup	Before	After	Before	After	Before	After
Total		316.8 ± 66.5	310.3 ± 71.5	285.9 ± 84.9	265.6 ± 80.6	456.2 ± 113.9	457.0 ± 107.2
Gender							
	Female	303.2 ± 62.3	308.3 ± 80.4	287.3 ± 74.4	275.8 ± 81.8	474.0 ± 105.9	475.2 ± 103.3
	Male	330.5 ± 69.3	312.3 ± 63.3	284.6 ± 96.0	255.5 ± 80.0	438.5 ± 121.1	438.7 ± 110.2
	p	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
Stature							
	Small	291.9 ± 76.3	332.0 ± 117.4	287.9 ± 59.2	274.0 ± 90.1	437.6 ± 75.8	466.9 ± 105.3
	Middle	324.9 ± 64.6	300.0 ± 56.9	262.0 ± 80.6	264.1 ± 82.1	453.7 ± 119.8	442.6 ± 108.8
	Tall	319.3 ± 65.3	312.4 ± 61.0	314.9 ± 95.6	263.5 ± 79.2	468.7 ± 126.4	470.0 ± 110.6
	p	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
BMI							
	Underweight	296.0 ± 29.5	282.6 ± 54.4	198.4 ± 31.1	180.3 ± 74.8	304.4 ± 45.0	275.8 ± 31.7
	Normal weight	315.3 ± 66.4	303.5 ± 59.3	287.7 ± 81.3	270.3 ± 73.3	485.8 ± 100.3	484.4 ± 88.1
	Overweight	329.4 ± 78.3	343.7 ± 106.7	308.8 ± 97.0	277.7 ± 98.6	401.8 ± 121.5	419.8 ± 120.5
	p	*n.s.*	*n.s.*	*n.s.*	*n.s.*	***0.006***	***0.001***

± – Standard deviation; BMI – body mass index; p – the statistical difference between groups; n.s. – not significant; correlation is significant at the 0.05 level.

Pre- and post-steering gait performances did not involve any crucial changes of the applied maximum pressure for the abovementioned phases. Moreover, the male/female and as well as small/middle/tall differences were not obtained. Additionally, at a push-off phase, it was found that underweight participants were applying significantly lower pressure comparing to the normal weight and overweight participants.

3.8.5 Modifications of the plantar area before and after steering the driving simulator

Average plantar contact area triggered by active frames

The visual illustration of the average contact area, triggered by active frames during the ROP, is represented in Figure 28. The horizontal axis of the figure is characterizing the plantar regions, while the vertical axis is placed the value of the contact area acquired before and after the driving process. The results are referring to the total sample size.

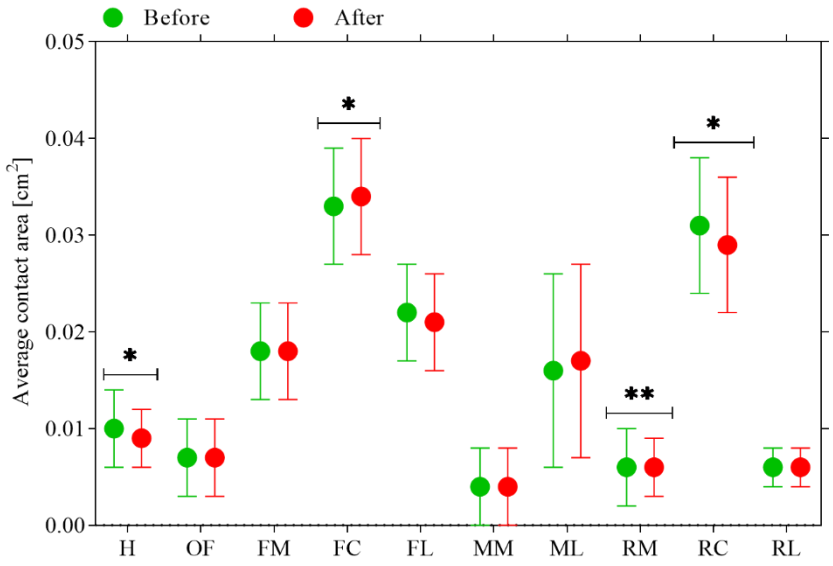


Figure 28. Illustration of the average plantar contact area before and after the driving process. H – hallux; OF – Other fingers; FM – Forefoot medial; FC – Forefoot central; FL – Forefoot lateral; MM - Mid-foot medial; ML – Mid-foot lateral; RM – Rearfoot medial; RC – Rearfoot central; RL – Rearfoot lateral; * correlation is significant at the 0.05 level; ** – correlation is significant at the 0.001 level.

Average contact area, considering the total plantar area as well as the previously defined regions, are represented in Table 52. Moreover, the table is showing the results of gait performance and its applied pressure for the sample size and the groups (gender, stature, and BMI) for the two different periods. Moreover, the changes in the covered area are compared between the subgroups and demonstrated (if the dissimilarity were considerable).

It was comparing the covered area by the group it was noted that gender-based differences were relevant under the rearfoot medial area, but only at gait performances at the pre-driving process. Assessing the results classify by the stature groups, the differences have not occurred. The average contact area during the ROP remained similar for the small, middle, and tall subjects. The mid-foot is noticeably unique for the BMI groups, were underweight participants were covering smaller plantar area than the rest BMI subgroups. Furthermore, the forefoot (medial, central, and lateral) was dominated by the overweight participants.

Table 52. Plantar average contact area before and after 120 minutes of drive

	Gender				Stature				BMI			
	Total	Female	Male	*p*	Small	Middle	Tall	*p*	Underweight	Normal weight	Overweight	*p*
Total foot [cm2]												
Before	0.152 ±0.020	0.151±0.018	0.153±0.022	*n.s.*	0.154±0.02	0.15±0.017	0.154±0.024	*n.s.*	0.152±0.012	0.149±0.018	0.164±0.023	*n.s.*
After	0.151 ±0.023	0.149±0.021	0.154±0.025	*n.s.*	0.15±0.025	0.149±0.015	0.155±0.03	*n.s.*	0.150±0.014	0.148±0.02	0.162±0.031	*n.s.*
Contralateral [cm2]												
Before	0.035 ±0.011	0.036±0.011	0.034±0.011	*n.s.*	0.037±0.012	0.035±0.012	0.034±0.009	*n.s.*	0.046±0.008	0.034±0.011	0.036±0.009	*n.s.*
After	0.036 ±0.014	0.036±0.014	0.037±0.013	*n.s.*	0.035±0.014	0.037±0.016	0.037±0.011	*n.s.*	0.035±0.007	0.035±0.014	0.042±0.011	*n.s.*
Hallux [cm2]												
Before	0.010 ±0.004	0.01±0.003	0.01±0.004	*n.s.*	0.011±0.003	0.01±0.004	0.01±0.004	*n.s.*	0.011±0.001	0.01±0.004	0.011±0.003	*n.s.*
After	0.009 ±0.003	0.009±0.003	0.009±0.003	*n.s.*	0.009±0.003	0.009±0.004	0.009±0.003	*n.s.*	0.009±0.001	0.009±0.003	0.009±0.003	*n.s.*
Other fingers [cm2]												
Before	0.007 ±0.004	0.007±0.005	0.007±0.003	*n.s.*	0.007±0.003	0.007±0.005	0.008±0.002	*n.s.*	0.007±0.002	0.007±0.004	0.008±0.003	*n.s.*
After	0.007 ±0.004	0.007±0.005	0.007±0.003	*n.s.*	0.006±0.003	0.007±0.005	0.007±0.002	*n.s.*	0.009±0.003	0.007±0.004	0.007±0.003	*n.s.*
Forefoot - medial [cm2]												
Before	0.018 ±0.005	0.017±0.005	0.018±0.006	*n.s.*	0.016±0.005	0.019±0.005	0.016±0.006	*n.s.*	0.023±0.002	0.016±0.005	0.02±0.005	***0.029***
After	0.018 ±0.005	0.018±0.005	0.018±0.006	*n.s.*	0.018±0.005	0.019±0.004	0.017±0.007	*n.s.*	0.018±0.003	0.017±0.005	0.02±0.008	*n.s.*
Forefoot - central [cm2]												
Before	0.033 ±0.006	0.033±0.006	0.033±0.006	*n.s.*	0.032±0.005	0.033±0.006	0.033±0.006	*n.s.*	0.042±0.008	0.032±0.005	0.033±0.005	***0.018***
After	0.034 ±0.006	0.034±0.007	0.034±0.006	*n.s.*	0.034±0.006	0.035±0.007	0.034±0.006	*n.s.*	0.041±0.006	0.034±0.006	0.034±0.006	*n.s.*
Forefoot - lateral [cm2]												
Before	0.022 ±0.005	0.021±0.005	0.022±0.006	*n.s.*	0.022±0.006	0.02±0.003	0.023±0.007	*n.s.*	0.020±0.001	0.021±0.005	0.026±0.005	*0.013*
After	0.021 ±0.005	0.021±0.005	0.022±0.005	*n.s.*	0.021±0.006	0.02±0.003	0.023±0.007	*n.s.*	0.023±0.005	0.02±0.004	0.025±0.007	***n.s.***
Mid-foot - medial [cm2]												
Before	0.004 ±0.004	0.003±0.003	0.004±0.005	*n.s.*	0.003±0.003	0.003±0.004	0.005±0.005	*n.s.*	0.000±0.000	0.004±0.004	0.003±0.003	***0.033***
After	0.004 ±0.004	0.003±0.003	0.004±0.005	*n.s.*	0.003±0.003	0.003±0.003	0.005±0.006	*n.s.*	0.000±0.000	0.004±0.004	0.003±0.004	***0.016***
Mid-foot - lateral area [cm2]												
Before	0.016 ±0.010	0.015±0.007	0.017±0.012	*n.s.*	0.017±0.007	0.014±0.009	0.018±0.013	*n.s.*	0.003±0.001	0.015±0.009	0.023±0.011	***0.004***
After	0.017 ±0.010	0.016±0.007	0.019±0.011	*n.s.*	0.016±0.008	0.017±0.006	0.02±0.014	*n.s.*	0.007±0.006	0.016±0.007	0.026±0.012	***0.002***
Rearfoot - medial [cm2]												
Before	0.006 ±0.004	0.007±0.004	0.006±0.003	***0.049***	0.008±0.004	0.006±0.003	0.006±0.004	*n.s.*	0.007±0.003	0.007±0.004	0.005±0.002	*n.s.*
After	0.006 ±0.003	0.006±0.003	0.005±0.003	*n.s.*	0.006±0.004	0.006±0.003	0.005±0.004	*n.s.*	0.006±0.003	0.006±0.003	0.005±0.002	*n.s.*
Rearfoot - central [cm2]												
Before	0.031 ±0.007	0.031±0.007	0.031±0.007	*n.s.*	0.031±0.007	0.031±0.007	0.031±0.008	*n.s.*	0.034±0.010	0.031±0.007	0.029±0.005	*n.s.*
After	0.029 ±0.007	0.029±0.007	0.029±0.007	*n.s.*	0.029±0.005	0.028±0.007	0.031±0.007	*n.s.*	0.031±0.008	0.029±0.007	0.029±0.006	*n.s.*
Rearfoot - lateral [cm2]												
Before	0.006 ±0.002	0.006±0.003	0.006±0.002	*n.s.*	0.007±0.003	0.006±0.002	0.005±0.002	*n.s.*	0.005±0.003	0.006±0.003	0.005±0.001	*n.s.*
After	0.006 ±0.002	0.006±0.002	0.006±0.002	*n.s.*	0.006±0.003	0.006±0.002	0.005±0.002	*n.s.*	0.007±0.002	0.005±0.002	0.006±0.002	*n.s.*

± - Standard deviation, BMI – body mass index, p – the statistical difference between groups, n.s. – not significant, correlation is significant at the 0.05 level

Average plantar contact area after two hours steering in the driving simulator, comparting with the initial walking was different. The average contact area during the ROP was reduced under the hallux (Z = -2.171, p<0.030). Moreover, the contact area at the central forefoot area has increased (t (43) =-2.052, p=0.046). Assessing the rearfoot (precisely the central (t (43) =2.798, p=0.008) and medial (Z = -2.789, p<0.005)) area were reduced.

Maximum contact area triggered by active frames

The maximum covered area during the ROP, before and after the driving process, is illustrated in figure 29. Figure 29 indicates the maximum average contact area (on the vertical axis) divided into plantar regions (on the horizontal axis) for the two different time sequences.

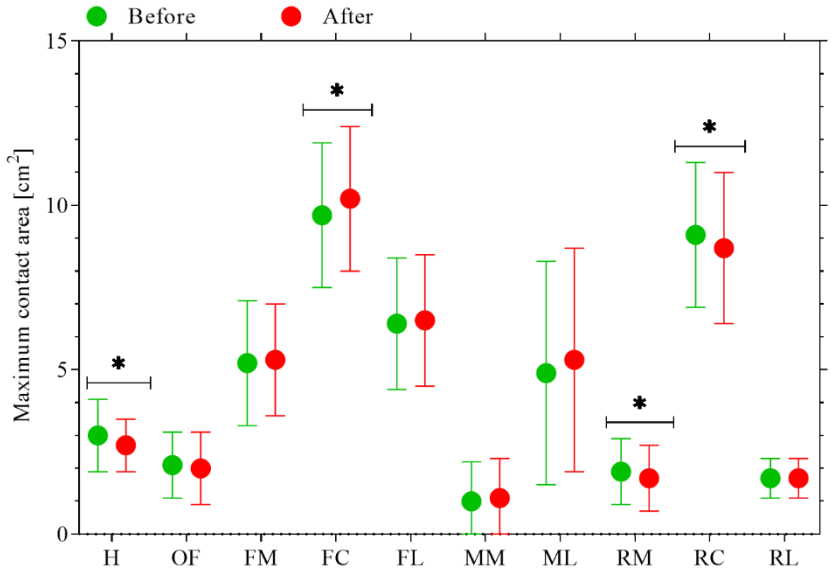


Figure 29. Illustration of the maximum contact area before and after the driving process. H – hallux; OF – Other fingers; FM – Forefoot medial; FC – Forefoot central; FL – Forefoot lateral; MM - Mid-foot medial; ML – Mid-foot lateral; RM – Rearfoot medial; RC – Rearfoot central; RL – Rearfoot lateral; * correlation is significant at the 0.05 level; ** – correlation is significant at the 0.001 level.

The values for the total and specific plantar area were gathered during the walking performances were represented in Table 53. The table contains descriptive statistics supported by the standard deviation and with the p – values describing if the statistically substantial variation has happened among the subjects classified into the groups.

Table 53. Maximum plantar contact area obtained at pre- and post-steering gait (mean and ± standard deviation)

		Gender				Stature				BMI			
		Total	Female	Male	*p*	Small	Middle	Tall	*p*	Underweight	Normal weight	Overweight	*p*
Total foot [cm2]													
	Before	45.0 ± 9.3	39.6 ± 4.9	50.3 ± 9.7	***<0.001***	39.6 ± 5.8	42.8 ± 7.0	52.9 ± 10.1	*n.s.*	41.9 ± 0.4	42.7 ± 7.9	54.0 ± 10.2	***0.004***
	After	45.1 ± 9.5	39.7 ± 5.0	50.5 ± 10.0	***<0.001***	39.1 ± 5.5	42.8 ± 5.3	53.9 ± 11.3	*n.s.*	43.1 ± 2.4	42.9 ± 7.4	53.7 ± 13.0	***0.037***
Contralateral [cm2]													
	Before	10.3 ± 3.4	9.5 ± 2.8	11.1 ± 3.8	*n.s.*	9.5 ± 2.9	9.8 ± 3.4	11.7 ± 3.7	*n.s.*	12.6 ± 2.3	9.6 ± 3.0	12.1 ± 4.0	*n.s.*
	After	11.0 ± 4.5	9.6 ± 4.3	12.3 ± 4.5	*n.s.*	9.1 ± 3.5	10.8 ± 5.0	12.8 ± 4.2	*n.s.*	10.0 ± 0.8	10.1 ± 4.5	14.2 ± 4.4	*n.s.*
Hallux [cm2]													
	Before	3.0 ± 1.1	2.6 ± 1.0	3.3 ± 1.2	*n.s.*	2.8 ± 0.9	2.8 ± 1.1	3.3 ± 1.2	*n.s.*	3.1 ± 0.6	2.8 ± 1.1	3.6 ± 1.0	*n.s.*
	After	2.7 ± 0.8	2.5 ± 0.7	2.9 ± 0.8	*n.s.*	2.4 ± 0.6	2.6 ± 0.9	2.9 ± 0.9	*n.s.*	2.7 ± 0.4	2.6 ± 0.9	2.8 ± 0.8	*n.s.*
Other fingers [cm2]													
	Before	2.1 ± 1.1	1.8 ± 1.1	2.3 ± 0.9	*n.s.*	1.7 ± 0.9	1.9 ± 1.1	2.6 ± 0.9	***0.032***	2.0 ± 0.5	1.9 ± 1.1	2.6 ± 1.0	*n.s.*
	After	2.0 ± 1.1	1.8 ± 1.2	2.2 ± 0.9	*n.s.*	1.7 ± 0.7	1.9 ± 1.2	2.6 ± 0.9	***0.010***	2.5 ± 0.8	1.9 ± 1.1	2.3 ± 1.1	*n.s.*
Forefoot - medial [cm2]													
	Before	5.2 ± 1.9	4.5 ± 1.4	5.9 ± 2.0	***0.009***	4.3 ± 1.6	5.4 ± 1.6	5.6 ± 2.3	*n.s.*	6.4 ± 0.8	4.7 ± 1.7	6.5 ± 1.9	***0.016***
	After	5.3 ± 1.7	4.8 ± 1.2	5.9 ± 2.0	*n.s.*	4.8 ± 1.3	5.4 ± 1.3	5.7 ± 2.4	*n.s.*	5.4 ± 1.3	5.0 ± 1.3	6.5 ± 2.6	*n.s.*
Forefoot - central [cm2]													
	Before	9.7 ± 2.2	8.6 ± 1.5	10.9 ± 2.3	***<0.001***	8.3 ± 1.2	9.5 ± 1.9	11.3 ± 2.3	*n.s.*	11.5 ± 1.3	9.2 ± 2.1	11.0 ± 2.1	***0.038***
	After	10.2 ± 2.2	9.1 ± 1.7	11.3 ± 2.1	***<0.001***	8.8 ± 1.6	9.9 ± 1.9	11.8 ± 2.2	*n.s.*	11.8 ± 0.4	9.8 ± 2.2	11.1 ± 2.3	*n.s.*
Forefoot - lateral [cm2]													
	Before	6.4 ± 2.0	5.6 ± 1.3	7.3 ± 2.3	***0.006***	5.7 ± 1.6	5.9 ± 1.3	7.9 ± 2.5	*n.s.*	5.4 ± 0.3	5.9 ± 1.6	8.6 ± 2.3	***0.002***
	After	6.5 ± 2.0	5.5 ± 1.3	7.4 ± 2.2	***0.002***	5.6 ± 1.5	5.9 ± 1.2	8.1 ± 2.6	*n.s.*	6.4 ± 0.7	6.0 ± 1.6	8.2 ± 2.9	***0.018***
Mid-foot - medial [cm2]													
	Before	1.0 ± 1.2	0.8 ± 0.7	1.3 ± 1.6	*n.s.*	0.9 ± 0.8	0.8 ± 1.1	1.6 ± 1.6	*n.s.*	0.0 ± 0.0	1.1 ± 1.3	1.1 ± 1.0	***0.031***
	After	1.1 ± 1.2	0.8 ± 0.7	1.3 ± 1.6	*n.s.*	0.9 ± 0.7	0.8 ± 0.9	1.7 ± 1.8	*n.s.*	0.0 ± 0.0	1.1 ± 1.2	1.1 ± 1.5	***0.018***
Mid-foot - lateral area [cm2]													
	Before	4.9 ± 3.4	3.9 ± 2.0	5.8 ± 4.2	*n.s.*	4.3 ± 2.0	4.2 ± 2.8	6.4 ± 4.7	*n.s.*	0.8 ± 0.4	4.4 ± 2.7	7.8 ± 4.1	***0.004***
	After	5.3 ± 3.4	4.3 ± 2.1	6.4 ± 4.1	*n.s.*	4.2 ± 2.2	4.9 ± 2.0	7.0 ± 5.0	*n.s.*	2.1 ± 2.1	4.7 ± 2.4	8.7 ± 4.3	***0.004***
Rearfoot - medial [cm2]													
	Before	1.9 ± 1.0	1.9 ± 0.9	1.8 ± 1.2	*n.s.*	2.0 ± 1.0	1.8 ± 0.8	1.9 ± 1.4	*n.s.*	1.9 ± 1.0	1.9 ± 1.2	1.7 ± 0.5	*n.s.*
	After	1.7 ± 1.0	1.6 ± 0.9	1.7 ± 1.1	*n.s.*	1.6 ± 0.9	1.7 ± 0.8	1.7 ± 1.4	*n.s.*	1.6 ± 1.1	1.7 ± 1.1	1.5 ± 0.6	*n.s.*
Rearfoot - central [cm2]													
	Before	9.1 ± 2.2	8.2 ± 1.7	10.0 ± 2.2	***0.006***	7.9 ± 1.8	8.8 ± 1.9	10.6 ± 2.0	***0.039***	9.2 ± 2.4	9.0 ± 2.3	9.4 ± 1.8	*n.s.*
	After	8.7 ± 2.3	7.8 ± 1.7	9.6 ± 2.4	***0.007***	7.6 ± 1.2	8.1 ± 2.0	10.6 ± 2.3	***0.031***	8.7 ± 1.8	8.5 ± 2.2	9.5 ± 2.6	*n.s.*
Rearfoot - lateral [cm2]													
	Before	1.7 ± 0.6	1.6 ± 0.6	1.9 ± 0.6	*n.s.*	1.8 ± 0.7	1.7 ± 0.6	1.7 ± 0.6	*n.s.*	1.5 ± 0.8	1.7 ± 0.6	1.7 ± 0.4	*n.s.*
	After	1.7 ± 0.6	1.5 ± 0.6	1.8 ± 0.6	***0.044***	1.6 ± 0.7	1.6 ± 0.6	1.8 ± 0.6	*n.s.*	1.9 ± 0.7	1.6 ± 0.6	1.9 ± 0.6	*n.s.*

± - Standard deviation; BMI – body mass index; n.s. – Not significant; p-values group difference; correlation is significant at the 0.05 level.

The maximum contact area of the total foot was more significant for the male, then comparing to female participants. The same outcomes indicated that subjects with higher BMI were covering a larger area than normal weight or underweight subjects. Assessing the results, which refers to the forefoot area, it was noted that the stature group did not have any significant differences. Moreover, the differences have appeared between the gender (males were covering bigger forefoot area than females), and as well as the BMI groups (were the overweight participants were dominant). Medial forefoot, after the driving process, did not indicate any mathematically essential changes between the gender group neither between the BMI group. The mid-foot covered area was different for the BMI subgroups, where again, overweight subjects were having larger values obtained during the walking performances. The rearfoot central area had higher values for the male participants, and as well as for the taller subjects classified into the stature group. The maximum covered area was showing the gender-based variations (showing that male applied greater values than females) after two hours of steering the driving simulator.

Besides the visual announcement that the values of maximum pressure under the hallux area are different, parametric Paired Sample T-test concluded that the variation of the values is statistically considered ($t(43) = 2.722$, $p=0.009$). After the long-time driving, participants started to cover the greater area under the central forefoot ($t(43) = -2299.$, $p=0.022$). The rearfoot area has shown different tending. The maximum contact area under the central ($t(43) = 2.796$, $p=0.008$) and medial ($Z = -2.789$, $p<0.005$) rearfoot has decreased, taking into consideration the total number of participants.

3.8.6 Plantar variables occurred among the population with the gait velocity reduction after the long-time driving

Changes in the plantar pressure variables between two walking periods

Eleven participants who reduced the gait velocity after the long-time driving were applying significantly more pressure under the mid-foot lateral area ($Z=-2.312$, $p=0.021$) comparing with the walking performance occurred slightly before steering the driving simulator. In this case, the mean peak pressure has increased by 23.2% (from 35.4 ±23.7 kPa to 43.6 ± 26.5 kPa).

It was established that under the fingers the average pressure was reduced during the ROP (hallux – $Z=-2.045$, $p=0.041$, while the *p*-value for the other finishers was founded at $t(10) =2.470$, $p=0.033$) comparing the differences of the applied average pressure under the plantar regions. Hallux average pressure had a drop from 19.5 ±10.0 kPa to 14.4 ±9.0, while other fingers had from 5.0 ± 3.0 kPa to 4.0 ±2.7 kPa.

Change of applied plantar (average and maximum) area between two walking periods

A significant difference between the two walking performances referred for the different time it was not established significant differences for the average contact area during the ROP. Furthermore, average maxim area had statistically significant changes at the finger and the central forefoot area. Hallux area were reduced from 3.6 ±1.2 cm^2 up to 2.9 ±0.9 cm^2 (where the p-value was $Z=-2.848$, $p=0.004$, $p<0.05$). The reduction of the average contact area under the other figures

was by 13.9 % (form 2.2 ±1.2 cm^2 to 1.9 ±1.1 cm^2) which was considered as significant (t (10) = 3.515, p=0.006). What is more, the central forefoot has had an increase of 4.9% (t (10) = -2.420, p=0.036) relating to the initial gait performances.

3.8.7 Correlation between gait velocity and plantar variables

Association between plantar pressure variables and gait velocity performed in the two different timelines are illustrated in Table 54. The statistical correlation was significant at the p-value 0.05.

Table 54. Correlation between gait velocity and plantar pressure variables

	Period	Mean peak pressure - Total [kPa]	Maximum pressure - push off [kPa]	Average pressure - contralateral [kPa]	Maximum pressure - contralateral [kPa]	Mean peak pressure - other fingers [kPa]	Mean peak pressure - medial forefoot [kPa]
Gait Velocity [cm/s]	Before	n.s.	n.s.	-.420**	n.s.	n.s.	-.298*
	After	.328*	.383*	-.379*	-.350*	.360*	n.s.

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant.

Increasing the gait velocity after two hours of driving had a weak influence on the mean peak pressure of the total foot. Moreover, the same effect was noted under the other fingers area and as well as throughout the push-off phase. With the decreasing the speed, maximum pressure was slightly increased under the contralateral area of the right foot. Additionally, walking more slowly than before the driving did not influence the medial forefoot area.

Statistical correlation between the modifications of the gait velocity and its influence on the plantar area, analyzing the sample size, are shown in Table 55. The table uses results obtained by parametric and nonparametric (Pearson's and Spearman's) test, and the p-value was considered at the 0.05.

Table 55. Correlation between gait velocity and plantar area variables

	Period	Average area - contralateral [cm^2]	Maximum area – contralateral [cm^2]	Maximum area - rearfoot medial [cm^2]	Maximum area - rearfoot central [cm^2]	Maximum area - rearfoot lateral [cm^2]
Gait Velocity [cm/s]	Before	-.494**	**-.534****	-.300*	-.317*	-.303*
	After	**-.504****	**-.521****	n.s.	n.s.	-.347*

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant.

A higher value of the gait velocity had not an impact on the rearfoot (central and lateral) area, comparing with the walking performances at the pre-driving process. Moreover, the contralateral area and rearfoot lateral remained in the same correlation with the walking speed.

3.8.7.1 Association between reduced gait velocity and plantar variables

Plantar pressure variables

Correlation between determinate population with the gait velocity decreased (eleven participants) after the long-time driving and associating with the plantar pressure variables is illustrated in Table 56. The table is showing results obtained by applying nonparametric Spearman's test, where the *p-value* was defined at 0.05.

Table 56. Correlation between gait velocity and plantar pressure variables – participants with decreased gait velocity

	Period	Mean peak pressure – Total [kPa]	Maximum pressure at mid stance [kPa]	Average total pressure - contralateral [kPa]	Mean peak pressure - medial forefoot [kPa]	Maximum total pressure - contralateral [kPa]
Gait Velocity [cm/s]	Before	**-.647***	**-.724***	**-.715***	**-.661***	n.s.
	After	n.s.	n.s.	**-.727***	n.s.	**-.709***

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant.

The outcomes indicated that slower walking had a strong influence of applied pressure at the contralateral area. Furthermore, decreasing the gait velocity did not influence the total mean peak pressure, neither the mean peak pressure occurred under the medial forefoot area. Additionally, the average pressure obtained during the ROP at the contralateral area remained with a similar correlation.

Plantar area variables

Table 57 is illustrating results obtained by gait performances (previously mentioned population – reduced walking speed after long-time driving) on the plantar area variables. Moreover, the illustrated results are obtained by nonparametric Spearman's test, where the *p-value* was established at 0.05.

Table 57. Correlation between gait velocity and plantar area variables – participants with decreased gait velocity

	Period	Maximum area - Contralateral [cm^2]	Average area - contralateral [cm^2]	Maximum area - rearfoot lateral [cm^2]	Average area - mid-foot lateral [cm^2]	Average area rearfoot - medial [cm^2]	Average area - rearfoot lateral [cm^2]
Gait Velocity [cm/s]	Before	**-.615***	n.s.	**-.738****	n.s.	n.s.	n.s.
	After	**-.709***	**-.712***	**-.743****	**-.611***	**-.775****	**-.710***

* correlation is significant at the 0.05 level; **correlation is significant at the 0.001 level, n.s. – Not significant.

Reducing the gait velocity after the 120 minutes of the driving process, selected participants were covering the larger contralateral area. Considering the plantar regions, the strong correlation of the gait velocity and increasing the average contact area was observed at the mod-foot lateral, and rearfoot (medial and lateral) areas.

CHAPTER 3
DISCUSSION

4 DISCUSSION

This investigation considered the influence of long-time driving on the drivers' gait performance. Furthermore, the evolution of PDP and its application of applied pressure distribution on the driver's seat pan was examined.

A mathematical comparison with an objective evaluation of subjectively perceived discomfort was added. The retrospective nature of the study is based on MSD prevalence in the last twelve months.

Participants' anthropometric attributes (age, weight, body height, among others) for further classification of the groups (gender, stature, and BMI) were used, and the evaluation of each characteristic with the objective measurements was applied.

Taking into consideration that the participants were not sharing the same anthropometric attributes, the results were varying between the previously defined groups. What is more, the prevalence of MSD symptoms is diverse among individuals.

4.1 Prevalence of MSD among participants

The occurrence of the lower limbs MSD

This study was designed to investigate the prevalence of MSD of drivers and to identify a possible risk associated with changes in gait performances caused by prolonged driving. The survey highlighted the prevalence of pain or discomfort in two different periods (past twelve months and in the past seven days) aiming attention to several anatomical parts. Moreover, the work absence (the questionnaire was referring to an inability to perform the driving tasks as well) was investigated.

Even though participants, in this case, drivers, were having the driving license on average seven and a half years, the amount of spending their time driving was less than five hours per week. Also, the drivers did not steer a vehicle more than two hours per day. The exposure time should be taken into consideration when comparing the results with other studies, which include only the professional drivers. Referring to various vehicles used by professional drivers (demanding different driving exposure, work-related tasks, among others) (J. Chen et al., 2004; C. K. Smith & Williams, 2014), and as such, drivers might be at the different risk scale (Akinpelu et al., 2011).

The occurrence of pain or discomfort felt in the lower limbs (considering the twelve months) has shown different pain distribution for each extremity part. Knee pain is thanking higher percentage values than the hips/thigh and ankle/feet pain assessing outcomes represented by the study sample size. Examining the higher percentage (34.1%) of the knee MSD caused by pain or discomfort within the gender group, it can be seen (Table 13) that the female participants reported knee MSD pain as the second most often (after lower back pain) among all body parts considered by the NMQ.

On the other hand, the male population has shown the different indicators of knee prevalence. The prevalence of knee MSD in the past twelve months was slightly higher (22.7%) than the rest lower

limb parts (hips/thigh and ankles/feet were sharing the same percentage distribution 18.2). Similar results were shown in studies analyzing male participants (Akinpelu et al., 2011; Reilly et al., 2000; Shamsul Bahri M Tamrin et al., 2014). Using a strategy of self-reported MS pain among truck drivers, results obtained on the prevalence of knee MSD was in the range from 26 until 35% (Sekkay et al., 2018).

Tamrin et al. (2014) have investigated the prevalence of MSD among Malaysian bus drivers. In their study, the total amount of participants who reported pain in the knee was 323 professional bus drivers, which was 27.5% percentage. Another study which reported a similar percentage of the knee MSD (27%) took place in Nigeria (Akinpelu et al., 2011). Akinpelu et al. (2011) included professional drivers working in public transport companies. The prevalence of MSD was investigated by applying the NMQ. Reason comparing these two studies is that the occurrence of the knee pain was similar even though the demographic characteristics and probably the anthropometric characteristics were different.

However, the prevalence of knee MSD pain was higher in some studies (Hussain, 2004; J. H. Kim et al., 2016; Mehta et al., 2019; Mozafari et al., 2015; Szeto & Lam, 2007) indicating a related percentage as reported by the female population in the current study. In research performed 2004 year (Hussain, 2004) involved 461 professional truck drivers. In total, 39% of the drivers were reporting MSD pain symptom obtained in the knee, following by ankle/feet (13%), and hip (8%) pain. As it was reported in this study, the prevalence of MSD in the lower limbs was reported more in the knees than in another lower extremity's parts (defined by questionnaire).

For instance, Szeto et al. (2007) completed research of Honk Kong urban bus drivers with a sample size of 481 bus drivers (there were 404 males and 77 female drivers). The distribution of knee pain was around 36% and was classified as fourth most often MSD pain among the drivers, after the lower back, neck, and shoulders.

To investigate the different joints affected by prolonged driving and its prevalence of MSD among professional truck drivers, Mehta et al. (2019) applied NMQ and numeric pain rating scale. In their research, 76.92% of total participants reported pain in a particular part of the body. In this study, the prevalence of MSD disorders in the test one year was reported by every participant. The reason could be the small number of subjects contributing to the research process, comparing with the other studies (Madhan, 2015; Mansfield & Marshall, 2001; S B M Tamrin et al., 2007) which involve more participants in the research process. Furthermore, the application of a questionnaire in the research and collecting data obtained during the process allows data analyses faster than when including more objective methods in the experimental procedure.

Taemin et al. (2014) moreover indicated an odd occurrence of MS symptoms occurred in both lower limbs (different percentage for right leg – 24%, and for the left leg 21%). The difference should be further examination to establish if the disparity among the lower extremities is statistically significant. Furthermore, it would be useful to apply the same method in a higher number of professional drivers with an age diversity (as well as different driving professions with the different vehicle design) and to establish if the disparity has happened.

Knee pain distribution was lined with the MS pain ensued in the knee (J. Chen et al., 2004) analyzing professional taxi drivers. The investigation was accomplished using the standardized NMQ fulfilled by 1242 applicants. The study has indicated that the knee was higher as the driving time increased. Examining four categories, established on daily driving exposure (up to 6 hours, between 6 and 8 hours, the third category was from 8 until 10 hours, and the final was with participants who drive more than 10 hours per day). As the driving time increases the prevalence of knee pain follows the trending. The MS knee pain goes from 11% (for the first category), 17% (second category), 19% (third category), and 20% for the participants who spend more than 10 hours per day steering the vehicle. Comparing with the current study and with previously mentioned knee pain prevalence, the obtained percentage of the knee pain was lesser

Examination of the main results obtained in the current study has shown similar results of the prevalence conducted in the lower limbs as in some study evaluated occurrence among professional drivers. It should be noted that the majority of the subject included in the research process were students that spent up to two hours of continuous sitting. Time spent sitting on the classes or during computer work cannot de expected similar harmful outcomes as it is in the vehicle (Mozafari et al., 2015; Jared M Porter & Gyi, 2002) – for example, WBV. WMSD are considering repetitive movements, heavy physical or psychological stresses, or dynamic discomfort, among others (Spielholz et al., 2008; Xia et al., 2019). The dynamic discomfort is considering the presence of WBV that can lead to many WMSD (Ebe & Griffin, 2000; Inagaki et al., 2000; Na et al., 2005).

Static posture in combination with the continuous long-time driving (defined as more than 2 hours per day (Okunribido & Lewis, 2010; Szeto & Lam, 2007)) might lead to lower limb MSD such as cardiovascular diseases (Thosar et al., 2015) as well as venous disorders (D'Souza et al., 2005; Łastowiecka-moras, 2017). More muscular disorders are related to prolonged sitting the same way as the pain caused sitting, muscle cramps (Wrona et al., 2015), lover limbs oedema (Belczak et al., 2015; Wrona et al., 2015), and more symptoms such as tightness, swelling, pain while walking, heaviness, itching (Wrona et al., 2015), among others. The consequences might be occurred in the bone structure, cause decreasing in bone density disorder if a person is seated more than four hours per day (J. Chen et al., 2004).

Considering the stature group (with subgroups defined as small, middle, and tall participants) were having a different prevalence of MSD in the lower limbs. The higher percentage of knee pain (63.6%) in the past twelve months among the small population could be lesser number of participants defined in the subgroup. Further analysis of the stature group has shown that middle participants (with the total number of 20 subjects) have shown detailed results of the MSD prevalence as female participants. BMI subgroup, participants classified as normal weight, were having similar results as the previously mentioned subgroups (female and middle height participants).

Prevalence of the lower limbs MSD among the participants in the past seven days was essential for the experimental process and further outcomes analysis. As it was defined in the exclusion criteria in the materials and methods part, participants could not have any MSD or pain in the lower limbs that can affect the gait performance before and after 120 minutes of steering the driving simulator.

Equal distribution of the lower limbs MSD occurrence was reported in the past seven days (with the percentage of 9.1) analyzing the sample size. Furthermore, the rest anatomical part and the occurrence of pain was assessed. The outcomes have shown that the back pain (again lower back was dominating comparing to the rest of body area) was weight the highest percentage of the MSD pain in the past seven days. Additionally, the neck and shoulder (left and right) were following the distribution. Still, if the results observed of the pain in the past seven days compared with the past twelve months, it may be concluded that the participants were having less MS pain in the whole body parts.

If the straightforward assessment is to be considered, it is essential to afterword support the results with statistical analysis. Gender-based differences between the lower limb pars (hips/thighs, knees, and ankles/feet) outcomes did differ between the male and female population. The gap of the knee and ankles/feet MS pain is higher among male participants in the past seven days, but the difference cannot be considered because it is not statistically substantial.

Mozafari et al. (2015) used a survey to determine the prevalence of MSD among truck drivers. In total, 19.1% of professional drivers have reported discomfort in the knee in the past year, but in the last week (prevalence of MSD occurred in the last seven days) was lesser than that (8.1%). The percentage is lower than 9.1% of the knee prevalence, comparing it with the current study. Professional truck drivers used in the previous study (Mozafari et al., 2015) were with a higher average year 37.94 ±5.9 years old drivers (in the current study was 27.4 ±4.7 years old participants) and higher BMI 26.02 ±2.9 kg/cm^2 (current study 23.5 ±4.0 kg/cm^2). Other lower limbs parts had smaller percentage than in this study (ankles/feet 3.5%, hips/thighs 2.3%, while in the current study was reported 9.1% of MS pain in the mentioned body parts in the last seven days).

4.2 Perceived discomfort during long-time driving

Defining discomfort or perceived pain during 120 minutes of the driving simulator was assessed to establish the participants' well-being. A modified scale with a defined body part was used to label the felt pain in a particular body part. The categorization of the discomfort during the driving was described into six different levels (starting from the first level which signifies “not uncomfortable” and finishing with thighs, the sixth, the level which was defined as extremely uncomfortable). Similar approaches could be seen by several studies (Sammonds et al., 2017; J. Smith et al., 2015; Varela et al., 2019), which besides the six-level scale were using a Borg scale to define perceived discomfort as precise as possible. This study did not include the Borg scale, as it was not the primary goal to analyze the subjective discomfort, but the focus was on the objective measurements of control of the physical parameters.

The measurement was performed during four-time sequences. During the initial recording, almost every single subject reported the first discomfort level (did not feel pain in any part of the body) accept one participant who reported second discomfort level (“a little uncomfortable”) in the lower back area. Besides this, it was a good starting position to assess if the subjective discomfort ratings do exceed the level obtained at the initial recording.

Furthermore, the average value changed at the 40th minute of the experimental process. The lower back pain was dominant and followed by the buttocks area. Single highest reported values reached the 4th level of discomfort, exception the ankle, where the discomfort achieved the 3rd level.

The discomfort felt in all participants body parts was significantly higher after one hour and twenty minutes of the constant drive. As time progress, the subject's discomfort is increasing (Hiemstra-van Mastrigt et al., 2017; Li et al., 2017; Sammonds et al., 2017; J. Smith et al., 2015). Sammonds et al. (2017) investigated driver's fidgets and movements in total duration of 140 minutes. The study includes 10 participants (six males and four females). The results are illustrating a similar progression of the discomfort of body parts. J. Smith et al. (2015) explored discomfort occurred in a body part during steering a driving simulator in the total exposure of one hour. A six-level scale has shown that the higher prevalence of discomfort occurred at the right ankle, at the end of the driving process. The reminding areas has shown similar results at the final recording.

Maximum values of perceived discomfort reached the 5th level (in case of reporting the sixth level, it would have been concern that the participants were not able to continue the driving process and the data acquisition would be stopped) at the final recording. Besides the shoulder pain, the remaining body parts have reported higher discomfort values than in the previous sequence of the data collection.

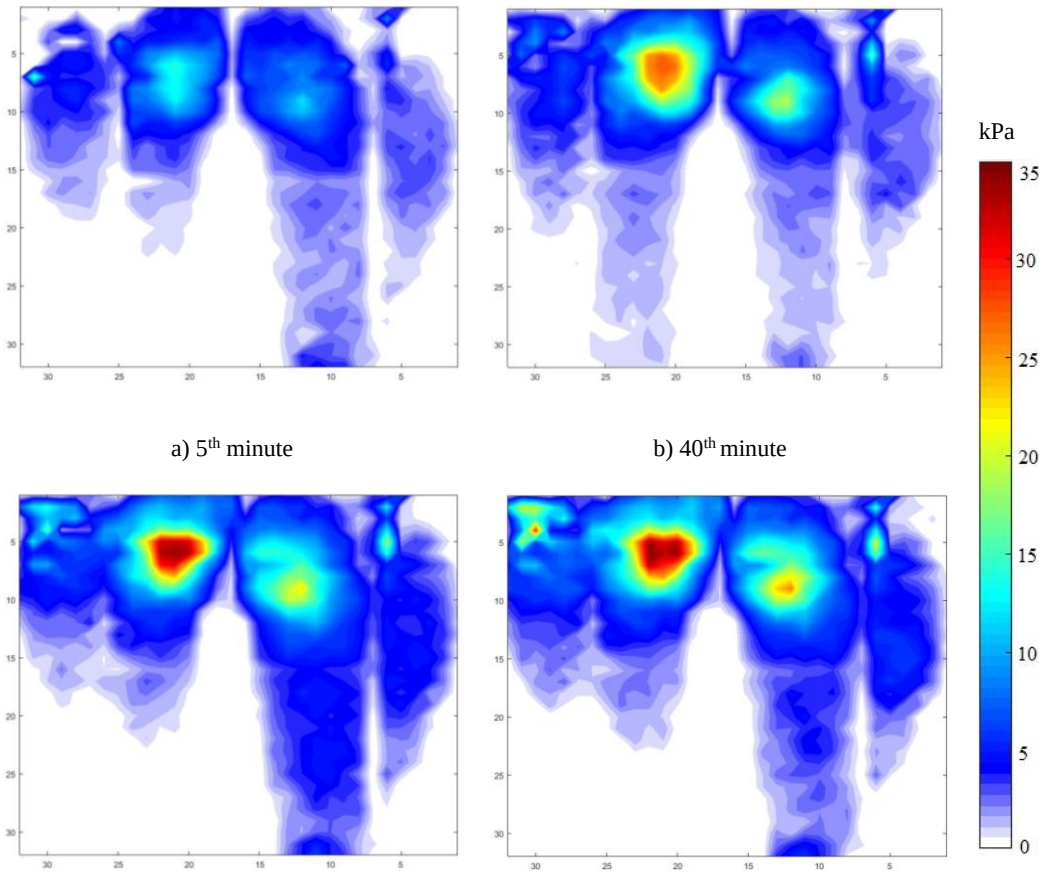
4.3 IP on the driver's seat pan

IP on the total seat pan area

This study investigates IP on the drivers' seat pan during the long-time driving. Firstly, the IP variables were representing the total seat area, evaluating applied pressure for the sample size and previously defined groups. Secondly, the total area was further separated into zones, which were representing the left and right side of the lower limbs area. Thirdly, the total area and zones were compared with PDP and perceived discomfort during 120 minutes of the driving.

The outcomes have shown that long-time driving influenced the IP variables. In other words, applied (average and peak) pressure as well as the contact area, considering the total seat pan area, increased over time. This finding has been supported by several articles (C Mergl, 2006; Na et al., 2005; J Mark Porter et al., 2003; J Mark Porter & Gyi, 1998). Some of the research report the growth of the applied pressure-dependent variables over time but do not provide any statistical proof (Le et al., 2014; Na et al., 2005). Na et al. (2005) indicated the increase of the IP at the end of the driving process, which was in a total length of 45 minutes – including sixteen participants. On the other hand, studies with more extensive research – driving more than two hours (Inagaki et al., 2000; J Mark Porter et al., 2003; Thakurta et al., 1995) were having the same results.

Average values of IP pressure on the drivers' seat pan is represented in Figure 30. Additionally, the figure does not represent the average value of the applied pressure of the sample size, but it is illustrating an example of one subject has grown IP variables during the driving process.



a) 5th minute b) 40th minute

c) 80th minute d) 120th minute

Figure 30 An example of applied average IP on the driver's seat pan in different time sequences

Nevertheless, the current study divided the total time into four sequences, within a distance of forty minutes. The time affecting each time sequence has been shown using a statistical method. Taking into consideration the groups difference over time (between the subject change of the applied pressure and covered area) outcomes were slight dissimilar. Interface average pressure indicated that during the time gender difference occurred in every single time sequence. Starting from the initial recording, male participants were applying higher average pressure on the total seat pan area.

Furthermore, analyzing the stature and BMI groups, the difference in IP (with the focus on average pressure) was reported only once per time sequence. Between the stature subgroups (small, middle, and tall participants) initial recording introduced a pressure variation, where small participants were reaching smaller pressure values. As the driving progress, the stature-based difference was not obtained. BMI subgroups occurred various IP variables (both average and peak pressure) during the 80th minute of steering the driving simulator. Smaller average pressure values developed under the normal weight participants, while the smallest peak pressure took place under overweight participants. The reason for lesser peak and higher average pressure under lower limbs occurred in the overweight participants might be higher body mass and anthropometric attributes with a focus on the dimensions of the anterior superior iliac.

The total contact area was different for BMI subgroups. Subjects classified as overweight were having statistically significant higher values than the rest two groups. Unique anthropometric characteristics may have altered and a substantial effect on the interaction between seated posture and IP. Various human attributes can have a different effect on pressure distribution, applied area, and similar pressure variables. Pelvic disparities in size and shape between the gender are reported in the literature (Moes, 2007; Vos et al., 2006). Females, in the sitting position, may apply grater covered area due to larger pubic arch, and more significant distance between ischial tuberosities (Vos et al., 2006). Additionally, this can result in better pressure distribution of weight on a seat surface.

Distance between bones (ischial tuberosities) plays a vital role in covering a greater contact area while the person is seated (Luboz et al., 2018; Marras & Kim, 1993). Anthropometric attributes are in correlation with applied pressure/contact area, and participants with smaller distances between the bones mentioned above will contribute with lesser contact area. In comparison, the opposite (higher values) will be associated with greater distances between the ischial tuberosities bones (Åkerblom et al.,1948; Marras et al. 1993). Additionally, having a larger amount of the fat under the buttocks area will influence the interface contact area on the seat pan, causing larger contact area and lesser pressure variables (Moes, 2007; Vos et al., 2006). The investigation done by this study supports the stated findings.

Participants with higher bone distances of anterior superior iliac and with more weight had to apply grater covered area over the seat pan. The outcomes obtained in this study indicated no mathematical relationship between the peak pressure variable and stature and BMI groups. Investigations done by Vos et al. (2006) and Paul et al. (2012) concluded that BMI was in correlation with the applied contact area. The different conclusion between Vos et al. (2006) and the current study is in the different sitting postures and methods. Vos et al. (2006) used office chairs which directly require different sitting strategies and further might impact the IP variables. Paul et al. (2012) determined that BMI have an association between IP variables that the rest anthropometric attributes.

Participants body height has been associated with applied IP, where taller participants had higher pressure under the lower limb areas (Na et al., 2005; Vos et al., 2006). Analyzed results did not indicate this type of tendency after the second recording (from 40th minute) considering the average pressure. Statistical analysis has shown that in this research that middle stature participants were having higher peak pressure values than the rest two groups.

Moreover, the time spent driving shown a statistically significant variation in the contact area, considering all decided subgroups. The difference occurred between the initial recording and second recording (corresponding to 40th minute of the driving process) had the highest value various than the following recoding. This difference has occurred for all (referring to gender, stature, and BMI) groups.

During steering the driving simulator, participants hands did not have armrest. Form the total body weight, 11% is conducted by upper limbs (Defloor & Grypdonck, 1999) and could potentially affect the IP. An investigation based on the male/female characteristics divergences has reported

that beside preferred interior dimensions of the driving venue (for example angle of seat backrest), the armrest may affect the amount to of the IP on seat pan (Na et al., 2005). It has been shown that male participants using the armrest significantly reduced the applied pressure, while on the other hand, female participants did not show any variation with or without the armrest (Na et al., 2005).

Considering the total applied area the average IP values were 4.4 ±0.8 kPa at the initial recording, at 40th minute were 5.3 ±0.9 kPa, at the third recording was 5.6 ±1.0 kPa, and the sample size reached 5.8 ±1.1 kPa at the final recording. This pressure value is considering the total area. This first 40 minutes the change was 0.9 kPa and afterwards the changes were not as significant. IP distribution affecting the reduction of the total blood flow volume by 1.2% in the lower limb muscle (biceps femoris) in the first 30 minutes of sitting (Le et al., 2014). If the total volume decreases up to 13.4% in the first 60 until 90 minutes, it is possible that a sited person feels discomfort until the 120th minute (Le et al., 2014).

As the final consequence of the uniformity of the pressure distribution on the buttocks/thigh area, tissue ischemia might occur (Bergstrand, 2009; Dharmarajan & Ugalino, 2002; Le et al., 2014). Different pressure threshold has been suggested. It could be seen that 5.6 kPa were obtained at the 120th minute assessing the total number of participants. Pressure enough to do capillary closing is suggested at 32 mmHg (or for more straightforward comparison converting it into Pa would be 4.3 kPa) (Jackson et al., 2009; Lewis et al., 2018). This value has reached the initial recording. Seat shape (J. Smith et al., 2015) or build-up materials possibly because of the high IP at the initial recording (D. Brienza et al., 2018; S. Y. Kim et al., 2016; Levy et al., 2014; Rhimi, 2017).

Methods for comfort/discomfort evaluation are separated into static and dynamic evaluation. During the experimental data acquisition, the WBV were excluded, because it was used driving simulator. Correlation between the IP variables is divided into research articles with the before mentioned parallel (S. Y. Kim et al., 2016). Statistical correlation between the IP variables was obtained, and the outcomes are illustrating a strong correlation between the variable. The association between the variables were obtained during the time.

Correlation between IP variables and the anthropometric attributes has indicated a moderate correlation. The important is to note that the association between the dependent variables did not occur for every single time sequence and did not contribute to the total anthropometric measurements. The moderate association was reported between weight and second/third recording.

Besides anthropometric attributes, participants age have a different interaction with IP variables and preferred sitting strategies. Stating this, Kyung et al. (2013) used different age groups and determined the statement aforesaid. It was approved that older participants were applying higher pressure under the right buttocks area, caused by different driving strategies. One of the reasons for adopting different driving strategies might be due to the lack of visual ability between the young/old drivers (Kyung & Nussbaum, 2013).

Furthermore, body height and knee height have reported a moderate correlation with the average pressure during the first 40 minutes of steering the driving simulator. Body height has been reported as one of the most critical factors to influence IP distribution (Vincent et al., 2012; Vos

et al., 2006). Subjects with higher body height tend to sit with a more open stance (extended joint angles –shoulder, elbow, and hip) (Le et al., 2014). As often reported, upper leg discomfort might be an adopted position of prolonged sitting (Le et al., 2014).

In the case of smaller diving venue, knee and hip angle might be more flexed and could affect different sitting strategies and further lead to uneven pressure distribution (Le et al., 2014) and therefore cause less blood flow in the lower limbs. Applied contact area under the right thigh had larger values for the participants taller than 175 cm than participants classified as middle and small (lower than 175 cm) (Kyung et al. 2008). Furthermore, with smaller weight values (participants with the weight lesser than 68 kg) reported more considerable discomfort in the buttock area (Le et al., 2014). One of the conclusions might be associated with the lesser fat percentage in the buttocks, which is unable to reduce the applied IP.

Additionally, participants who favoured greater horizontal distances inside the vehicle were producing higher average pressure on the driver's seat. The backrest angle had a low correlation with the average pressure on the total area. This support the conclusion that the taller participants were applying higher IP during the long-time driving.

IP variables were correlated with reported perceived discomfort for each time sequence during the long-time driving. After analyzing the findings, it was concluded that a weak positive correlation between the covered seat pan area existed and reported ankle pain after eighty minutes of the driving process. Participants with higher lower back pain were covering lesser contact area at the second recording. This association is weak, as well. Using a seven-point scale and including sixteen male participants (Na et al. 2005) did not establish a correlation between perceived discomfort and diverse IP variables.

Additionally, Hartung et al. (2006) experimented with a total length of 45 minutes, but the drive did not continue (it was consistent in a few segments). The study includes taller participants with a weight range from 72 to 76 kg. Besides the more detailed subjective evaluation of discomfort (including 17 anatomical landmarks with six levels of discomfort) did not find a correlation between body parts and discomfort ratings.

Furthermore, analyzing the total area and including IP variables and linking it with perceived discomfort in a body part appears to have an association in a few research (Milivojevich et al., 2000; Thakurta et al., 1995). Thakurta et al. (1995) experimented in a real environment with a duration until 120 minutes. Majority of participants were males (27), and a few females (9), drivers. The pressure distribution was in correlation with outcomes obtained using local comfort/discomfort 10-point scale. Additionally, the findings were not supported by statistical examination. Several years after their investigation, Milivojevich et al. (2000) completed a laboratory experiment with an equal distribution of gender participants (six male and six female). It was establishing a correlation between subjective perceived discomfort and pressure distribution over time.

The IP variables defined by seat pan zones

Further analysis of the IP demonstrated that the pressure under the IT bones is the highest than the rest of the lower limbs' parts. IP under the buttocks area might be up to eleven times greater than the rest of the lower limbs' parts (upper of lower thigh area) (Slayton et al., 2017). To support an enormous amount of pressure, gluteus muscle (Figure 3) and IT bones are supporting and absorbing the pressure. An anthropometric characteristic is having a significant role in defining a tissue tolerance to handle the IP under the area, as mentioned above (Defloor & Grypdonck, 2000). Pressure thresholds have been suggested (Defloor & Grypdonck, 2000; Goossens, 2007; Hanson et al., 2006; Jackson et al., 2009; C Mergl, 2006; Newson & Rolfe, 1982; Telfer et al., 2009), but the thresholds values are not equal. Applied IP above the stated threshold values will reduce the blood flow and potentially cause an MSD (still, this is refereeing to overuse, often and prolonged static sitting) (Belczak et al., 2015; D'Souza et al., 2005; Cees W J Oomens et al., 2015; Thosar et al., 2015; Wrona et al., 2015). Furthermore, studying the IP cannot predict the sub-dermal tissue strains and stresses (Linder-Ganz et al., 2007; C W J Oomens et al., 2010; Cees W J Oomens et al., 2015) but could prevent skin injuries (Luboz et al., 2018) and long-time deep tissue damages (C W J Oomens et al., 2010; Stekelenburg et al., 2006). In the other worlds, the IP measurement only evaluates the pressure between subject body parts and the surface area (Linder-Ganz et al., 2007).

Prolonged driving exposure, in combination with preferred driving strategies and work-related task, might influence the IP over time. Besides its nonequal distribution, values of pressure variables under the lower limbs areas as well as that the seat supports (bolsters) were increasing. The average IP occurred under the right lower limb, taking into consideration all body areas, is giving a slightly higher value. This could be an affection of the driving strategies during the time (Hiemstra-van Mastrigt et al., 2017). Differences between the gender group have demonstrated that male drivers were applying higher average pressure at the right upper thigh and bolster, while on the left lower limbs statistically higher values were obtained under the lower thigh area. Uneven pressure distribution, especially under the thigh area (Hartung, 2006; C Mergl, 2006), might lead to hamper blood circulation and cause lower limb discomfort (Goossens, 2007).

Average IP under the buttocks area was 5.7 ± 2.0 kPa (right buttock) and 4.9 ± 1.6 kPa (left buttock) at the initial recording. Taking into consideration thresholds values suggested by Hartung et al. (2006) obtained values in the current study do not exceed suggested thresholds. Driving after 40 minutes brought different values under the thighs and buttocks areas. This time, buttocks were having on average pressure of 7.2 ± 2.8 kPa and 6.4 ± 2.5kPa. After 80th minute the values were even higher 7.7 ± 2.8 at the right side, and left was up to 7.3 ± 2.8 kPa. The final recording brought 7.9 ± 3.0 and 7.5 ± 3.1 kPa of average pressure under the buttocks area. Obtained average pressure values at the interface of the drivers' seat pan exceed the recommended values by a few investigations (Defloor & Grypdonck, 2000; Goossens, 2007; Hanson et al., 2006; Jackson et al., 2009; Newson & Rolfe, 1982; Telfer et al., 2009).

BMI subgroups have the most different values, considering the average pressure divided by areas. The average pressure distribution was the highest among underweight participants who reported,

considering the 120 minutes of the driving process, range from 7.7 ±1.6 kPa until 12.2 ±3.8 kPa under the buttocks area. The other two subgroups (normal weight and overweight participants) reported lesser pressure than subjects classified as underweight. Participants with greater distances between the anterior superior iliac bones and with more kilograms were applying higher IP on the drivers' seat pan bolsters.

Mergl et al. (2006), in their research, indicated a correlation between anthropometric areas and reported discomfort. The results demonstrated a strong correlation with maximum pressure and pressure gradient and the buttocks area. Front of the thigh as well revealed a strong correlation with the percentage of load, mean pressure, maximum pressure, and pressure gradient. Kyung et al. (2008) in hist study divided pressure pumping technology into six areas and correlated with dependent variables. A significant correlation between the left thigh with a whole-body comfort rating. For the rest variables and regions, no correlation was found. The results obtained by the Principal Component Analysis correlated 22 out of 36 variables (significant correlated) with the later Kyung et al. (2013) study. Considering the lower limbs: Taller subjects (>171 cm) reported discomfort in the hip and knee. Upper leg discomfort was reported by more decadent subjects (>71 kg) (Le et al. 2014). The ideal pressure distribution was suggested by Zenk et al. (2008). Minimum pressure was required under the thigh area and higher values under the buttocks area (the results were represented in a percentage (front of the thigh: 0.4%, buttocks: 66.5%).

4.4 Adopted driving postures

In order to design the better interior dimensions of the drivers' seat position, nonadjustable pedals, steering wheel, and the driving seat can interfere with the outcome of the experiment. This problem might be drastically reflected in case of prolonged sitting when the driver feels discomfort/pain in a specific part of the body and selects a new posture in order to be more comfortable (Anshel, 2005; Jeong & Park, 2017).

During the period between the 5^{th} and 40^{th} minutes, the driver adopted a posture with minimal joint angle variation. Hanson et al. (2006) reported similar findings but taking into consideration the period from 5^{th} to 20^{th} minute. The opposite happened with Barkla (1964) were 30 minutes of experimental data was enough to obtain reliable results and to conclude optimum driving posture. Our observation showed that this trend continues until the 80^{th} minute when some joint angles start to change. The upper limbs, which have the most significant changes in the angles among gender, start showing variation at the 80^{th} minute until the end of the experimental protocol. On the other side, the lower limb joint angle changes are minimal throughout the entire protocol.

Due to the male participants' average height of 176.42 ± 6.12 (cm), they can be classified as tall persons (Kyung & Nussbaum, 2009), which is noteworthy since Porter et al. (1998) concluded that tall males tend to have a more open/extended posture. Although the effect on the posture of long-time driving is in agreement with a previous study (J Mark Porter & Gyi, 1998), the adopted posture along time does not mean that the drivers felt more comfortable (Kyung & Nussbaum, 2009). Participants divided by stature, did not show the statistically significant difference in PDP.

Joint angles were not varied between the small, middle, and tall subjects, with the only accepted in the ankle joint adopted on the second recording (after 40 minutes of the drive). Participants divided by BMI groups did not show any difference in preferred 3D joint angles during the driving process.

Table 58 comparing results published in previous research under different conditions and current investigation. The results are referring to 3D joint angles, preferred or optimum, after a particular time of the driving process. The methods of defining the outcomes (Table 58) are various throughout the research.

Table 58. Recommended 3D joint angles

	Flexion / Extension of main joint angles (°)					
Research	Ankle	Knee	Hip	Shoulder	Elbow	Wrist
Porter et al (1998)	80-113	99-138	90-115	19-75	86-164	-
Park et al (2000)	82-116	120-152	103-131	7-36	86-116	-
Vogt (2005)	103	119	99	22	127	-
Hanson (2009)	90-111*	109-157*	92-109*	14-68*	96-160*	159-219*
Kyung (2009)	82-88**	84-91**	79-87**	1-29**	85-120**	129-170**
Current study	114.2	123.1	92.9	40.2	118.3	143.7

* left side of the body; ** group number 1.

The interpretation of the results in the current study refers to the average 3D joint angles during the entire period of driving, which can be seen as similar to those reported by Porter et al. (J Mark Porter & Gyi, 1998). However, the ankle angle does differ from all studies, with several possible reasons for that fact. Schmidt et al. (2014) mentioned a problem with determining a unique approach in defining optimum or preferred joint angles.

Determination of the driving postures can be found in different studies but with a variety of approaches, measuring methods, and the time duration (Andersson et al., 1974; Hanson et al., 2006). Analyzing adopted postures, Hanson et al. (2006) did not find any postural difference between adopted joint angles in the time duration between 5^{th} and 25^{th} minute. In this study, assessing the sample size, the difference in PDP was not obtained comparing 5^{th} and 120^{th} minute of steering.

Evolution of the driving strategies

In order to identify a driving strategy over time, the current study used a statistical method to identify and classify the PDP and its affection on the driver's seat pan. J. Park et al. (2014) used clustering method to identify a driving strategy in three different vehicles (coupe, sedan, and SUV). The investigation includes four participants (20 male and 20 female) with the age range from 20 to 50 years old. The experiment was held in a laboratory in a total length of 10 minutes. It was concluded that female participants preferred slouched or erect driving posture, while male participant preferred reclined posture (J. Park et al., 2014) as the reason was referred difference in the anthropometric characteristics.

Driving postures defined by the second cluster characterized participants that parents to adopt flexed knee angles (knee bent) as well as lower hip angles than the rest two clusters during the

initial recording. Choosing this type of the lower limbs' angles had lesser pressure under the right and left lower thigh, while under the buttock's areas were reported the highest-pressure values than the rest two clusters.

Driving poster by the cluster number 6, taking into consideration the lower limbs angles, were more relaxed than the lower limbs angles defined at the initial recording. This posture was having the majority of female participants (total number 14, while the male was only 3) characterized as normal weight drivers. This setting strategy was having different applied pressure on the drivers' seat pan. The lesser average pressure was under the left thigh area. The highest IP was applied by driving strategy defined by cluster number (majority male participants, total number 10).

Classification of preferred driving strategies and influence on the drivers' seat pan might point out at the cluster 9 as the worst driving strategy since it directly influenced IP and has shown the highest value comparing it with the remaining cluster subgroups. (Naddeo et al., 2015; J. Park et al., 2014; S J Park et al., 2015; Vink & Hallbeck, 2012). As a consequence, a more significant amount of the average pressure has occurred under the buttocks are (left and the right side). The final recording brings a difference of the driving strategies only in the main joint angles of the lower limbs.

4.5 Influence of gait velocity on the linear kinematic variables

Comparison of gait linear kinematics before and after long-time driving

Influence of steering the driving simulator on participants gait was assessed, and the outcomes were compared between two different time sequences (before and after the drive). Gait linear kinematic variables were further paralleled among main groups defined in the methodology parts, as well as a new group of participants based on the gait velocity differences (between the post- and pre-steering gait performance).

After spending two hours steering the driving simulator, participants walking strategy has changed. The gait velocity has increased by 3.6%, relating to the initial walk. The step frequency increased as well, while the total time and the distance reminded without statistical differences between the two periods. The differences between the walking speed are significant, even though participants were performing the walk at the self-selected comfortable speed. For instance, human walking speed has been ranged from 1.23 to 1.25 m/s (Chiu & Wang, 2007; Segal et al., 2004), taking into consideration the used energy by performing the gait, while grater speeds require higher muscles activities of the lower limbs (Chiu & Wang, 2007). As such, the walking speed has been classified as "vital sign" (Bohannon et al., 2011) and significant predictor of different diseases or MSD (Bohannon et al., 2011; Eils et al., 2002; Mickle et al., 2010). Several studies illustrated data based on the self-selected gait velocity (Allet et al., 2008; Bohannon et al., 2011; Fryzowicz et al., 2018; Van Deursen, 2004). Fryzowicz et al. (2018) in their study included 28 healthy women aged 21 years on average to walk barefoot on a pathway length of 14 meters. The gait was performed on their preferred comfortable speed, where the values were 1.37 ± 0.11 m/s on average.

Furthermore, barefoot walking was investigated by Staab et al. (1992), including participants aged between 20 and 60 years old. Performed walking speed were different for the age groups, where young were walking faster at 114.0 cm/s, followed by middle-aged participants (111.8 cm/s), and at the end walking speed for the older participants were the slowest (94.7 cm/s). In this study, participants average age was 27.4 ±4.7 years old and the gait velocity, taking into consideration both periods, was considerably smaller (initial walking speed was 93.5 ± 12.6 cm/s, and after the driving the gait velocity was 96.9 ± 15.3 cm/s) than the performed walk similarly aged participants in the previously mentioned research (Chung & Wang, 2010; Fryzowicz et al., 2018). Evaluating the results gathered in this study with the walking speed in Staab et al. (1992) study, subjects' gait velocity was closed to older than to middle or young participants. Comparing the results collected in this study with the walking speed in Staab et al. (1992) research, subjects' gait velocity was closed to older than to middle or young participants. Even though both investigations are considering the barefoot walking, the predicted space for the gait was more prominent than in this research (maximum seven meters of the walking path). This might be one of the explanations of why the participants were having smaller gait velocity values than previous studies. The second reason could be that participants were asked to walk barefoot before and after the steering the driving simulator, while the driving itself was considering wearing shoes.

Assessing the obtained values of the walking speed and comparing it with the experiment performed by Öberg et al. (1993) (who evaluated different walking speed including 233 healthy participants) it can be concluded that in this study subjects were having slower gait performance for both periods. The results illustrated in the study Öberg et al. (1993), taking into consideration the same age range (which in case of this study was from 20 until 40 years old), referred that slower walking speed was varied from 83.0 until 93.0 cm/s, while normal walking velocity was classified from 122.0 until 132.0 cm/s.

Gender-based differences on the gait velocity (Chiu & Wang, 2007; Chung & Wang, 2010; Fryzowicz et al., 2018; Pataky et al., 2008) were not constituted in this study. Females aim to rise the step length in order to keep the walking speed with the male participants (Bohannon et al., 2011; Chiu & Wang, 2007). At the very beginning of the experiment, the gait performance (takin into attention included spatiotemporal variables) did not differ among the genders. Furthermore, after the long-time driving, the only difference appeared in the step length, but the conclusion was different than described by Chiu et al. (2007), where females tend to adopt greater step length than male. Male participants were applying larger steps by 7.0 % than female while remaining spatiotemporal variables did not show any statistically significant differences. Knowing that the gait velocity is directly related to the step length, it could be emphasized that the male population intended to increase the walking speed after the long-time driving (Kirkwood et al., 2011). Additionally, comparing with another research, it could be seen that in this research step length was smaller (on average before driving: 55.2 ±5.2 cm, and after driving: 56.0 ±7.6 cm) than in Fryzowicz et al. (2018) study where was reported 64.0 ±0.04 cm. Evaluating the results obtained by female, the gait velocity has increased for the majority of the population while the step length reminded (statistically) not changed.

Candance has increased as well after the prolonged driving process. The number of steps per minute has increased by 3.1%, similar to gait velocity, as expected. Decreasing the cadence will directly result in slower walking speed (Cobb et al., 2004; Franklin et al., 2015; Segal et al., 2004; Van Deursen, 2004). Nevertheless, barefoot walking is having a higher frequency of steps comparing to shoe walking (Segal et al., 2004; Van Deursen, 2004). In this study, after the steading, the driving simulator, the average number of steps per minute was 105.4 ±9.9 which was related to the slow walking speed (Chiu & Wang, 2007; Franklin et al., 2015; Segal et al., 2004; Van Deursen, 2004).

Further analysis of the gait variables has shown that participants were applying different forces, considering both lower limbs, during the gait performance. The differences appear between participants with considerable differences in the anthropometric attributes (Fryzowicz et al., 2018). Moreover, participants right lower limb, after long-time driving, was applying extra impulse values [Ns], while the significant mathematical change did not appear between the two-time line in the left lower limb.

Kinematics and dynamics characteristics of the walk are influenced by increasing/decreasing the gait velocity (Fryzowicz et al., 2018). Increasing the speed after the driving was having for a consequence reducing the stance phase, which could be categorized that participants were walking with more confident (Ma et al., 2018).

Post driving walk leads to more MS dynamic load and as well as significant muscle activity (Chiu & Wang, 2007; Fryzowicz et al., 2018) which were further influencing another spatiotemporal characteristic (decreased support time and stance phase). Finally, impulse under the right lower limb has increased, and the majority of the participants began to apply more force than before the driving process. The long-time driving process may trigger physiological and psychophysical responses, causing muscle exertion during the extended time driving, and participants lost control of their self-selected comfort speed (Chiu & Wang, 2007). The different walking strategy might require more muscle activity of the lower limbs and probably dissimilar angular kinematics after two hours of the driving process (Chung & Wang, 2010; Franklin et al., 2015; Fryzowicz et al., 2018; Segal et al., 2004).

Assessing the variation of the gait velocity, as one of the leading indicators of the risk of falls (Eils et al., 2002; Hausdorff et al., 1997; Hollman et al., 2011; Kirkwood et al., 2011; Ma et al., 2018) it was established groups of eleven participants (25% of the sample size) had reduced their gait velocity after the steering the driving simulator. Their walking strategy was with more causing, with significantly increasing double support and stance time during the gait. Reducing the step length could be one of the most critical indicators for risk of fall associated participants (Hausdorff et al., 1997; Kirkwood et al., 2011; Merker et al., 2018; Mickle et al., 2010). Defined participants with the potential risk of falls after the long-time driving, were significantly reduced gait velocity (with average speed 87.6 ±16.9 m/s), while the step length reduced by 1.5 cm (with the average values before 55.2 ±6.0 cm and after the driving 53.7 ±4.4 cm), which the drop was not significant for the selected participants. Decrease of step length by 3 cm could include interior the walking stability (Kirkwood et al., 2011). Reducing walking speed up to 1 m/s will develop risk of falling

up to 7 % (Kirkwood et al., 2011). It must be noted that the population classified as a potential for risk of falls have reduced the gait velocity for 0.07 m/s after the long-time driving.

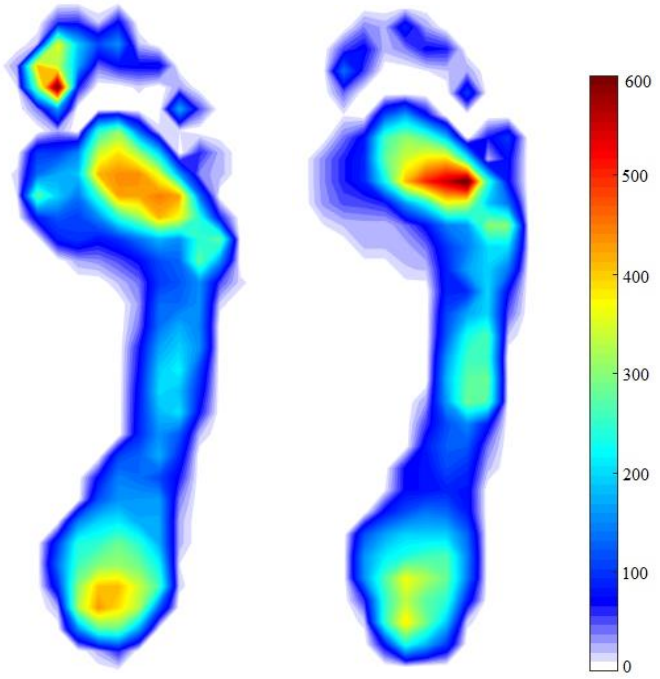
Lower activity level (driving static posture in the total duration of 120 minutes) might lead to decrease gait velocity (Riddiford-Harland et al., 2015), or possible muscle fatigue located in the lower limbs (do Carmo Aprigio et al., 2020; Hausdorff et al., 1997). Declaring that participants with higher BMI are associated with a higher prevalence of risk of falls (Wu & Madigan, 2014), reduction of walking speed has occurred among (majority) normal-weight participants (nine from eleven) while only two participants were classified as overweight. Based on the established conclusion, the classed group may be described as a group with a low risk of falls (Kirkwood et al., 2011).

Influence of walking speed on the plantar variables

Post driving process has significantly influenced the plantar pressure and covered area during the walking performances. As it was established above, participants adopted gait with a higher velocity which had as an influence different pressure distribution and covered area in the right plantar region. The total maximum area has decreased under the hallux and rearfoot (medial and central), while the central forefoot maximum area has increased. The same conclusion is applied for the average pressure during the ROP. The peak pressure has decreased under the hallux and medial rearfoot region, while the forefoot (central) peak pressure has increased comparting to the gait performed before the driving process. Furthermore, similar values have occurred, analyzing the average pressure during the ROP. The average pressure under hallux has reduced, while the average pressure appeared below the central forefoot had significantly larger values than the first walking.

As the gait speed increased, the pressure and force under the hallux and central forefoot area are increasing (Burnfield et al., 2004; Riddiford-Harland et al., 2015; Rosenbaum et al., 1994; Segal et al., 2004). In this research, the results have indicated that the total pressure during the ROP has transmitted to the central forefoot area (Dhanendran et al., 1980; Hughes et al., 1990). This might be classified as unusual behaviour because with increasing walking speed pressure under the hallux and the rearfoot area linear increased with the velocity progression taking into consideration barefoot and in-shoe walking (Burnfield et al., 2004; Rosenbaum et al., 1994; Segal et al., 2004).

Transmission of the mean peak pressure distribution between the two time periods is represented in Figure 31. This illustration is represented by one randomly selected participant who substantially increased the gait velocity after the long-time driving, but still representing the results achieved by the majority of participants (with the significant speed boost straight after the driving process). Moreover, the scale is defined in the kPa with the colour gradation (from colder colours implying to smaller values, up to warmer colours referring to higher values).

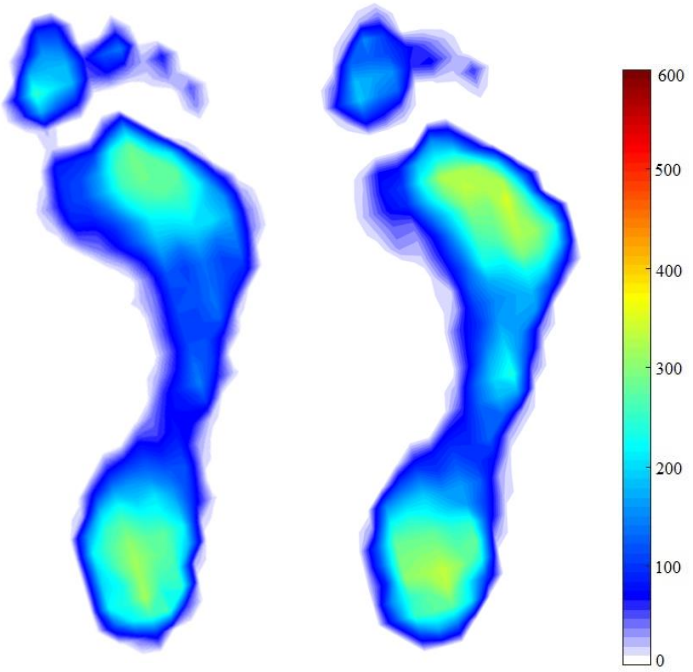


a) Before b) After

Figure 31. Changes in the mean peak pressure distribution between two walking periods

During the push-off stage of the ROP hallux and the toes are having an important role (Dhanendran et al., 1980; Hughes et al., 1990), and decreasing motion of the foot ankle may influence the pressure distribution applied in the plantar regions (Verdu-Roman et al., 2020; Weist et al., 2004). It is suspect that the long-time driving caused the local muscles fatigue of the foot which have affected the ROP and transmitted the pressure from the hallux to the central forefoot area (Jacob, 2001; Weist et al., 2004), which might be linked to increased dorsiflexion in the metatarsophalangeal joints (Nagel et al., 2008). If the local muscles fatigue continues to affect the pressure distribution under the central forefoot area, it may overload the metatarsals heads and lead to, possible future, fractures (Dhanendran et al., 1980; Nagel et al., 2008).

Figure 32 is illustrating an example of a participant with the walking speed reduction, comparing to the initial walking, after the long-time steering the driving simulator. Moreover, the results are representing the mean peak plantar pressure with the scale (symbolizing the kPa). Based on the visual analysis, figures 31 and 32 are differently affected by the walking speed. Increasing gait velocity affected plantar pressure. On the other side, slower walking had for a consequence to reduce average pressure under the fingers area, while the maximum pressure below the mid-foot lateral was significantly higher. Additionally, the peak contact area was increased at the central forefoot and decreased under the hallux and other fingers area after 120 minutes of the driving.



a) Before b) After

Figure 32. Mean peak plantar pressure distribution of participants with the risk of falls

Eleven participants, classified as a group with low risk of falls, have adopted more specific roll-over pattern. During the ROP, at the push-off phase, average pressure has decreased for the fingers. Nevertheless, this time the average pressure did not substantially transmit to the central forefoot area, as happened with the participants who adopted higher gait velocity after the long-time driving. Furthermore, higher peak pressure at the mid-foot lateral area could possible mean that participants had a foot pain (Riddiford-Harland et al., 2015) or by low activity level caused by prolonged driving (Menz et al., 2012; Riddiford-Harland et al., 2015). This assumption does not need to be the case with this study, because the mean peak pressure could be linked with slower walking speed (Pataky et al., 2008; Rosenbaum et al., 1994) or caused by local muscle fatigue (Dhanendran et al., 1980; do Carmo Aprigio et al., 2020; Merker et al., 2018) and was unable to perform the normal ROP. This notion might be possible knowing that reduction of the pressure under the fingers could be caused by muscles weakness or fatigue (Nagel, Fernholz, Kibele, & Rosenbaum, 2008).

CHAPTER 4
CONCLUSIONS

5 CONCLUSIONS AND PERSPECTIVES OF FUTURE WORK

5.1 Conclusions

This thesis aimed to investigate changes of the gait performance after long-time driving and to identify a possible factor that can indicate a potential musculoskeletal symptom of drivers' lower limbs. Based on the results, represent throughout the thesis, the following conclusions can be drawn:

I. Perceived body discomfort was significant after the 80th minute of the driving process, with the highest occurrence in the lower back area and followed by the buttocks area.

II. Preferred driving angles in the lower limbs did not change during the 120 minutes of steering the driving simulator. Different driving angles was observed between the gender population, where male participants adopted more open/extended posture and female more closed/flexed postures of the upper limbs. Changing preferred driving angles in the upper extremities is linked with long-time driving and might consequently lead to muscles fatigue.

III. The findings did not indicate any statistically significant correlation between preferred driving strategies and perceived body discomfort.

IV. Applied IP and covered are on the drivers' seat pan has increased over the driving time. Uneven pressure distribution has been observed, with the highest prevalence under the buttocks and upper thighs area. Defined threshold by several research articles was reached at the 40th minute of the driving process. Therefore, it can be expected that higher pressure values under the lower limbs hampered blood circulation and caused discomfort. Participants with higher weight were resulting in a greater covered area and applied pressure on the seat pan.

V. Besides weak negative correlations, the statistical method did not reveal any significant correlation between applied interface pressure variables and perceived local or total body discomfort.

VI. Low activity level, during the long-time driving, has influenced walking strategy. The majority of participants gait velocity has increased, which may be classified as physiological and psychophysical responses caused by prolonged driving. Adopting different gait velocity, after the driving process, declare that subjects have lost control of their self-selected comfortable walking strategy. The pressure under the hallux has shifted to the central forefoot area during the push-off phase. Additionally, it might be classified as unusual behaviour caused by local foot muscles fatigue and unable the flexor muscles to perform the basic routine during the roll-over process. If the process continues in the future, the possible failure/injury of the metatarsals' heads could be expected.

VII. Eleven participants (which correspond to 25% of the total sample size) were classified as subjects with low risk of falls. Their walking strategy has changed, adopting more caution gait with slower walking speed, and prolonged stance and double support phase. Moreover,

the step length has reduced for 1.5 cm, comparing to initial walking, but the difference was not supported by statistical analysis.

Reported subjective discomfort indicated growth of the lower limbs pain (buttocks/knee, and lower leg/ankle) over time. The objective measurements demonstrated static driving strategies and excessive values of the IP variables during the driving period. Participants with higher pressure under the defined lower limbs areas were in risk of developing hamper of the blood circulation, which can be associated with the growth of perceived lower limb pain/discomfort. Contribution to the enhancement of the pain over the driving period had preferred static driving posture. Changed self-selected comfortable gait velocity suggested that participants lost control of the gait and adapted new walking pattern (increasing or decreasing the gait velocity). Developed discomfort/pain (as a symptom of musculoskeletal disorders) might be associated with overuse injuries (with the distinctive accent on the muscles injuries caused by reduced blood flow) demonstrated in Table 4.

5.2 Study limitation

This study investigates the adverse effects of the prolonged driving process on the gait performances, drivers' postural control and applied IP on the seat pan over time. A sample of forty-four subjects, composed of staff and students at the University of Porto, 22 of which were male and 22 females, voluntarily agreed to participate in this study. The application of the current result is quite limited since the study population was composed of nonprofessional and young drivers who were steering driving simulator in a controlled condition. Moreover, the classification of the leading research groups (defined in the methodology part) did not have an equal distribution of the participants (this assumption does not apply to gender distribution). Lack of participants was among small subjects (smaller than 165 cm) which counted in the total of eight people, while underweight participants (classification done by BMI) were including only three people.

A further study limitation is referring to methodological issues. Data acquisition based on the gait performance required barefoot walking, using pressure mat (Tactile) in this purpose required to take shoes off before each gait. After the driving process was ended, participants needed to go out of the driving simulator and to take the shoes off, which directly required a minute or two. Action mentioned above may have an impact on the barefoot gait.

Each subject did synchronization of PDP and applied IP on the drivers' seat pan. This methodological issue may cause a minor correction in the driving angles because the subject was aware of the data acquisition.

The total duration of steering the driving simulator was 120 minutes, in a virtual control environment without any physical harmfulness. Driving in such a condition, especially in a virtual environment, do not require a full focus on the driving tasks. Consequently, the impact on the applied pressure or PDP might be possible.

5.3 Future perspectives

Future investigation is necessary to validate the kinds of the conclusion that were drawn from the study. Concerning this, future research should focus on the following:

- Comparison between the left and right side of preferred driving angles and establishing if there is a difference in the main joint angles.
- Validating the group describe as low risk of falls, assessing the foot centre of pressure and confirming the probability.
- Evaluating minimum foot clarence to determinate if the participants are at risk of slips after the driving process.
- Determination of the angular kinematics of the lower limbs is indicating the possible issue caused by gait velocity divergence.
- Distinguish risk group or the group with the highest risk for the variables defined for the gait, driving postures and applied IP.
- Correlation between the variables using the Principal Component Analysis and resolve if there is an association between the driving angles/applied pressure and gait performances.
- Approval of the methodology in the real conditions, including professional drivers different age range. Moreover, the sample profile must remain equally distributed by gender, stature, and BMI.

6 BIBLIOGRAPHY

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APPENDIX

Appendix 1 – Consent form for research participation

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CONSENT FORM FOR RESEARCH PARTICIPATION

Influence of long time driving on lower limbs musculoskeletal symptoms and physical control

Tese do Programa Doutoral em Segurança e Saúde Ocupacionais da Universidade do Porto.

Student/ Estudante: Marko Cvetković

Number/ Número: 201602337

I am a Ph.D. student of Occupational Safety and Health of the University of Porto (U.Porto). I am planning to conduct a research, in which I invite you to take part. This form has essential information about the relevance of this study, what is going to be asked of you in case you decide to be part of this study, and the way your information will be processed if you choose to participate. This Ph.D. research is supervised by Professor João Manuel Abreu dos Santos Baptista, from the Faculty of Engineering at the University of Porto (FEUP).

Sou um estudante do programa Doutoral em Segurança e Saúde Ocupacionais da Universidade do Porto (U.Porto). Estou a realizar um trabalho de investigação para o qual o convido a participar. Este texto contém informações essenciais sobre a relevância deste estudo, bem como o que lhe será pedido caso decida participar e a forma como suas informações serão processadas nesse caso. Este trabalho de investigação é supervisionado pelo professor João Manuel Abreu dos Santos Baptista, da Faculdade de Engenharia da Universidade do Porto (FEUP).

Please read the following information carefully. If you agree with the proposal made to you, please sign this document. If you have some doubts when reading this consent, please do not hesitate to ask. In the next paragraphs, we will try to answer the most frequently asked questions.

Por favor, leia cuidadosamente as informações seguintes. Se concordar em participar, assine este documento. Se tiver alguma dúvida ao ler este consentimento, não hesite em perguntar. Nos próximos parágrafos, tentaremos responder às perguntas mais frequentes.

Why are you doing this study?

Porque é que este estudo está a ser desenvolvido?

You are being asked to participate in a research study about drivers and assessment of body posture and its negative effect on steering a vehicle. The purpose of the study is to establish what symptoms of musculoskeletal disorders and loose of lower limbs physical control can be caused by prolonged driving. Based on the results, the preventive measures will be proposed to prevent the possible disorders.

Está a ser convidado a participar numa pesquisa sobre condutores, avaliação da postura corporal e o seu eventual efeito negativo na condução de um veículo. O objetivo do estudo é o de saber que sintomas de problemas musculosqueléticos e de perda de controle físico dos membros inferiores podem ser causados pela condução prolongada. Com base nos resultados, serão propostas medidas preventivas para prevenir os possíveis problemas.

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What will I do if I choose to be in this study?

O que terei de fazer se optar por participar deste estudo?

The research is beginning with your preparation for the experiment. This implies anthropometric and weight measurements and dressing the markers. As soon as you be prepared, the research will follow three phases.

O ensaio tem início com a sua preparação. Isto implica efetuar medidas antropométricas, de peso e colocar os marcadores. Assim que você estiver preparado, o ensaio prosseguirá com três tarefas.

The first task requires you to walk for one minute.

A primeira tarefa requer que você caminhe durante cerca de um minuto.

The second task will be to perform driving in a car simulator for two hours. For the period of driving, you will be asked about your health condition and comfort/discomfort you are feeling in the moment.

A segunda tarefa será a de realizar a condução num simulador de condução durante duas horas. Ao longo do período de condução, serão efetuadas perguntas sobre sintomas de saúde e de conforto / desconforto que estará a sentir no momento.

In the third and last task, you will be asked to walk again for one minute.

Na terceira e última tarefa, será solicitado a caminhar novamente durante um minuto.

With the end of the third phase the experiment finishes.

Com conclusão da terceira tarefa, o ensaio termina.

Study time: Study participation will take approximately two hours and fifteen minutes.

Duração do ensaio: A duração do ensaio será de, aproximadamente, duas horas e quinze minutos.

This research is going to be video-recorded in order to provide all necessary data of the volunteer's body posture during the research. These tapes will be saved in the computer hard drive, and they will only be used by the researcher (Marko Cvetković). If you prefer not to be video-recorded, the experiment cannot be continued.

O ensaio será gravado em vídeo, a fim de fornecer todos os dados necessários da postura corporal durante os testes. As gravações serão guardadas no disco rígido de um computador e só serão utilizadas pelo investigador (Marko Cvetković). Se não quiser ser filmado, a experiência não se poderá realizar.

Study location: All study procedures will take place at the laboratory G003 in the Department of Civil Engineering of FEUP.

Local do estudo: Todos os procedimentos do estudo terão lugar no laboratório G003, no Departamento de Engenharia Civil da FEUP.

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Financial Information

Informação financeira

Participation in this study will involve no cost to you. You will not be paid for participating in this study.

A participação neste estudo não implicará custos para o voluntário. O voluntário também não será pago por participar neste estudo.

What are my rights as a research participant?

Quais são os meus direitos como participante do ensaio?

Participation in this study is voluntary. You do not have to answer any question you do not want to answer. If at any time and for any reason, you would prefer not to participate in this study, please feel free not to. If at any time you would like to stop participating, please tell me. We can take a break, stop and continue at a later date, or stop altogether. You may withdraw from this study at any time, and you will not be penalized in any way for deciding to stop participation.

A participação neste estudo é voluntária. Não precisa responder a nenhuma pergunta que não queira responder. Se, a qualquer momento e por qualquer motivo, você preferir não participar deste estudo, sinta-se à vontade para não participar. Se a qualquer momento você quiser parar de participar, por favor avise-me. Podemos fazer uma pausa, parar e continuar numa data posterior, ou parar completamente. Pode retirar-se deste estudo a qualquer momento, não sendo penalizado de forma alguma por decidir parar de participar.

If you decide to withdraw from this study, the researchers will ask you if the information already collected from you can be used.

Se decidir retirar-se deste estudo, os investigadores irão perguntar se as informações já recolhidas com a sua participação podem ser usadas.

What if I am a University of Porto student or employee?

E se eu for estudante ou funcionário da Universidade do Porto?

You may choose not to participate or to stop participating in this research at any time. This will not affect your class standing, grades, employment, or any other aspects of your relationship with the U.Porto.

Pode optar por não participar ou parar de participar desta pesquisa a qualquer momento. Isto não afetará a sua posição de professor, as notas, emprego ou quaisquer outros aspetos da sua relação com a U.Porto.

Whom can I contact if I have questions or concerns about this research study?

Com quem posso entrar em contato se tiver dúvidas ou preocupações sobre este estudo?

If you have questions, you are free to ask them at any time. You may contact the main researcher, Marko Cvetković, a Ph.D. student of Occupational Safety and Health at FEUP, through telephones numbers +381659009660 and +351936994730 and email address marko.cvetkovic.33@gmail.com.

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What are the possible risks or discomforts?

Quais são os possíveis riscos ou desconfortos?

To the best of our knowledge, the things you will be doing have no more risk of harm than you would experience in everyday life.

Até onde sabemos, as coisas que fará não terão mais risco de dano do que experimentaria na vida cotidiana no mesmo período.

What are the possible benefits for me or others?

Quais são os possíveis benefícios para mim ou para terceiros?

You are not likely to have any direct benefit from being in this research study. This study was designed to learn more about: (1) what lower limbs musculoskeletal symptoms can occur and (2) what level of lower limbs physical control loss can be caused by a prolonged car driving activity. The study results can be used not only to help professional and non-professional drivers to prevent musculoskeletal disorders but also to promote passengers and road safety in the future.

Você provavelmente não terá nenhum benefício direto por participar neste estudo de pesquisa. Este estudo foi elaborado para aprender mais sobre: (1) que sintomas musculosqueléticos dos membros inferiores podem ocorrer e (2) qual o nível de perda de controle físico nos membros inferiores pode ser causado por uma atividade prolongada de condução. Os resultados do estudo poderão ser usados não apenas para ajudar motoristas profissionais e não profissionais a prevenir distúrbios musculosqueléticos, mas também para promover a segurança rodoviária dos passageiros no futuro.

How will you protect the information you collect about me, and how will that information be shared?

Como serão protegidas as informações recolhidas durante o ensaio em que participei e como essas informações serão compartilhadas?

Results of this study may be used in publications and presentations, but your data will be always handled confidentially. If the results of this study are published or presented, individual names and other personally identifiable information will not be used.

Os resultados deste estudo podem ser usados em publicações e apresentações, mas os seus dados pessoais serão sempre tratados confidencialmente. Se os resultados deste estudo forem publicados ou apresentados, os nomes individuais e outras informações de identificação pessoal não serão usados.

The collected data may be used in future research studies or within other researches – if the collected data is shared, any information that could possibly identify you will be removed.

Os dados recolhidos podem ser usados em pesquisas futuras ou incluídos noutras pesquisas - se os dados recolhidos forem compartilhados, qualquer informação que possa identificá-lo será removida.

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Se tiver dúvidas, é livre para as colocar a qualquer momento. Para isso, pode entrar em contato com o investigador principal, Marko Cvetković, estudante de Doutoramento em Segurança e Saúde Ocupacionais da FEUP, através dos telefones +381659009660 e +351936994730 e endereço de email marko.cvetkovic.33@gmail.com.

Consent

Consentimento informado

I understand that my participation in this research is voluntary, I am free to refuse to participate, and I am free to withdraw from the research at any time. My refusal to participate or withdrawal of consent will not affect my treatment in any way /my relationship with FEUP or my relationship with the U,Porto.

Entendo que minha participação neste ensaio é voluntária, tenho a liberdade de me recusar a participar e sou livre para não participar do ensaio a qualquer momento. A minha recusa em participar ou a retirada do consentimento não afetará, de forma alguma, o meu relacionamento com a FEUP ou o meu relacionamento com a U, Porto.

I have read this form, and the research study has been explained to me. I have been given the opportunity to ask questions, and my questions have been answered. If I have additional questions, I have been told whom to contact. I agree to participate in the research study described above and will receive a copy of this consent form.

Li este formulário e o ensaio foi-me devidamente explicado. Eu tive a oportunidade de fazer perguntas e as minhas perguntas foram respondidas. Se tiver mais perguntas, disseram-me com quem entrar em contato. Concordo em participar no trabalho de investigação acima descrito e receberei uma cópia deste documento de consentimento.

Your Signature Confirms:

A assinatura confirma que:

- I have read what this study is about and understood the risks and benefits. I have had adequate time to think about this and had the opportunity to ask questions, and my questions have been answered.
- I agree to participate in the research project understanding the risks and contributions of my participation, that my participation is voluntary, and that I may end my participation.
- I agree to be video-recorded during the research.
- A copy of this Informed Consent Form has been given to me for my records.
- Li sobre o que é este estudo e entendi os seus riscos e benefícios. Tive tempo suficiente para pensar sobre o assunto e tive a oportunidade de fazer perguntas, e as minhas perguntas foram respondidas.
- Concordo em participar do projeto de investigação e entendendo os riscos e as contribuições da minha participação,
- Concordo que a minha participação é voluntária e que posso a posso terminar quando entender.
- Concordo em ser gravada(o) em vídeo para efeitos da investigação.
- Concordo em ser fotografado.

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- Foi-me dada uma cópia deste Termo de Consentimento Livre e Esclarecido para os meus registros.

_____

(nome complete do voluntário)

_____ _____

Assinatura do voluntário Data

Researcher's Signature:

Assinatura do investigador:

I have explained this study to the best of my ability. I invited questions and gave answers. I believe that the participant fully understands what is involved in being in the study, any potential risks of the study and that he or she has freely chosen to be in the study.

Expliquei este estudo com o melhor das minhas capacidades. Ouvi perguntas e dei respostas. Acredito que o participante entendeu completamente o que está envolvido ao participar no estudo, quaisquer riscos potenciais e que escolheu livremente participar.

_____ _____

Assinatura do investigador Data

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Appendix 2 – Research approval by Ethical committee

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COMISSÃO DE ÉTICA

PARECER Nº84/CEUP/2019

PARECER DA COMISSÃO DE ÉTICA DA UNIVERSIDADE DO PORTO SOBRE O PROJETO:

Influence of long time driving on lower limbs musculoskeletal symptoms and physical control

SUBMETIDO POR:

Marko Cvetković

INSTITUIÇÃO DE ORIGEM

Faculdade de Engenharia da Universidade do Porto (FEUP)

Relator: Prof. Doutor Fernando Jorge Monteiro

outubro 2019

O requerente, Marko Cvetković, estudante de doutoramento do DemSSO - Programa Doutoral, dirigiu-se à CEUP, no sentido de solicitar a sua aprovação para o projeto "Influence of long time driving on lower limbs musculoskeletal symptoms and physical control", que visa desenvolver no âmbito do seu doutoramento.

O problema que se coloca é o estudo da permanência prolongada em posições estáticas e inadequadas, por mais de 2 horas, a que estão sujeitos os condutores profissionais, e que podem induzir dor muscular, diminuir o volume muscular, afetar a circulação e provocar doenças arteriais e edema nas zonas inferiores dorsais. A prevenção destas doenças requer uma análise sistemática de veículos em termos de ergonomia e de aspetos biomecânicos da posição de condução sentado. A exposição a vibrações do veículo pode agravar a situação.

A proposta tem como objetivos a avaliação de *performance* e identificação de sintomas associados a problemas musculares da região lombar inferior, incluindo:

1- Identificação dos tipos de movimento que ocorrem na zona lombar inferior durante a condução;
2- Identificação das posições adotadas pelos condutores durante o seu serviço;
3- Análise do resultado de diferentes pressões aplicadas pela região lombar dos condutores nos seus assentos;
4- Concluir sobre o efeito da exposição prolongada (pelo menos 2 horas consecutivas e frequência diária) em serviço na subsequente qualidade da marcha;
5- Correlacionar os dados obtidos experimentalmente com os dados já registados de sintomas associados à zona lombar inferior.

A proposta integra uma completa revisão da bibliografia sobre o tema e uma realização de trabalho experimental a decorrer na Faculdade de Desporto da U.Porto e no Labiomep, onde estão localizados os equipamentos que serão utilizados no estudo.

É exposto igualmente o plano de trabalhos propostos, bem como a sua motivação.

O aspeto essencial que faz com que o requerente solicite parecer a esta comissão prende-se com a necessidade de se efetuar o estudo sobre voluntários (condutores profissionais) que deverão cumprir um protocolo de teste claramente apresentado.

A inclusão de cada voluntário no grupo de estudo basear-se-á em critérios clínicos, que incluem a ausência de doenças musculares ou do esqueleto na região lombar inferior. Alterações significativas entre os dois lados da região lombar serão consideradas critério de exclusão. A zona articular da bacia de cada voluntário será marcada. O grupo de estudo será sujeito a medidas antropométricas no início das experiências para se obter dados para análise. Nenhum procedimento é invasivo ou induz qualquer tipo de sofrimento aos voluntários.

Na primeira fase os voluntários terão de fazer uma marcha durante 1 minuto. A marcha será analisada e registada para registo a distribuição de pressão em tempo real durante a caminhada.

Na segunda fase os voluntários serão colocados num automóvel e a experiência decorrerá durante 120 minutos. O carro colocado no laboratório faz correr um programa de simulação computacional e não produz vibrações que causem dano nem haverá libertação de gases de escape que possam prejudicar a saúde do voluntário ou da equipa. Vários testes à saúde do voluntário decorrerão durante o ensaio para verificar se esta está em condições normais. Se em algum momento é detetada qualquer anomalia o ensaio será de imediato interrompido.

Na terceira fase é feito um teste de marcha logo após a fase 2, que decorrerá da mesma fase do efetuado na primeira fase.

O estudo irá recolher uma grande qualidade de dados, aos quais será aplicada a estatística adequada à sua variedade.

O estudo incluirá no total 30 trabalhadores voluntários (15 homens e 15 mulheres de idades compreendidas no intervalo [19-40]. As condições, motivação, necessidades e objetivos do estudo serão descritos aos potenciais voluntários, e o documento de consentimento informado apresentado é claro.

A proteção de dados estará salvaguardada pois não haverá identificação para efeito de divulgação de resultados de nenhum dos voluntários, mas apenas registo dos seus dados medidos nas experiências, e não serão estabelecidas correlações entre os resultados e os sujeitos estudados.

O momento indicado para o início do projeto é Julho de 2019, pelo que estará em princípio pronto a começar.

Não parece assim haver neste projeto qualquer aspeto que o fira do ponto de vista ético.

Neste sentido, a C.E.U.P., reconhecendo o interesse científico do trabalho e o seu potencial impacto, e nada vendo que possa contrariar qualquer dimensão ética, dá parecer favorável à realização do estudo proposto nos termos e condições enunciados.

Universidade do Porto, 22 de outubro de 2019

O Relator

Prof. Doutor Fernando Jorge Monteiro

O Presidente da CEUP

Prof. Doutor Luís Carlos Amaral

Appendix 3 – The Nordic Questionnaire – English language

Adapted version of the Nordic musculoskeletal questionnaire (Kuorinka et al., 1987)

This questionnaire is anonymous and aims to obtain information about its musculoskeletal symptoms linked to work.

PLEASE, be as coherent as possible in your responses

The date of inquiry _____/_____/2018

Sex (draw a circle around the correct answer): 1 Female 2 Male

What year were you born?..... What equipment do you use?.....What is your shift?.....

How many years and months have you been doing your present type of work? …….years + …..months

On average, how many hours a week do you work? ..... hours per week

How much do you weight? ..... kg. How tall are you? ……..cm

Are you right-handed or left-handed – (draw a circle around the correct answer)?

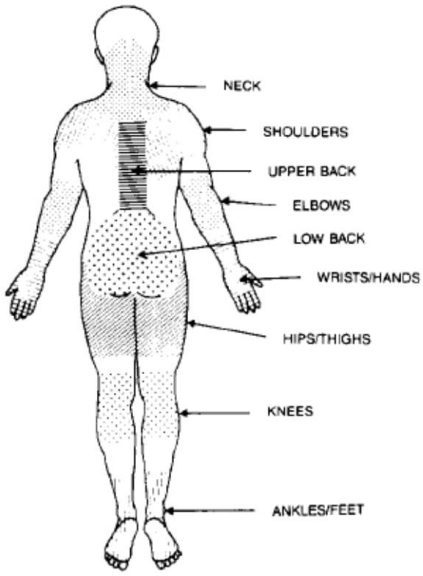
1 right-handed 2 left-handed 3 ambidextrous (both handed)

Fill in the following table, marking the square corresponding to your state of discomfort, fatigue or pain, according to the body segments considered. In case of discomfort, indicate the intensity of the discomfort, according to the following scale.

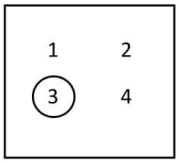
Intensity of discomfort / pain: 1 - Mild 2 - Moderate 3 - Intense 4 – Unbearable

To be respond by all operators					To be answered only by those who have had troubles			
Have you at any time during last 12 months had troubles (ache, pain, discomfort) in:					Have you had trouble at any time during the last 7 days			Have you at any time during the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble?
1 Neck			1	2	2 Neck			3 Neck
No ☐	Yes ☐		3	4	No ☐	Yes ☐		No ☐ Yes ☐
4 Shoulders					5 Shoulders			6 Shoulders
No ☐	Yes ☐	In the right	1	2	No ☐	Yes ☐	In the right shoulder	No ☐ Yes ☐
	Yes ☐	In the left	3	4		Yes ☐	In the left shoulder	
	Yes ☐	In both				Yes ☐	In both shoulders	
7 Elbow					8 Elbow			9 Elbow
No ☐	Yes ☐	In the right	1	2	No☐		Yes ☐	No ☐ Yes ☐
	Yes ☐	In the left	3	4			Yes ☐	
	Yes ☐	In both					Yes ☐	

10 Wrists/hands				11 Wrists/hands		12 Wrists/hands	
No ☐	Yes ☐	In the right	1	2	No ☐	Yes ☐	No ☐	Yes ☐
	Yes ☐	In the left	3	4		Yes ☐		
	Yes ☐	In both				Yes ☐		
13 Upper back			1	2	14 Upper back		15 Upper back	
No ☐		Yes ☐	3	4	No ☐	Yes ☐	No ☐	Yes ☐
16 Low back			1	2	17 Low back		18 Low back	
No ☐		Yes ☐	3	4	No ☐	Yes ☐	No ☐	Yes ☐
19 One or both hips/thighs			1	2	20 One or both hips/thighs		21 One or both hips/thighs	
No ☐		Yes ☐	3	4	No ☐	Yes ☐	No ☐	Yes ☐
22 One or both knees			1	2	23 One or both knees		24 One or both knees	
No ☐		Yes ☐	3	4	No ☐	Yes ☐	No ☐	Yes ☐
25 One or both ankles/feet			1	2	26 One or both ankles/feet		27 One or both ankles/feet	
No ☐		Yes ☐	3	4	No ☐	Yes ☐	No ☐	Yes ☐



Example of intensity marking:



Appendix 4 - The Nordic Questionnaire – Portuguese language

Versão adaptada do questionário nórdico músculo-esquelético (Kuorinka et al., 1987)

Este questionário é anónimo e pretende obter informações sobre a sua sintomatologia músculo-esquelética ligada ao trabalho.

Seja, POR FAVOR, o mais coerente possível nas suas respostas.

Data do inquérito: _____/_____/2018

Sexo (desenhe um círculo à volta da resposta correcta): 1 Feminino 2 Masculino

Em que ano nasceu? ..... Qual o equipamento utilizado? ..... Qual o turno? .....

Há quantos anos e meses é que se encontra a exercer a actual actividade? ..... anos + ... meses

Em média, quantas horas trabalha por semana? ..... horas por semana

Qual o seu peso? ..... kg. Qual a sua altura? ..... cm

É dextro ou esquerdino/canhoto — (desenhe um círculo à volta da resposta correcta)?

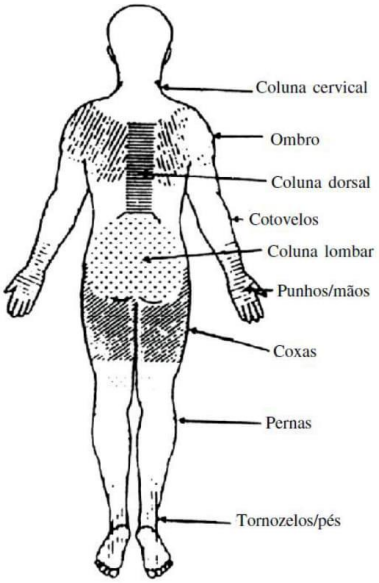
1 Dextro 2 Esquerdino/canhoto 3 Ambidextro

Preencha a tabela seguinte, assinalando com uma cruz o quadrado correspondente ao seu estado de incómodo, fadiga ou dor, em função dos segmentos corporais considerados. No caso de sentir desconforto, refira qual a intensidade do mesmo, de acordo com a escala seguinte.

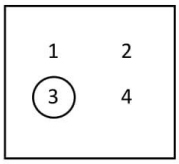
Intensidade do incómodo/dor: 1 — Leve 2 — Moderado 3 — Intenso 4 — Insuportável

Para responder por todos os operadores		Para responder apenas pelos operadores que tenham problemas	
Teve algum problema durante os últimos 12 meses (fadiga, desconforto ou dor) nos seguintes segmentos? Se sim, refira qual a sua intensidade, assinalando-a com um círculo.		Teve algum problema durante os últimos 7 dias?	Nos últimos 12 meses esteve impedido de realizar o seu trabalho normal devido a este problema?
1 Coluna cervical Não ☐ Sim ☐	1 2 3 4	2 Coluna cervical Não ☐ Sim ☐	3 Coluna cervical Não ☐ Sim ☐
4 Ombros Não ☐ Sim ☐ No direito Sim ☐ No esquerdo Sim ☐ Nos dois	1 2 3 4	5 Ombros Não ☐ Sim ☐ No direito Sim ☐ No esquerdo Sim ☐ 0Nos dois	6 Ombros Não ☐ Sim ☐
7 Cotovelos Não ☐ Sim ☐ No direito Sim ☐ No esquerdo Sim ☐ Nos dois	1 2 3 4	8 Cotovelos Não ☐ Sim ☐ Sim ☐ Sim ☐	9 Cotovelos Não ☐ Sim ☐
10 Punhos/mãos Não ☐ Sim ☐ No direito Sim ☐ No esquerdo Sim ☐ Nos dois	1 2 3 4	11 Punhos/mãos Não ☐ Sim ☐ Sim ☐ Sim ☐	12 Punhos/mãos Não ☐ Sim ☐
13 Coluna dorsal Não ☐ Sim ☐	1 2 3 4	14 Coluna dorsal Não ☐ Sim ☐	15 Coluna dorsal Não ☐ Sim ☐
16 Coluna lombar Não ☐ Sim ☐	1 2 3 4	17 Coluna lombar Não ☐ Sim ☐	18 Coluna lombar Não ☐ Sim ☐

19 Ancas/coxas		1	2	20 Ancas/coxas		21 Ancas/coxas	
Não ☐	Sim ☐	3	4	Não ☐	Sim ☐	Não ☐	Sim ☐
22 Pernas/joelhos		1	2	23 Pernas/joelhos		24 Pernas/joelhos	
Não ☐	Sim ☐	3	4	Não ☐	Sim ☐	Não ☐	Sim ☐
25 Tornozelos/pés		1	2	26 Tornozelos/pés		27 Tornozelos/pés	
Não ☐	Sim ☐	3	4	Não ☐	Sim ☐	Não ☐	Sim ☐



Exemplo da marcação de intensidade:



Appendix 5 - Form sheet summarizing the rejection criteria which will be used to conduct the systematic review

Data base / Journal	Keyword 1 x Keyword 2							
	Number of Selected Articles	Number of Collected Articles	Number of included articles after criteria insertion					
			Date	Document type	Source type	Language	Off topic	Other
IEEE Xplore								
Inspec								
Science Direct								
Taylor and Francis								
ASC								
DOAJ								
Emerald								
Ingenta								
Scopus								
Springer								
Web of Science								
PubMed								
Science Magazine								