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IEVA ALEKNAITĖ-DAMBRAUSKIENĖ

RESEARCH AND DEVELOPMENT OF UNSTABLE SEAT FOR THE WELLNESS OF THE EMPLOYED IN SEDENTARY JOBS

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IEVA ALEKNAITĖ-DAMBRAUSKIENĖ

RESEARCH AND DEVELOPMENT OF UNSTABLE SEAT FOR THE WELLNESS OF THE EMPLOYED IN SEDENTARY JOBS

Doctoral dissertation
Technological Sciences, Mechanical Engineering (T 009)

Kaunas, 2022

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AMMR – anybody managed model repository,
AP – anterior-posterior,
ASIS – anterior superior iliac spine,
BMI – body mass index,
BOB – biomechanics of bodies,
CAST – calibration anatomical system technique,
CE – contractile element,
CGM – conventional gait model,
cLBP – chronic lower back pain,
DOF – degree of freedom,
DTS – direct transmission system,
EEG – electroencephalography,
EMG – electromyography,
ES – erector spine muscle,
FE – finite element,
fMRI – functional magnetic resonance imaging,
ICA – independent component analysis,
IOR – Instituto Ortopedico Rizzoli,
L_0 – segment length of the original segment,
L_1 – segment length of the scaled segment,
LBP – lower back pain,
MF – multifidus muscle,
ML – medial-lateral,
MRI – magnetic resonance imaging,
MVC – maximal voluntary contraction,
MVIC – maximal voluntary isometric contraction,
NLBP – non-specific lower back pain,
OE – obliques ecternus muscle,
p – original nodal location,
PEE – parallel elastic element,
PET – positron emission tomography,
PSD – power spectral density,
R – percentage of ratio,
RA – rectus abdominis muscle,
R_{fat} – fat percent,
RIS – repetitive strain injury,
S – 3x3 scaling matrix,
s – position vector of the node in the local coordinate system,
SD – standard deviation,
SEE – serial elastic element,
sEMG – surface electromyography,
SS – static sitting,
t – translation,

TA – transversus abdominis muscle,
TMS – transcranial magnetic stimulation,
WB – wobble board,
WBB – wobble board on the bearing surface.

INTRODUCTION

Relevance of a topic

About 60–80% of individuals are experiencing lower back pain in their lifetime [115]. Non-specific lower back pain is the pain without the known cause and represents about 90–95%, the rest percentages represent specific lower back pain [45]. The study combining 28 countries analyzed lower back pain prevalence in adolescence [105]. The important fact is that adolescents have lower back pain monthly or more frequently, and this prevalence increases with age [105]. This prevalence is ranged from 28% (Lithuania, Poland, and Russia) to 50.5% (The Czech Republic) [59].

Concerning that non-specific lower back pain is a very important and major player in the public health, which can highly affect productivity, work ability, and even life. It is very important to prevent the very early stages of pain or even occurrence. Lower back pain (LBP) is a common problem among people who spend their time in a static sitting position at the office. The more important fact is that 37% of lower back pain globally is work-related [103]. The studies indicate that the lower back pain incidence in one year follow up is ranging from 23 to 83% among the office workers [16, 96].

There are many studies done *in vitro* and *in vivo* about analyzing sitting position. It is difficult to say that one or another sitting position is more loaded than the other, because sitting without and with backrest can strongly vary in spine loading. According to the study [66], the intradiscal pressure during unsupported sitting can increase by 40% from the standing position. The intradiscal pressure is about 0.46 MPa while sitting relaxed without backrest, whereas sitting actively with straight back, the intradiscal pressure is 05.5 MPa, and sitting with backrest is about 0.27 MPa [118]. There are a lot of ways and strategies to reduce the pain or the occurrence of the lower back pain. There are a lot of different suggestions in the ergonomic chair market with different backrests, head, and lumbar spine support or even dynamic chairs to improve the sitting behavior during the prolonged hours in the office. Very often, the dynamic chairs are used for the reduction of musculoskeletal disorders related to the sitting position. The study [106] shows that the dynamic chairs can decrease the negative effects of prolonged sitting position by increasing small movements of the spine and promoting proper spine curvatures. When the proper movement of the spine is generated, there is quite good proof of increment of deep muscles activity, which are very important in spine stabilization and proper posture. Individuals who suffer from LBP show an atrophy of lumbar multifidus, and lumbar trunk muscles are inactive for 30% of the sitting time [49]. People with cLBP had delayed trunk muscle onset in response to the unexpected perturbations [46]. It means that the reflex response is delayed because of proprioceptive signals impairment. The proper solution of this impairment could be including sudden unexpected perturbations, which can influence the reflex and strengthen them [70] in a sitting or standing positions. More and more studies are indicating the balance perturbations and brain cortex activity during it [113]. According to the study [121], the prefrontal cortex is responsible for different cognitive functions, including balance performance and training [92]. Thus, including dynamic chairs in an office area can be a good decision to prevent the lower back pain and increase worker productivity.

Research aim and objectives

The aim of the research is to create an innovative unstable seat, which increases the activity of the trunk muscle and brain cortex. In order to achieve this aim, the following objectives have been formulated:

1. To find out correlations between brain, muscles activity, and balance under different sitting positions.
2. To investigate biomechanical and kinematical parameters of human pelvis movement under different experimental conditions.
3. To apply and compare experimental results of spine movements on different sitting surfaces to find out the stresses and strains on the model of the lumbar spine.
4. To compare experimental results of muscles activity with musculoskeletal modeling results.
5. To create the unstable seat prototype according to the results of theoretical and experimental research.

Research methods

The theoretical and experimental investigations were conducted in this research. All experimental studies were performed at the Institute of Mechatronics in Kaunas University of Technology.

The experimental study was done using a superficial electromyography method, which allows to measure muscle activity. In order to get the muscle activity, 12 channels of TeleMyo DTS 2400R G2 (Noraxon USA Inc.) electromyograph were used. There were used 5 of 12 wireless sensors, which were attached directly to the skin and wirelessly transduced the signal. The results were primarily processed with Noraxon MR 3.12 software. Another method, which was used during the experimental research, was electroencephalography. The electroencephalograph g.Nautilus Research (g.tec medical engineering GmbH, Austria) had 32 wireless channels cap, which was placed directly on the person's head. The data were collected and processed by using g.BSanalyze software package for Matlab. The next method was three-dimensional motion capture, which obtained kinematic data by 10 motion capture cameras (Oqus7+ Qualisys AB, Gothenburg, Sweden), and for the data analysis, Qualysis Track Manager software was used.

The theoretical study was accomplished by using COMSOL Multiphysics (COMSOL Inc.) software to create a finite element model of the spine. The geometry of the models as well as designing unstable chair prototype were done with SolidWorks (Dassault Systèmes SolidWorks Corp.) software. For the inverse dynamic analysis, the AnyBody Technology Modeling System (AnyBody Technology, Aalborg, Denmark) was used.

Scientific novelty

1. The methodology of unstable seat development was created using biomechanical and physiological research methods.
2. The relationship between balance maintenance in a sitting position, muscles, and brain activity was found. When balance maintenance becomes more challenging, the muscle and brain activity increases.
3. The experimental data from the lumbar spine amplitude of movement parameters when pelvis movement is performed were applied to 3D lumbar spine and sacrum finite element model.
4. The unique unstable seat was created to increase the pelvis movement in two planes (sagittal and frontal).

Statements for the defence

1. The experimental study results showed an increment of trunk muscle activity and brain activity on the test stand of the wobble board on the bearing surface, comparing with other wobble board and regular chair. The trunk muscle and brain activity increases when the balance becomes more challenging in a sitting position.
2. The experimental conditions of spine and sacrum amplitude of movement on different tested sitting tools were applied into developed three-dimensional lumbar spine and sacrum model. The less loading and stresses on a spine intervertebral disc showed performance in sagittal and frontal planes on the wobble board on the bearing surface, compared with other sitting tools.
3. The developed unstable seat prototype has two, sagittal and frontal planes motion, and original design of it, which can engage trunk muscle activity during exercising.

Practical value

1. The unstable seat prototype can be implemented in a workplace as a prevention of lower back pain, which can help to increase the muscle activity.
2. The two planes motion of unstable seat prototype can be a good practical tool in late stages of rehabilitation after lower back pain treatment, because it engages pelvis movements, which are very important in the deep muscle activation and restoration of spine stabilization.
3. The methods of unstable seat creation can be widely adopted for the other devices creation, which can increase worker productivity and help with reducing disorders related to the lower back pain.

Research approbation and publications

The results of this dissertation have been published in 4 scientific papers: 3 in the journals with impact factor indexed in Web of Science database, and 1 in the conference proceedings.

Moreover, the results were presented at 2 international conferences:

1. BIOMDLORE 2021, 13th International Conference, Vilnius, Lithuania, October 21–23, 2021, Vilnius, Lithuania.
2. Baltic Congress of Physiotherapy, Riga, 2020.

Structure of the dissertation

The dissertation consists of an introduction, five sections, conclusions, a list of 127 references, a list of author's publications, curriculum vitae, acknowledgements, and annexes. The volume of the dissertation is 128 pages, 59 figures, and 4 tables.

The first section reviews the lumbar spine anatomy, musculoskeletal disorders of the lumbar spine, sitting position at the workplace, and its relationship with lower back pain, trunk muscles, and brain activity, loading on a spine intervertebral disc during sitting position, and kinematic measurements. Moreover, in the first section, the review and analysis of different ergonomic chairs and patents related to chairs and sitting positions can be found. Furthermore, the formulation of the thesis aim and objectives are presented in this section.

The second section consists of various biomechanical and physiological experiments with subjects sitting on different types of chairs. Moreover, there is presented a test stand of an unstable (seat) prototype. There are widely explained methods of electromyography, electroencephalography, and kinematic analysis.

The third section presents musculoskeletal modeling, inverse kinematic analysis under given experimental data results. The comparison of musculoskeletal modeling and experimental data are explained in this section as well.

The fourth section describes 3D lumbar spine and sacrum finite element model validation, experimental data results implementation of this model, and the loads, stress, and strains are given after the analysis.

The fifth part of the section presents the mechanical analysis of linear static loading of the unstable seat prototype.

The summarized theoretical and experimental studies are presented in the last conclusions section.

1. LITERATURE REVIEW

1.1. Anatomy of lumbar spine, sacrum, and pelvis

The spine is a very complex system and consists of passive and active structures. The passive structures of the spine provide stability and limit the range of motion, while the active components control movement. The spine or vertebral column is composed of vertebrae and intervertebral discs [116], the anterior longitudinal ligament, posterior longitudinal ligament, ligamentum flavum, intertransverse ligaments [117]. Moreover, an important structure, which ensures passive stability, is facet joints. Each passive structure contributes to the stability during movements and under different loadings [117].

The most important role of the spine is to protect the spinal cord, support the mass of the body, withstand external forces, and allow mobility and flexibility [33]. Muscles and ligaments of the spine connect with the trunk and create spinal stability and postural control [33]. Vertebral column has cervical, thoracic, lumbar, sacral, and coccygeal regions (Fig. 1) [58]. There are two lordotic curves, i.e., cervical and lumbar, and two kyphotic curves, i.e., thoracic, sacrum, and coccyx. The kyphotic curve is primary, because a fetus has C shaped spine [58]. After birth, the secondary curve (lordosis) gradually appears in the cervical and lumbar regions.

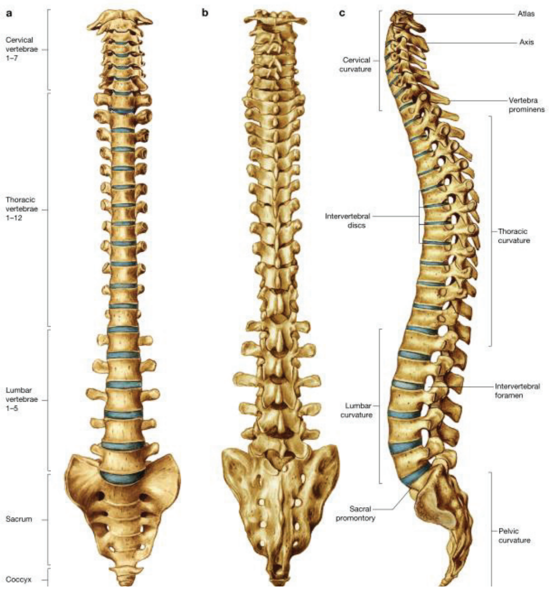


Figure 1. An adults spine:. aAnterior, posterior, and lateral views [58]

The lumbar spine vertebrae are the biggest because they need to absorb loads from the chest and cervical spine and transfer it to the pelvis and lower limbs [11]. Axial impulses deform the lumbar spine because of it; the discs and longitudinal ligaments absorb energy and allow it to return to an upright position [11]. Lumbar spine discs consist of the hydrated nucleus pulposus, which is surrounded by annulus fibrosus, from top and bottom of disc vertebral endplates that lay on it. Moreover, the lumbar spine discs have the greatest cross-sectional area, because they must withstand the biggest load. From approximately 1200 lumbar discs, cross-sectional areas varied from 1400–1700 mm^2 and from 7.6 to 9.4 mm of height, respectively (Fig. 2) [33]. The annulus fibrosus creates the concentric resistance for the axial compression. When the load appears, the annulus fibrosus buckles inwards and outwards. When the nucleus pulposus is compressed, it braces and stiffen the annulus fibrosus (Fig. 3) [11].

The lumbar spine has a small amplitude of movement in flexion and extension, about 13° per segment [11], while all segments together provide a flexion from standing more than 50° (±28.0°) and rotation about 7–7.5° [33]. Most stresses and strains act on the lumbar spine when the weight is added in flexion and rotation. About 95% of individuals have lumbar spine nerves disorders, lower back pain (with or without leg pain), weakness, loss of feelings, compared with other spine regions [33].

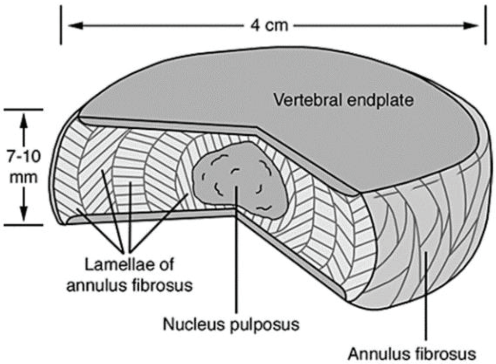


Figure 2. Vertebral disc consisting of nucleus pulposus, annulus fibrosus, and vertebral endplate [33]

The sacrum consists of 5 fused vertebrae (without intervertebral discs), which have a connection with the pelvis in the sacro-iliac joint. Until the age of 17–18, the vertebrae of the sacrum starts fusing, and at the 23 years of age, they become fully fused [33]. The sacrum is important because it connects the spine with iliac bones and has an important role in the hip stability [69]. The sacro-iliac joint is the largest axial joint. It transfers the load between the lumbar spine and extremities. In some cases (15–30% of cases), sacro-iliac joint can be the source of the lower back pain [54, 43], because of the ligaments, hypo- or hypermobility, shear forces, inflammation, and soft tissue injuries [43].

Coccyx has 3–5 vertebrae, which are fused and do not have intervertebral discs. The muscles, which create the pelvic floor, ligaments, and pelvic tendons attach to the coccyx and support and stabilize the body in a sitting position [33].

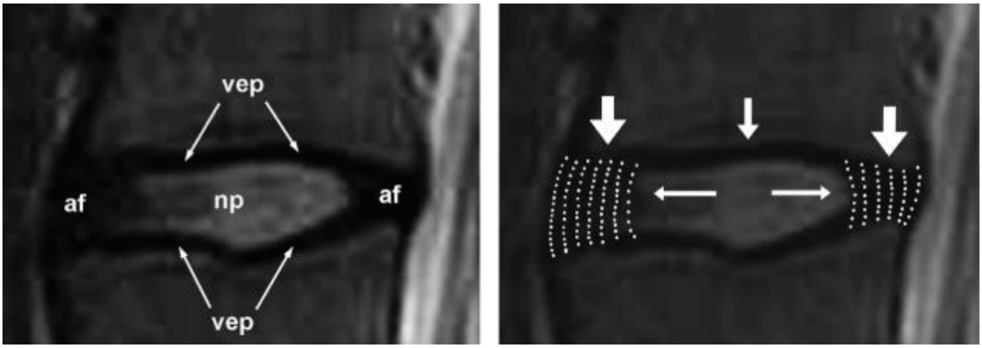


Figure 3. Components of the disc: af – annulus fibrosus, np – nucleus pulposus, vep – vertebral endplate;. wWhen compression acts, the nucleus pulposus creates radial pressure to brace the annulus and prevent it from buckling under the load [11]

1.2. Lower back pain

About 60–80% of individuals experience lower back pain in their lifetime [115]. Lower back is defined as extending from the twelfth rib to iliac crest [45]. The non-specific lower back pain is the pain without the known cause and represents about 90–95%, the rest percentages represent specific lower back pain [45]. Specific lower back pain is defined when one of these conditions appears: cancer, tumor, disc herniation, vertebral fracture, while non-specific lower back pain does not have any seen changes in imaging tests, and no specific nociceptive cause can be identified [37]. It is important to note that the lower back pain in childhood predicts lower back pain in adult life. The study combining 28 countries analyzed lower back pain prevalence in adolescence [105]. The important fact, which was noticed, is that adolescents have lower back pain monthly or more frequently, and this prevalence increases with age [105]. This prevalence ranged from 28% (Lithuania, Poland, and Russia) to 50.5% (The Czech Republic) [59].

According to the literature [37], the individuals, who suffer from the lower back pain, have additional pain in other body areas and as well have mental health problems when compared with people who do not have lower back pain (Fig. 4). The emotional and psychological factors (anxiety, depression, pain are related to fear behavior, catastrophisation) lead to the poor prognosis of non-specific lower back pain (NLBP). Thus, in order to understand NLBP, it is very important to evaluate the biopsychosocial model to view illness as an interaction of cellular, tissue, cognitive, and interpersonal factors [104].

The radiological proof of cause of spine pain navigates clinicians to specific reasons of lower back pain. There is degenerative disc disease, which is defined by the degeneration of intervertebral discs. This appears due to the aging processes, environmental factors. According to the literature [33], the disc degeneration is caused by 50–70% of genetic inheritance and as usual in the lower back.

Radicular pain is the pain when the nerve root is affected or squeezed, and mostly, it is termed sciatica. Radiculopathy is characterized as weakness, loss of sensation, or a combination of both [37]. Mostly it is diagnosed by straight leg raise test, history of dermatomal leg pain, and radiological tests. The radiculopathy is the consequence of a herniated disc, which squeezes the nerve root.

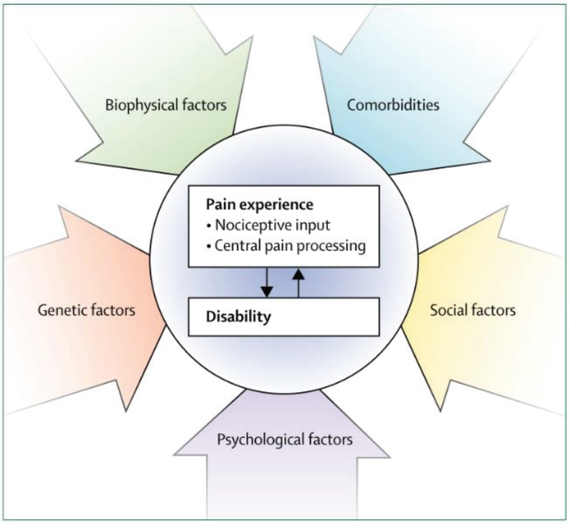


Figure 4 . The complex interaction of different sources, which cause lower back pain [104]

Lumbar spinal stenosis is another clinical condition when the spine canal is narrowing due to the degenerating changes [37]. In most cases, the pain appears when the individual stands or extends the spine, and the relief comes after the spinal flexion.

Non-specific lower back pain does not have any pathoanatomical cause, that is why there is no specific treatment for this condition. In most cases, non-specific lower back pain is related to the physical and physiological factors, lifestyle, obesity, and depression [82]. However, the management of the pain must be considered and prescribed, such as education, non-pharmacological therapies (exercises, manual therapy, massage, acupuncture), analgesic medicines. It is important to mention that te bed rest in most cases should be avoided, and a little movement or going to work is necessary under lower back pain conditions [59]. There are interventions to prevent lower back pain, when limiting exposure to risk factors: use of lifting devices in workplaces, braces to support the spine and ergonomic furniture, but most of these interventions have only face validity.

1.3. Trunk muscles activity

A very important factor is trunk muscle activity when talking about the lower back pain (LBP). The main muscles, which can be defined as core muscles are rectus abdominis, internal and external obliques, erector spinae, lumbar multifidus, quadratus lumborum, diaphragm and pelvic floor, and iliac psoas (Fig. 5) [77]. These muscles are the center of the body where kinetic chains transfer forces to the extremities. All these muscles (Fig. 5) should work great to keep the strong core. Typically, the persons who suffer from LBP show an atrophy of lumbar multifidus, and lumbar trunk muscles are inactive for 30% of the sitting time [49].

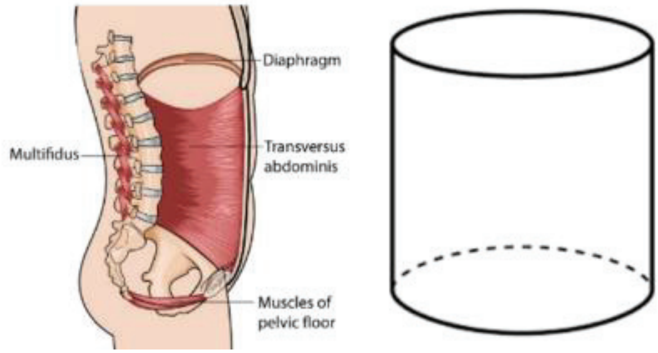


Figure 5. Core muscles comparison with cylinder: multifidus, diaphragm, transversus abdominis, and muscles of pelvic floor

The research [86] analyzed the sitting position of two groups of participants, i.e., with chronic lower back pain (cLBP) and healthy controls. The participants with cLBP had a shorter sitting time, developed a significant increase in pain, and showed a larger perceived of exertion, compared with the control group during sitting. The authors have observed the significant activation of muscles increment in root mean square, which indicates the on-going fatiguing process during sitting. The increased variation in lumbar muscle system led to tiny changes in lumbar intervertebral positions during sitting; this was mostly seen in people with cLBP; the same was noticed in another study [68]. Another important factor has shown that people with cLBP had delayed trunk muscle onset in response to the unexpected perturbations [46]. The possible explanation can be that the reflex response is delayed because of proprioceptive signals impairment. The proper solution of this impairment could be incorporating sudden unexpected perturbations, which can influence the reflex and strengthen them [70] in a sitting or standing position or during the exercises.

In order to see what is the activity of one or another muscle, the method of electromyography (EMG) can be applied. It is quite a popular method, which can be divided into superficial electromyography (sEMG) and invasive electromyography (with fine-wire or needle electrodes) [47]. sEMG allows to measure different muscle activation patterns, muscular performance, helps patients to train their muscles and detect muscle response in ergonomic studies. The method can be widely applied in medical research, rehabilitation, ergonomics, and sport science [47]. Very often, sEMG is used during exercises, standing/sitting positions, or even fatigue to see what is the activity of muscle. In order to get a good signal, it is important to prepare the skin where the electrodes will be placed. About 5 kOhm indicates good skin impedance. There are several ways of preparation of the skin in order to achieve this. The most popular method is cotton pad and alcohol, another way is a conductive cleaning paste, a special abrasive paste, or a very fine sand paper [47]. In order to compare the muscle activity on different days between individuals, the EMG signal should be normalized. The EMG signal normalization needs to be performed for every muscle, which is of interest. There are several ways to normalize signal [67]: maximal voluntary isometric contraction (MVIC), peak activation value that is obtained during the exercise/task during the investigation, submaximal isometric contraction and peak to peak amplitude of the maximum. All these methods have pros and cons; thus, it is very important to adapt these normalization methods according to a specific research.

1.4. Lower back pain related to the prolonged seated position at workplace

Concerning that non-specific lower back pain is a very important and major player in the public health, which can highly affect productivity, work ability, and even life. It is very important to prevent the very early stages of pain or even occurrence. Lower back pain (LBP) is a common problem among people who spend their time in a static sitting position at the office. The more important fact is that 37% of lower back pain globally is work-related [103]. The studies indicate that the lower back pain incidence in one year follows up range from 23 to 83% in the office workers , 96]. Nature and severity of physical work, working postures, and methods of manual lifting and handling are linked with the development of lower back pain [103]. Due to this reason, there are a lot of tools and ergonomic equipment, which are involved in the workplace to improve workers' health. The office workers have three common sitting postures: upright, slumped, and forward-leaning [17]. Slumped sitting position reduces the activity of stabilizing trunk muscles, which can provoke lower back pain or discomfort, while forward-leaning increases multifidus and iliocostalis lumborum pars thoracis muscles activity [17].

A potential mechanism, which is associated with the lower back pain, is known as insufficient lumbar stability [8], reduced proprioception, which causes impaired postural control [10]. Trunk postural control is often assessed when using unstable seats to perform the sitting tasks [2]. The larger center-of-pressure, while sitting on an unstable seat, indicates poorer postural control [2, 1]. Balance control is a leading component of human every day motor activities, such as standing, walking, or sitting, and its impairment is associated with an increased risk of falling [63, 119], functional independence [119], lower back pain due to the impaired motor control mechanism. A complex interplay between the sensory and the motor systems allows a good control of posture and balance [63]. The efficient control of the center of mass by proper muscle activation is essential in maintaining a good equilibrium in standing and sitting. Thus, reduced somatosensory input can affect the postural control in lower back pain.

A lot of different chairs are suggested by different backrests, head, and lumbar spine support to improve sitting behavior during the prolonged hours in the office (Fig. 6). Moreover, very often, the dynamic chairs are used to reduce sitting related musculoskeletal disorders. According to another study [106], dynamic chairs can decrease the negative effects of prolonged sitting position by increasing small movements of the spine and promoting proper spine curvatures. The systematic review of occupational interventions for the prevention of back pain revealed that only exercises with or without education, which can be applied in a workplace, have the potential to prevent lower back pain [103]. According to studies [126, 111], the exercise therapy resulted in a small improvement in pain and function; however, the greater effect can be reached when exercises are designed individually and supervised.

Short breaks with active rest during the prolonged sitting position at work could possibly reduce the lower back pain, because during the active rest, muscles are activated: the static position is changed. The study [111], which focused on the short exercises in the standing position during working breaks for information technology workers, showed negative results in the prevention of lower back pain; however, the study was conducted for people who had a minor level of LBP intensity, and probably, it was a strong point to reduce LBP.

Figure 6. Different ergonomic and active chairs

As several types of base have been used in unstable sitting, such as a central ball bearing [78, 88, 83], central ball and springs [31, 93, 62, 94, 53], and hemispherical bases [18, 101, 13]. The important feature of an unstable base of support, such as chairs with movable seats, is that it increases the range of the pelvis movement or forces the pelvis movement [119]. The more engaging is the pelvis motion, the more engaging are the muscles supporting the spine. Therefore, the movements of the spine during sitting and loadings during daily activities are very important in prevention and diagnosis [3] of lower back pain. According to study [23], different sitting positions and different movements, such as a transition from standing to sitting [80], act differently on the lumbar spine. The literature shows that there is no optimal sitting position [84, 123]; however, the regular movements and proper lumbar lordosis can prevent lower back pain. Regular movements, such as lateral bending, can improve fluid flow in healthy intervertebral discs [64], because during prolonged sitting position, it increases muscle fatigue, decreases intervertebral disc nutrition, and reduces blood flow in muscles [115]. Musculoskeletal discomfort is one of the factors that can arouse lower back pain for healthy individuals [115]. There are many risk factors (wrong posture, prolonged sitting position, lifting, etc. [73]), which can arouse lower back pain caused by insufficient lumbar stability [8], impaired postural control [10].

The authors [21] analyzed the effect on different dynamic office chairs on erector spinae electromyography, shrinkage, and trunk kinematics parameters. In this study, two types of dynamic chairs, which allow rotation of backrest and seat, and one static chair were used. The authors have found that dynamic chairs can improve shrinkage; however, the trunk kinematics and EMG highly depend on the task specificity, but not the chair type. Other important findings in the study [27], where dynamic chairs and conventional chair as reference were compared, found that the erector spinae activity did not statistically increase on the dynamic chairs, compared with the reference chairs. While various office tasks differently affected erector spinae muscle activity. Similar findings can be seen in another study [35]. All these three studies analyzed conventional chairs with moving backrests, different backrest support, and various seats. Another important study [48] analyzed less conventional chairs, such as inverted dynamic chair (seat with upwards side to side movement) and advanced dynamic chair (with convex sitting surface, which moves downwards side to side) with the reference of conventional chair. This is the continuation of the previous study [50] where the physiological motion axis was analyzed during free sitting and then tried to adapt it to different chairs (Fig. 7). The chair, which met the recommendation of motion axis at the level of 11th thoracic vertebra, showed very good lateral flexion of the spine with the stable upper body. Another important finding was that this physiological motion axes matched spinal motion during walking. Thus, continuing the study [48], the authors wanted to see whether the backrest support during the active sitting can be matched with additional motion axis on the upper body stability. The results have shown that advanced dynamic principal chair is severely restricted with the backrest, while inverted dynamic chair showed good results and can promote active sitting with backrest support. The study [109], which analyzed the blood circulation during sitting on the active seat, CoreChair showed a small increment of calf circumference during the first, second, and third hour of sitting when compared with regular chairs. The authors thought that during sitting on CoreChair, the blood circulated during sitting time and the blood pooling reduced.

There are different active chairs with different impact on the body, as observed before. However, according to the systematic review, the modification of the workplace, such as lumbar supports, lifting techniques, insoles, chair backrests, or dynamic sitting showed limited evidence for the reduction of the lower back pain. Earlier systematic review [75] as well did not show an effect on the reduction of the lower back pain using dynamic chairs. The healthy sitting posture is active with regular movements, optimal sitting posture, and this can help for lumbar postural health [114]. The problem of dynamic sitting is that most of the dynamic chairs increase in the upper body movements; however, the motion of the lower back is more important, because the muscles are inactive for a long period of sitting time. The science and chair manufacturers showed small steps of changes [50, 48], and the active chairs can be more valuable when evaluating physiological and biomechanical parameters.

Figure 7. Physiological motion axis during free siting, on different types of chairs and when in walking [50]

There are many patented chairs and seats, which were created to improve sitting posture, reduce back pain, and improve blood circulation. In the US patent US 2019/0104851 (A1) [15] (published in 2019 04 11) (Fig. 8), the seating device is presented as well as the device benefits and applicability (https://patents.google.com/patent/US10588415B2/en), and a method of using a seating device, including a base and bearings. This seat is operably associated with the base via bearings for movement relative thereto. Based on the user input, the seat can move towards the leading edge in the direction of travel away from the seat centered over the base.

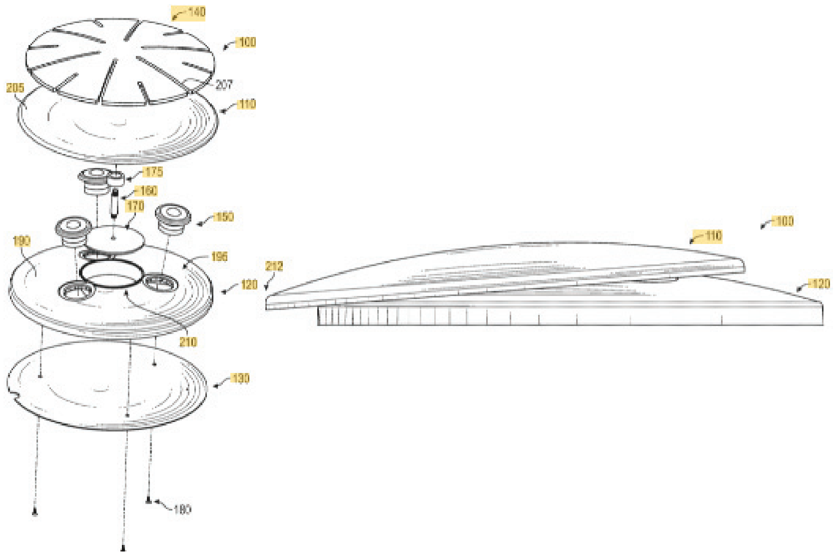


Figure 8. The US patent of seating device US 2019/0104851 (A1) [15]

It was said that the patent where the user's muscle are engaged to maintain an upright posture during this movement as well helps to improve the user's motor control, stability, and strength over the time. Moreover, the authors of a patent said that the muscles of the hips, lower back, abdominals, and pelvic floor are engaged to decelerate motion of the seat as gravity acts on the user's center of gravity and increases blood circulation in a moving body region.

Another patent US 2005/0173952 (A1) [51] (Fig. 9) is about the chair, which can move and convert the movements into control signals for controlling a cursor (pointer) on a display screen in order to prevent repetitive strain injuries (RIS) complaints.

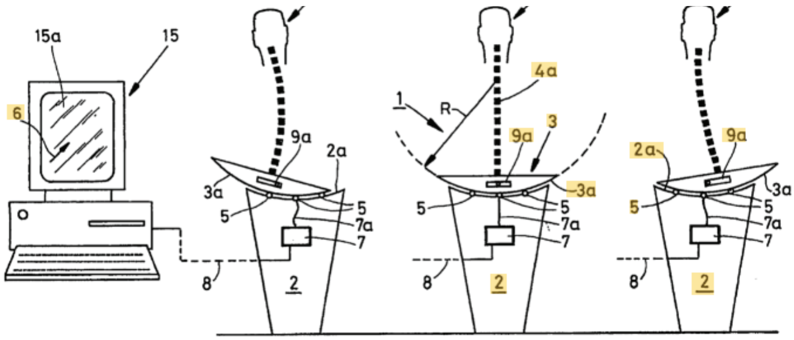


Figure 9. The US patent US 2005/0173952 (A1) cChair with means for controlling a cursor [51]

A rocking chair US 2011/0089733 (A1) (Fig. 10), according to the authors, can efficiently recover tired lumbar muscles, prevent, or relax lumbago, or train lumbar muscles during rehabilitation. Lumbar muscles are always exercised when a person returns to the seat in a neutral position in order to maintain balance [72].

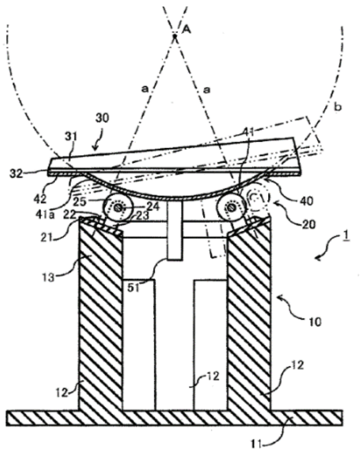


Figure 10. Rocking chair, patent US 2011/0089733 (A1) [72]

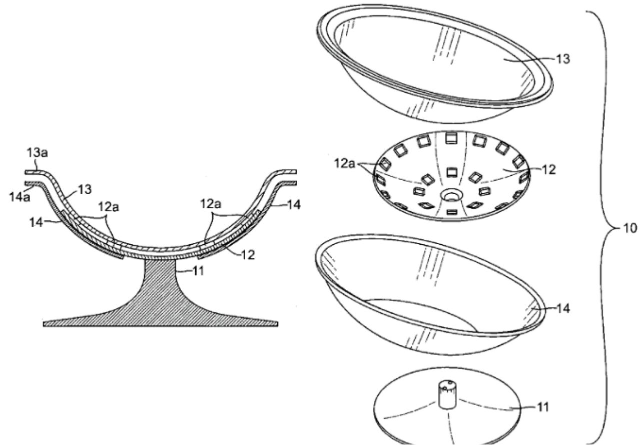


Figure 11. Swivel and reclining chair, patent US 7,938.489 (B2) [71]

There are a lot of other patents [15, 51, 72, 71] (Fig. 11), which provide the movement of pelvis in a sitting position, have concave and convex surfaces, and mostly move on bearings. All these are created to strengthen the stability of the trunk, improve motor control, reduce lower back pain, solve reduced blood circulation, relieve tension and strains. However, there is poor scientific justification of influence of these chairs on different physiological and biomechanical parameters of the human body.

1.5. Cortical activity during the balance maintenance

For everyday activities, balance is an essential mechanism, which allows a lot of movements under different conditions. Without good balance control, there are possible injuries and an increased risk of falls. There are a lot of systems responsible for the good balance control and posture cerebellum, spinal cord, cortical structures [41]. More and more studies are indicating about the balance perturbations and brain cortex activity during it [113]. There are a few methods to analyze cortical activity: electroencephalographic (EEG) method, functional magnetic resonance imaging (fMRI), positron emission tomography (PET), and transcranial magnetic stimulation (TMS) [113].

Electroencephalography is a method that reads electrical activity from the cortex generated by the brain structures. The EEG is picked up by the metal electrodes and conductive gel/pasta [108]. There are different methods that can be used in the application of electrodes on a scalp according to the international 10-10 electrode system or the international 10-20 electrode system. The electrodes that are matching in a software can be different, and it is called EEG montage. There are few main montages: bipolar, referential, average reference montages [97], but the montage mostly depends on what the researcher would like to see in clinical or research areas, and which method is preferable. Each montage represents the differences between two electrodes; for example, if bipolar montage is used, the difference between two electrodes is displayed (Fp1-F3). If the referential method is used, the difference between Fp1-REF is obtained [26]. In the referential montage, very often, the reference can be chosen from several options: uni-mastoid or ear, linked mastoids or ear, Cz electrode, average or reference [122]. The uni-mastoid reference is often used because this reference has very low impedance [122], which can show purer activity of other electrodes, with which the montage is made.

There are four basic groups of brain waves (Fig. 12): gamma (>30 Hz), beta (13–30 Hz), alpha (8–13 Hz), theta (4–8 Hz), delta (0.5–4 Hz) [97, 108], which represents different associations of brain state and disorders, mood, emotions, tasks, movement, etc. Every wave has a different oscillation amplitude, and it ranges from 0.5 to 100 μV. Moreover, both hemispheres (right and left) of the cerebrum are divided into four lobes: frontal, parietal, occipital, and temporal [97].

According to the study [121], the prefrontal cortex is responsible for different cognitive functions, including balance performance and training [92]. In most cases, the balance maintenance and cortical activity connections are analyzed during standing [41, 110, 40]; however, there is a lack of studies, which analyze sitting position and cortical activity. The researchers have shown that cortical activity increases during static balance tasks, unperturbed quiet standing, and during unstable stance and react to the postural movements [110, 102]. Moreover, the studies analyzing electroencephalography (EEG) signals during external balance perturbations showed higher demands on balance control. This is associated with higher theta activity located in the medial fronto-central cortical area [40, 41]. Theta activity increment during the balance tasks is not only in the fronto-central cortex but as well include centro-parietal regions [40], which are involved in sensory integration and sensorimotor coordination. The functional significance of frontal and parietal brain areas involvement during balance control is supported by the longitudinal studies on the effects of balance training on neural structure [107]. Gray matter volume increased in frontal and parietal cortical areas after six weeks of continuous balance training, and this was correlated with the improvements in balance performance [107]. Moreover, it is important to mention that the subjects explored and evaluated different movement coordination patterns to improve performance in the dynamic balance tasks [107], various components of motor learning as a means to induce neuroplasticity [22].

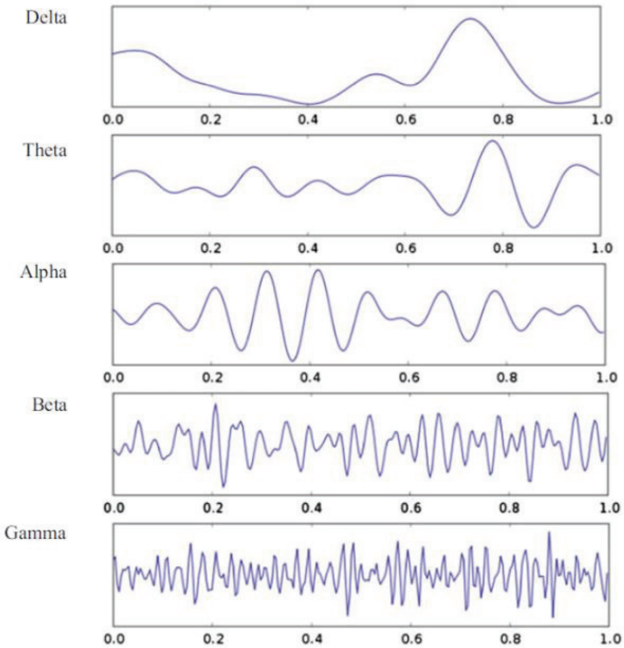


Figure 12. Examples of different types of EEG waves [97]

1.6. Kinematic measurements of the body movement

There are a lot of different 3D motion capture systems to measure the human body kinematics (Vicon, Qualisys etc.). This equipment is used by the researchers, biomechanics, physicians, and engineers in a wide range of application: human biomechanics (clinical gait, functional assessment, gait research, sound and motion, psychology, MRI for human and underwater), sports (running, baseball, cycling, golf, and swimming), engineering (automotive, robotics), entertainment (virtual reality and animation), and animal biomechanics.

The 3D motion capture system has high speed cameras. The number of cameras can vary from three to twelve or even more. The additional tools, which are necessary during the motion capture filming and analysis include: reflective markers, L frame, a wand, a server, a computer, and cameras. The markers are reflective and describe the position of the measuring points. The principle of motion capture system is that the cameras detect the reflective markers to get 2D coordinates [79]. Motion capture systems usually use many markers and many cameras; thus, these cameras are synchronized with each other. When the cameras capture the markers, this data is transferred to a computer (Fig. 13). Before the measurement, the calibrations of L frame, wand, and cameras are performed.

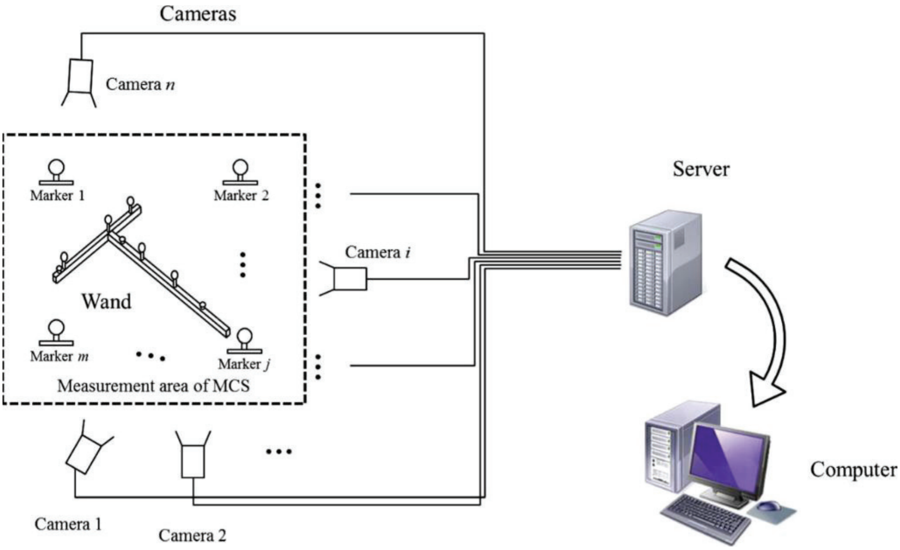


Figure 13. Set up of motion capture system [79]

Markers can be of different sizes, and mostly, it depends on the body area where this marker will be attached. It can be measured with full body kinematics or lower body kinematics. For these cases, there are different marker placement protocols: Helen–Heyes (Fig. 14) [20], Calibration Anatomical System Technique (CAST), Instituto Ortopedico Rizzoli (IOR) [52], Conventional Gait Model (CGM) [124], running, animation protocols. In order to choose the right protocol, it is important to know in which area this will be used and for what movement. Sometimes, it is as well important to choose the right protocol, when the biomechanical model will be transferred to modeling software in order to calculate inverse kinematics: OpenSim, AnyBody, Biomechanic of Bodies (BOB), etc.

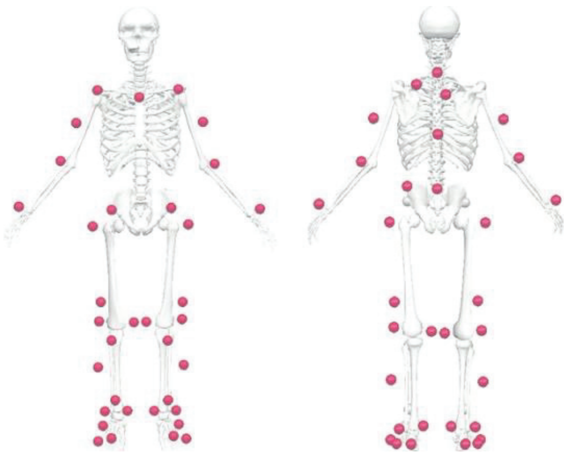


Figure 14. Modified Helen-Hayes marker protocol [20]

1.7. The influence of mechanical loading in a sitting position

In order to know more about the spine loadings and kinematics, there are used such research methods, i.e., in silico or in vitro. These methods can predict the worst and the best position of the spine under the given load. Very often, when wanting to know in which position the spine is less loaded, the finite element (FE) studies are performed. A method of the FE modeling can predict the value and the distribution of outputs, such as: displacement, stresses, loads for the given outputs.

In many studies [89, 25], there are described the intradiscal pressure, the stresses only in the main positions, which are mostly used during daily life: standing, sitting, laying (supine, prone, or on a side), forward flexion, extension or standing and lifting the box, transition from standing to sitting, etc. The muscles that are acting as the most important can be described as actuators, controllers, and stabilizers of the trunk [25]. These roles are very important, because it can save the spine from different unexpected, static, or dynamic loadings. Excessive loadings can be harmful to spine and intervertebral discs, and due to these loadings, back disorders and pain can occur.

Sitting position

There are many in vitro and in vivo studies conducted on analyzing the sitting position. It is difficult to say that one or another sitting position is more loaded, because there are many factors, which can influence the loading. Sitting without and with backrest can strongly vary on spine loading.

According to the first study [66], intradiscal pressure during unsupported sitting can increase by 40% from the data obtained in the standing position. Other in vivo study [118] has shown that when sitting relaxed without backrest, the intradiscal pressure is about 0.46 MPa; when sitting with maximum flexion, it is 0.83 MPa; when sitting actively with straight back, the intradiscal pressure is 0.55 MPa; while sitting with backrest, it is about 0.27 MPa. However, it is important to mention that the spinal loads depend on the supported or unsupported sitting as well as individual parameters, such as spine shape, kyphosis angle, and arm position [24]. Important findings on spine load were made in the study [90], where different chairs were compared (Fig. 15). This study compared the loads related to the sitting on a stool, which was 100%; thus, the higher load was only when sitting on physiotherapy ball, which mainly increased by about 7% from sitting on a stool. The reduction of 35% of the load has the sitting on a chair, and 41% reduction was seen when sitting on an office chair.

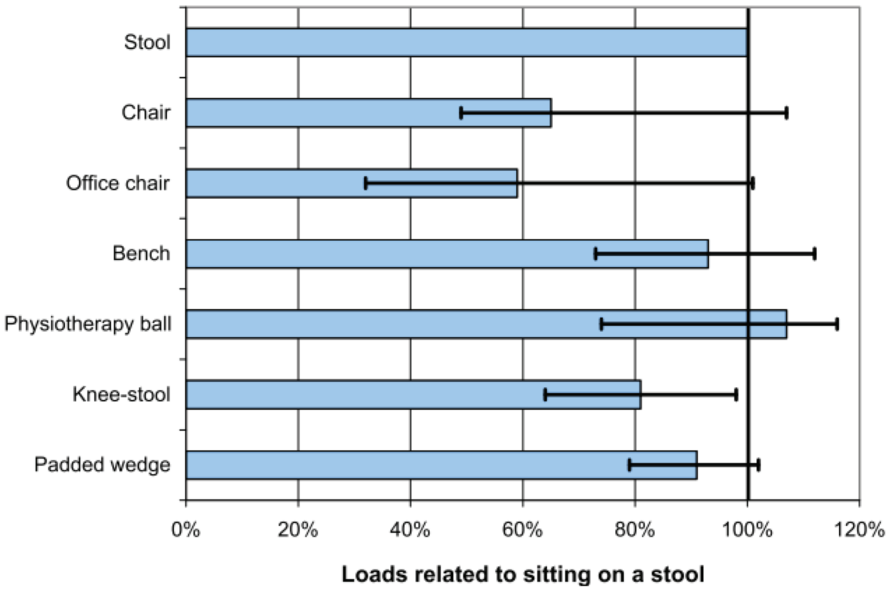


Figure 15. Sitting on different types of seats influeces act different forces on vertebral body: sitting on a stool was equal to 100% [91]

1.8. Musculoskeletal modeling

Musculoskeletal modeling is the tool, which allows to understand the internal mechanisms of the body during motion. Due to the minor ability to do in vivo studies, the musculoskeletal modeling is truly non-invasive and can estimate muscles, ligaments, and joint forces [98]. There is quite a wide range of application of musculoskeletal modeling in movement analysis [5], product optimization design, ergonomics [19], sports [6], orthopedics and rehab, assistive devices [56]. There are many software, such as AnyBody Modeling System, OpenSim [38], which can help to calculate inverse dynamics.

When discussing AnyBody Modeling System, there are used two types of muscle model, i.e., Hill muscle models and Cross bridge models. The Hill muscle models are mainly used in the AnyBody Modeling System. This muscle model type is based on the experiments with frog muscles, and mathematical expression are based on the simple muscle fiber length and contraction velocity. The Hill muscle model consist of the contractile element (CE), which represents the muscle and its contractile properties; another component is a serial elastic element (SEE) that mainly describes elasticity of the tendon and aponeurosis; parallel elastic element (PEE) represents the elasticity of the tissue, which surrounds the muscle [38]. Moreover, it is important to mention the pennation angle (Fig. 16), which influences the generation of force of the muscle and the total muscle's force-length-velocity relationship [38]. Hill-type muscle models are classified as 0-d elements due to the lack of mass and inertia [36].

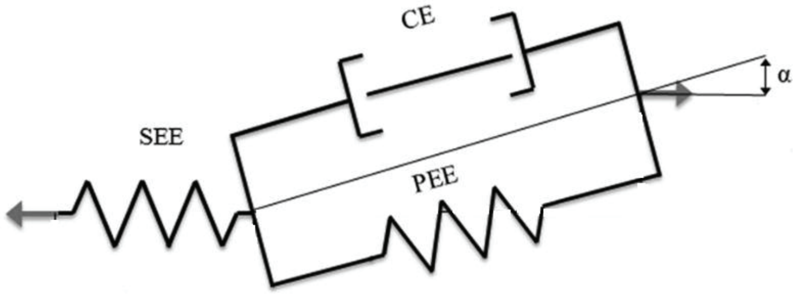


Figure 16. Hill muscle model type: parallel elastic element (PEE), serial elastic element (SEE), contractile element (CE), pennation angle (a) [38]

Another important aspect is scaling of musculoskeletal models. Basically, all models, which are presented in AnyBody Modeling System, are based on cadaver data, which are scaled by using simplistic linear scaling laws (Fig. 17) [57]. In order to calculate inverse dynamics, it is very important to know the kinematical data. The technology, which can provide the kinematical data, is human motion input, which can be obtained from the motion capture technology. This technology defines the trajectories of markers attached to the human body. The multiple synchronized video cameras track small reflective markers and get the motion into the computer. This markers trajectories data are as an input to the musculoskeletal modeling systems. However, according to the authors [7], there are a few problems, which need to be considered before calculating inverse dynamics:

1) Noise: the noise appears because of the soft tissue artefacts, which appear when the humans change positions. The markers slightly slide with the skin.
2) Kinematic over-determinacy: the segments from the motion capture data have minimum three markers, which means nine degrees of freedom (DOF), but the segment has only six independent DOF. The joint constraints further increase the over-determinacy.
3) Kinematic under-determinace: this mostly happens when internal segments (bones) are not visible by the motion capture (i.e., shoulder blades); thus, it is left under determinate.
4) Missing marker visibility: sometimes, it happens when markers are occluded for periods of time during the motion capture procedure.

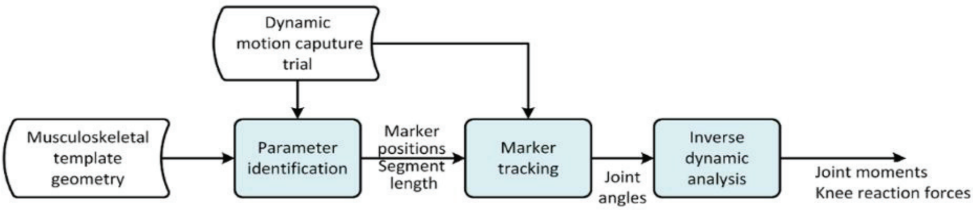


Figure 17. The framework of the AnyMoCap model, linearly scaled model [58]

In order to solve these problems, there are many tools, which can be used: more markers on body segment, optimization algorithms, or sort of Kalman filter to find the motion of the model [7]. Moreover, when the inverse dynamic is calculated, there is a need to manually place the markers and scale each body segment. The markers should be placed corresponding to the motion capture data from the experiment. The authors of the study [57] proposed three methods to scale the model: linear scaling, anatomical landmark scaling, and kinematically scaling. All three methods were compared in modelling the gait. For the kinematically scaled models, there were seen about 6 cm change in the hip joint position, and this could be due to the soft tissue artefacts. The prediction of knee contact force has shown that the kinematically scaled model is better compared with linearly and anatomical landmark scaled models. It is very important in a gait, because the knee contact force is very sensitive to the knee moment. However, the linearly scaled model showed good results of prediction of the total knee contact force.

1.9. Formulation of the aim and objectives of the dissertation

There are a lot of active (dynamic) chairs, which allow to be active during the working day; however, there is a lack of dynamic chairs, which can promote lower body movement instead of the upper body movement. The lower body and the pelvis movements are very important to avoid atrophy of multifidus muscle, engage more deep muscles during the movement, and supply intervertebral disks with appropriate flow of water and nutrients. The static sitting on a traditional chair reduces the muscle activity as well as the cognitive function during the working hours [14]. There have been studies made where postural control and balance maintenance increase the theta activity of the fronto-central and centro-parietal cortical regions [63]. This increment shows that the activity of cognitive function increases. Moreover, there is a lack of studies where brain activity is measured during the sitting or even unstable sitting. The majority of the chairs, which are developed, mainly increase the upper body movements rotational or side to side movements; however, there is no dynamic chair where two movements of the pelvis are implemented: anterior-posterior and lateral-medial. According to the study [87], the motion in anterior-posterior directions is important for the stabilization, while medial-lateral directions do not produce stiffness control. The novelty of the thesis is the methodology of unstable seat development from the biomechanical and physiological point of view.

The aim of the research is to create an innovative unstable seat, which increases the activity of trunk muscle and brain cortex. In order to achieve this aim, the following objectives have been formulated:

1. To find out the correlations between brain, muscles activity, and balance under different sitting positions.
2. To investigate biomechanical and kinematical parameters of human pelvis movement under different experimental conditions.
3. To apply and compare experimental results of spine movements on different sitting surfaces to find out the stresses and strains on the model of the lumbar spine.

4. To compare the experimental results of muscles activity with musculoskeletal modeling results.
5. To create an unstable seat prototype according to the results of theoretical and experimental research.

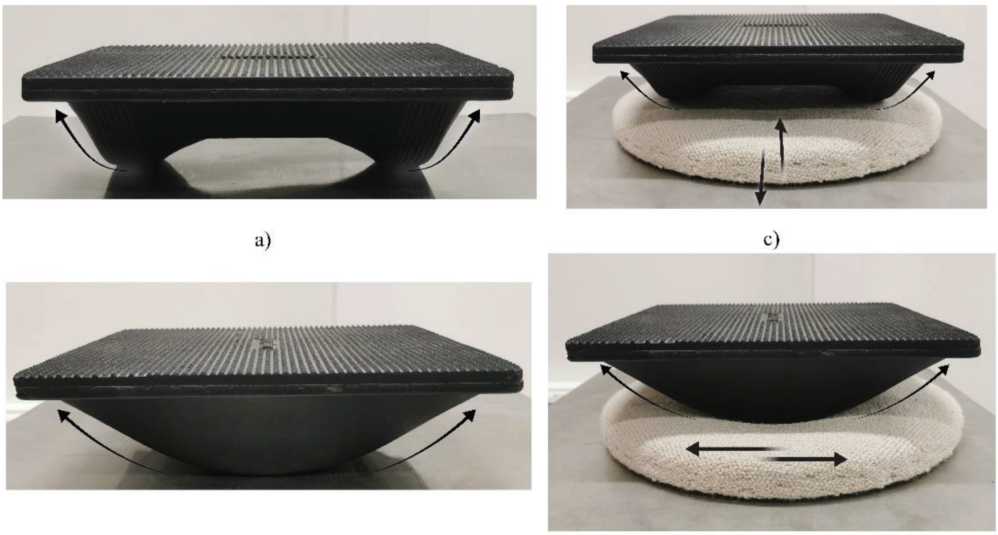
2. EXPERIMENTAL RESEARCH OF MUSCLES, BRAIN, AND KINEMATIC PARAMETERS DURING SITTING ON UNSTABLE SURFACE

2.1. Test stand of a wobble board on the bearing surface

As it was mentioned in the literature review, there is a lack of studies where pelvis movement of anterior-posterior and medial-lateral directions on a wobble board and a wobble board on the bearing surface analyzed in a deeper way of physiological and biomechanical parameters. Due to this reason, the experimental research of muscles, brain, and kinematics parameters were conducted.

A test stand of custom-made wobble board on the bearing surface (WBB) was made, (Fig. 18 b), which was published in the article [4]. The test stand WBB consisted of six small bearings, which can move freely in all directions: anterior-posterior, lateral-medial. A simple wobble board (WB) is made of the flat top surface and hemisphere bottom. This WB can have motion in multiple planes, and it was used as an additional tool as well to evaluate the anterior-posterior and medial-lateral pelvis movement and compare it with the test stand WBB and static sitting.

The aim of the experiment was to find out the relation between brain, muscle activity, and balance under different sitting positions in order to investigate biomechanical and kinematical parameters of human pelvis movement on different sitting tools.



a) c)

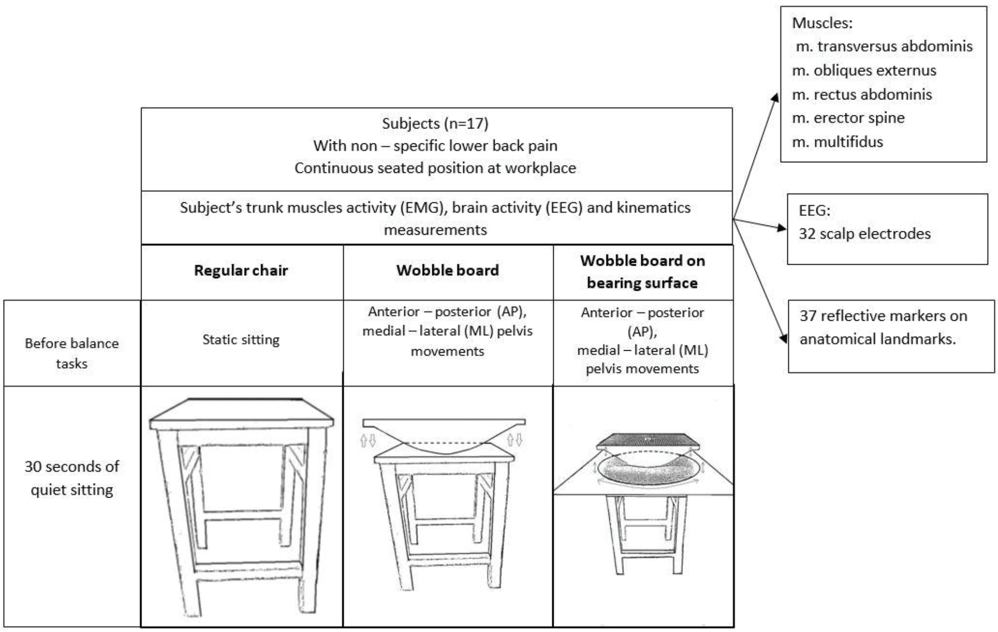
b) d)

Figure 18. a) Aa simple wobble board (WB) in anterior-posterior view, and b) medial-lateral view, and c) a wobble board on the bearing surface (WBB) in anterior-posterior view, and d) medial-lateral view

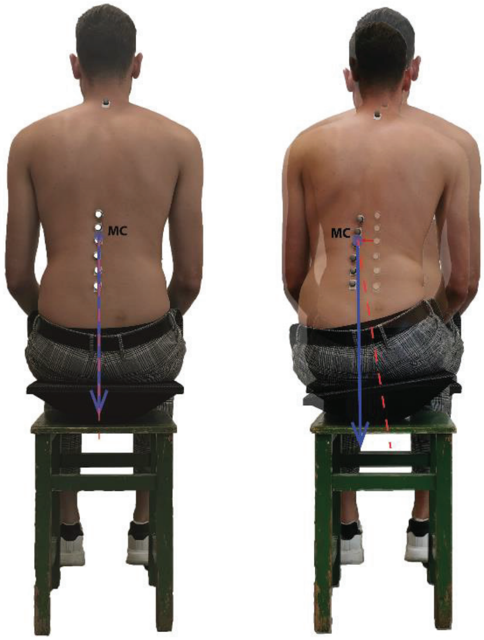
2.2. Research protocol overview

Three different equipments were used for the experiment: regular chair, wobble board (WB,) and custom-made wobble board on the bearing surface (WBB) (Fig. 19). The boundary conditions of sitting on different sitting surfaces were hips and knees flexed 90°, the support was both feet on the ground and pelvis on the sitting surface. The hands were not placed on the table. The tasks were divided into 3 groups: static sitting, anterior-posterior (AP) pelvis movement on a wobble board (WBAP), medial-lateral (ML) pelvis movement on a wobble board (WBML), anterior-posterior pelvis movement on a wobble board on the bearing surface (WBBAP), medial-lateral pelvis movement on a wobble board on the bearing surface (WBBML). Each experimental test lasted 60 s in total. During these tasks, simultaneously, the kinematics of body segments, electromyography (EMG) of five trunk muscles, electroencephalography (EEG) of 32 scalp electrodes were measured. Before the balancing movements, all subjects sat quietly for 30 s (Fig. 19). While subjects performed the tasks in different experimental conditions, a 3D motion capture system was used to record the trajectory of the calibrated anatomical systems technique.

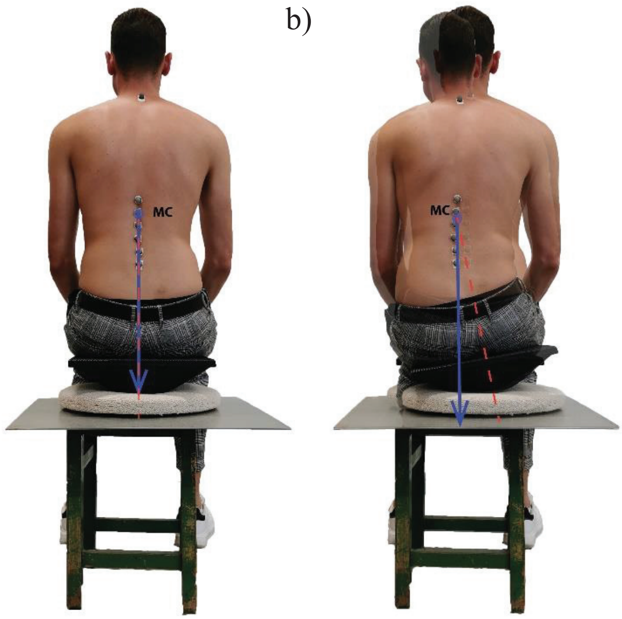
There can be seen different center of mass movement when sitting and performing medial-lateral movement on WB and WBB in Fig. 19 b and c. When sitting on WB, the center of mass shifts with the seat movement; however, when sitting on WBB, the center of mass shifts lesser during movement. In this case, WBB increases the lower back movement more compared with WB.



a)



b)



c)

Figure 19. Experimental research protocol (a), center of mass movement on a wobble board (b) and center of mass movement of a wobble board on the bearing surface (c)

2.3. Statistical analysis

The data was analyzed with statistical package SPSS version 23.0. The data was checked with Shapiro–Wilk normality test; however, the collected data is not normally distributed. For a small sample, the nonparametric Wilcoxon test was used to compare the related samples. The data level for the statistical significance was set at $p < 0.05$. The data was presented as median $x_{me} = (\bar{x} \pm SD)$. The descriptive statistics and Spearman correlation coefficients were calculated to determine the amount of shared variance between the dependent variables. When participants sat on two different unstable surfaces, the amplitude of anatomical points of movement and EEG signals changes were calculated to see the possible correlation between these two data sets.

2.4. Experimental study of a wobble board on the bearing surface influence on the trunk muscles activity

In order to find out the difference between different sitting surface and pelvis movement, the trunk muscles activity was measured. Seventeen subjects with non-specific lower back pain and continuous seated position at the workplace were involved in the study. All the participants were verbally informed of the protocol, read and signed a consent form. The ethical approval was obtained from the Regional Ethics committee (Lithuanian University of Health Sciences). The Helsinki Declaration (1964) and its later amendments followed as well. The remaining 17 subjects that were used in the analyses were 28 ± 5.22 years old and 177 ± 9.4 cm tall, 71.5 ± 12.81 kg weight.

The experimental study was done by using the superficial electromyography (sEMG) method, which allows to measure muscle activity. In order to get muscle activity, 12 channels of TeleMyo DTS 2400R G2 (Noraxon USA Inc.) electromyograph were used (Fig. 20). There were used 5 of 12 wireless sensors, which were attached directly to the skin and wirelessly transduced the signal. The trunk muscles activity was measured during the balance tasks. Bipolar sEMG activity was recorded by using the surface electrodes from the right side of: m. transversus abdominis (TA) 2 cm inferior and medial to the anterior superior iliac spine and parallel to the fibers of the TA [29], m. obliques externus (OE), m. rectus abdominis (RA) 4 cm to the side from the umbilicus, lower border of electrode at umbilicus level [29], m. erector spine (thoraco-lumbar part) (ES) 5 cm lateral to T9 spinous process [61], m. multifidus (MF) aligned with a line from caudal tip posterior spina iliac superior to the interspace between L1 and L2 interspace at the level of L5 spinous process [127] (Fig. 21). There are many studies, which are analyzing one-sided [61] or two-sided [27] EMG. The study analyzed one-sided EMG of the dominant side of every participant, which was the right side. The purpose was to compare muscles activity on different sitting surfaces, but not to compare different sides of the body or to see the symmetry during the movement. Before placing the surface electrodes on the skin, it was shaved, swabbed, and rubbed with alcohol to reduce skin impedance.

Figure 20. The setup of EMG system: electromyograph (1), channels (2), electrodes (3), alcohol wipes (4)

For further calculations and results comparison between the participants, the maximum voluntary isometric contraction (MVIC) was performed for each muscle, and the sEMG amplitude was recorded at the same time. MVIC was performed for every muscle three times; the trial lasted 5 seconds with the rest interval between every trial. The mean MVIC EMG amplitude was calculated for each of the three, 5 seconds windows, and these data were used for the proportion calculations to get the %MVIC. The data obtained from the task procedures of the pelvis were converted to the percentage, according to the proportion calculation.

After measurement, the offline data processing of electromyography was done for all subjects with the software Noraxon MR 3.12. sEMG data were band-pass filtered (the frequency range 5–500 Hz), then the full wave was rectified and smoothened. The amplitude of sEMG data was normalized by using the mean dynamic activity method [32].

Figure 21. Electrodes placement on muscles: 1 – m. erector spine (thoraco – lumbar part) (ES), 2 – m. multifidus (MF), 3 – m. rectus abdominis (RA), 4 – m. obliques externus (OE), 5 – m. transversus abdominis (TA)

The sEMG data were analyzed with statistical package SPSS version 23.0. For a small sample, the nonparametric Wilcoxon test was used. The data level for the statistical significance was set at $p < 0.05$. The data were presented as median x_{me}= ($\bar{x} \pm SD$).

The increment of MF, EO, and TA muscles activity was observed on WBBAP, compared with WBAP, (Fig. 22); however, these results were not statistically significant. Erector spine muscle, which activity on WBBAP was 2.45 (3.35 ± 3.74)% and WBAP 0.79 (1.56 ± 5.38)%. The result was statistically significant (Z = -2.430, p = 0.015). Moreover, the multifidus muscles activity was higher on WBBAP, compared with WB1; however, this was not statistically significant results (p = 0.326). Transversus abdominis muscle activity increased on WBBAP, compared with WBAP; however, this was not statistically significant (p = 0.301). Moreover, the externus obliques muscle activity increased on WBBAP, compared with WBAP, but this was not statistically significant (p = 0.163). However, rectus abdominis muscle activity was lower on WBBAP, compared with WBAP, but this was not statistically significant (p = 0.918).

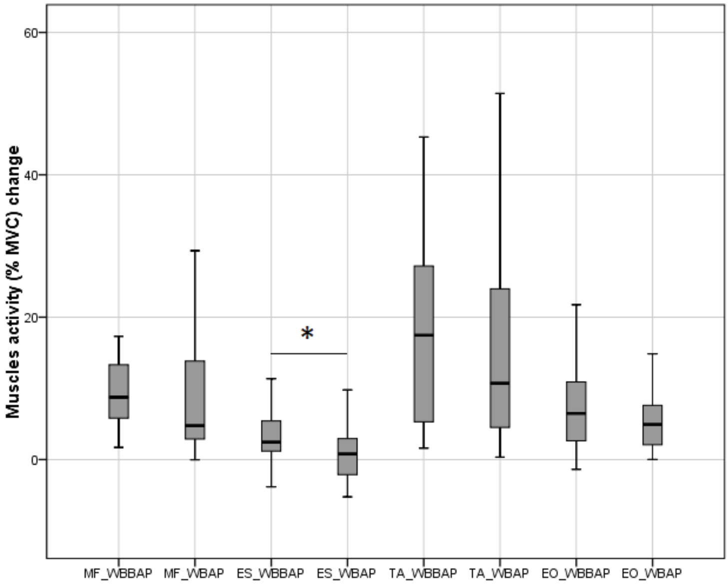


Figure 22. Muscles activity change in anterior-posterior motion on a wobble board (WBAP) and muscles activity in anterior-posterior motion on a wobble board on the bearing surface (WBBAP): * indicates statistically significant differences p < 0.05. MF – multifidus muscle, ES – erector spine muscle, TA – transversus abdominis muscle, EO – externus obliques muscle, RA – rectus abdominis muscles

Significant differences of MF, ES, and EO activity change on a lateral-medial pelvic movement in sitting on WB and WBB was observed (Fig. 23). The muscles activity change was measured from the static sitting. The MF muscle activity on WBBML was 8.52 (10.79 ± 7.52)%. The increment was statistically significant (Z = -3.124, p = 0.002) when compared with WBML 1.24 (1.95 ± 5.75)%. Moreover, the superficial muscle ES activity on WBBML increased by 7.98 (7.60 ± 5.33)%; however, on WBML, the increment was smaller 1.35 (2.56 ± 3.26)%. The difference of the ES muscles on WBBML and WBML was statistically significant ($Z = -3.067$, $p = 0.002$). The abdominal wall muscle EO activity on WBBML was 4.87 (4.81 ± 3.73)%, on WBML was 0.77 (0.44 ± 5.44)%; the difference was statistically significant ($Z = -2.166$, $p = 0.03$).

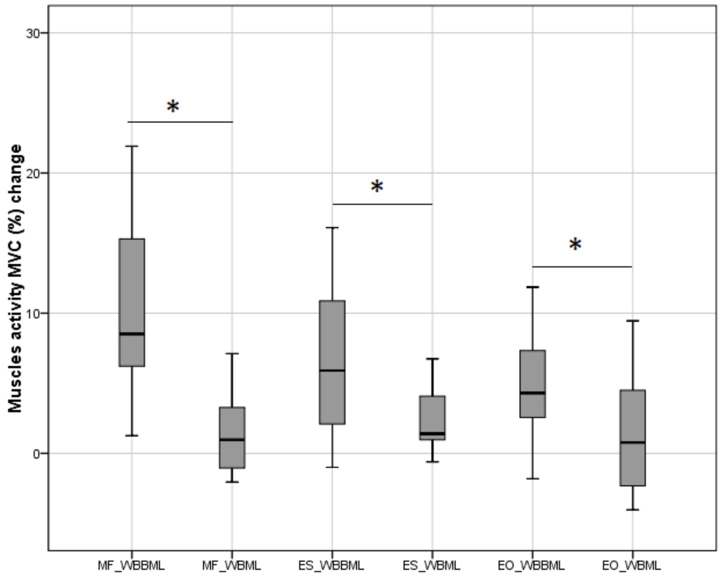


Figure 23. Muscles activity change in the lateral-medial motion on a wobble board (WBML) and muscles activity in the lateral-medial motion on a wobble board on the bearing surface (WBBML): * indicates statistically significant differences $p < 0.05$, MF – multifidus muscle, ES – erector spine muscle, TA – transversus abdominis muscle;, EO – externus obliques muscle, RA – rectus abdominis muscles

Moreover, it is important to evaluate the muscles activity on the WBB and compare the same group of the back muscles, which performs spine extension, and abdominal group, which performs spine flexion. The back muscles consist of m. multifidus and m. erector spine. Thus, when multifidus muscle 16.52 (16.77 ± 8.83)% and erector spine muscle 10.52 (10.75 ± 5.33)% were compared on the WBB in anterior-posterior movement; the activity of multifidus muscle was greater ($Z = -2.172$, $p = 0.03$) (Fig. 24). When performing medial-lateral movement on WBB, the multifidus muscle was 16.49 (18.07 ± 10.65)%, and the erector spine muscles were 17.02 (15.72 ± 7.34)%; however, this was not statistically significant difference ($Z = -0.879$, $p = 0.379$).

The abdominal muscles consist of m. transversus abdominis, m. externus obliques, and m. rectus abdominis. When transversus abdominis muscle activity 23.68 (27.50 ± 19.08)% was compared with externus obliques muscle activity 14.38 (16.37 ± 8.41)% on WBBAP, the transversus abdominis muscle activity was statistically significantly greater (Z = -2.223, p = 0.026) (Fig. 25). Moreover, the activity on WBBAP was statistically significantly greater (Z = -3.206, p = 0.001) when the transversus abdominis muscle and rectus abdominis muscle were compared, 23.68 (27.50 ± 19.08)% and 4.8 (6.36 ± 4.12)%, respectively. Moreover, the externus obliques muscle activity 14.38 (16.37 ± 8.41)% on a WBB in anterior-posterior movement was greater, compared with rectus abdominis activity 4.8 (6.36 ± 4.12)%.

When movement was performed in the medial-lateral direction on WBB, the higher muscle activity had transversus abdominis muscle 19.59 (23.46 ± 15.34)% than the externus obliques 11.89 (12.50 ± 6.59)% (Z = -2.223, p = 0.026) and rectus abdominis 4.80 (6.92 ± 4.85)% (Z = -3.309, p = 0.001) (Fig. 26). Moreover, externus obliques muscle had higher activity 11.89 (12.50 ± 6.59)% compared with rectus abdominis muscle 4.80 (6.92 ± 4.85)%; this was statistically significant results (Z = -2.224, p = 0.026).

These comparisons have shown that the WBB activates deeper layer muscles, which are responsible for the spine stabilization, compared with superficial muscles. The activity comparison is important in WBB development and instability adjustment for every person.

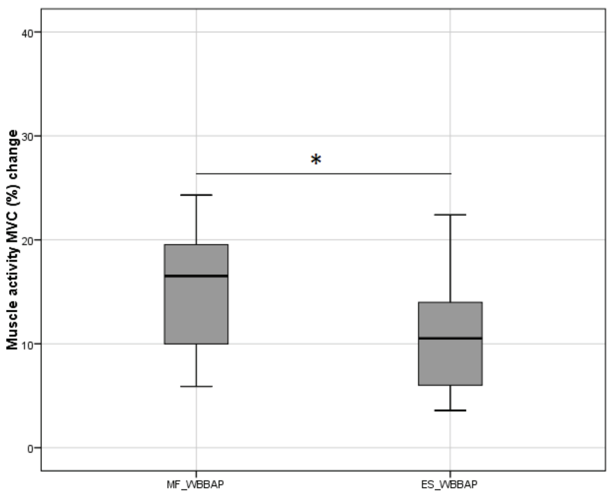


Figure 24. Muscles activity change on WBB in AP motion: * indicates statistically significant differences p < 0.05, MF – multifidus muscle, ES – erector spine muscle

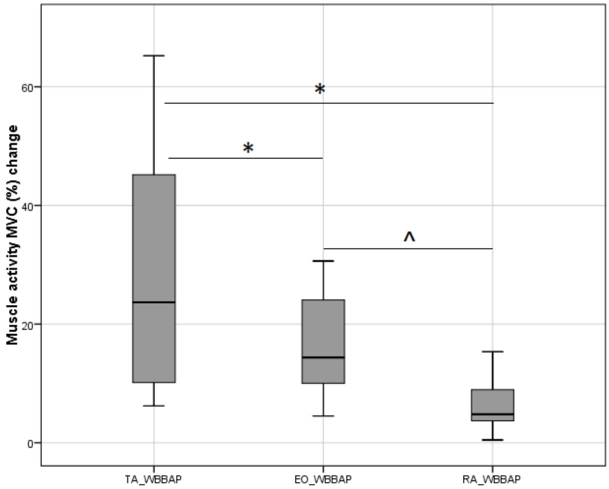


Figure 25. Muscles activity change on WBB in AP motion: *,^ indicates statistically significant differences $p < 0.05$, TA – transversus abdominis muscle, EO – externus obliques muscle, RA – rectus abdominis muscles

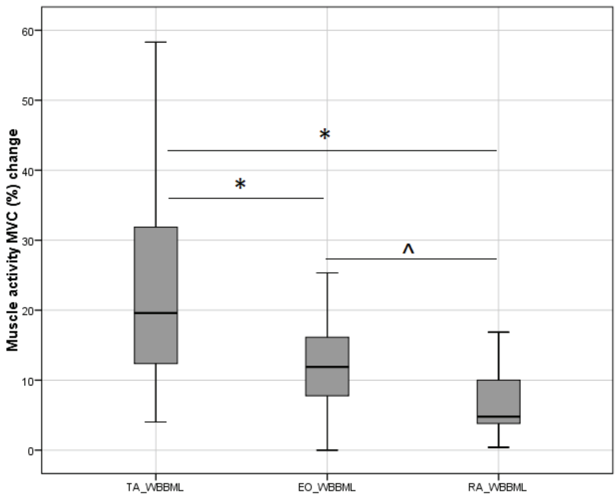


Figure 26. Muscles activity change on WBB in ML motion: *,^ indicates statistically significant differences $p < 0.05$, TA – transversus abdominis muscle, EO – externus obliques muscle, RA – rectus abdominis muscles

2.5. Experimental study of a wobble board on the bearing surface influence on the cortical activity

Electroencephalography was recorded from 32 scalp locations overlying the whole scalp (Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, AF3, AF4, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, PO7, PO3, PO4, PO8, Oz) [41] and equally distributed over both hemispheres according to the International 10:20

system, using a wireless EEG amplifier, g. Nautilus (g.tec medical engineering GmbH, Austria) (Fig. 27). Electrode PO8 was placed directly on the mastoid bone beneath the EEG cap. The referent position was placed at the right ear. Active electrode sites were prepared by rubbing the scalp with a blunt-tipped needle, which was subsequently used to apply conductive electrode gel (g.gamma gel). The mastoid electrode site was additionally prepared by scrubbing the skin with an alcohol pad [81]. The impedances at primary electrode sites (i.e., mastoids) were <10 kΩ before the start of the data collection. All other active electrode sites were similarly prepared, but impedance values were not generally <10 kΩ before the start of data collection. For the female subject with longer hair, the impedance at several electrode sites were maintained at 50 kΩ level. The sampling rate was set to 250 Hz. Before starting to measure the EEG signal, the band-pass filter was set to 0.5–100 Hz, and the notch filter was set to 50 Hz [9]. The signals were measured by using Simulink programmable block modules.

Figure 27. Set up of the EEG measurement: wireless electroencephalograph with cap (1), gamma gel (2), base station (3)

In order to investigate the cortical activity changes on two different unstable surfaces, the power values for theta (4–8 Hz) and alpha (8–13 Hz) frequency bands were calculated (Hanning window).

According to the previous studies [41, 99], the regions of interest were defined as follows: frontal (F3, Fz, F4), fronto-central (FC1, FC2, C3, Cz, C4), centro-parietal (CP1, CP2, P3, Pz, P4) (Fig. 28).

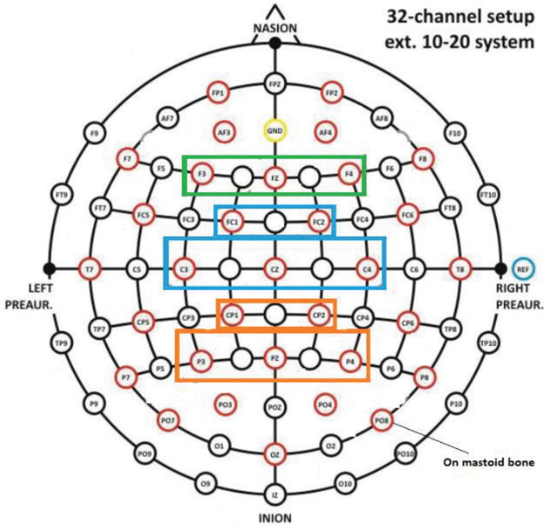


Figure 28. Regions of interest: green – frontal, blue – fronto-central, orange – centro-parietal

The data were collected and processed by using g.BSanalyze software package for MATLAB. The EEG data were first high pass filtered (Butterworth filter, highpass: 0.5 Hz) to remove the noise in the lower frequencies. A semiautomatic algorithm was used to exclude segments contaminated by the artefacts. For the remaining segmented data of each balance condition, an Independent Component Analysis (ICA) algorithm implemented in g.BSanalyze was used for ICA decomposition [41]. The segmented data were then baseline corrected.

Alpha Power Spectral Density (PSD)

Anterior-posterior pelvic motion

Alpha wave power spectral density (PSD) in the frontal area on WBBAP was 163.85 (210.07 ± 119.71) μV^2 while in a static sitting (SS) 58.87 (72.61 ± 51.16) μV^2 (Fig. 29). The difference was statistically significant ($Z = -2.701$, $p = 0.007$). The lower statistically significant difference ($Z = -1.956$, $p = 0.05$) in the frontal area was observed when compared to WBAP 99.08 (134.67 ± 89.56) μV^2 and SS 58.87 (72.61 ± 51.16) μV^2.

Moreover, alpha wave PSD in the fronto-central area on WBBAP was 200.88 (220.46 ± 186.96) μV^2 while in a static sitting (SS) 91.87 (93.23 ± 67.63) μV^2; the difference was statistically significant ($Z = -2.578$, $p = 0.01$). Almost the same results can be seen in WBAP 175.06 (199.12 ± 165.55) μV^2 compared to SS 91.87 (93.23 ± 67.63) μV^2, ($Z = -2.341$, $p = 0.019$).

In the centro-parietal area, PSD of alpha wave in WBBAP was 163.93 (162.27± 99.15) μV^2, while in SS, it was 82.92 (88.92 ± 42.53) μV^2; the difference was statistically significant ($Z = -2.040$, $p = 0.041$). However, in centro-parietal area, PSD of alpha wave in WBAP was 122.34 (131.52 ± 70.62) μV^2, while in SS, 82.92 (88.92 ± 42.53) μV^2; the change was not statistically significant ($Z = -1.334$, $p = 0.182$).

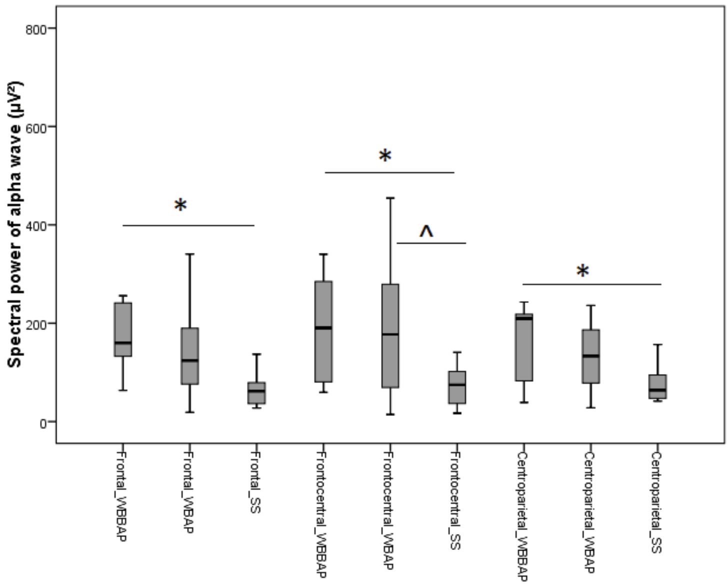


Figure 29. PSD of alpha wave in frontal, fronto-central, centro-parietal regions on a wobble board (WB) and a wobble board on the bearing surface (WBB) in anterior-posterior (AP) motion compared with static sitting (SS): * indicates statistically significant differences $p < 0.05$, ^ iIndicates statistically significant differences $p < 0.05$

Lateral-medial pelvic motion

Alpha wave power spectral density (PSD) in the frontal area on WBBML was 113.47 (154.62 ± 116.64) μV^2, while in a static sitting (SS), 58.87 (72.61 ± 51.16) μV^2; the difference was statistically significant ($Z = -2.845$, $p = 0.004$) (Fig. 30). However, there was no statistically significant difference ($Z = -1.511$, $p = 0.131$) when compared to WBML 106.47 (140.30 ± 140.17) μV^2 and SS 58.87 (72.61 ± 51.16) μV^2.

Moreover, alpha wave PSD in the fronto-central area on WBBML was 119.05 (201.50 ± 176.85) μV^2, while in a static sitting (SS), 91.87 (93.23 ± 67.63) μV^2; the difference was statistically significant ($Z = -2.432$, $p = 0.015$). The same statistically significant result ($Z = -2.118$, $p = 0.034$) can be seen in WBML 132.34 (163.34 ± 154.56) μV^2 compared with SS 91.87 (93.23 ± 67.63) μV^2.

In the centro-parietal area, PSD of alpha wave in WBBML was 110.98 (218.34 ± 199.42) μV^2, while in the SS, it was 82.92 (88.92 ± 42.53) μV^2; the difference was statistically significant ($Z = -2.201$, $p = 0.028$). However, in centro-parietal area, PSD of alpha wave in WBML was 115.11 (150.02 ± 113.44) μV^2, while in SS, 82.92 (88.92 ± 42.53) μV^2; the change was not statistically significant ($Z = -1.433$, $p = 0.152$).

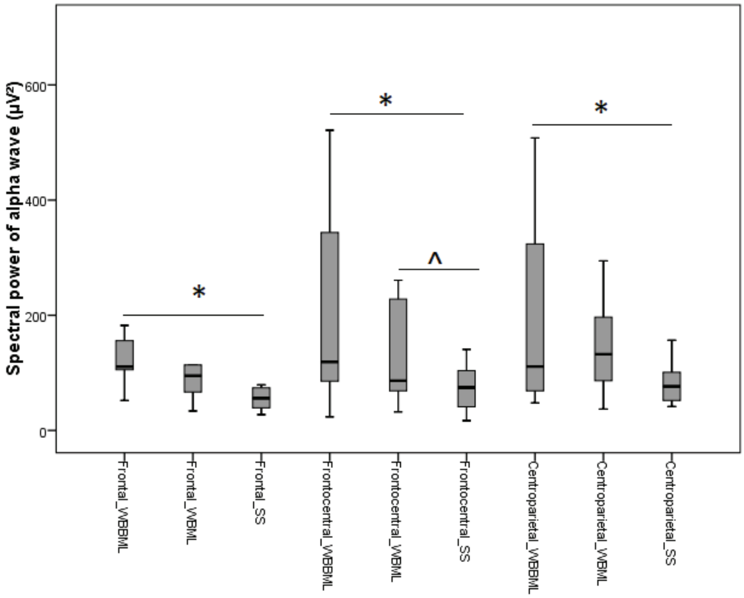


Figure 30. PSD of alpha wave in frontal, fronto-central, centro-parietal regions on a wobble board (WB) and a wobble board on the bearing surface (WBB) in lateral-medial (2) motion compared with the static sitting (SS): * indicates statistically significant differences $p < 0.05$, ^ iIndicates statistically significant differences $p < 0.05$

Theta Power Spectral Density (PSD)

Anterior-posterior pelvic motion

Theta wave power spectral density (PSD) in frontal area on WBBAP was 159.88 (223.69 ± 114.41) μV^2, while in a static sitting (SS), 60.73 (74.30 ± 46.73) μV^2; the difference was statistically significant ($Z = -2.803$, $p = 0.005$) (Fig. 31). The statistically significant difference ($Z = -2.134$, $p = 0.033$) in the frontal area was observed when compared to WBAP 109.08 (145.23 ± 87.69) μV^2 and SS 60.73 (74.30 ± 46.73) μV^2.

Moreover, theta wave PSD in the fronto-central area on WBBAP was 218.94 (226.64 ± 137.71) μV^2, while in a static sitting (SS), 55.81 (75.86 ± 42.32) μV^2; the difference was statistically significant ($Z = -2.803$, $p = 0.005$). Almost the same results can be seen in WBAP 147.15 (192.28 ± 192.12) μV^2 compared with SS 55.81 (75.86 ± 42.32) μV^2, ($Z = -2.551$, $p = 0.011$).

In centro-parietal area, PSD of theta wave in WBBAP was 122.87 (220.90 ± 193.40) μV^2, while in the SS, it was 62.94 (68.32 ± 30.69) μV^2; the difference was statistically significant ($Z = -2.293$, $p = 0.022$). Moreover, in centro-parietal area, PSD of alpha wave in WBAP was 129.24 (206.92 ± 206.24) μV^2, while in SS, 62.94 (68.32 ± 30.69) μV^2; the change was statistically significant ($Z = -3.040$, $p = 0.002$).

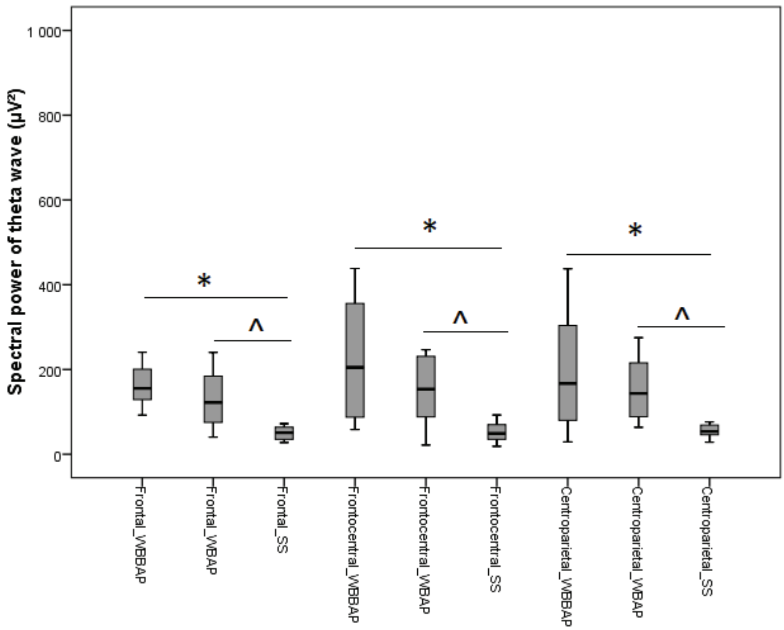


Figure 31. PSD of theta wave in frontal, fronto-central, centro-parietal regions on a wobble board (WB) and a wobble board on the bearing surface (WBB) in anterior-posterior (AP) motion compared with static sitting (SS): * indicates statistically significant differences $p < 0.05$, ^ indicates statistically significant differences $p < 0.05$

Lateral-medial pelvic motion

Theta wave power spectral density (PSD) in the frontal area on WBBML was 110.66 (221.19 ± 254.39) μV^2, while in the static sitting (SS), 60.73 (74.30 ± 46.73) μV^2; the difference was statistically significant ($Z = -2.803$, $p = 0.005$) (Fig. 32). Moreover, there was a statistically significant difference ($Z = -2.134$, $p = 0.033$) when compared to WBML 99.16 (161.58 ± 194.60) μV^2 and SS 60.73 (74.30 ± 46.73) μV^2.

Moreover, theta wave PSD in the fronto-central area on the WBBML was 141.91 (267.26 ± 316.74) μV^2, while in the static sitting (SS), 55.81 (75.86 ± 42.32) μV^2; the difference was statistically significant ($Z = -2.803$, $p = 0.005$). The same statistically significant result ($Z = -2.551$, $p = 0.011$) can be seen in WBML 127.66 (167.49 ± 146.84) μV^2 compared with SS 55.81 (75.86 ± 42.32) μV^2.

In centro-parietal area, PSD of theta wave in WBBML was 247.01 (287.61 ± 220.59) μV^2, while in the SS, it was 62.94 (68.32 ± 30.69) μV^2, the difference was statistically significant ($Z = -2.293$, $p = 0.022$). Moreover, in the centro-parietal area, PSD of theta wave in WBML was 132.06 (172,.78 ± 150.48) μV^2, while in SS, 62.94 (68.32 ± 30.69) μV^2; the change was not statistically significant ($Z = -3.040$, $p = 0.002$).

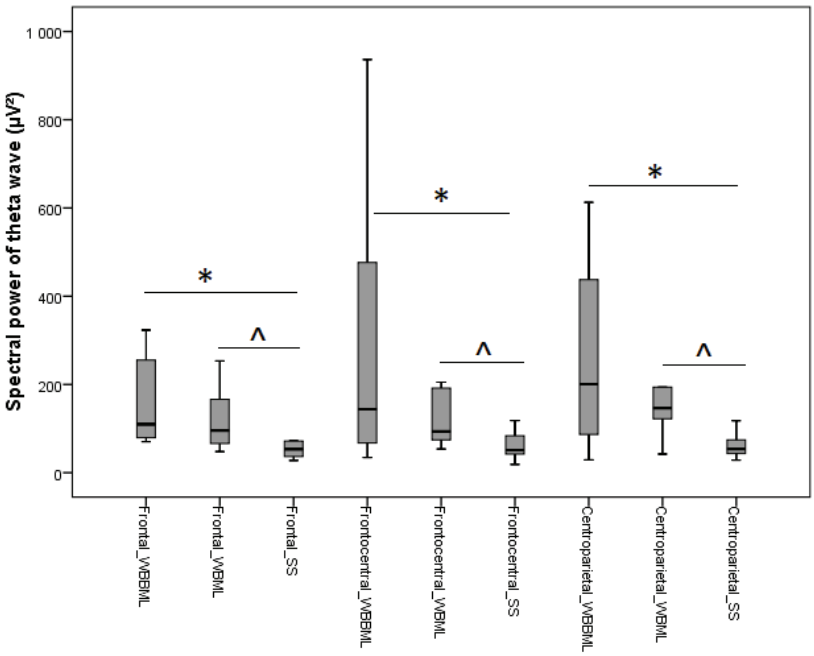


Figure 32. PSD of theta wave in frontal, fronto-central, centro-parietal regions on a wobble board (WB) and a wobble board on the bearing surface (WBB) in lateral-medial (ML) motion compared with the static sitting (SS): * indicates statistically significant differences $p < 0.05$, ^ indicates statistically significant differences $p < 0.05$

2.6. Kinematic parameters

Three-dimensional kinematic data were recorded by the motion capture with 10 cameras (Oqus7+ Qualisys AB, Gothenburg, Sweden) and the Qualysis Track Manager software at a sampling frequency of 300 Hz. The Helen–Hayes marker set was used for measuring the full-body kinematics. For this study, two anatomical points were of major interest: pelvis point-anterior superior iliac spine (ASIS) and spine region point 10th vertebra of the thoracic spine. The amplitudes of these anatomical points were calculated during the pelvis movements (lateral-medial, anterior-posterior) on two different surfaces from direct kinematics. During the kinematic analysis, the main purpose was to see the difference during sitting on the WB and WBB in amplitude of movement of different anatomical points.

Significant differences ($Z = -3.408$, $p = 0.001$) were observed in the displacement of anterior-posterior motion of anterior superior iliac spine (ASIS) on WBBAP 43.22 (43.59 ± 16.68) mm; the amplitude of movement was smaller than on WBAP 95.27 (93.53 ± 32.52) mm (Fig. 33). Moreover, the marker on the thoracic spine (Th10) displacement was analyzed in anterior-posterior motion, and the significant difference ($Z = -3.332$, $p = 0.001$) was found on WBBAP; the displacement was smaller 36.96 (43.32 ± 20.48) mm compared with WBAP 75.14 (81.23 ± 40.66) mm.

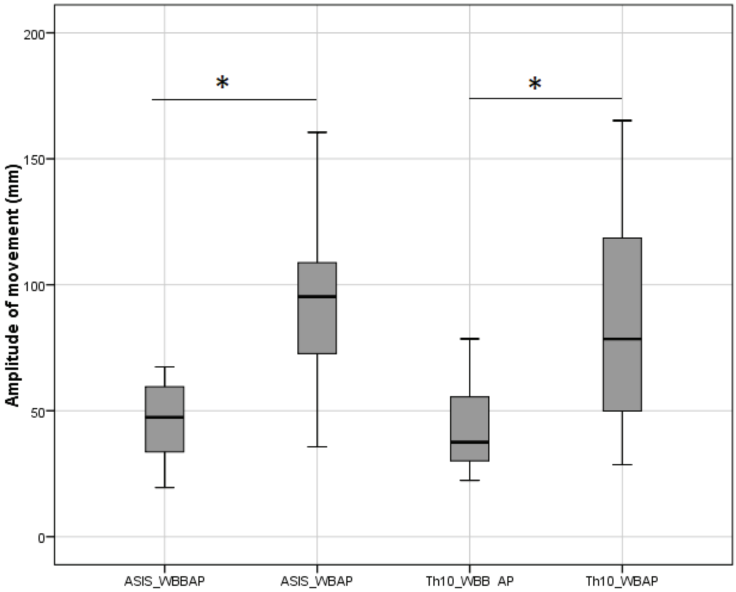


Figure 33. Mean of ASIS and Th10 amplitude of movement in anterior-posterior pelvic motion on a wobble board on the bearing surface (WBBAP) and a wobble board (WBAP); * indicates statistically significant differences $p < 0.05$

Significant differences ($Z = -3.680$, $p < 0.001$) were observed in the amplitude of movement of lateral-medial motion of anterior superior iliac spine (ASIS) on WBB1 69.65 (73.84 ± 23.02) mm; the amplitude of movement was smaller than on WB1 101.24 (104.85 ± 30.54) mm (Fig. 34). Moreover, the marker on the thoracic spine (Th10) amplitude of movement was analyzed in lateral-medial motion, and there was no significant difference observed.

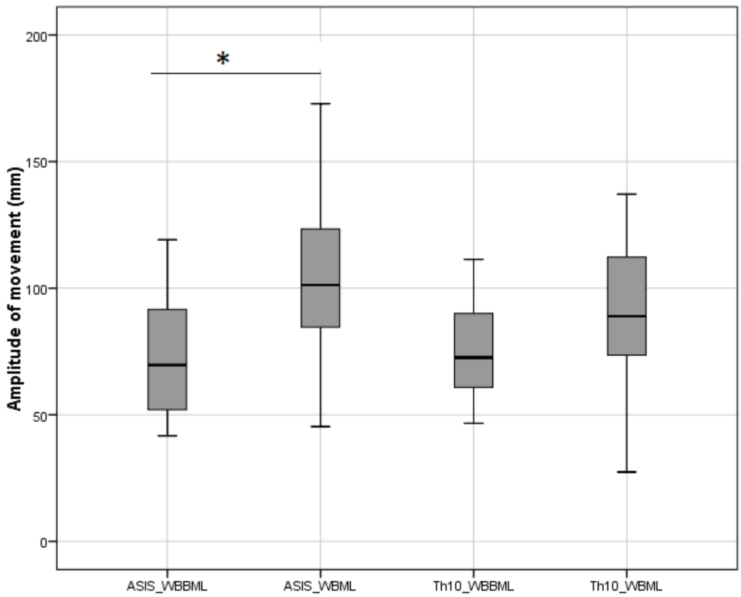
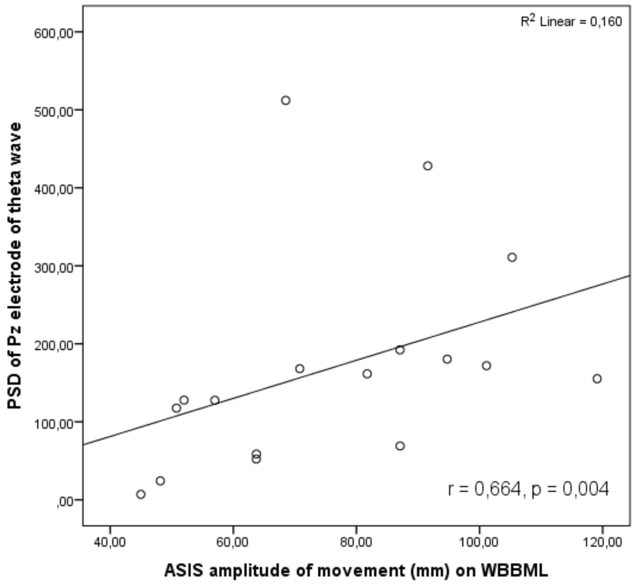


Figure 34. Mean of ASIS and Th10 amplitude of movement in lateral-medial pelvic motion on a wobble board on the bearing surface (WBBML) and a wobble board (WBML); * indicates statistically significant differences $p < 0.05$

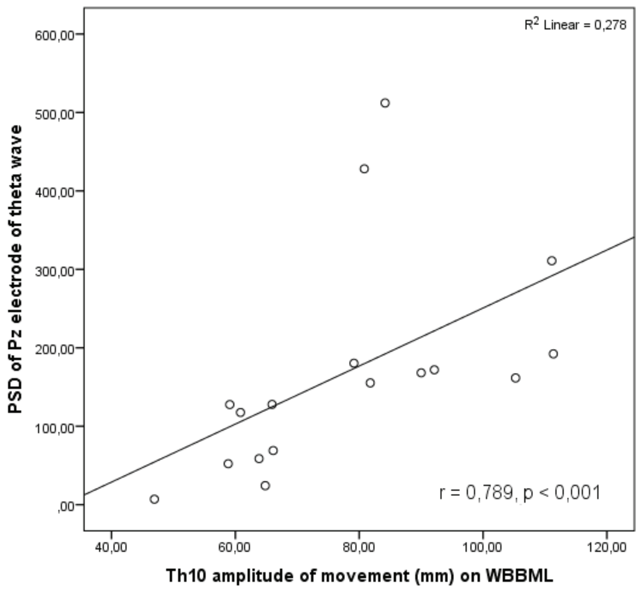
2.7. Correlation analysis

Correlation analysis was performed by comparing Fz, Cz, and Pz electrodes PSD and amplitude of movement of ASIS and Th10 anatomical points in two different movements, i.e., anterior-posterior pelvic motion as well as lateral-medial pelvic motion on two different platforms. There were no significant correlations on the wobble board. Moreover, there has not been found any significant correlations in the anterior-posterior pelvic movement.

However, the significant correlations displayed in Fig. 35 were seen in lateral-medial movement on WBB of theta power on Pz electrode position with Th10 amplitude of movement ($r = 0.789$, $p < 0.001$); minor correlation was seen with ASIS amplitude of movement ($r = 0.664$, $p = 0.004$).



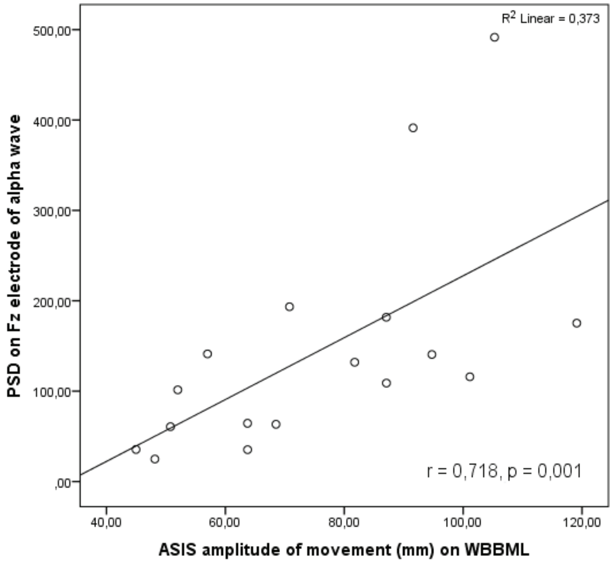
a)



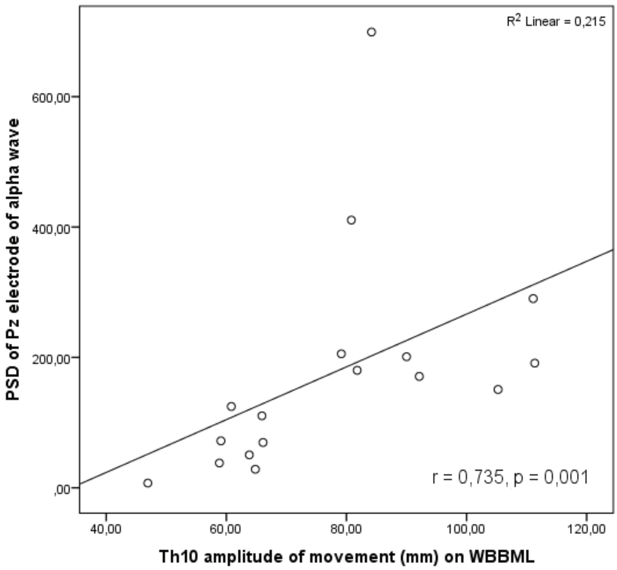
b)

Figure 35. Correlations between cortical activity (y axis) and ASIS (a), Th10 (b) anatomical points amplitude of movement (x axis) on WBB in lateral-medial movement; for theta power on the electrode position Pz

Alpha power of Fz electrode is displayed in Fig. 36, which correlated with Th10 amplitude of movement in lateral-medial motion on WBB ($r = 0.657$, $p = 0.02$) as well as Cz electrode (r = 0.673, p = 0.023) and Pz electrode power (r = 0.735, p = 0.001). Moreover, the correlation of alpha power in the lateral-medial motion was seen in the ASIS amplitude of movement and Fz electrode (r = 0.718, p = 0.001).



a)



b)

Figure 36. Correlations between cortical activity (y axis) and Th10, ASIS anatomical points amplitude of movement (x axis) on WBB in lateral-medial movement; for alpha power on electrodes position Fz (a) and Pz (b)

2.8. Section conclusions

The purpose of this research was to evaluate and compare subjects' trunk muscles activity, cortical theta and alpha activity, and kinematic body segments movement in static sitting and when sitting on different platforms, i.e., wobble board and wobble board on the bearing surface. In scientific literature, there is a lack of research where sitting balance was analyzed as a factor, which induce cortical activity. There are only a few studies where position transition from sitting to standing are analyzed [91, 60, 65, 12]. However, different sitting conditions are still analyzed not enough. In the present study, cortical theta activity was observed on two different surfaces, i.e., wobble board and wobble board on the bearing surface when performing two movements: anterior-posterior and lateral-medial pelvic movements. It was assumed that on a custom made wobble board on the bearing surface, the pelvic motions will be more challenging, according to the trunk muscles, cortical activity, and kinematic parameters, compared with simple wobble board.

The cortical theta power showed higher activity in fronto-central and centro-parietal regions. Moreover, when two different sitting surfaces were compared: static sitting and WBB, static sitting and WB, there could be observed that theta activity increased on both surfaces compared with the static sitting ($p < 0.05$); however, it could be seen that the increment was higher on custom made wobble board on the bearing surface (WBB), but this was not statistically significant. From the results, there could be seen a tendency that sitting on a custom-made wobble board on the bearing surface can be more challenging than on a simple wobble board, but it is important to note that this tendency was not for all participants. Because of this reason, it is important to adjust the balance level individually. The important correlation was found between Pz electrode position of theta power and T10 ($r = 0.789$) and ASIS ($r = 0.664$) amplitude of movement in lateral-medial pelvic movement. From the correlation analysis, it may be considered that the most challenging balance for individuals mostly occurs in the lateral-medial movement on a wobble board on the bearing surface. The studies have indicated that cortical theta activity increases in fronto-central region [95, 113, 100] as well as in the centro-parietal cortex [40, 41]. Moreover, other researches have shown theta wave increase during single leg stance, and it was interpreted as an involvement of the anterior cingulate cortex in monitoring postural instability [120, 112]. According to the studies [99, 112], the frequency modulation in the theta, alpha, and beta bands are related with the postural instability.

Another important aspect in the balance tasks occurs in alpha wave excitation. When two different sitting surfaces were compared, i.e., static sitting and WBB, static sitting and WB, it could be seen that alpha activity increased on WBB, compared with the static sitting ($p < 0.05$) in all areas; however, when WB was compared with static sitting, the significant increment was seen only in fronto-central region ($p < 0.05$). The highest PSD (when comparing static sitting and WBB, static sitting and WB) was seen in fronto-central area, compared with others, and these findings coincide with other researches [42, 41] with the increase of task difficulty, the alpha activity as well increases in frontal and central areas; from this point of view, the task on a wobble board on the bearing surface was more challenging. There has been found an important correlation of alpha wave on Pz ($r = 0.789$) electrode with Th10 amplitude of movement in lateral-medial movement on a wobble board on the bearing surface; minor correlation was seen on Cz electrode position ($r = 0.673$). This correlation reveals that the amplitude of anatomical point of Th10 was optimal to induce with balance related center activation in the cortex. The studies have reported that the activation of the fronto-central and centro-parietal cortex during self-initiated postural movement and unpredicted postural perturbations in standing position, suggesting the supplementary motor area and the foot area of sensorimotor cortex were the possible sources in the initiating of postural movement [63, 112, 110].

The amplitude of the movement of anatomical points ASIS and Th10 can be seen lower on a wobble board on the bearing surface compared with a wobble board in anterior-posterior and lateral-medial movements ($p < 0.05$). The lower amplitudes of the anatomical points have shown greater physiological response and more stabilization during this movements on WBB. The experiment where balancing on the wobble boards show large motion of the base of support has a relatively small motion of the upper body [88]. According to the amplitude of movement of anatomical points, the muscles activity is higher where the amplitude of movement of anatomical points are lesser. It could be because of the higher efforts, which were needed to do the pelvic movements. The study [8] indicates that the motor control challenge for the individuals is to use their lumbar spine to minimize the seat displacement, when sitting on unstable surface with smaller movements representing a better performance.

The activity increment in MF, ES, and EO muscles were observed in the lateral-medial movement on a wobble board placed on the bearing surface compared with a wobble board ($p < 0.05$). According to the study [87], the motion in anterior-posterior directions show stabilizing moment, but in medial-lateral directions, the authors did not see stiffness control, subsequently identifying the cause of muscle(s) that could exhibit such behavior; thus, it was not studied and/or the CNS does not employ stability control in the medial-lateral directions. During anterior-posterior movement, there was a significant increase only in the ES muscle on a wobble board placed on the bearing surface. This custom-made wobble board on the bearing surface can be used as a training device, which can be included in a workplace. As it can be seen from the other studies [74, 44] where dynamic chairs are used instead of the basic office chairs, where the amount of spinal motion in sitting increases. Moreover, trunk muscles activation does not change or increase [44, 34, 76]. Thus, this wobble board on the bearing surface, which can move in anterior-posterior and lateral-medial directions, can arouse trunk muscles activity, especially in lateral-medial movement.

3. MUSKULOSKELETAL MODELING

The simulation was performed by using the AnyBody Modeling System (AnyBody Technology, Aalborg, Denmark). This software is designed for the multibody analysis of musculoskeletal systems in various motions and static positions. The AnyBody Technology system allows to create different parts of the body or use of a wide range of models in the AnyBody Managed Model Repository (AMMR). All models in the AMMR can be used as a starting point; thus, a full AnyMoCap body model was used in this investigation. This starting model is related to the motion capture analysis system, and all captured subjects of the experiment can be transferred to AnyMoCap framework. The aim of the musculoskeletal modeling was to compare the experimental muscles activity with the model muscle activity. The modeling of musculoskeletal system was performed in order to create a human and chair connection, which later can be easily modified and adapted to different person.

The protocol of musculoskeletal modeling is shown in (Fig. 37). The kinematic data from the motion capture the analysis where pelvic motion on a wobble board on the bearing surface in anterior-posterior and lateral-medial directions were performed. All marker trajectories were connected via bones into a simplistic human model. Then, all data were converted to C3D file, which is the output of the previous mentioned movement and transferred to the AnyBody Modeling System.

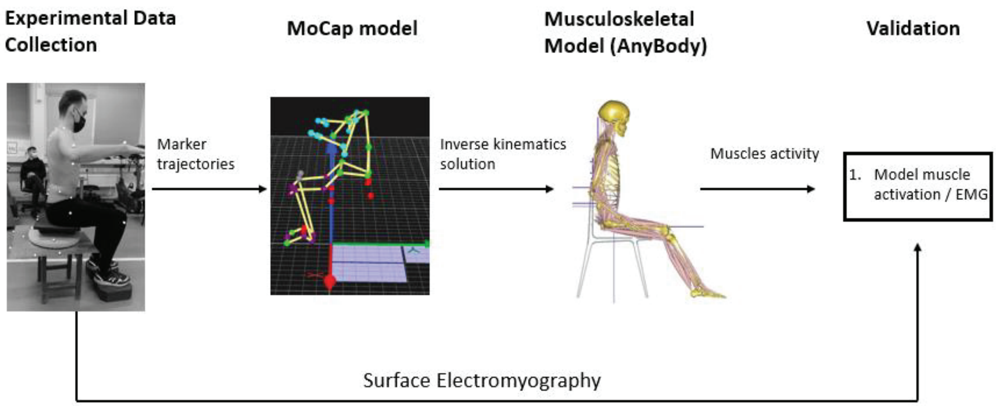


Figure 37. The flow chart of each experiment, including: body kinematics (MoCap), surface electromyography (sEMG), and musculoskeletal modeling; during this experiment, the surface electromyography and model muscle activation was compared

The human model had different joints with different degrees of freedom (DoF) in it. Knee and ankle joints were set as revolute joint and had 1 DoF, while hip and lumbar vertebra joints were set as spherical joints and had 3 DoF; pelvis had 6 DoF (Fig. 38). The skull, chest, and arms were eliminated from the model.

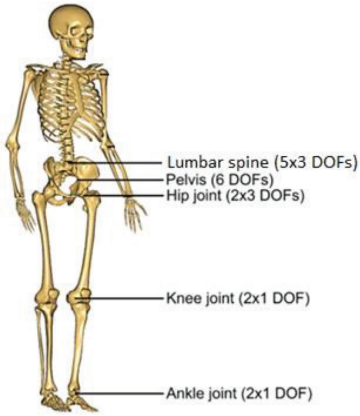


Figure 38. Visualization of the skeletal model and every joint degrees of freedom.

The model in the AnyBody musculoskeletal system was created according to MoCap data where the chair was adjusted according to the body model parameters (Fig. 39).

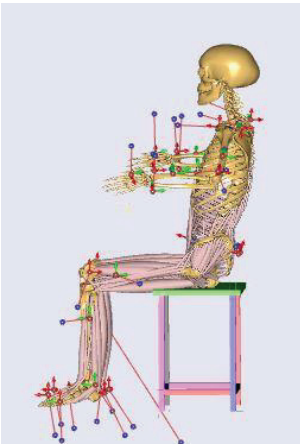


Figure 39. Seated human model in AnyBody musculoskeletal modeling system

The body mass and height of the subject were considered. The musculoskeletal model was anthropometrically scaled. The scaling of length-mass-fat was performed. The tissues: muscle, fat, and other (bone, cartilage, skin, blood, etc.), percentage was calculated. The fat percentage was taken from the body mass index (BMI). The segments in this configuration correspond to a 50th percentile European male. The linear scaling results are defined in the following equation [85]:

$$s = Sp + t. \quad (1)$$

where s is the position vector of the node in the local coordinate system of the scaled segment, p – original nodal location, S – 3x3 scaling matrix, t – translation.

When the mass and segment lengths are known, it is possible to compute the cross-sectional area. The local coordinate systems follow the ISB conventions [85]. The y-axis denotes the longitudinal direction, and x and z, the cross-sectional directions. This leads to a scaling law where the y scaling differs from x and z. It is presumed that the y direction scaling of the form is as follows:

$$S_{22} = k_L = \frac{L_1}{L_0}; \quad (2)$$

where L_1 – segment length of the scaled segment, L_0 – segment length of the original segment. Assuming the known masses, the mass ratio can be obtained:

$$k_m = \frac{m_1}{m_0}, \quad (3)$$

$$S_{11} = S_{33} = \sqrt{\frac{k_m}{k_L}}. \quad (4)$$

The last unknown is fat percent (R_{fat}). The percentages of entire body are provided in Table 1.

Table 1. The percentages of entire body

Other (organs, blood, skeleton, etc.)	R_{other}
Fat	R_{fat}
Muscles	R_{muscle}
Total	100%

When the length-mass-fat scaling is performed, the mathematical expression is defined:

$$R_{muscle} = 1 - R_{fat} - R_{other}; \quad (5)$$

where R – percentage of ratio.

$$F = F_0 \frac{k_m}{k_L} \frac{R_{muscle,1}}{R_{muscle,0}} = F_0 \frac{k_m}{k_L} \frac{1 - R_{other} - R_{fat,1}}{1 - R_{other} - R_{fat,0}}; \quad (6)$$

where subscripts of 1 represent the scaled configuration, 0 represents the reference model.

In order to calculate the percentage of body fat, the authors [30] proposed the method of two regression equations of the relation between BMI and percentage of the body fat.

R_{fat} for men:

$$R_{fat} = -0.09 + 0.0149 \cdot BMI - 0.00009 \cdot BMI^2. \quad (7)$$

R_{fat} for women:

$$R_{fat} = -0.08 + 0.0203 \cdot BMI - 0.000156 \cdot BMI^2; \quad (8)$$

where BMI – body mass index, which is defined as the ration between the body mass and the square of body height.

3.1. Results of the muscle activations

After the modeling in Anybody modeling system, the model muscle activity was calculated. For the expression of experimental and model muscle activity comparison, the agreement was calculated. The agreement was calculated in MATLAB as the percentage where both EMG activity and model muscle activations were above or below the threshold of 50% at the same time [3, 28]. The y axis was normalized from the maximum values of the experimented tasks. The comparison was chosen to provide for the spine muscles, which are very important during sitting tasks. There were compared anterior-posterior and medial-lateral movement on a wobble board on the bearing surface.

The model and experimental EMG agreement was high during medial-lateral movement on a wobble board on the bearing surface: >60% agreement of multifidus (Fig. 40) and >70% of agreement in the erector spine muscles (Fig. 41).

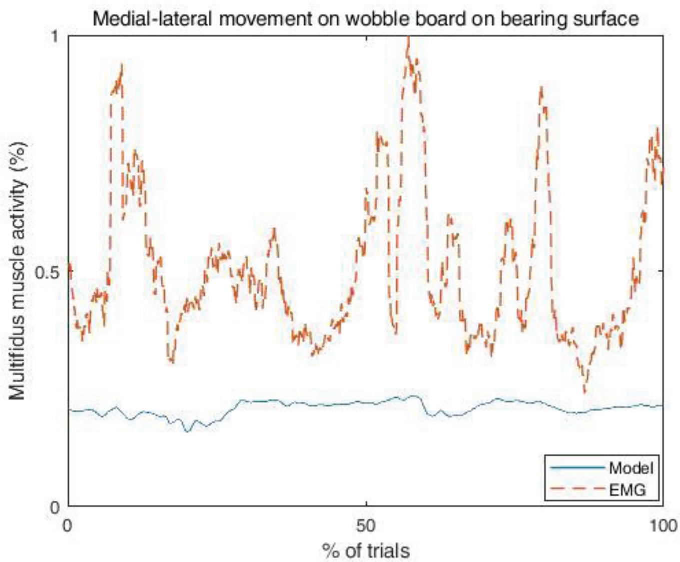


Figure 40. Model activations and sEMG activations of the multifidus muscle during medial-lateral movement on a wobble board on the bearing surface; there are shown 3 cycles of the movement; the activations are normalized to the maximum activations over the activity

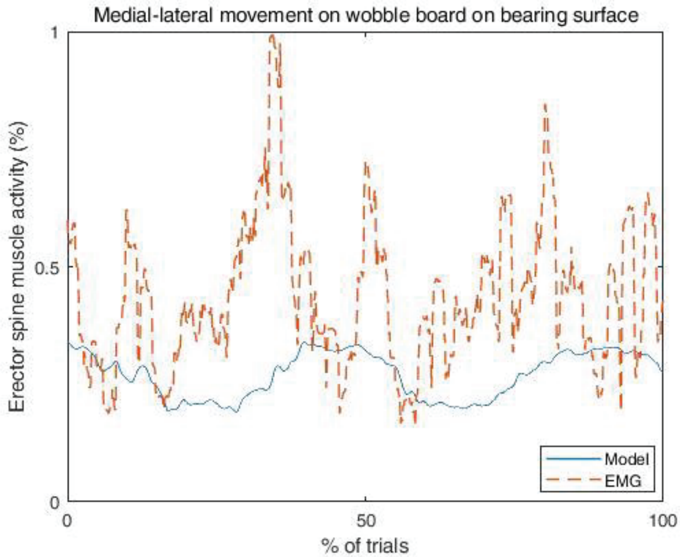


Figure 41. Model activations and sEMG activations of the erector spine muscle during medial-lateral movement on a wobble board on the bearing surface; there are shown 3 cycles of the movement; the activations are normalized to the maximum activations over the activity

Model muscle activity and the experimental results in anterior-posterior movement on a wobble board on the bearing surface, the highest agreement had multifidus muscles, which was about 93% (Fig. 42), and less agreement had the erector spine muscle 80.95% (Fig. 43).

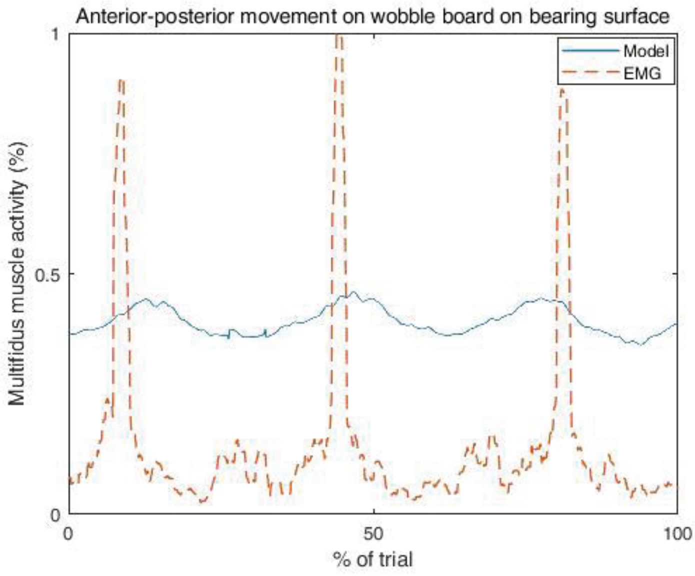


Figure 42. Model activations and sEMG activations of the multifidus muscle during anterior-posterior movement on a wobble board on the bearing surface; there are shown 3 cycles of the movement; the activations are normalized to the maximum activations over the activity

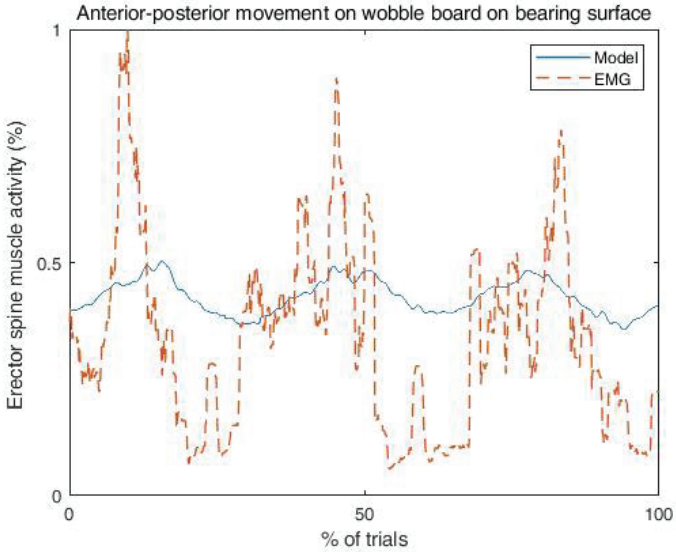


Figure 43. Model activations and sEMG activations of the erector spine muscle during anterior-posterior movement on a wobble board on the bearing surface; Tthere are showned 3 cycles of the movement; the activations are normalized to the maximum activations over the activity

The agreement was seen high in all movement and muscle; however, in anterior-posterior movement, the agreement was bigger, because the sagittal plane movement of the pelvis gives more stabilizing movement, while in medial-lateral movement, the stiffness control is smaller. There has been found that none of the model muscle activity was higher than the threshold 0.5; however, the EMG activity was higher than 0.5. The surface electromyography, where there are different factors, which can affect the activity, such as tissue type, changes in the geometry between muscle belly and electrode site [47]. These factors can have an impact on the higher or lower muscle activity. Moreover, model muscles were chosen directly without additional tissue layers or other factors, which are important in surface electromyography. Furthermore, the factor of poor co-contraction of the surrounding muscles in a model cannot be excluded.

3.2. Section conclusions

Overall, the results have shown that a good agreement, more than 80%, had the multifidus muscle and erector spine muscle in anterior-posterior movement and more than 70% in the medial-lateral movement, when comparing model and the experimental results. During anterior-posterior movement in the experimental results, there can be seen co-contraction of the muscle on a different side from the measured, which shows more stabilization. However, the model muscle activity cannot evaluate the co-contraction, because this is managed by the central nervous system, which gets a signal to co-activate, when one muscle works concentrically, and others work eccentrically.

4. MODELING OF LUMBAR SPINE AND SACRUM

A 3-dimensional (3D) lumbar spine and sacrum FE model was taken from the online database [125] (Fig. 44). COMSOL Multiphysics (COMSOL Inc.) software has been chosen for modeling a 3D model of FE lumbar spine and sacrum. The 3D lumbar spine and sacrum FE model consists of 5 lumbar spine vertebrae, 5 intervertebral discs, the sacrum, and ligaments. The main purpose of this modelling was to compare stresses and strains on different sitting surfaces, i.e., WB and WBB, and get to know how the movement in medial-lateral direction affects the intervertebral discs and which sitting surface is safer for the discs.

The material and component properties that have been used in this model were adapted from the previously published literature [55]. Cortical bones and cartilaginous endplates were modeled as linear elastic bodies; the annulus ground substance was modeled as hyper-elastic bodies when using Mooney–Rivlin model. Fiber rings were modeled as composite shell, which consists of seven layers. Every collagen fiber layer is sloped 70° angle to the opposite side. The ligaments that connect and stabilize the vertebral column were modeled as nonlinear springs, which work on tension conditions.

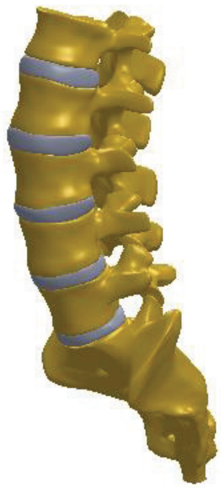


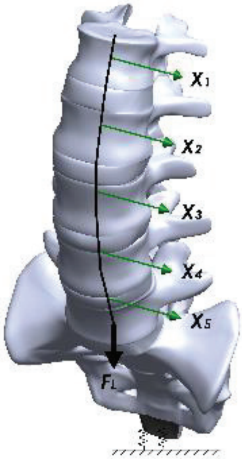
Figure 44. The geometry of 3D lumbar spine and sacrum

Table 2. Material properties of the FE model (material properties are set according to Liu et al. [55])

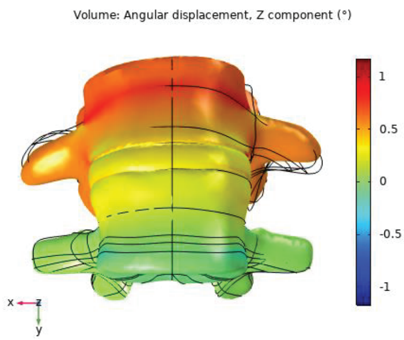
Spinal components	Material behavior	Mechanical properties
Cortical bone	Linear elastic	E = 12 000 MPa, ν = 0.3
Cartilaginous endplate		E = 23.8 MPa, ν = 0.4
Cancellous bone		E = 200 MPa, ν = 0.25
Annulus ground substance	Hyper-elastic (Mooney–Rivlin)	C_{10} = 0.18, C_{01} = 0.045
Nucleus pulposus		C_{10} = 0.12, C_{01} = 0.030
Collagen fibers	Nonlinear force-displacement curve	

4.1. Validation of functional unit of lumbar spine

Firstly, the validation of functional unit of lumbar spine (L4, intervertebral disc, and L5) study was performed. The 3D lumbar spine and sacrum model was fixed at the lower bottom of the sacrum. Along the spine, the load of 400N was applied, trying to imitate human body weight on the spine. The simulation was performed by using the obtained experimental data (Fig. 45). In this study, the predictions of angular displacements were compared with the data from previously published reports to validate the model. For the functional unit of L4–L5 with the material properties in Table 2 was applied for the displacements to see if this corresponds to the data reported by the other scientists. The bottom part of L5 was fixed. The moment of force applied at the superior surface of L4 to simulate lateral bending was 1.0 Nm, and the maximum angular displacement was 1.17° (Fig. 45) Using the same moment of force, the corresponding data reported by Heuer et al. were 1.28° [39].



a)



b)

Figure 45. Validation of functional unit of of lumbar spine: a) spine loading scheme b) functional unit of lumbar spine angular displacement in lateral bending when the moment is 1.0 Nm

4.2. Application of experimental results for 3D lumbar spine model

The kinematic data of the lumbar spine (L1–L5) and sacrum processus spinosus of vertebra were taken. Three-dimensional kinematic data were recorded by the motion capture with 10 cameras (Oqus7+ Qualisys AB, Gothenburg, Sweden) and the Qualisys Track Manager software at a sampling frequency of 300 Hz. The Helen–Hayes marker set was used for measuring the full-body kinematics. Additional markers on five vertebras of the lumbar spine were attached (Fig. 46).

During the experiment, the subject performed two movements on two different platforms: lateral-medial (ML) movements on a wobble board (WB) and on a wobble board on the bearing surface (WBB). The amplitude of movement of processus spinosus of every motion was taken (Table 3).

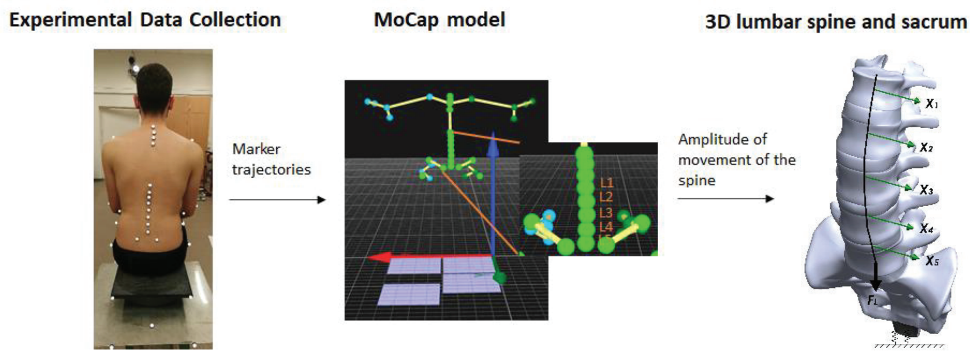


Figure 46. Full body kinematics: L1 – L5 processus spinousus amplitude of movement

Table 3. Amplitudes of movement of lumbar spine procesus spinosus on a wobble board on the bearing surface (WBB) and on a wobble board (WB) medial-lateral (ML) movements

Amplitude of movement (mm)	L1	L2	L3	L4	L5
WBB_ML	69.53	70.68	72.9	74.45	77.23
WB_ML	122.37	132.55	135.06	133.46	124.77

4.3. Investigation of loading on the intervertebral discs of lumbar spine when applying experimental results

After fixating the lower vertebrae at S2 with a spring, its movement corresponds to the amplitudes of movement from the data obtained during the experiment (Table 4).

Table 4. Sacrum amplitude of movement on a wobble board on the bearing surface (WBB) and on a wobble board (WB) medial-lateral (ML) movements

Sacrum (S2) amplitude of movement	
	Medial-lateral movement (ML)
WBB	5.0 mm
WB	15.14 mm

The following results were obtained by calculating the stresses and strains on the intervertebral disc. During the lateral movements of the pelvis on a wobble board on the bearing surface, the maximum stress obtained at the L2 and L3 intervertebral discs was 0.1 MPa, while during the same movements on a wobble board, the maximum stress was at the L1 and L2 intervertebral discs of 0.6 MPa (Fig. 47).

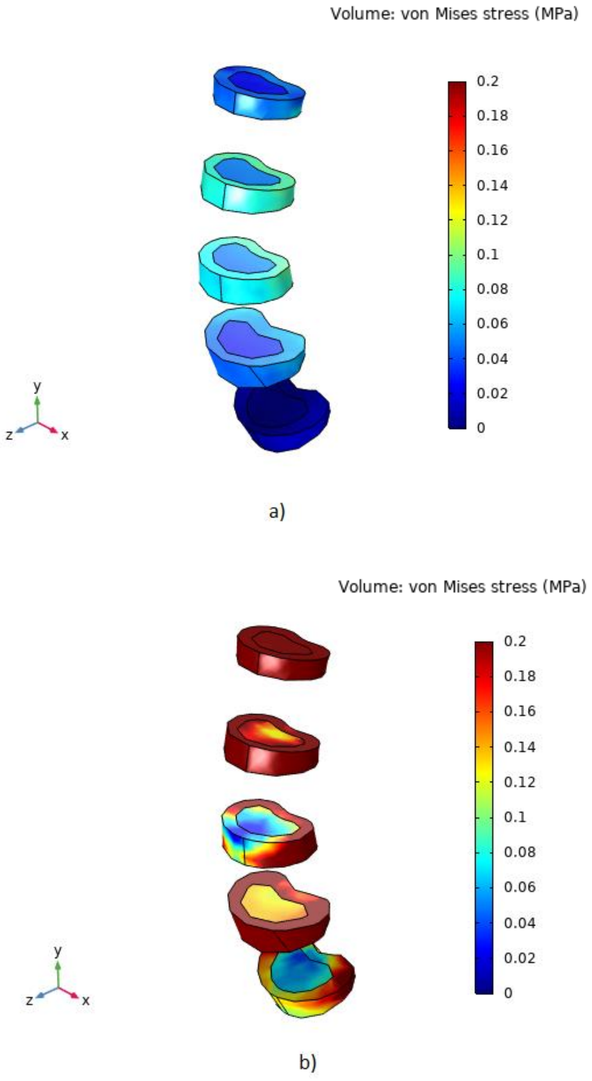
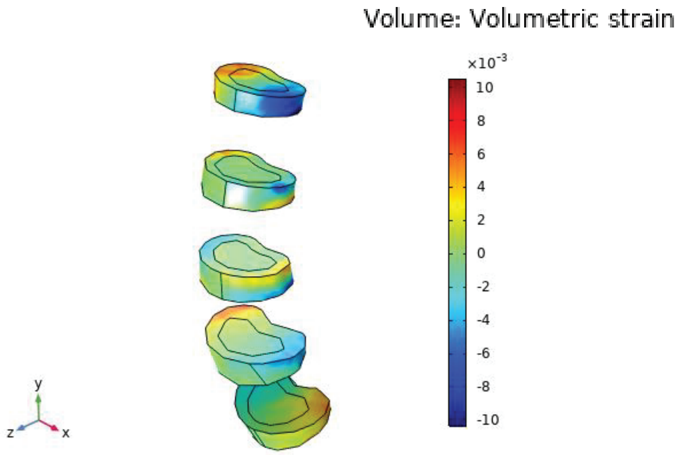
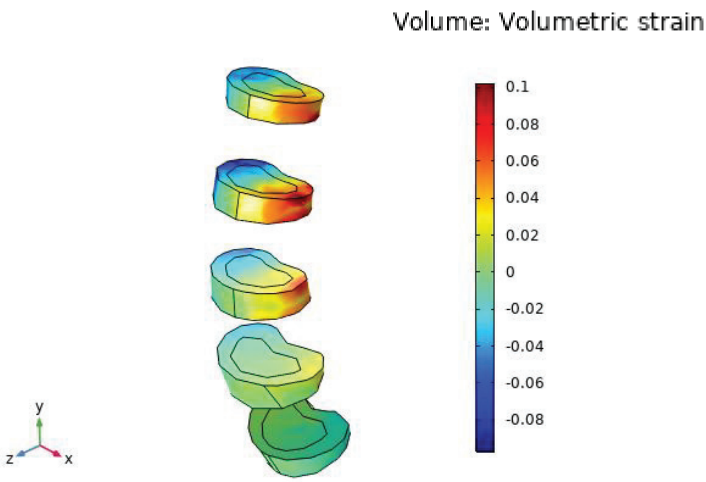


Figure 47. Stresses on lumbar spine intervertebral discs during medial-lateral movement a) on a wobble board on the bearing surface and b) on a wobble board



a)



b)

Figure 48. Strains on lumbar spine intervertebral discs during medial-lateral movement a) on a wobble board on the bearing surface and b) on a wobble board

4.4. Section conclusions

In this section, there were presented the experimental results application to 3D lumbar spine model. The experimental results were obtained from the 3D motion capture analysis system, where L1–L5 processus spinousus and sacrum amplitude of movement were tracked during anterior-posterior and medial-lateral movement on a wobble board on the bearing surface and on a wobble board. The results were applied to the lumbar spine and sacrum model to get to know which movement and which seat will be safer for the intervertebral discs.

The amplitude of movement was lower on a wobble board on the bearing surface in medial-lateral and anterior-posterior movements. The interesting finding was that the amplitude of movement on a WBB increased from L1 to L5 vertebras, while on the WB, it was quite similar and high in all segments. This could be explained because of the motion axis of different sitting tools. In this case, it is better to get less amplitude of movement, which gradually increases from L1 to L5 vertebra, because in the experimental conditions, the amplitude of movement was final, and there is a possibility to give less amplitude of movement of the chair for a person to adopt individually with no damage in intervertebral discs.

The maximum stress on the intervertebral disc was 0.1 MPa during lateral-medial movements of the pelvis on a wobble board on the bearing surface, while the maximum stress on the intervertebral disc was 0.6 MPa during the same movements on a wobble board. According to the study [118], when sitting actively with a straight back, the intradiscal pressure is 0.55 MPa, while sitting with backrest is about 0.27 MPa. The movements on a wobble board on the bearing surface are safer for the intervertebral discs, because it creates less stresses.

5. DEVELOPMENT OF UNSTABLE SEAT PROTOTYPE

In the literature review, there are explained a lot of inventions, patents of unstable chairs and seats. In a patent application, there are mostly described inventions, which can help to solve one or another problem related to the musculoskeletal disorders. However, these patented inventions lack physiological and biomechanical justification on the human body. Another area where unstable seats can be found is market. There are a few chairs, which had been approved from the scientific point of view, and this is a good step to create a chair to fulfill human needs.

The prototype of unstable seat, which was created during the doctoral studies (Fig. 49), has two planes motion (frontal and sagittal), which has the total amplitude of movement in the anterior-posterior directions of 100 mm, while in lateral-medial direction, 100 mm. These two directions encourage performing pelvic movements during prolonged hours of sitting. According to the experimental results, it encourages deep muscles layer activity, and according to the spine modeling results, it creates very low stress on the intervertebral discs, while performing the movement in anterior-posterior and medial-lateral directions. The movement is initiated by the person who is sitting on a seat (2), the small bearings (1), which are located on the sides, two on each side in the front, and two on each side in the back. Small bearings allow moving freely without resistance.

The dimensions of the unstable seat prototype are as follows: length – 430 mm, width – 450 mm, height – 510 mm. The base of the unstable seat prototype dimensions are as follows: length – 420 mm, width – 660 mm. The bearing diameter is 50 mm; bearing with flange diameter is 62 mm.

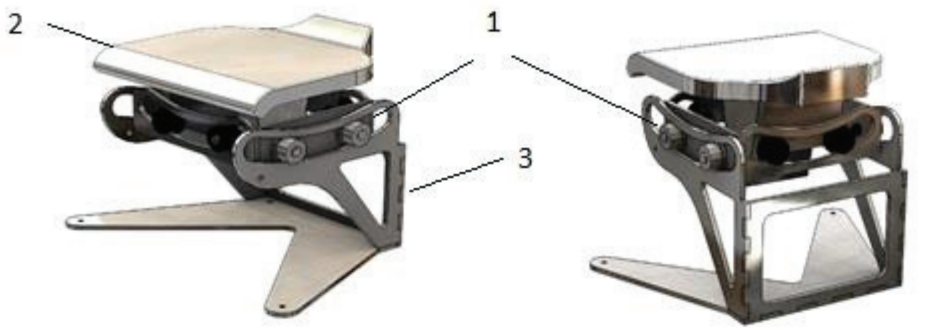


Figure 49. Prototype of unstable seat: 1 – small bearings, 2 – seat, 3 – frame

5.1. The linear static load analysis

The mechanical properties of material S275 H steel have been taken into account in the preparation of the finite element model according to EN 1993-1-1 (2005):

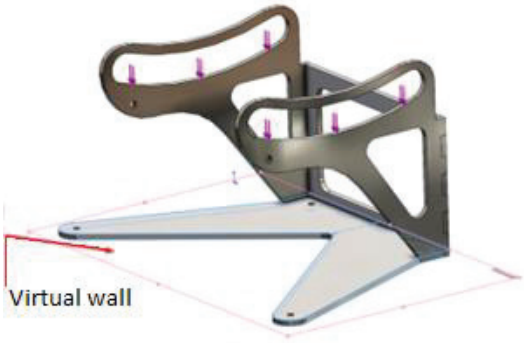
Eurocode 3: design of steel structures:

- Modulus of Elasticity 210 $\times 10^9$ Pa;
- Density 7800 kg/m^3;

- Yield strength for nominal thickness of the element t ≤ 40 mm is 275 MPa;
- Yield strength for the nominal thickness of the element 40 mm < t ≤ 80 mm is 255 MPa;
- Poisson's ratio is 0.33.

The 3D model of the unstable seat prototype was made with SolidWorks (Dassault Systèmes SolidWorks Corp.) software. The model was meshed before running the linear static analysis. During the linear static analysis displacements, the stresses under the effect of applied loads of the unstable seat were calculated. The meshed model (Fig. 50 a) contains 270951 nodal points and has 162591 spatial finite elements. There are 812853 degrees of freedom of the model.

a)



b)

Figure 50. a) Meshed model of an unstable seat prototypeprototipe; the arrows indicate the static load of 3000 N, b) fixation of the chair frame with virtual wall.

The chair frame was fixated with virtual wall (Fig. 50 b). A load of 3000 N (300 kg) was applied to the sides of the chair frame.

After linear static analysis was performed, the results (Fig. 51) have shown the displacement under applied static load condition. The maximum displacement was 3.29 mm. The von Mises stress test distribution of the unstable seat prototype frame is 171 MPa (Fig. 52 a). In the picture (Fig. 52 b), they are filtered to 50 MPa.

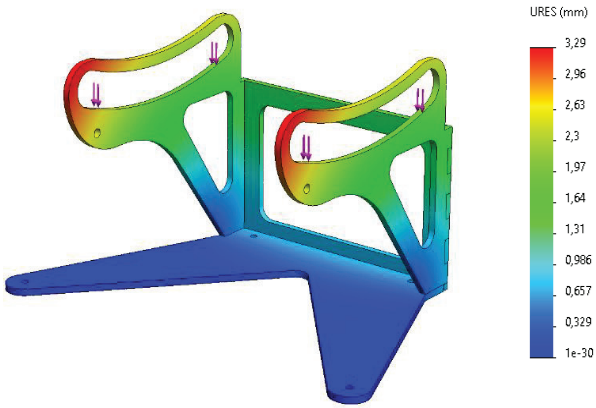


Figure 51. Seat frame displacement under static load

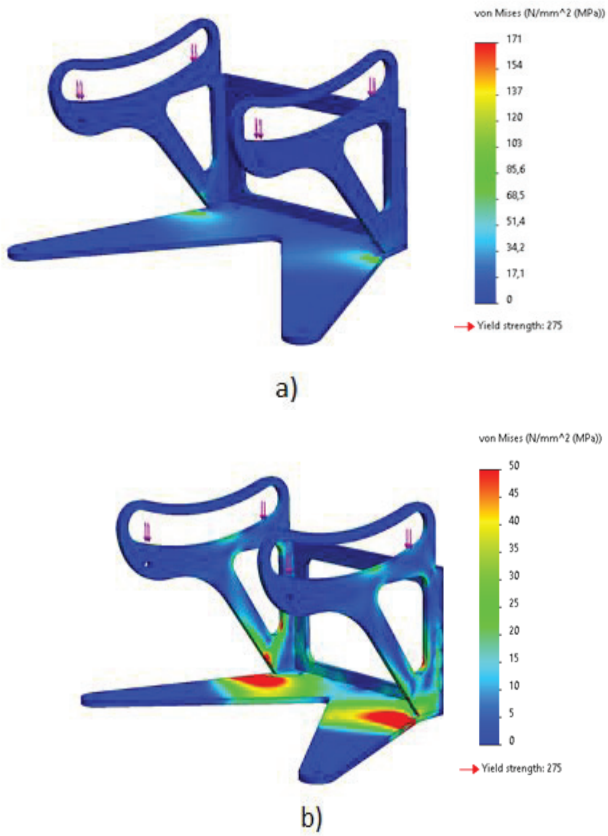


Figure 52. Seat frame von Mises stress test distribution under static load

Summarizing the strength calculation results of the seat frame structures for the load case, the following can be stated: the loading of the frame structure total deformations reaches 3.29 mm, the maximum equivalent of von Mises stresses in the frame structure is 171 MPa.

Predominantly static stress is calculated according to the formula:

$$R_d \leq R_{eH}/\gamma_{MO}\,; \tag{9}$$

where R_d is the design material resistance, R_{eH} is the yield strength, $\gamma_{M0} = 1.5$ is the partial safety factor for elastic strength resistance (yield).

The material of the frame structure is steel S275 with yield stress of 275 MPa.

$$171 \leq 275/1{,}5 = 183\, 171 \leq 275/1.{,}5 = 183 \text{ MPa}$$

After proper results of the linear static load analysis, the unstable seat prototype was manufactured (Fig. 53 c). The prototype has two strict motions in anterior-posterior and medial-lateral directions. The chair amplitude of movement was based on the experimental findings of the maximal amplitude of the pelvis movement. The boundary conditions of the chair movement in lateral direction is 100 mm, in anterior-posterior direction, it is 100 mm. The angle of the lateral anterior-posterior movements of the unstable seat prototype are 10°. The two planes motion was not found in the developed unstable chairs, which were analyzed in the literature review chapter. The reaction of the human body physiological and biomechanical parameters to the prototype was again experimentally checked in the laboratory and compared with the results of the experimental setup with a wobble board on the bearing surface (WBB). In Fig. 53 and Fig. 19 (section 2), there can be seen different center of the mass movement when sitting and performing medial-lateral movement on different sitting surfaces. When sitting on WB, the center of mass shifts with the seat movement; however, when sitting on a WBB and unstable seat prototype, the center of the mass stays at the same position during the movement. This shows better lower back movement, which is important for the prevention of lower back pain during the activation of the deeper layer of the trunk muscles, which stabilize the spine.

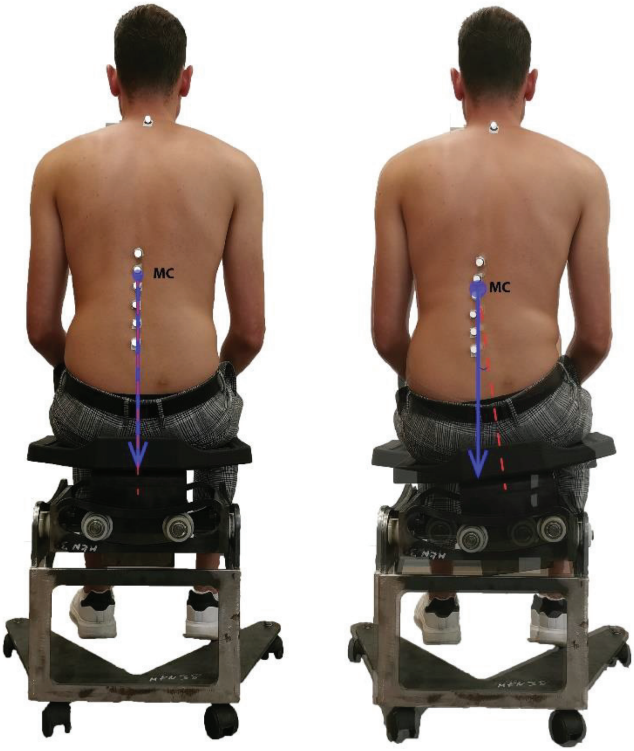


Figure 53. Position of the center of mass (MC) on the unstable seat prototype.

The electromyography of five trunk muscles and kinematic measurements of body segments were conducted on the unstable seat prototype. During the measurements, three different sitting tools were used: a wobble board, a wobble board on the bearing surface, and an unstable seat prototype (Fig. 53). The experimental protocol of EMG and kinematic measurements were used, same as it was mentioned in section 2. Five trunk muscle activities were measured. For the normalization of EMG data, the percentage of maximum voluntary isometric contraction (MVIC) was performed. The full-body kinematics with additional markers on lumbar spine vertebra processus spinosus were tracked during the experiment.

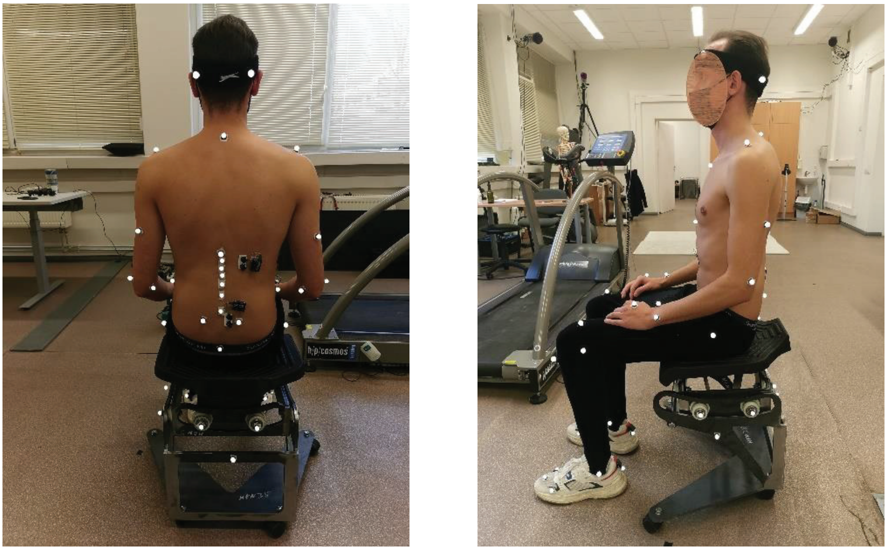


Figure 54. Subject on the unstable seat prototype with electromyography sensors and motion capture analysis markers on the anatomical landmarks and additional markers on the lumbar spine vertebra

5.2. The results of pelvis angle on three different sitting tools

The angle of the lateral pelvis movement was calculated from three points: Th10 (10^{th} vertebra of thoracic spine), LASI (left anterior superior iliac spine), and RASI (right anterior superior iliac spine).

The results have shown that in the lateral movement on a wobble board, the angle was 8°, while on a wobble board on the bearing surface, the angle was 5°; the same angle was seen on the prototype, i.e., 5° (Fig. 55).

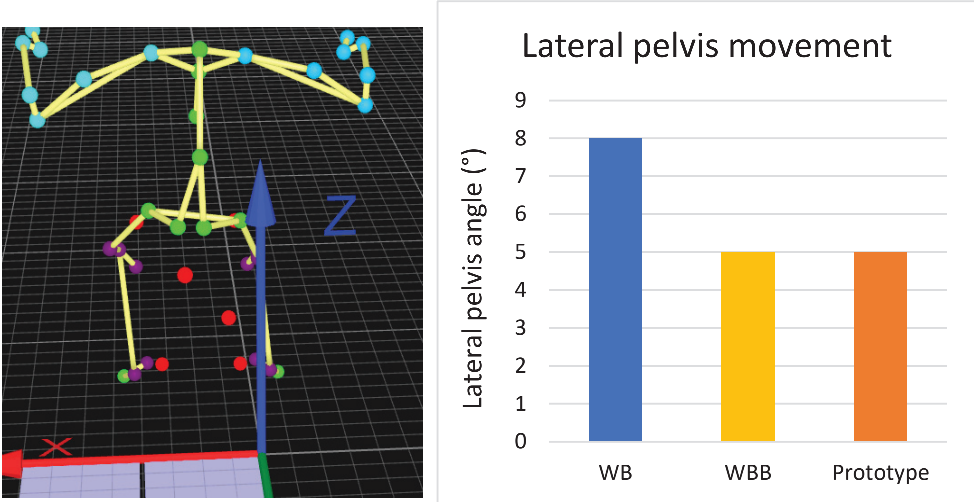


Figure 56. Results of the lateral pelvis movement angle on three different sitting tools: WB, WBB, prototype

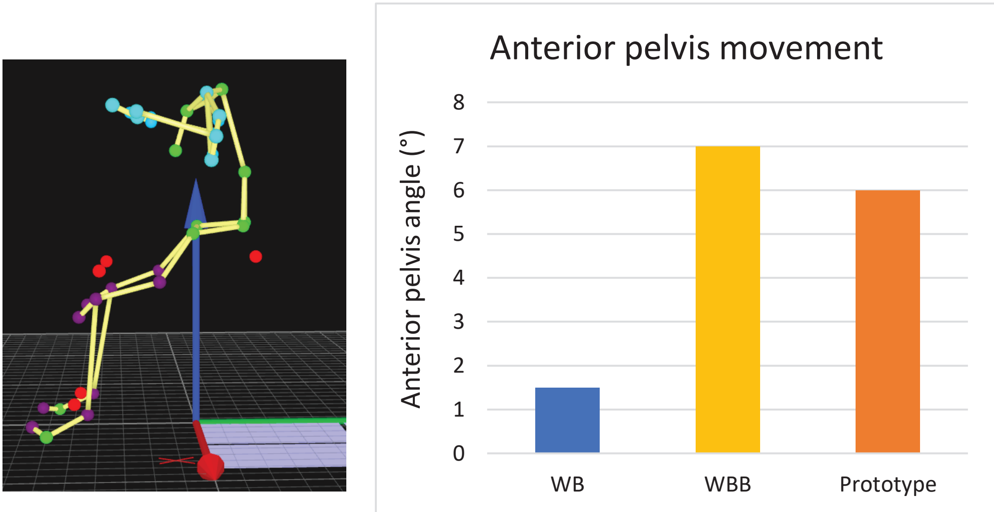
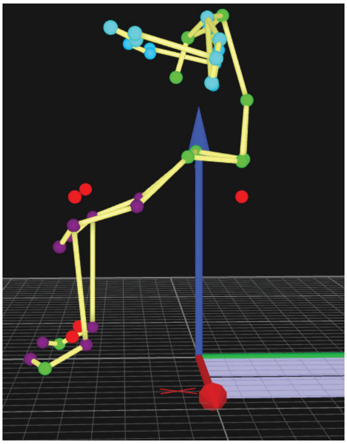


Figure 55. Results of the anterior pelvis movement angle on three different sitting tools: wobble board (WB), wobble board on the bearing surface (WBB), prototype

The angle of anterior and posterior pelvis movement was calculated from three points: Th10 (10th vertebra of thoracic spine), RPSI (right posterior superior iliac spine), and RASI (right anterior superior iliac spine). The result in the anterior pelvis movement (Fig. 56) on a wobble board was 1.5°, on a wobble board on the bearing surface, the angle was 7°; furthermore, on the prototype, it was 6°. Moreover, the results of posterior pelvis movement (Fig. 57) on a wobble board was 1°, on a wobble board on the bearing surface, the angle was 8°, and on the prototype, it was 5°.



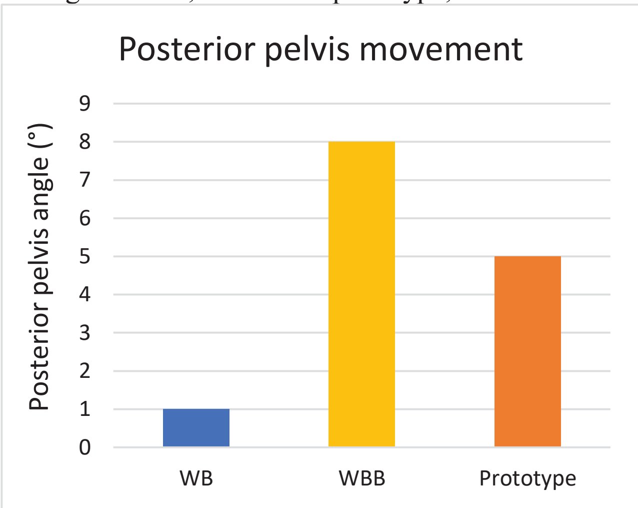


Figure 57. Results of the posterior pelvis movement angle on three different sitting tools: wobble board (WB), wobble board on the bearing surface (WBB), prototype

The results have shown that in the anterior and posterior pelvis movements, the angles differ not much on the WBB and prototype.

5.3. The results of trunk muscle activity on three different sitting tools

The main idea of this experiment was to see how muscle activity is different or similar to a wobble board on the bearing surface and prototype. The results of five trunk muscle activity on three different surfaces have shown increment of deep layer trunk muscle activity on a wobble board on the bearing surface and on the prototype, compared with a wobble board.

In anterior-posterior pelvis movement (Fig. 58), multifidus muscle had 23% on WB, 33% on WBB, and 39% on the prototype, and the multifidus muscle activity increases on the prototype by about 6%. The transversus abdominis muscle activity on the WB was 36%, on the WBB, 71%, and on the prototype, 78%. The difference between the WBB and the prototype was only 7%. Other muscles: erector spine, rectus abdomins, and externus obliques, had lower activity: 9%, 4%, and 5%, respectively, on the prototype comparing with WBB.

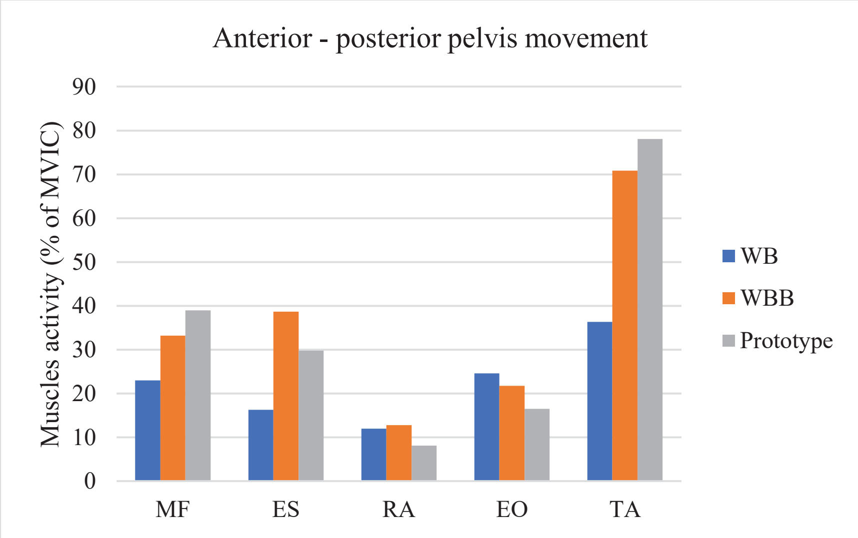


Figure 58. Muscle activity (% of MVIC) in anterior-posterior pelvis movement on a wobble board (WB), a wobble board on the bearing surface (WBB), prototype

In medial-lateral pelvis movement (Fig. 59), externus obliques muscle had 29% on WB, 23% on WBB, and 35% on prototype. The transversus abdominis muscle activity on WB was 43%, on WBB, 63%, and on prototype, 86%. Other muscles: multifidus, erector spine, and rectus abdomins, had lower activity: 6%, 4%, and 1%, respectively, on the prototype comparing with WBB.

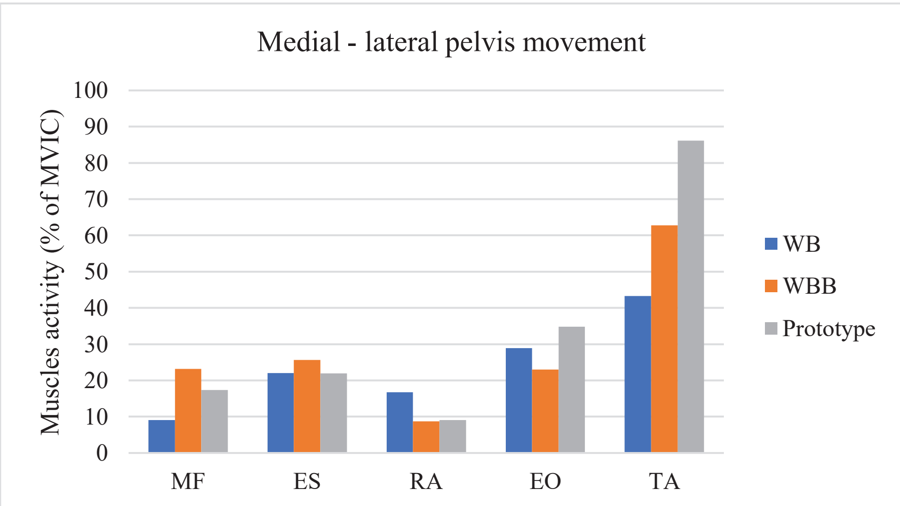


Figure 59. Muscle activity (% of MVIC) in medial-lateral pelvis movement on a wobble board (WB), a wobble board on the bearing surface (WBB), prototype

5.4. Section conclusions

In this section, the prototype of unstable seat was presented. The prototype of unstable seat allows performing two planes motion in anterior-posterior and medial-lateral directions due to the reason to activate deep layer trunk muscle and encourage lower body movement than the upper body. The physiological and biomechanical parameters have shown good results while performing movements on the unstable seat prototype.

There was performed a linear static load analysis of the unstable seat prototype frame with the loading of frame structure total deformations that reached 3.29 mm, the maximum equivalent von Mises stresses in the frame structure was 171 MPa. The partial safety factor was 1.5, while in this experiment, t was 1.6.

The physiological and biomechanical measurements analysis has shown quite good agreement with the test stand of a wobble board on the bearing surface and unstable seat prototype. The angle of the pelvis lateral movement was the same on a WBB and prototype, while in the anterior pelvis movement, the difference was only 1°, and in the posterior pelvis movement, it was 3° lesser than in the prototype.

Moreover, the muscle activity in anterior-posterior pelvis movement did not differ by more than 10%, when compared with the test stand of WBB and unstable seat prototype. However, in medial-lateral movement, around 20% greater activity was on the prototype, compared with the WBB, and this activity had externus obliques and transversus abdominis muscle to increase more spine stabilization during medial-lateral movement.

CONCLUSIONS

1. When balance becomes more challenging, the muscles and brain activity increases. Deep trunk muscles activity in AP movement increases 2 times, and in ML movement, it increases from 4 to 7 times on a wobble board on the bearing surface, compared with a simple wobble board, $p < 0.05$. This increment shows better spine stabilization moment during movement on a WBB. Alpha power spectral density increases 2 times in anterior-posterior and 1.5 time in medial-lateral pelvic motion, compared with the static sitting, while theta power spectral density increases up to 3 times in anterior-posterior and medial-lateral pelvic motion, compared with the static sitting, $p < 0.05$, which shows increment of cognitive and balance task performance during this movements.
2. The amplitude of movement of the human anatomical points in sitting on a wobble board on the bearing surface is minor compared with a wobble board, $p < 0.05$. The reduction of amplitude of movements on WBB reduces the upper body movement with better physiological response of the electromyography results.
3. The maximum stress on the intervertebral disc was 0.1 MPa during lateral-medial movements of the pelvis on a wobble board on the bearing surface, while the maximum stress on the intervertebral disc was 0.6 MPa during the same movements on a wobble board. The movements on a wobble board on the bearing surface are safer for the intervertebral discs, because it creates less stresses.
4. In medial-lateral movement on a wobble board on the bearing surface, multifidus muscle agreement with a musculoskeletal model was 60%, and the erector spine was 70%. In anterior-posterior movement on a wobble board on the bearing surface, the multifidus muscle agreement was 93.36%, while erector spine muscle had 80.95% agreement with the musculoskeletal model.
5. The unstable seat prototype, which allows performing anterior-posterior and medial-lateral movements of the pelvis, was created. The experimental results, when the unstable seat prototype and WBB were compared, have shown the same angle in lateral pelvis movement. In anterior pelvis movement, the difference was 1°, and in posterior pelvis movement, it was 3° lesser on the prototype, compared with WBB.

SUMMARY

ĮŽANGA

Problematika

Per visą savo gyvenimą apie 60–80 % žmonių populiacijos jaučia nugaros skausmą [115]. Nespecifinės kilmės nugaros skausmas, be aiškios patologijos, sudaro apie 90–95 %, likusieji procentai priklauso specifiniam nugaros skausmui, kuris turi aiškią patologiją. Nugaros skausmas yra dažna problema asmenims, dirbantiems sėdimą darbą. Globaliai apie 37 % nugaros skausmų yra susiję su darbo aplinka [103]. Yra daug tyrimų, atliktų *in vitro* ir *in vivo*, kurie nurodo, kokią apkrovą sukuria skirtingos sėdėjimo padėtys tarpslanksteliniams diskams. Remiantis studija [66], tarpslankstelinio disko spaudimas sėdėjimo padėtyje be atramos gali padidėti iki 40 % lyginant su stovima padėtimi. Sėdint be atramos ir atsipalaidavus spaudimas į tarpslankstelinius diskus siekia 0,46 MPa, palyginimui sėdint aktyviai, tiesia nugara – 0,55 MPa, o sėdint atsirėmus į kėdės atlošą – 0,27 MPa [118]. Siekiant sumažinti nugaros skausmą sėdint arba užkirsti kelią skausmo atsiradimui, rinkoje yra siūloma įvairių ergonominių aktyvių kėdžių. Dinaminės kėdės [106] gali sumažinti statinės sėdėjimo padėties neigiamą įtaką, sukurdamos mažus stuburo judesius ir gerindamos laikyseną. Asmenims, kurie praleidžia ilgą laiką sėdėdami statinėje padėtyje, yra matoma giliųjų liemens raumenų *m. multifidus* atrofija [49]. Sėdint ant dinaminių kėdžių liemens raumenys yra suaktyvinami, didinamas darbo produktyvumas. Tačiau rinkoje pastebimas trūkumas dinaminių kėdžių, kurios būtų individualizuojamos ir sukurtų apatinės nugaros dalies judesius, sumažindamos viršutinės dalies judesius; taip pat trūksta tai įrodančių išsamių mokslinių tyrimų.

Tyrimo tikslas ir uždaviniai

Tyrimo tikslas – sukurti inovatyvią nestabilią sėdynę, kuri didins liemens raumenų ir smegenų žievės aktyvumą. Pasiekti šiam tikslui yra išsikelti uždaviniai:

1. Ištirti liemens raumenų ir smegenų aktyvumo koreliacijas esant skirtingoms nestabilioms sėdėjimo padėtims.
2. Ištirti žmogaus fiziologinius, biomechaninius ir kinematinius parametrus jam sėdint ant skirtingų sėdynių ir atliekant dubens judesius.
3. Ištirti juosmeninės stuburo dalies įtempius ir deformacijas, pritaikant eksperimento metu gautas stuburo judėjimo amplitudes.
4. Palyginti eksperimento metu gautą raumenų aktyvumą su skeleto–raumenų sistemos modeliavimo rezultatais.
5. Sukurti nestabilios sėdynės prototipą remiantis teoriniais ir eksperimentiniais tyrimų rezultatais.

Tyrimo metodai

Buvo atlikti eksperimentiniai ir teoriniai tyrimai. Visi tyrimai vykdyti Kauno technologijos universitete, Mechatronikos institute.

Eksperimentinių tyrimų metu taikyta elektromiografijos metodika, skirta raumenų aktyvumui išmatuoti. Tyrimo metu naudotas: 12 kanalų elektromiografas *TeleMyo DTS 2400R G2* (*Noraxon USA Inc.*), 5 bevieliai jutikliai iš 12 galimų, kartu su elektrodais, kurie buvo priklijuoti tiesiai ant odos, ir bevieliu būdu perduotas raumenų aktyvumo signalas į kompiuterį. Gauti rezultatai buvo apdoroti su *Noraxon MR 3.12* programine įranga.

Kitas metodas, taikytas eksperimentinių tyrimų metu – elektroencefalografijos. Elektroencefalografas *g.Nautilus Research* (*g.tec Medical Engineering GmbH*, Austrija) turi 32 bevielius kanalus, įtvirtintus kepurėlėje, kuri dedama tiesiai žmogui ant galvos. Duomenys surinkti ir apdoroti naudojant *g.BSanalyze* programinę įrangą, skirtą dirbti programinės įrangos *Matlab* aplinkoje.

Kitas metodas, taip pat taikytas eksperimentinių tyrimų metu – trimatė (3D) judesio analizės sistema, kurią sudarė 10 didelio greičio kamerų (*Oqus7+ Qualisys AB*, Gothenburgas, Švedija), kurios fiksuoja žmogaus kinematinius judesius. Duomenys apdoroti naudojant *Qualysis Track Manager* programinės įrangos paketą.

Teoriniai tyrimai atlikti naudojant *COMSOL Multiphysics* (*COMSOL Inc.*) programinę įrangą, su kuria buvo sukurtas trimatis (3D) juosmeninės stuburo dalies ir kryžkaulio baigtinių elementų modelis. Modelio geometrija taip pat, kaip ir nestabilus sėdynės prototipas, modeliuoti su *SolidWorks* (*Dassault Systèmes SolidWorks Corp.*) programinės įrangos paketu. Atvirkštinės dinamikos analizei naudota *AnyBody Technology* modeliavimo sistema (*AnyBody Technology*, Alborgas, Danija).

Mokslinis naujumas

1. Sukurta nestabilios sėdynės prototipo kūrimo metodologija, taikant biomechaninius ir fiziologinius žmogaus parametrų tyrimus.
2. Ištirtas ryšys tarp pusiausvyros išlaikymo, liemens raumenų ir smegenų aktyvumo. Sunkėjant pusiausvyros išlaikymui, didėja liemens raumenų ir smegenų aktyvumas.
3. Eksperimento metu gautos stuburo judėjimo amplitudės, atliekant dubens judesius ant skirtingų sėdynių, buvo pritaikytos trimačiam (3D) juosmeninės stuburo dalies ir kryžkaulio baigtinių elementų modeliui.
4. Sukurtas nestabilus sėdynės prototipas, kuris gali judėti ir sukurti dubens judesius dviejose plokštumose (sagitalinėje ir frontalinėje).

Ginamieji teiginiai

1. Eksperimentinių tyrimų metu gautas didesnis raumenų ir smegenų aktyvumas testuojant ant bandymo stendo palyginus su kitais panašiais sėdėjimo

įrenginiais. Liemens raumenų ir smegenų aktyvumas didėja, kai pusiausvyros išlaikymas tampa sudėtingesnis sėdimoje padėtyje.
2. Eksperimento metu gautos stuburo judėjimo amplitudės buvo pritaikytos trimačiam (3D) juosmeninės stuburo dalies ir kryžkaulio baigtinių elementų modeliui. Mažesnė apkrova ir įtempiai stuburo tarpslanksteliniams diskams buvo matomi pritaikius stuburo judėjimo amplitudes ant bandymų stendo, lyginant su kitais sėdėjimo įrenginiais.
3. Sukurtas inovatyvus nestabilus sėdynės prototipas gali judėti dviejose plokštumose, sagitalinėje ir frontalinėje, skatindamas dubens judėjimą, taip pat didesnį raumenų ir smegenų aktyvumą atliekant šiuos judesius.

Praktinė vertė

1. Nestabilus sėdynės prototipas gali būti pritaikytas darbo aplinkoje kaip prevencinė priemonė prieš nugaros skausmus, kuri gali padidinti liemens raumenų aktyvumą ir produktyvumą visą darbo dieną.
2. Nestabilus sėdynės prototipas, provokuojantis dubens judesius sagitalinėje ir frontalinėje plokštumose, gali būti puikus įrankis vėlesniais reabilitacijos etapais, siekiant suaktyvinti giliuosius liemens raumenis ir atkurti stuburo optimalų mobilumą bei stabilumą.
3. Nestabilaus sėdynės prototipo kūrimo metodologija gali būti pritaikyta kitų prietaisų, skirtų didinti darbo produktyvumą, ergonomiką bei mažinti juosmeninės stuburo dalies skausmus, kūrimui.

Darbo rezultatų aprobavimas

Darbo rezultatai buvo publikuoti 4 moksliniuose žurnaluose: 3 – *Web of Science* duomenų bazėje recenzuojamuose leidiniuose su citavimo indeksu ir 1 – konferencijų pranešimų leidiniuose. Tyrimų rezultatai buvo pristatyti 2 tarptautinėse mokslinėse konferencijose:

1. BIOMDLORE 2021, 13-oji tarptautinė konferencija, 2021 m. spalio 21–23 d., Vilnius, Lietuva.
2. Baltic Congress Of Physiotherapy, Ryga, 2020.

Paskutiniais doktorantūros studijų metais gautas Technologinės plėtros (TPP) projekto finansavimas, susijęs su nestabilios sėdynės prototipo tobulinimu, nr. TPP-04-098.

Darbo apimtis

Darbą sudaro: įvadas, 5 skyriai, išvados, literatūros sąrašas, autorės publikacijų sąrašas, 1 priedas. Disertacijos apimtis: 128 puslapiai, 59 paveikslėliai, 4 lentelės. Literatūros sąrašą sudaro 127 šaltiniai.

1. LITERATŪROS APŽVALGA

Kaip jau minėta įžangoje, per visą savo gyvenimą apie 60–80 % žmonių populiacijos jaučia nugaros skausmą [115]. Nespecifinės kilmės nugaros skausmas, be aiškios patologijos, sudaro apie 90–95 %, likusieji procentai priklauso specifiniam nugaros skausmui, kuris turi aiškią patologiją. Tyrimo, kuris sujungė 28 valstybes, metu buvo analizuojamas apatinės nugaros dalies skausmo paplitimas tarp paauglių [105]. Svarbus faktas yra tas, kad paaugliai apatinės nugaros dalies skausmą jaučia kiekvieną mėnesį ar net dažniau, ir šis paplitimas didėja su amžiumi [105]. Paplitimas šioje amžiaus grupėje svyruoja nuo 28 % (Lietuvoje, Lenkijoje ir Rusijoje) iki 50,5 % (Čekijos Respublikoje) [59].

Nespecifinės kilmės nugaros skausmas yra labai svarbus ir netgi pagrindinis visuomenės sveikatos aspektas, kuris gali labai stipriai paveikti darbo produktyvumą, gebėjimus ar net gyvenimą. Prevencija labai svarbi ankstyvojoje stadijoje ar netgi prieš atsirandant skausmui. Nugaros skausmas yra dažna problema asmenims, dirbantiems sėdimą darbą. Kaip jau minėta, globaliai apie 37 % nugaros skausmų yra susiję su darbo aplinka [103]. Studijos nurodo, kad apatinės nugaros dalies skausmai vienerių metų laikotarpiu gali svyruoti nuo 23 % iki 83 % tarp biuro darbuotojų , [96].

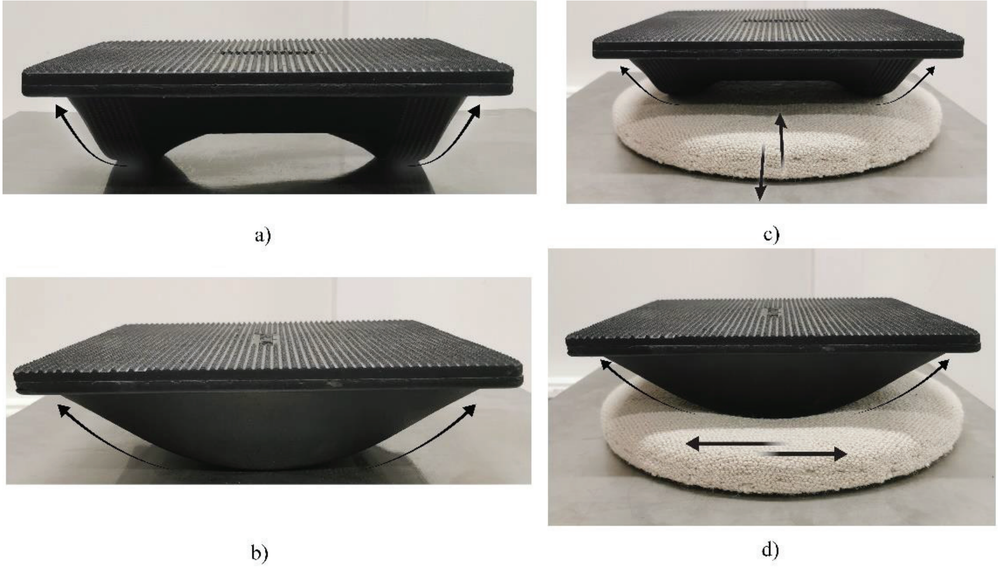
Yra daug tyrimų, atliktų *in vitro* ir *in vivo*, kurie nurodo, kokią apkrovą sukuria skirtingos sėdėjimo padėtys tarpslanksteliniams diskams. Pasakyti, kad viena ar kita sėdėjimo padėtis yra labiau žalojanti nei kita, sudėtinga, nes tai, ar sėdima su atlošu, ar be jo, gali turėti didelę įtaką stuburo apkrovai. Remiantis studija [66], tarpslankstelinio disko spaudimas, esant sėdėjimui be atramos, gali padidėti iki 40 % lyginant su stovima padėtimi. Sėdint be atramos ir atsipalaidavus spaudimas į tarpslankstelinius diskus siekia 0,46 MPa, palyginimui sėdint aktyviai, tiesia nugara – 0,55 MPa, o sėdint atsirėmus į kėdės atlošą – 0,27 MPa [118]. Sumažinti nugaros skausmą sėdint arba užkirsti kelią skausmo atsiradimui yra įvairių būdų. Rinka siūlo įvairius ergonominių kėdžių variantus: su skirtingais atlošais, galvos ir juosmeninės stuburo dalies atrama, arba net dinamines kėdes tam, kad būtų pagerinti sėdėjimo įpročiai – ilgas darbo valandas praleidžiant statinėje sėdėjimo padėtyje. Dinaminės kėdės [106] gali sumažinti statinės sėdėjimo padėties neigiamą įtaką, sukurdamos mažus stuburo judesius ir gerindamos laikyseną. Kai yra tinkamas stuburo judėjimas, tuo metu galime gauti gerą giliųjų raumenų aktyvumo atsaką, kuris labai svarbus stuburo stabilizacijai ir laikysenai. Asmenims, kurie praleidžia ilgą laiką sėdėdami statinėje padėtyje, matoma giliųjų liemens raumenų, dauginių raumenų (*m. multifidus*) atrofija, taip pat juosmeninės dalies raumenys yra apie 30 % neaktyvūs viso sėdėjimo metu [49]. Asmenys su chronišku apatinės nugaros dalies skausmu kenčia uždelstą liemens raumenų įsijungimą į darbą esant netikėtai perturbacijai [46]. Tai reiškia, kad refleksų lanko atsakas vėluoja dėl propriocepcinio signalo sutrikimo. Tinkamas sprendimas, siekiant suaktyvinti raumenis, galėtų būti netikėtos perturbacijos įtraukimas sėdimose ar stovimose padėtyse, kurios gali pagerinti refleksų atsaką ir sustiprinti jį [70]. Vis daugiau studijų atliekama tiriant pusiausvyrą ir smegenų aktyvumą [113]. Remiantis studija [121], prefrontalinė žievė yra atsakinga už skirtingas kognityvines funkcijas, įskaitant pusiausvyros išlaikymą ir treniravimą [92]. Todėl, sėdint ant dinaminių kėdžių, liemens raumenys yra aktyvinami, didinamas darbo produktyvumas. Vis dėlto, rinkoje pastebimas trūkumas dinaminių kėdžių, kurios būtų tinkamai valdomos, individualizuojamos ir sukurtų apatinės nugaros dalies judesius, sumažindamos viršutinės dalies judesius; taip pat trūksta tai įrodančių išsamių mokslinių tyrimų.

2. RAUMENŲ IR SMEGENŲ AKTYVUMO, KINEMATINIŲ PARAMETRŲ EKSPERIMENTINIS TYRIMAS SĖDINT ANT NESTABILAUS PAVIRŠIAUS

2.1 Nestabilios sėdynės bandymų stendas

Išanalizavus mokslinius straipsnius matoma, kad dubens judesys pirmyn– atgal ir į šonus, kurį galima atlikti sėdint ant nestabilaus paviršiaus, yra ganėtinai mažai analizuotas iš fiziologinės ir biomechaninės pusės. Dėl šios priežasties atlikti eksperimentiniai tyrimai, kurių metu buvo matuojamas raumenų ir smegenų aktyvumas, taip pat kinematiniai žmogaus ir skirtingų sėdynių judėjimo parametrai.

Buvo sukurtas nestabilios sėdynės maketas, kuris sudarytas iš plokštumos ir po ja esančių mažų guoliukų, kurie gali laisvai judėti įvairiomis kryptimis: pirmyn–atgal ir į šonus. Eksperimento metu taip pat buvo naudojama įprasta kėdė ir dar viena nestabili platforma, sudaryta iš plokščios sėdimosios dalies ir pusapvalės apačios.



1 pav. Nestabili platforma (a; b) ir nestabilios sėdynės maketas (c; d): a) kryptimi pirmyn–atgal; b) šonine kryptimi; c) kryptimi pirmyn–atgal; d) šonine kryptimi

2.2 Eksperimentinio tyrimo protokolas

Eksperimentinio tyrimo metu buvo naudojami trys skirtingi sėdimieji paviršiai: įprasta kėdė, nestabili platforma (dubens judesys pirmyn–atgal ir į šonus) ir nestabilios sėdynės maketas (dubens judesys pirmyn–atgal ir į šonus) (**1 pav.**). Kiekvienas eksperimentas truko po 60 s. Atliekant šias užduotis tuo pat metu buvo matuojami kūno segmentų judėjimai su trimate (3D) judesio analizės sistema, raumenų aktyvumas su elektromiografu ir smegenų aktyvumas su elektroencefalografu.

2.3 Nestabilios sėdynės bandymų stendo įtaka liemens raumenų aktyvumui

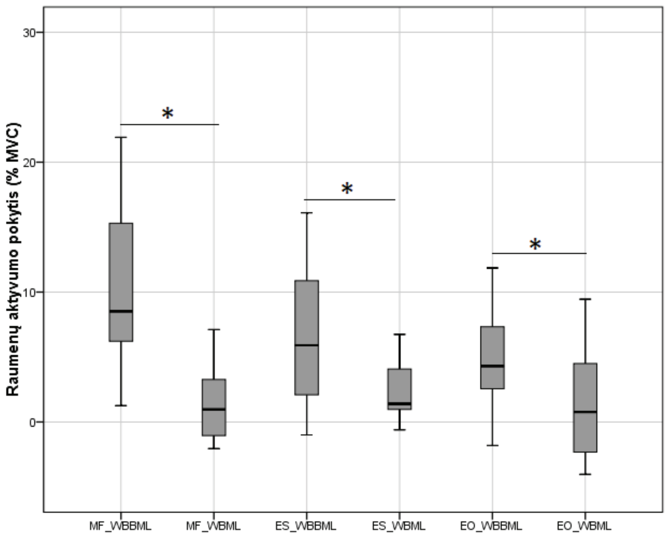
Eksperimentiniam tyrimui atlikti gautas Regioninės bioetikos komiteto leidimas (Lietuvos sveikatos mokslų universitetas). Tyrime dalyvavo 17 asmenų (28 ± 5,22 m. amžiaus), turinčių nespecifinės kilmės apatinės nugaros dalies skausmą ir dirbančių sėdimą darbą.

Eksperimentinio tyrimo užduočių metu buvo matuojamas penkių liemens raumenų aktyvumas: išorinio įstrižinio pilvo raumens, tiesiojo pilvo raumens, skersinio pilvo raumens, tiesiamojo nugaros raumens (krūtininės–juosmeninės dalies), dauginių nugaros raumenų. Užduočių metu asmenys turėjo pirmuoju atveju – sėdėti ramiai, antruoju atveju – atlikti dviejų krypčių dubens judesius ant nestabilios plokštumos, trečiuoju atveju – atlikti dviejų krypčių dubens judesius ant nestabilios sėdynės bandymų stendo.

2 pav. Elektrodų klijavimo vieta ant raumenų: 1 – tiesiamasis nugaros raumuo (ES); 2 – dauginis nugaros raumuo (MF); 3 – tiesusis pilvo raumuo (RA); 4 – išorinis įstrižinis pilvo raumuo (OE); 5 – skersinis pilvo raumuo (TA)

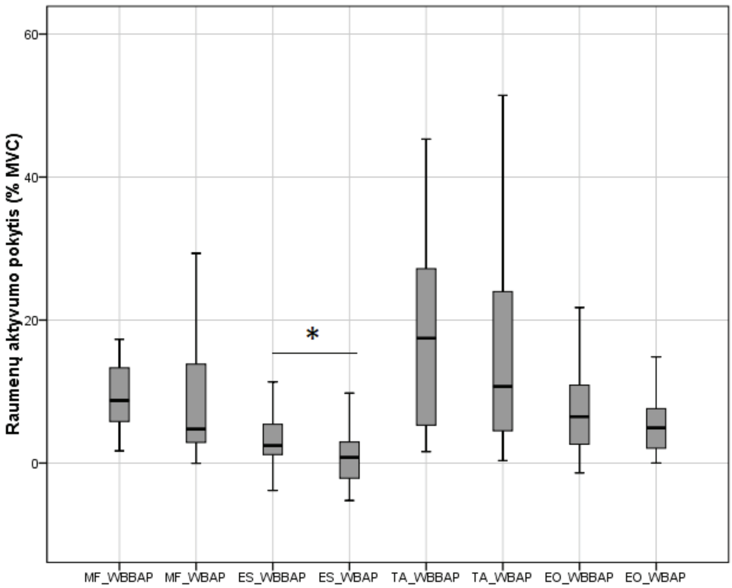
Raumenų aktyvumas matuotas elektromiografu *Telemyo2400R G2* (*Noraxon MR 3.12*). Paviršiniai dvipoliai elektrodai buvo priklijuoti ant pasirinktų raumenų pilvelių, bevieliai jutikliai buvo užklijuoti ant odos, virš matuojamo raumens elektrodo (**2 pav.**). Prieš imdamiesi užduočių, kiekvienas asmuo atliko maksimalų valingą izometrinį raumens susitraukimą (MVIC), kiekvienam raumeniui atskirai. Gauta MVIC reikšmė buvo prilyginta procentinei daliai – 100 %, kiekvienas kitas, atliktas eksperimento metu, judesys buvo apskaičiuotas kaip tam tikra procentinė dalis nuo MVIC. Šis skaičiavimas pasirinktas tam, kad būtų galima palyginti skirtingų asmenų rezultatus. Prieš procentinės dalies skaičiavimą gauti duomenys buvo apdoroti kompiuterine programa *Noraxon MR 3.12*. Duomenys buvo filtruojami (5–500 Hz), rektifikuojami ir glotninami. Statistinei duomenų analizei pasirinktas neparametrinis Vilkoksono kriterijus, statistinis reikšmingumas nustatytas, kai $p < 0,05$. Duomenys išreikšti mediana $x_{me} = (\bar{x} \pm SD)$.

Tyrimo metu nustatyta, kad atliekant šoninius dubens judesius (**3 pav.**) ant nestabilios sėdynės bandymų stendo buvo gautas didesnis dauginių nugaros raumenų (MF) ($p = 0,002$), tiesiamojo nugaros raumens (ES) ($p = 0,002$) ir išorinio įstrižinio pilvo raumens (EO) ($p = 0,03$) aktyvumo pokytis, lyginant su sėdėjimu ant nestabilios plokštumos. Pokytis vertintas sėdint ant stabilaus paviršiaus (įprastos kėdės). Taip pat buvo matomas skersinio pilvo raumens aktyvumo pokyčio padidėjimas ant nestabilios sėdynės bandymų stendo, tačiau jis statistiškai reikšmingai nesiskyrė sėdint ant nestabilios plokštumos ($p = 0,334$). Tiesiojo pilvo raumens aktyvumo padidėjimas buvo matomas ant nestabilios sėdynės bandymų stendo, lyginant su nestabilia plokštuma, tačiau statistiškai reikšmingo patikimumo nebuvo ($p = 0,191$).



3 pav. Raumenų aktyvumo pokytis atliekant šoninius dubens judesius (ML) ant nestabilios plokštumos (WBML) ir nestabilios sėdynės bandymų stendo (WBBML). * nurodo statistiškai reikšmingą skirtumą $p < 0,05$; MF – dauginis nugaros raumuo; ES – tiesiamasis nugaros raumuo; TA – skersinis pilvo raumuo; EO – išorinis įstrižinis pilvo raumuo; RA – tiesusis pilvo raumuo

Tyrimo rezultatai rodo, kad atliekant dubens judesius pirmyn–atgal (**4 pav.**) buvo matomas tik tiesiamojo nugaros raumens aktyvumo pokyčio padidėjimas, atliekant judesius ant nestabilios sėdynės bandymų stendo ($p = 0,015$). Dauginių nugaros raumenų aktyvumas buvo didesnis atliekant judesius ant nestabilios sėdynės bandymų stendo, palyginus su nestabilia plokštuma, tačiau rezultatai nebuvo statistiškai reikšmingi ($p = 0{,}326$). Taip pat skersinio pilvo raumens aktyvumas buvo didesnis atliekant judesius ant nestabilios sėdynės bandymų stendo, palyginus su nestabilia plokštuma, tačiau rezultatai nebuvo statistiškai reikšmingi ($p = 0{,}301$). Išorinių įstrižinių pilvo raumenų aktyvumas buvo didesnis atliekant judesius ant nestabilios sėdynės bandymų stendo, palyginus su nestabilia plokštuma, tačiau rezultatai nebuvo statistiškai reikšmingi ($p = 0{,}163$). Visgi tiesiojo pilvo raumens aktyvumas buvo mažesnis atliekant judesius ant nestabilios sėdynės bandymų stendo, palyginus su nestabilia plokštuma, tačiau rezultatai nebuvo statistiškai reikšmingi ($p = 0{,}918$).



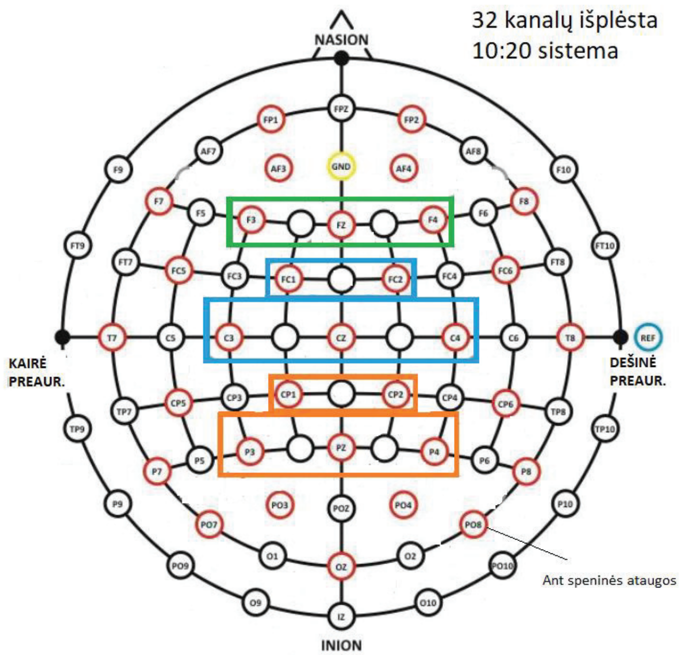
4 pav. Raumenų aktyvumo pokytis atliekant dubens judesius pirmyn–atgal (AP) ant nestabilios plokštumos (WBAP) ir nestabilios sėdynės bandymų stendo (WBBAP). * nurodo statistiškai reikšmingą skirtumą $p < 0{,}05$; MF – dauginis nugaros raumuo; ES – tiesiamasis nugaros raumuo; TA – skersinis pilvo raumuo; EO – išorinis įstrižinis pilvo raumuo; RA – tiesusis pilvo raumuo

2.4 Nestabilios sėdynės bandymų stendo įtaka smegenų žievės aktyvumui

Siekiant nustatyti nestabilios sėdynės bandymų stendo įtaką smegenų žievės aktyvumui buvo pasirinktas elektroencefalografijos metodas. Elektroencefalografas *g. Nautilus* (*g.tec Medical Engineering GmbH*, Austrija) turi kepurėlę su 32 elektrodais, kurie paskirstyti pagal tarptautinę 10:20 sistemą. Buvo pasirinktas referencinis montažas ir referencinis elektrodas uždėtas ant speninės ataugos. Kiekvienas elektrodas buvo užpildytas laidžiu geliu (*g.gamma gel*). Referencinio elektrodo varža buvo <10 kΩ, visų kitų elektrodų varža siekė iki 50 kΩ, ypatingai moterims su ilgais plaukais. Atrankos dažnis buvo nustatytas iki 250 Hz. Prieš pradedant matuoti EEG signalą, juostos pralaidumo filtras nustatytas nuo 0,5–100 Hz, o triukšmo filtras nustatytas ties 50 Hz [99]. Signalai buvo matuojami naudojant *Simulink* programuojamus blokų modulius.

Tyrimų metu buvo atlikta teta (4–8 Hz) ir alfa (8–13 Hz) bangų spektrinė galios analizė, siekiant palyginti smegenų žievės aktyvumą ant skirtingų sėdimųjų paviršių.

Remiantis atliktomis studijomis [24], [100], buvo pasirinkti smegenų žievės regionai (**5 pav.**): kaktinės skilties (F3, Fz, F4), kaktinės–centrinės (FC1, FC2, C3, Cz, C4), centrinės–momeninės (CP1, CP2, P3, Pz, P4).



5 pav. Regionai: žalias – kaktinis, mėlynas – kaktinis–centrinis, oranžinis – centrinis–momeninis

Duomenys surinkti ir apdoroti su programinės įrangos *Matlab* papildiniu *g.BSanalyze*. EEG duomenys pirmiausia nufiltruoti (Butterworth filtras, pagrindinė linija (magistralė): 0,5 Hz) tam, kad būtų pašalintas triukšmas žemesniuose dažniuose. Buvo naudojamas pusiau automatinis algoritmas, kad pašalintų išskirtus artefaktus. Panaudotas nepriklausomas komponentų analizės (ICA) algoritmas, kuris buvo programinėje įrangoje *g.BSanalyze* [24]. Segmentuotiems duomenims buvo atlikta pradinės linijos korekcija.

Alfa bangos galios spektro rezultatai

Tyrimų rezultatai parodė, kad alfa bangos galios spektras atliekant dubens judesius pirmyn–atgal ant sėdynės bandymų stendo, palyginus su statiniu sėdėjimu, statistiškai reikšmingai padidėjo kaktinėje ($p = 0{,}007$), kaktinėje– centrinėje ($p = 0{,}01$) ir centrinėje–momeninėje ($p = 0{,}041$) dalyse. Atliekant dubens judesius pirmyn–atgal ant nestabilios plokštumos, statistiškai reikšmingai padidėjo bangos galios spektras tik kaktinėje–centrinėje dalyje ($p = 0{,}019$), tačiau reikšmingo skirtumo nebuvo stebima kaktinėje ir centrinėje–momeninėje dalyse ($p < 0{,}05$), palyginus su statiniu sėdėjimu.

Alfa bangos galios spektras atliekant dubens judesius į šonus ant sėdynės bandymų stendo, palyginus su statiniu sėdėjimu, statistiškai reikšmingai padidėjo kaktinėje dalyje ($p = 0{,}004$), kaktinėje–centrinėje ($p = 0{,}015$) ir centrinėje–momeninėje ($p = 0{,}028$). Atliekant dubens judesius į šonus ant nestabilios plokštumos, palyginus su statiniu sėdėjimu, spektras statistiškai reikšmingai padidėjo tik kaktinėje–centrinėje dalyje ($p = 0{,}034$), tačiau reikšmingo skirtumo nebuvo stebint kaktinėje ir centrinėje–momeninėje dalyse ($p < 0{,}05$).

Teta bangos galios spektro rezultatai

Tyrimų rezultatai parodė, kad teta bangos galios spektras atliekant dubens judesius pirmyn–atgal ant sėdynės bandymų stendo, palyginus su statiniu sėdėjimu, statistiškai reikšmingai padidėjo kaktinėje dalyje ($p = 0{,}005$), kaktinėje– centrinėje ($p = 0{,}005$) ir centrinėje–momeninėje ($p = 0{,}022$). Atliekant dubens judesius pirmyn–atgal ant nestabilios plokštumos, palyginus su statiniu sėdėjimu, statistiškai reikšmingai padidėjo kaktinėje dalyje ($p = 0{,}033$), kaktinėje– centrinėje ($p = 0{,}011$) ir centrinėje–momeninėje ($p = 0{,}002$).

Teta bangos spektrinė galia atliekant dubens judesius į šonus ant sėdynės bandymų stendo, palyginus su statiniu sėdėjimu, statistiškai reikšmingai padidėjo kaktinėje dalyje ($p = 0{,}005$), kaktinėje–centrinėje ($p = 0{,}005$) ir centrinėje–momeninėje ($p = 0{,}022$). Atliekant dubens judesius į šonus ant nestabilios plokštumos, palyginus su statiniu sėdėjimu, spektrinė galia statistiškai reikšmingai padidėjo kaktinėje dalyje ($p = 0{,}033$), kaktinėje–centrinėje ($p = 0{,}011$) ir centrinėje–momeninėje ($p = 0{,}002$).

2.5 Kinematinė analizė

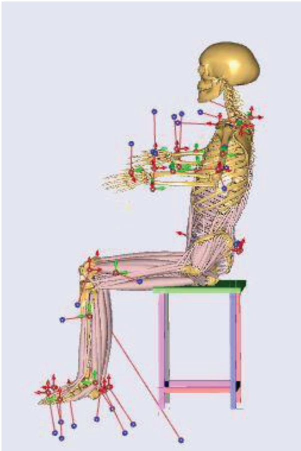
Žmogaus kūno judesiams užfiksuoti buvo naudojama trimatė (3D) judesio analizės sistema. Judesius sekė 10 didelio greičio kamerų (*Oqus7+ Qualisys AB*, Gothenburgas, Švedija), duomenys buvo įrašomi naudojant *Qualysis Track Manager* programinės įrangos paketą, fiksavimo dažnis buvo nustatytas ties 300 Hz. Viso kūno kinematinei analizei atlikti naudotas *Helen-Hayes* žymeklių dėjimo protokolas. Tyrimo metu buvo sekama priekinio viršutinio klubakaulio dyglio (ASIS) ir dešimto krūtininės stuburo dalies slankstelio keterinės ataugos (Th10) judesių amplitudė, atliekant skirtingus dubens judesius ant skirtingų sėdimųjų paviršių.

Rezultatai parodė, kad atliekant dubens judesius pirmyn–atgal ant sėdynės bandymų stendo, ASIS judėjimo amplitudė mažesnė nei atliekant judesius ant nestabilios plokštumos ($p = 0{,}001$), taip pat buvo matoma mažesnė Th10 judėjimo amplitudė ant sėdynės bandymų stendo, palyginus su judesiu ant nestabilios plokštumos ($p = 0{,}001$).

Atliekant dubens judesius į šonus ant sėdynės bandymų stendo ASIS judėjimo amplitudė mažesnė nei atliekant judesius ant nestabilios plokštumos ($p < 0{,}001$). Th10 judėjimo amplitudė ant sėdynės bandymų stendo statistiškai reikšmingai nesiskyrė, palyginus su judesiu ant nestabilios plokštumos ($p > 0{,}05$).

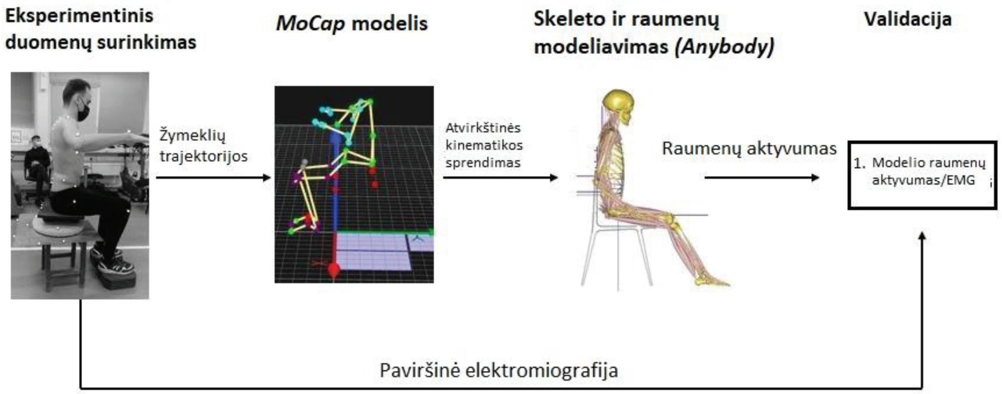
3. ŽMOGAUS RAUMENŲ–SKELETO SISTEMOS MODELIAVIMAS

Žmogaus raumenų–skeleto sistemos modeliavimas atliktas naudojant *AnyBody Modeling System* (*AnyBody Technology*, Alborgas, Danija). Ši programinė įranga yra sukurta atlikti raumenų–skeleto judesių bei statinių padėčių analizei. *AnyBody Technology* sistema leidžia kurti įvairias kūno dalis arba naudoti jau sukurtus modelius, patalpintus į *AnyBody Managed Model Repository* (AMMR). Visi AMMR modeliai gali būti naudojami kaip atskaitos taškas, norint pritaikyti eksperimento metu gautus duomenis. Šiame tyrime buvo naudojamas visas *AnyMoCap* žmogaus modelis (**6 pav.**).



6 pav. Sėdinčio žmogaus modelis *AnyBody* modeliavimo programoje

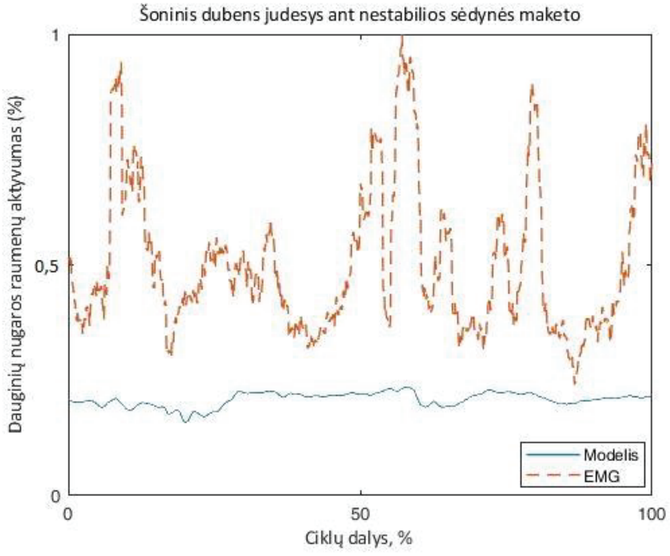
Šis pradinis modelis, paimtas iš AMMR, yra susijęs su trimačio (3D) judesio matavimo ir analizės sistema (**7 pav.**). Tai reiškia, kad duomenys, gauti iš trimatės (3D) judesio analizės sistemos, buvo perkelti į *AnyMoCap* žmogaus modelį, kurio kūno dalių segmentai buvo pritaikyti remiantis eksperimento metu gautais žymeklių judėjimo duomenimis. Skeleto ir raumenų sistemos modeliavimo tikslas buvo palyginti eksperimentinį raumenų aktyvumą su modelio raumenų aktyvumu.



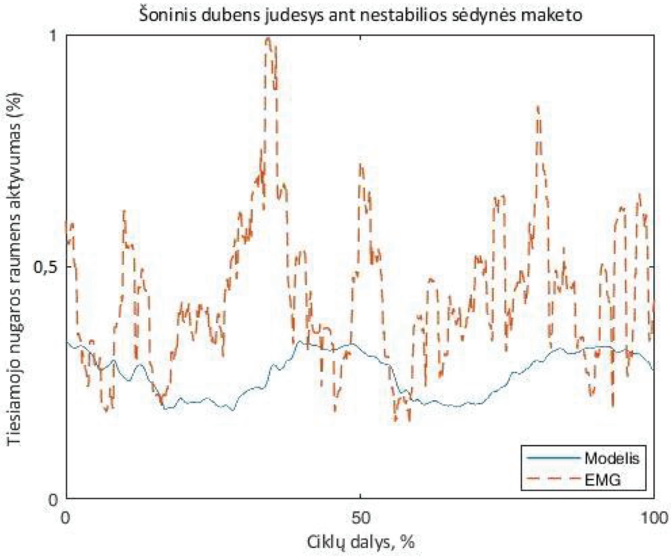
7 pav. Kiekvieno eksperimento tyrimų schema: žmogaus kūno kinematika, paviršinė elektromiografija (sEMG) ir skeleto–raumenų sistemos modeliavimas. Atliekant šį tyrimą palyginta paviršinė elektromiografija (sEMG) ir modelio raumenų aktyvumas

Sutapimas buvo apskaičiuotas kaip procentas, kai tiek EMG aktyvumas, tiek modelio raumenų aktyvacijos buvo didesnės arba mažesnės už 0,5 slenkstį tuo pačiu metu.

Modelio raumenų aktyvumas gerai sutapo su eksperimentine EMG veikla. Modelio ir eksperimento EMG sutapimas buvo didelis dubens šoninio judesio metu ant nestabilios sėdynės maketo, palyginimui dauginio nugaros raumens sutapimas siekė >60 % (**8 pav.**), o tiesiamojo nugaros raumens >70 % (**9 pav.**).

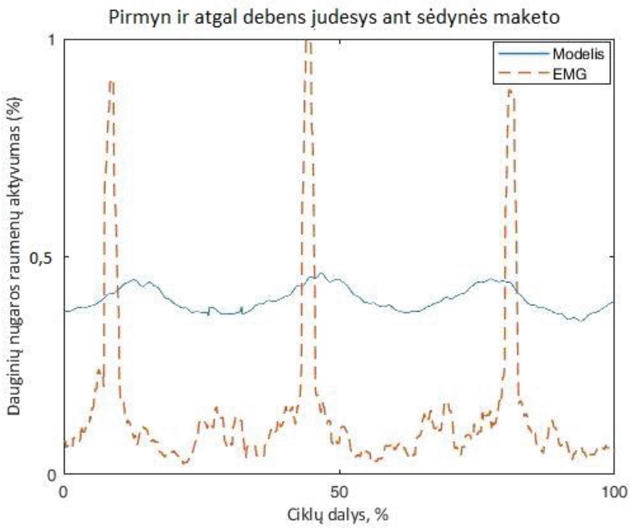


8 pav. Dauginio nugaros raumens modelio ir paviršinės elektromiografijos raumenų aktyvumas atliekant šoninius dubens judesius ant nestabilaus paviršiaus. Grafikuose pavaizduoti trys dubens judesio ciklai, kurių pradžios laikas sutampa. Raumenų aktyvumas normalizuotas pasirinkus maksimalią atliekamo judesio reikšmę

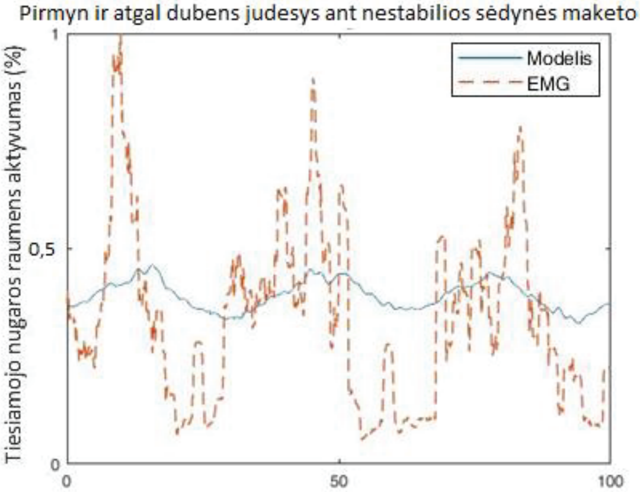


9 pav. Tiesiamojo nugaros raumens modelio ir paviršinės elektromiografijos raumenų aktyvumas atliekant šoninius dubens judesius ant nestabilaus paviršiaus. Grafikuose pavaizduoti trys dubens judesio ciklai, kurių pradžios laikas sutampa. Raumenų aktyvumas normalizuotas pasirinkus maksimalią atliekamo judesio reikšmę

Modelio ir eksperimento metu gauti raumenų aktyvumo rezultatai, atliekant dubens judesį pirmyn–atgal, puikiai sutapo vertinant dauginius nugaros raumenis 93 % (**10 pav.**), mažesniu sutapimu išsiskyrė tiesiamasis nugaros raumuo – 80,95 % (**11 pav.**) sutapimo.



10 pav. Dauginio nugaros raumens modelio ir paviršinės elektromiografijos raumenų aktyvumas atliekant dubens judesius pirmyn–atgal ant nestabilaus paviršiaus. Grafikuose pavaizduoti trys dubens judesio ciklai, kurių pradžios laikas sutampa. Raumenų aktyvumas normalizuotas pasirinkus maksimalią atliekamo judesio reikšmę



11 pav. Tiesiamojo nugaros raumens modelio ir paviršinės elektromiografijos raumenų aktyvumas atliekant dubens judesius pirmyn–atgal ant nestabilaus paviršiaus. Grafikuose pavaizduoti trys dubens judesio ciklai, kurių pradžios laikas sutampa. Raumenų aktyvumas normalizuotas pasirinkus maksimalią atliekamo judesio reikšmę

Atlikus analizę buvo matomas didelis sutapimas atliekant abu dubens judesius, ypatingai dubens judesį pirmyn–atgal, nes atliekant dubens judesius sagitalinėje plokštumoje yra labiau stabilizuojami nugaros segmentai, o štai atliekant šoninius dubens judesius stabilizacijos kontrolė yra žymiai mažesnė.

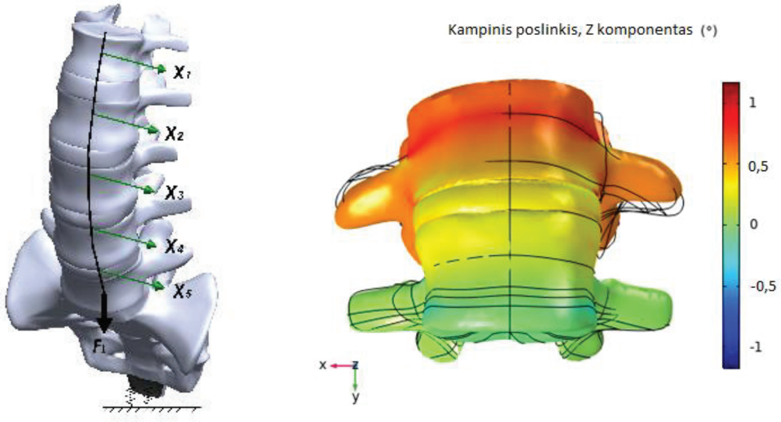
4. JUOSMENINĖS STUBURO DALIES IR KRYŽKAULIO MODELIAVIMAS

Trimatis (3D) juosmeninės stuburo dalies ir kryžkaulio baigtinių elementų (FE) modelis naudotas iš laisvai prieinamos duomenų bazės [125]. FE juosmens ir kryžkaulio trimačiam (3D) modeliui kurti pasirinkta *COMSOL Multiphysics* (*COMSOL Inc.*) programinė įranga. Kuriant baigtinių elementų tarpslankstelinio disko ir juosmens stuburo modelius panaudoti *Comsol MultiPhysics* poroelastiškumo, koeficiento formos PDE ir Truss moduliai. Trimatis (3D) juosmeninės stuburo dalies ir kryžkaulio FE modelis sudarytas iš 5 juosmeninės stuburo dalies slankstelių, 5 tarpslankstelinių diskų, kryžkaulio ir raiščių.

Šiame modelyje naudojamos medžiagos ir komponentų savybės buvo pritaikytos iš anksčiau paskelbtos literatūros [121]. Kaulai ir kremzlinės galinės plokštelės buvo modeliuojami kaip linijiniai elastingi kūnai, tarpslankstelinio disko skaidulinio žiedo medžiaga modeliuojama kaip hiperelastiniai kūnai, taikant Mooney–Rivlin modelį. Tarpslankstelinio skaidulinio disko žiedai buvo modeliuojami kaip kompozicinis kevalas, kurį sudaro septyni sluoksniai. Kiekvienas kolageno skaidulų sluoksnis yra pasviręs 70° kampu į priešingą pusę. Raiščiai, jungiantys ir stabilizuojantys stuburą, buvo modeliuojami kaip netiesinės spyruoklės, veikiančios įtempimo sąlygomis.

4.1 Stuburo funkcinio vieneto validacija

Pirmiausia atlikta stuburo funkcinio vieneto (L4, tarpslankstelinio disko ir L5) validacija. Mūsų tyrime kampinių poslinkių prognozės palygintos su anksčiau paskelbtais moksliniais duomenimis, siekiant patvirtinti modelį. Stuburo funkciniam vienetui buvo pritaikyti poslinkiai siekiant išsiaiškinti, ar tai atitinka kitų mokslininkų pateiktus duomenis. L5 slankstelio apatinė dalis buvo įtvirtinta. Jėgos momentas, veikiamas viršutiniame L4 slankstelio paviršiuje, siekiant imituoti šoninį lenkimą, buvo 1,0 Nm, gautas didžiausias kampinis poslinkis esant šoniniam lenkimui – 1,17° (**12 pav.**) Naudojant tą patį jėgos momentą, autorių Heuer ir kt. pateikti duomenys buvo 1,28° [122].

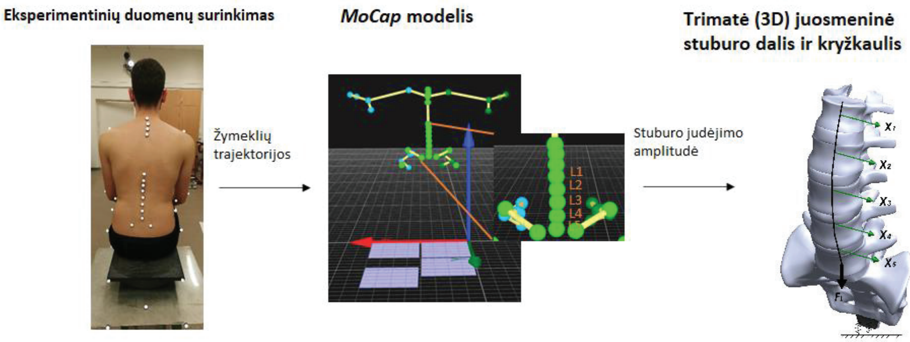


a) b)

12 pav. Stuburo funkcinio vieneto (L4, tarpslankstelinio disko ir L5) validacija: a) apkrovos ir įtvirtinimo schema; b) apskaičiuotas kampinis poslinkis, imituojant šoninį lenkimą

4.2 Eksperimento rezultatų pritaikymas trimačiam (3D) juosmeninės stuburo dalies modeliui

Trimatis (3D) juosmeninės stuburo dalies ir kryžkaulio modelis buvo suvaržytas apatinėje kryžkaulio dalyje. Stuburui pritaikyta 400 N ašinė apkrova, bandant imituoti žmogaus kūno svorį, tenkantį stuburui. Modeliavimas atliktas, pritaikant eksperimento metu gautus duomenis. Iš eksperimento buvo paimti stuburo juosmeninės dalies (L1–L5) ir kryžkaulio keterinių ataugų poslinkių duomenys. Trimačiai kinematiniai duomenys buvo fiksuojami 3D judesio analizės sistema (*Qualisys AB*, Geteborgas, Švedija) ir duomenys apdoroti *Qualisys Track Manager* programine įranga, taikant 300 Hz filmavimo dažnį. Helen–Hayes žymeklių rinkinys buvo naudojamas viso kūno kinematikai matuoti. Papildomai ant penkių juosmeninės stuburo dalies slankstelių keterinių ataugų buvo pritvirtinti papildomi žymekliai (**13 pav.**).



13 pav. Viso kūno kinematika: L1–L5 keterinių ataugų judėjimo amplitudės

Eksperimento metu tiriamasis atliko du judesius dviem skirtingomis platformomis: pirmyn–atgal (AP) ir į šonus (ML). Kiekvieno judesio metu paimta slankstelio keterinės ataugos judėjimo amplitudė (**1 lentelė**).

Judėjimo amplitudė (mm)	L1	L2	L3	L4	L5
WBB_ML	69,53	70,68	72,9	74,45	77,23
WB_ML	122,37	132,55	135,06	133,46	124,77

1 lentelė. Slankstelio keterinės ataugos judėjimo amplitudė ant sėdynės bandymų stendo (WBB) ir ant nestabilios plokštumos (WB), atliekant šoninius (ML) dubens judesius

4.2 Apkrovų pasiskirstymo juosmeninėje stuburo dalyje analizė

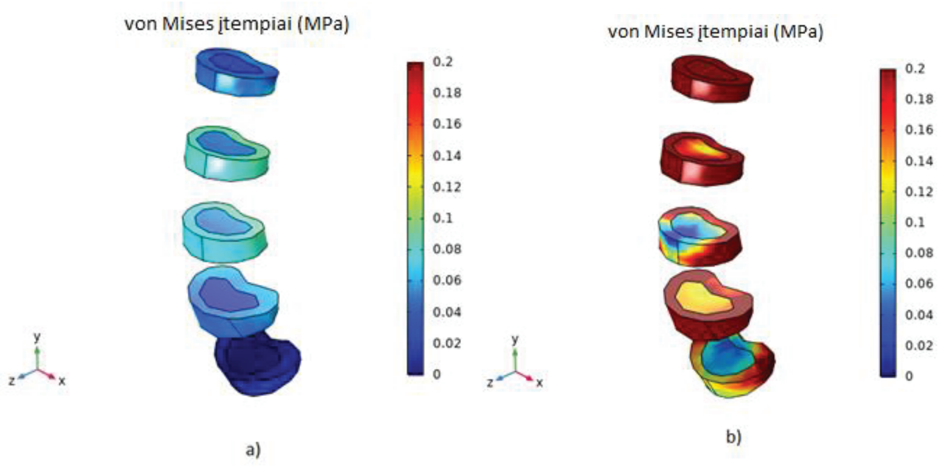
Įtvirtinus apatinį slankstelį ties S2 su spyruokle, kurios judėjimas atitinka judėjimo amplitudes iš eksperimento metu gautų duomenų (**2 lentelė**), buvo pritaikytos dubens judesių, lenkimo–tiesimo bei šoninio lenkimo judėjimo amplitudės ties kiekvieno slankstelio keterine atauga atskirai.

Kryžkaulio ties S2 judėjimo amplitudės	
	Šoninis judesys
WBB	5,0 mm
WB	15,14 mm

2 lentelė. Kryžkaulio judėjimo amplitudė ant sėdynės bandymų stendo (WBB) ir ant nestabilios plokštumos (WB), atliekant šoninius (ML) dubens judesius

Apskaičiavus įtempius ir deformacijas, tenkančias tarpslanksteliniam stuburo diskui, gauti tokie rezultatai. Atliekant šoninius dubens judesius ant sėdynės bandymų stendo maksimalus įtempis, gautas ties L2 ir L3 tarpslanksteliniu disku, siekė 0,1 MPa

(**14 pav.**), o atliekant tuos pačius judesius ant nestabilios plokštumos maksimalus įtempis buvo ties L1 ir L2 tarpslanksteliniu disku ir siekė 0,6 MPa.

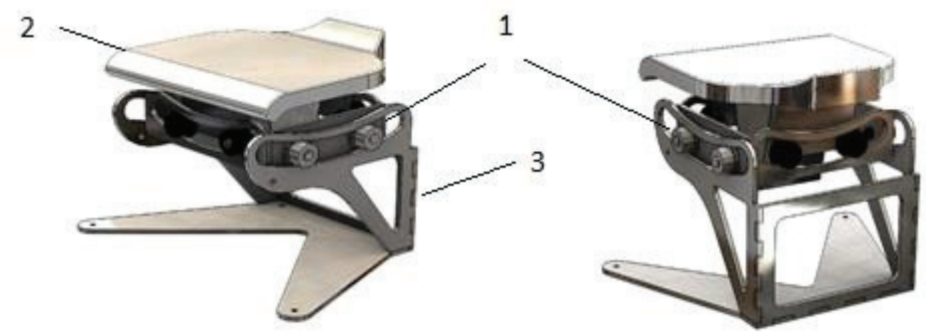


14 pav. Juosmeninės stuburo dalies tarpslankstelinių diskų įtempiai atliekant šoninį dubens judesį: a) ant nestabilaus paviršiaus ir b) ant nestabilios sėdynės prototipo

5. NESTABILIOS SĖDYNĖS PROTOTIPO TOBULINIMAS

Literatūros apžvalgoje aprašyta gana daug nestabilių kėdžių ir sėdynių išradimų bei patentų. Patentinėse paraiškose dažniausiai aprašomi išradimai, galintys padėti išspręsti vieną ar kitą problemą, susijusią su raumenų ir kaulų sistemos sutrikimais. Tačiau šie patentiniai išradimai neturi fiziologinio ir biomechaninio pagrindimo žmogaus organizmui. Kita sritis, kurioje galima rasti nestabilių kėdžių ar sėdynių, yra rinkoje esantys produktai. Keletas kėdžių buvo patvirtintos moksliniais tyrimais, ir tai yra labai svarbu kuriant kėdę pagal žmogaus poreikius.

Disertacijos rengimo metais sukurtas nestabilios sėdynės prototipas (**15 pav.**) turi dviejų plokštumų judesį (frontalinį ir sagitalinį), kurio bendra judėjimo amplitudė pirmyn–atgal kryptimis yra 7 cm, o šonine kryptimi – 10 cm. Šios dvi kryptys skatina atlikti dubens judesius, esant ilgai statinei (sėdimai) padėčiai darbe. Remiantis eksperimentinių tyrimų rezultatais matoma, kad nestabilios sėdynės bandymų stendas skatina giliųjų liemens raumenų aktyvumą, o išanalizuoti stuburo modeliavimo rezultatai parodė, kad sukuriama labai maža apkrova tarpslanksteliniams diskams, atliekant judesius kryptimis pirmyn–atgal bei į šonus. Judėjimą inicijuoja asmuo, sėdintis ant sėdynės (2), kad sėdynė lengvai judėtų, nestabilios sėdynės prototipo šonuose yra sumontuoti guoliai (1) po du kiekviename šone, sėdynės priekyje ir užpakalinėje dalyje.



15 pav. Nestabilios sėdynės prototipas: 1 – guoliukai; 2 – sėdynė; 3 – rėmas

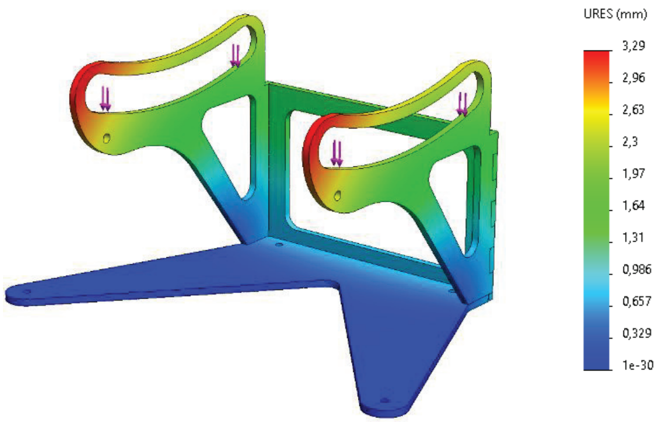
5.1 Tiesinė statinės apkrovos analizė

Trimatis (3D) nestabilios sėdynės modelis sukurtas naudojant *SolidWorks* programinės įrangos paketą. Tiesinė statinė apkrovos analizė skaičiuoja poslinkius ir įtempius, veikiant apkrovoms. Nestabilios kėdės tinklelio modelyje yra 270 951 mazginių taškų ir 162 591 erdvinių baigtinių elementų. Nestabilios kėdės modelis turi 812 853 laisvės laipsnių.

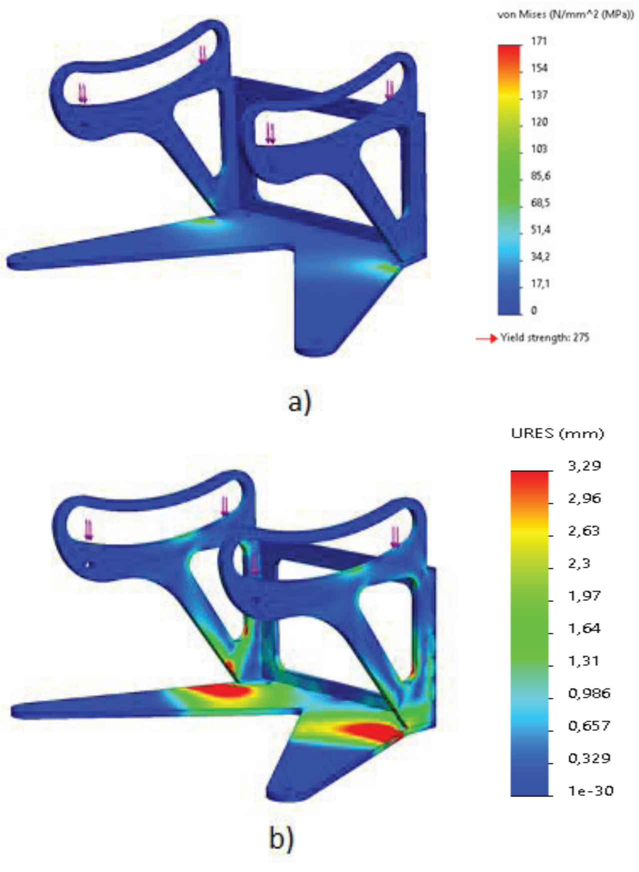
Rengiant baigtinių elementų modelį pagal EN 1993-1-1 (2005), atsižvelgta į medžiagos S275 H plieno mechanines savybes: Eurokodas 3: Plieninių konstrukcijų projektavimas:

- tamprumo modulis – 210 × 109 Pa;
- tankis – 7800 kg/m^3;
- takumo riba (angl. *Yield strength*) esant nominaliam elemento storiui t ≤ 40 mm – 275 MPa;
- takumo riba pagal nominalų elemento storį 40 mm < t ≤ 80 mm – 255 MPa;
- Puasono koeficientas – 0,33.

Kėdės rėmo šonai buvo apkrauti 3000 N (300 kg) jėga, paskirstyta po 1500 N kiekviename šone. Atlikta poslinkio skaičiavimo analizė. Rezultatai rodo, kad maksimalus poslinkis (**16 pav.**) yra 3,29 mm nestabilios kėdės modelio šonų galuose. Nestabilios sėdynės rėmo von Mises įtempių pasiskirstymas buvo 171 MPa (**17a pav.**), **17b pav.** pritaikytas 50 MPa filtras.



16 pav. Nestabilios kėdės rėmo poslinkiai, esant tiesinei statinei apkrovai



17 pav. Nestabilios sėdynės von Mises įtempių pasiskirstymas atlikus tiesinę statinę analizę: a) visas sėdynės rėmo modelis; b) pritaikytas 50 MPa filtras

Gavus tiesinės statinės apkrovos analizės rezultatus, pagamintas nestabilios sėdynės prototipas (18 pav.). Žmogaus kūno fiziologinių ir biomechaninių parametrų reakcija į prototipą buvo dar kartą eksperimentiškai patikrinta laboratorijoje ir palyginta su sėdynės bandymų stendo rezultatais.

a) b)

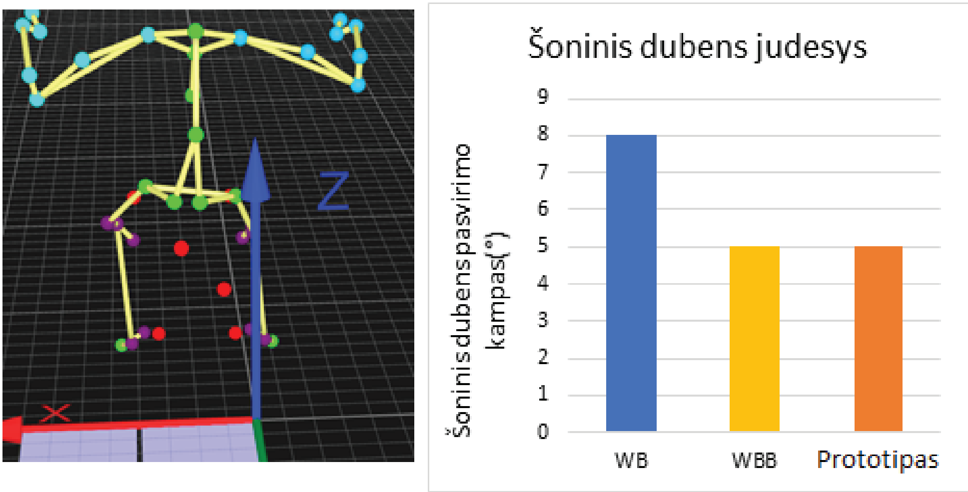
18 pav. Nestabilios sėdynės prototipas

Eksperimentinio tyrimo metu buvo išmatuotas penkių liemens raumenų aktyvumas ir išanalizuota žmogaus kūno segmentų kinematika ant nestabilios sėdynės prototipo. Atliekant matavimus panaudoti trys skirtingi sėdėjimo įrankiai: nestabili plokštuma, nestabilios sėdynės maketas ir nestabilios sėdynės prototipas (18 pav.). Eksperimentinis EMG ir kinematinių matavimų protokolas buvo naudojamas toks pat, kaip minėta 2 skyriuje. Norint normalizuoti elektromiografijos duomenis, atliktas maksimalus valingas izometrinis kiekvieno raumens susitraukimas, kuris buvo pateiktas procentine išraiška. Eksperimento metu buvo stebima viso kūno kinematika su papildomais žymekliais ant juosmeninės stuburo dalies, slankstelių skersinių ataugų.

5.2 Dubens kampo rezultatai ant trijų skirtingų sėdėjimo įrenginių

Šoninio dubens judėjimo kampas buvo apskaičiuotas iš trijų taškų: Th10 (10-asis krūtinės ląstos slankstelis), LASI (kairysis priekinis viršutinis klubakaulio dyglys) ir RASI (dešinysis priekinis viršutinis klubakaulio dyglys).

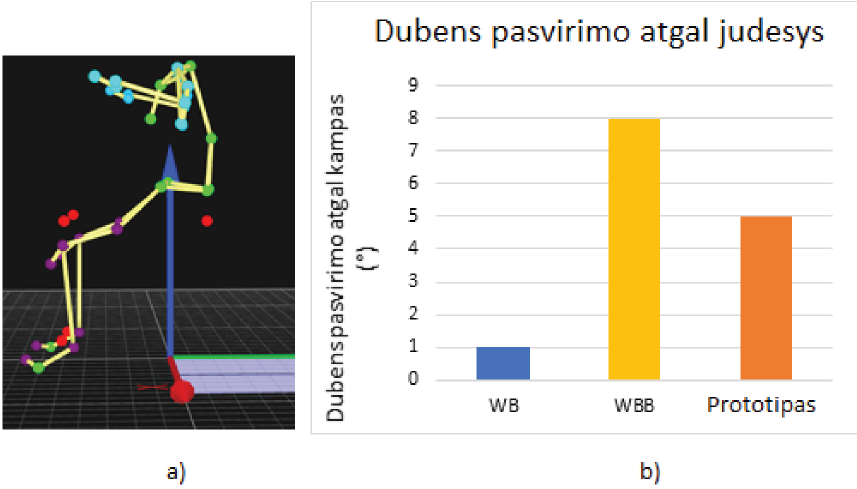
Rezultatai parodė, kad šoninio judėjimo metu dubens judėjimo kampas ant nestabilios plokštumos siekė 8°, ant nestabilios sėdynės maketo kampas buvo 5°, o ant prototipo – 5°. Šoninio dubens judėjimo kampai ant sėdynės maketo ir prototipo yra vienodi.



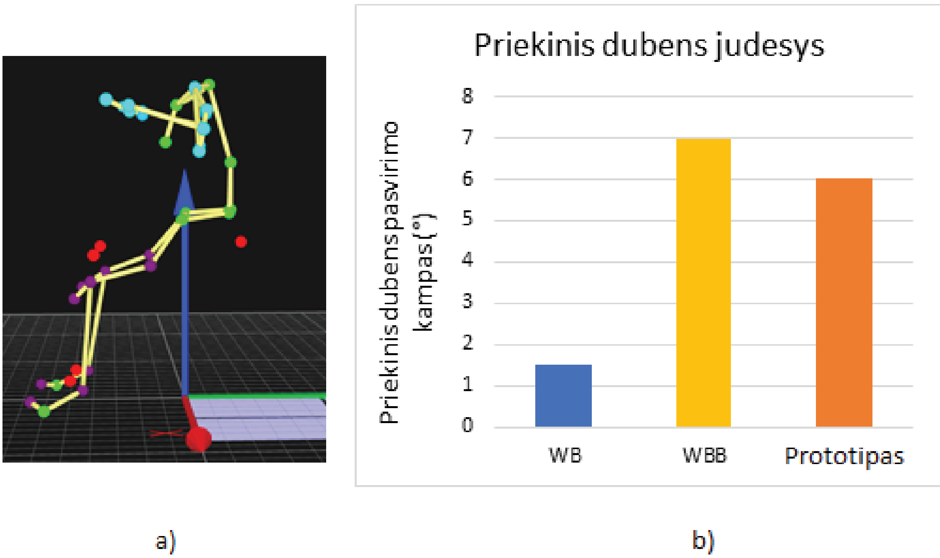
a) b)

19 pav. Trimatis (3D) šoninio dubens judesio kampas (a) ant trijų skirtingų sėdėjimo prietaisų (b): WB, WBB, prototipo

Dubens judėjimo pirmyn–atgal kampas buvo apskaičiuotas iš trijų taškų: Th10 (10-asis krūtinės ląstos slankstelis), RPSI (dešinysis užpakalinis viršutinis klubakaulio dyglys) ir RASI (dešinysis priekinis viršutinis klubakaulio dyglys). Priekinio dubens judėjimo rezultatai (20 pav.) ant nestabilios plokštumos – 1,5°, ant nestabilios sėdynės maketo siekė 7°, o ant prototipo – 6°. Išanalizavus dubens judesio atgal rezultatus ant nestabilios sėdynės maketo kampas buvo 8°, ant nestabilios plokštumos – 5°, o ant prototipo – 1°.



20 pav. Trimatis (3D) galinis dubens pasvirimo atgal kampas (a) ant trijų skirtingų sėdėjimo prietaisų (b): WB, WBB, prototipo



21 pav. Trimatis (3D) priekinis dubens pasvirimo kampas (a) ant trijų skirtingų sėdėjimo prietaisų (b): WB, WBB, prototipo

5.3 Liemens raumenų aktyvumo rezultatai ant trijų skirtingų sėdėjimo paviršių

Pagrindinė šio eksperimento idėja – pamatyti, kaip raumenų aktyvumas skiriasi arba yra panašus ant nestabilios sėdynės maketo ir prototipo. Buvo matomas padidėjęs giliųjų liemens raumenų aktyvumas ant prototipo, lyginant su nestabilia plokštuma.

Judesio pirmyn–atgal metu dauginio nugaros raumens aktyvumas buvo 23 % ant nestabilios plokštumos, 33 % ant nestabilios sėdynės maketo ir 39 % – ant prototipo. Apie 6 % dauginio nugaros raumens aktyvumas buvo didesnis ant prototipo. Skersinio pilvo raumens aktyvumas ant nestabilios plokštumos buvo 36 %, ant nestabilios sėdynės maketo – 71 %, ant prototipo – 78 %. Skirtumas tarp nestabilios sėdynės maketo ir prototipo buvo tik 7 %. Kitų raumenų: tiesiamojo nugaros raumens, tiesiojo pilvo raumens ir išorinių įstrižinių pilvo raumenų aktyvumas buvo mažesnis: atitinkamai 9 %, 4 % ir 5 % ant prototipo, palyginti su nestabiliu sėdynės maketu.

Šoninio dubens judesio metu išorinio įstrižinio pilvo raumens aktyvumas buvo 29 % ant nestabilios plokštumos, 23 % ant nestabilios sėdynės maketo ir 35 % – ant prototipo. Skersinio pilvo raumens aktyvumas ant nestabilios plokštumos buvo 43 %, ant nestabilios sėdynės maketo – 63 % ant prototipo – 86 %. Kitų raumenų: dauginių nugaros, tiesiamojo nugaros ir tiesiojo pilvo raumens aktyvumas buvo mažesnis: 6 %, 4 % ir 1 % atitinkamai ant prototipo ir nestabilios sėdynės maketo.

IŠVADOS

1. Kai pusiausvyros išlaikymo sunkumas didėja, raumenų ir smegenų aktyvumas taip pat didėja, $p < 0{,}05$. Giliųjų liemens raumenų aktyvumas padidėjo 2 kartus pirmyn–atgal kryptimis, o šonine – nuo 4 iki 7 kartų ant sėdynės bandymų stendo, lyginant su duomenimis ant nestabilios plokštumos, $p < 0{,}05$. Šis padidėjimas rodo geresnę stuburo stabilizaciją atliekant judesius ant nestabilios sėdynės maketo. Alfa ir teta bangų galios spektro tankis didėja atliekant dubens judesius ant sėdynės bandymų stendo 2 kartus pirmyn–atgal ir 1,5 karto atliekant judesius į šonus; o štai teta bangų galios spektro tankis didėja atliekant dubens judesius ant sėdynės bandymų stendo iki 3 kartų pirmyn–atgal ir šonine kryptimis palyginus su statiniu sėdėjimu, p < 0,05; tai rodo suaktyvėjusį kognityvinių ir pusiausvyros užduočių atlikimą.
2. Žmogaus anatominių taškų ASIS ir Th10 judėjimo amplitudė, atliekant judesius ant sėdynės bandymų stendo, mažesnė nei atliekant dubens judesius ant nestabilios plokštumos, $p < 0{,}05$. Judesio amplitudės sumažėjimas ant nestabilaus sėdynės maketo rodo mažesnį viršutinės kūno dalies judesį, esant geresniems elektromiografijos tyrimo rezultatams.
3. Atliekant šoninius dubens judesius ant sėdynės bandymų stendo maksimalus įtempis į tarpslankstelinį diską siekė 0,1 MPa, o štai atliekant tuos pačius judesius ant nestabilios plokštumos maksimalus įtempis į tarpslankstelinį diską siekė 0,6 MPa. Judesiai ant sėdynės bandymų stendo yra saugesni tarpslanksteliniams diskams, nes sukuria mažesnius įtempius.
4. Atliekant šoninius dubens judesius ant nestabilios sėdynės maketo dauginių nugaros raumenų aktyvumo sutapimas su skeleto–raumenų sistemos modelio

raumenų aktyvumu yra 60 %, o tiesiamojo nugaros raumens – 70 %. Aliekant judesius pirmyn–atgal ant nestabilios sėdynės maketo dauginių nugaros raumenų sutapimas siekė 93,36 %, o tiesiamojo nugaros raumens sutapimas buvo mažesnis – 80,95 %. Apibendrinant rezultatus, matomas geras sutapimas su eksperimentiniais ir modelio rezultatais; tačiau šoninio judėjimo sutapimas yra mažesnis, o tai rodo mažiau stuburo stabilizacijos šio judėjimo metu.

5. Buvo sukurtas nestabilios sėdynės prototipas, kuris leidžia atlikti dubens judesius pirmyn–atgal ir šonine kryptimi. Eksperimento rezultatai, kurių metų buvo palygintas nestabilios sėdynės prototipas su WBB, parodė tą patį kampą, atliekant šoninį dubens judesį. Priekinio dubens pasvirimo judesio metu skirtumas siekė 1° ir galinio pasvirimo metu dubens kampas buvo 3° mažesnis ant prototipo, lyginant su WBB.

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[S1; LT; OA] Aleknaite-Dambrauskiene, Ieva; Domeika, Aurelijus; Gudžiūnas, Vaidotas; Zaveckas, Vidmantas. Pilot study of wobble seat on trunk muscles activity and kinematics // Mechanika. Kaunas : KTU. ISSN 1392- 1207. eISSN 2029-6983. 2021, vol. 27, no. 2, p. 155-158. DOI: 10.5755/j02.mech.26612. [Science Citation Index Expanded (Web of Science); Scopus; Academic Search Complete] [IF: 0,597; AIF: 3,975; IF/AIF: 0,150; Q4 (2020, InCites JCR SCIE)] [M.kr.: T 009, M 005] [Indėlis: 0,250]

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1. [S1; NL] Aleknaite-Dambrauskiene, Ieva; Domeika, Aurelijus; Zvironas, Arunas. Cortical activity, kinematics and trunk muscles activity response to pelvis movements during unstable sitting // Technology and health care. Amsterdam : IOS Press. ISSN 0928-7329. eISSN 1878-7401. 2022, vol. 30, iss. 1, p. 243-255. DOI: 10.3233/THC-219007. [Science Citation Index Expanded (Web of Science); Scopus; MEDLINE] [IF: 1,285; AIF: 4,115; IF/AIF: 0,312; Q4 (2020, InCites JCR SCIE)] [M.kr.: M 001, T 007, T 009].
2. [S1; NL] Domeika, Aurelijus; Aleknaite-Dambrauskiene, Ieva; Poskaitis, Vytautas; Zaveckas, Vidmantas; Grigas, Vytautas; Zvironiene, Ausra. A pilot study on the influence of exercising on unstable training machine on balance control and trunk muscles activity // Technology and Health Care. Amsterdam : IOS Press. ISSN 0928-7329. eISSN 1878-7401. 2018, vol. 26, suppl. 2, p. S595-S604. DOI: 10.3233/THC-182506. [Science Citation Index Expanded (Web of Science); Scopus; Academic Search Complete] [IF: 0,787; AIF: 3,108; IF/AIF: 0,253; Q4 (2018, InCites JCR SCIE)] [M.kr.: T 009, M 005].
3. [S1; LT; OA] Aleknaite-Dambrauskiene, Ieva; Domeika, Aurelijus; Gudžiūnas, Vaidotas; Zaveckas, Vidmantas. Pilot study of wobble seat on trunk muscles activity and kinematics // Mechanika. Kaunas : KTU. ISSN 1392- 1207. eISSN 2029-6983. 2021, vol. 27, no. 2, p. 155-158. DOI: 10.5755/j02.mech.26612. [Science Citation Index Expanded (Web of Science); Scopus; Academic Search Complete] [IF: 0,597; AIF: 3,975; IF/AIF: 0,150; Q4 (2020, InCites JCR SCIE)] [M.kr.: T 009, M 005].

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2015–2017	Master's degree in Rehabilitation, Lithuanian University of Health Sciences.
2017–present	PhD studies, Kaunas University of Technology.

Work experience:

2015–2017	Engineer, Kaunas University of Technology, Institute of Mechatronics, Studentų St. 56-124, Kaunas.
2017–present	Junior scientific researcher, Kaunas University of Technology, Institute of Mechatronics, Studentų St. 56-124, Kaunas.
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Annex 1

KAUNO REGIONINIS BIOMEDICININIŲ TYRIMŲ ETIKOS KOMITETAS

Lietuvos sveikatos mokslų universitetas, A. Mickevičiaus g. 9, LT 44307 Kaunas, tel. (+370) 37 32 68 89;el.paštas: kaunorbtek@lsmuni.lt

LEIDIMAS ATLIKTI BIOMEDICININĮ TYRIMĄ

2020-06-17 Nr. BE-2-34

Biomedicininio tyrimo pavadinimas: „Sėdimą darbą dirbančių asmenų sveikatinimui ir darbingumo didinimui skirto įrenginio kūrimas ir tyrimai“.	
Protokolo Nr.:	**AD-3**
Data:	**2020-05-14**
Versija:	**3.0**
Asmens informavimo forma	**Versija: 4.0, data: 2020-05-14**
Pagrindinis tyrėjas:	**Aurelijus Domeika**
Biomedicininio tyrimo vieta: Įstaigos pavadinimas: Adresas:	**Kauno technologijos universitetas** Studentų g. 56, LT 51424 Kaunas

Išvada:
Kauno regioninio biomedicininių tyrimų etikos komiteto posėdžio, įvykusio **2020 m. birželio mėn. 2 d.** (protokolo Nr. BE-10-6) sprendimu pritarta biomedicininio tyrimo vykdymui.

Mokslinio eksperimento vykdytojai įsipareigoja: (1) nedelsiant informuoti Kauno Regioninį biomedicininių Tyrimų Etikos komitetą apie visus nenumatytus atvejus, susijusius su studijos vykdymu, (2) iki sausio 15 dienos – pateikti metinį studijos vykdymo apibendrinimą bei, (3) per mėnesį po studijos užbaigimo, pateikti galutinį pranešimą apie eksperimentą.

Kauno regioninio biomedicininių tyrimų etikos komiteto nariai			
Nr.	Vardas, Pavardė	Veiklos sritis	Dalyvavo posėdyje
1.	Prof. Edgaras Stankevičius	Fiziologija, farmakologija	Taip
2.	Prof. Skaidrius Miliauskas	Pulmunologija, vidaus ligos	Taip
3.	Med. dr. Jonas Andriuškevičius	Chirurgija	Taip
4.	Doc. Gintautas Gumbrevičius	Klinikinė farmakologija	Taip
5.	Prof. Kęstutis Petrikonis	Neurologija	Taip
6.	Dr. Ramunė Kasperavičienė	Filologija	Taip
7.	Žydrūnė Luneckaitė	Visuomenės sveikata	Taip
8.	Aušra Degutytė	Visuomenės sveikata	Taip
9.	Jurgita Laurinaitytė	Teisė	Ne

Kauno regioninis biomedicininių tyrimų etikos komitetas dirba vadovaudamasis etikos principais nustatytais biomedicininių tyrimų Etikos įstatyme, Helsinkio deklaracijoje, vaistų tyrinėjimo Geros klinikinės praktikos taisyklėmis.

Kauno RBTEK pirmininkas Prof. Edgaras Stankevičius

LIETUVOS SVEIKATOS MOKSLŲ UNIVERSITETAS * KAUNO REGIONINIS BIOMEDICININIŲ TYRIMŲ ETIKOS KOMITETAS

Annex 2

PATVIRTINTA
Lietuvos bioetikos komiteto
biomedicininių tyrimų ekspertų grupės
2016 m. lapkričio 15 d. sprendimu
PAKEISTA
Lietuvos bioetikos komiteto
biomedicininių tyrimų ekspertų grupės
2018 m. sausio 16 d. sprendimu

INFORMUOTO ASMENS SUTIKIMO FORMA

Biomedicininio tyrimo pavadinimas: Sėdimą darbą dirbančių asmenų elektrinio raumenų ir smegenų aktyvumo parametrų tyrimas atliekant pusiausvyros užduotis.

Protokolo Nr.: AD-3

Užsakovas: Kauno technologijos universitetas

Adresas: K. Donelaičio g. 73 Tel.: +370 (37) 300 000 El. paštas: ktu@ktu.lt

Užsakovo atstovas: Doc. dr. Leonas Balaševičius

Atsakingas tyrėjas[1]: Dr. Aurelijus Domeika

Tyrimo centro pavadinimas: KTU Mechatronikos Institutas Biomechatronikos laboratorija

Adresas: Studentų g. 56 Tel.: +370 37 300 909 El. paštas: aiste.aldakauskaite-rakutiene@ktu.lt

1. Kokia šio dokumento paskirtis?

Šioje formoje pateikiama Jums skirta informacija apie biomedicininį tyrimą, aptariamos tyrimo atlikimo priežastys, mokslinio tyrimo procedūros, nauda, rizika, galimi nepatogumai ir kita svarbi informacija. Jei nuspręsite dalyvauti, prašysime Jūsų pasirašyti šią sutikimo formą, kuria sutinkate tyrimo metu vykdyti tyrėjo ir tyrimo komandos nurodymus. Pasirašydami šį dokumentą, sutinkate dalyvauti moksliniame tyrime. Neskubėkite ir atidžiai perskaitykite šį dokumentą, jei nesupratote kokio nors žodžio ar teiginio, visus iškilusius klausimus būtinai užduokite tyrėjui ar kitiems tyrimo

[1] Jeigu tyrėjo adresas nesutampa su tyrimo centro adresu – nurodykite abu

komandos nariams. Prieš priimdami sprendimą, galite pasitarti su šeimos nariais, draugais ar savo gydytoju.

2. Kodėl atliekami biomedicininiai/ klinikiniai tyrimai?

Svarbu suprasti, kad nors biomedicininio tyrimo metu Jums bus atliekami manualiniai raumenų testavimai, testai, atmetantys neurologinę simptomatiką, jaučiantiems apatinės nugaros dalies skausmus, elektrodų klijavimai ant odos paviršiaus ir ant galvos, nepažeidžiant odos vientisumo, biomedicininis tyrimas iš esmės skiriasi nuo įprastos (kasdienės) klinikinės praktikos. Įprastos (kasdienės) klinikinės praktikos tikslas yra Jus (t. y. konkretų asmenį, pacientą) išgydyti ir/ar pagerinti Jūsų sveikatos būklę. Pagrindinis biomedicininio (mokslinio) tyrimo tikslas – gauti naujų medicinos mokslo žinių, kurios ateityje padėtų kitų lėtinį nugaros skausmą jaučiančių pacientų sveikatai. Kitaip tariant, pagrindinis šio tyrimo tikslas nėra tiesioginė nauda Jūsų sveikatai.

3.Kodėl atliekamas šis tyrimas?

Šio tyrimo tikslas – nustatyti ir įvertinti sėdimą darbą dirbančių asmenų elektrinį smegenų ir raumenų ląstelių aktyvumą, atliekant statines ir dinamines pusiausvyros užduotis. Šiuo metu gydytojai pacientams, jaučiantiems lėtinį nugaros skausmą skiria reabilitaciją, masažą ar kitą gydymą, bet nė vienas jų nėra pakankamai veiksmingas. Šis tyrimas leis nustatyti, kokios sėdėjimo padėtys darbo metu bus tinkamiausios ir sumažins lėtinį nugaros skausmą.

Iš visų rizikos faktorių susijusių su darbo aplinka, kaip pasekmė, net 37 proc. tenka nugaros skausmui, tai yra, didžiausias skaičius iš visų patiriamų pažeidimų (World Health Organization). Vienas ketvirtis dirbančių populiacijos asmenų kiekvienais metais paveikiami apatinės nugaros dalies skausmo. Net apie 77 proc. viso darbo laiko praleidžiame sėdėdami, daugiausia apie 51 proc. ilgiau nei 30 minučių (Evans R.E. et al., 2012). Todėl šio tyrimo metu bus mėginama išsiaiškinti, ar skirtingos sėdėjimo padėtys ant nestabilių paviršių bus veiksmingesnis būdas už sėdėjimą įprastoje padėtyje.

4. Kokie asmenys pasirenkami dalyvauti šiame tyrime?

Kviečiame Jus dalyvauti klinikiniame tyrime, nes dirbate sėdimą darbą ir atitinkate pagrindinius išvardytus tyrimo kriterijus. Pagrindiniai įtraukimo į šį tyrimą kriterijai yra šie: darbingas amžius; sėdima darbo padėtis, nespecifinės kilmės nugaros skausmas.

5. Kas atlieka/užsako šį biomedicininį / klinikinį tyrimą?

Šį klinikinį tyrimą atlieka Kauno technologijos universiteto doktorantė Ieva Aleknaitė-Dambrauskienė, pagrindinis tyrėjas – doc. dr. Aurelijus Domeika. Tyrimo užsakovas Kauno technologijos universitetas, jo įgaliotas atstovas doc. dr. Leonas Balaševičius.

6. Tikimybė patekti į skirtingas tiriamųjų grupes ir dalyvavimo šiose grupėse ypatybės.

Šiame tyrime bus viena tiriamųjų grupė.

7. Kiek truks Jūsų dalyvavimas šiame tyrime?

Bendra tyrimo trukmė –treji metai. Jūs dalyvausite vieną dieną, t. y. nuo pirmo vizito, kai pasirašysite informuoto asmens sutikimo formą,

8. Kokiose šalyse bus vykdomas šis tyrimas?

Tyrimas bus atliekamas Lietuvoje.

9. Kiek tiriamųjų dalyvaus numatyta šiame tyrime?

Tikimasi, kad šiame biomedicininiame tyrime dalyvaus iki 30 žmonių.

10. Ką Jums reikės daryti?

Prašysime Jūsų atsakyti į keletą Oswestry klausimyno klausimų, kurie susiję su Jūsų nugaros skausmų sukeltais apribojimais, taip pat, pasiteirausime Jūsų antropometrinių duomenų, paklausime, kaip ilgai tęsiasi patiriamus lėtiniai nugaros skausmo simptomai, koks Jūsų fizinis aktyvumas, kaip ilgai praleidžiate laiko darbe sėdėdami . Klausimyne užrašyta informacija bus koduota. Jei sutiksite dalyvauti tyrime, Jums reikės atvykti į Kauno technologijos universitetą vieną kartą. Šio vizito metu tyrėjas atliks elektromiografijos ir elektroencefalografijos tyrimą. Atliekant šiuos tyrimus nemalonių pojūčių nejausite, ji neskausminga. Elektromiografijos metu bus matuojamas raumenų aktyvumas, ant odos bus klijuojami elektrodai. Elektroencefalografijos metu ant galvos bus dedama kepurėlė su elektrodais ir po elektrodais bus pilamas nedidelis kiekis gelio, dėl geresnio smegenų aktyvumo laidumo.

Tyrimo metu bus atliekamos šios procedūros: elektroencefalografinis tyrimas, elektromiografinis tyrimas, manualinis raumenų testavimas, neurologinius simptomus paneigiantys testai, pusiausvyros užduotys. Įprastinio vizito metu pas gydytoją šios procedūros nėra atliekamos.

Raumenų ir smegenų aktyvumo matavimai trunka apie 120 min.

Tyrimo metu, matuojant smegenų ir raumenų aktyvumą, reikės atlikti pusiausvyros užduotis (stovėti ir sėdėti) ant nestabilios pusiausvyros platformos. Pusiausvyros sudėtingumas bus parenkamas kiekvienam asmeniui individualiai, todėl užduotys bus atliekamos jūsų komforto zonos ribose.

11. Ar dalyvavimas biomedicininiame tyrime Jums bus naudingas? / Kokios naudos galite tikėtis dalyvaudami šiame tyrime?

Tyrimas nėra tęstinis, jis truks apie dvi valandas ir bus skiriamas tik vienas vizitas. Todėl tiriamieji naudos gali nepajusti. Sveikata nei pagerės nei pablogės.

12. Kokia su dalyvavimu šiame tyrime susijusi rizika ir nepatogumai?

Atliekant smegenų ir raumenų aktyvumo matavimus nemalonių pojūčių nepatirsite. Galite patirti nepatogumą matuojant smegenų aktyvumo signalus, nes bus naudojami elektrodai, kurie bus pripildyti skysto gelio, todėl po procedūros galvos oda ir plaukai bus nešvarūs (aplipę geliu).

Dalyvaudami šiame tyrime galite patirti ir kitų nepatogumų, tokių kaip sugaištas laikas vykstant į tyrimo vietą ar pildant tyrimo klausimynus. Elektromiografijos metodas neskausmingas, bet lipnių elektrodų laikiklių tvirtinimo vietoje gali šiek tiek sudirgti ir parausti oda.

Jei dėl nenumatytų aplinkybių (force majore ar nenugalima jėga, trečiųjų asmenų nusikalstamos veikos ir pan.), kurios tyrėjui nėra žinomos ir kurioms įtakos tyrėjas negali daryti, konfidenciali informacija taptų prieinama tretiesiems asmenims, kuriems ją suteikti nebuvote davęs sutikimo, tyrėjas iš karto Jus apie tai informuos. Tačiau tyrėjas visais būdais stengsis užtikrinti, kad Jūsų asmens duomenys, tvarkomi šio biomedicininio tyrimo tikslu, nebūtų prieinami tretiesiems asmenims, kuriems jos suteikti nebuvote davęs sutikimo ir įgyvendins-duomenų saugumo priemones, skirtas apsaugoti asmens duomenis nuo atsitiktinio ar neteisėto atskleidimo, taip pat nuo bet kokio kito neteisėto tvarkymo.

13. Jei atsitiktų kas nors negero? (Informacija apie draudimą)

Tyrimo metu galintys pasitaikyti nežalojantys sveikatos, greitai praeinantys nepageidaujami reiškiniai (pvz., odos paraudimas, elektrodų klijavimo vietose), bus stebimi, dokumentuojami, numatytoje kompiuterinėje programoje. Papildomi tyrimai nebus atliekami jei to nereikalauja įprastinis ištyrimas. Tyrimo metu nebus pažeistas odos vientisumas, nebus imami jokie mėginiai (kraujo, seilių ir t.t.), todėl žalos tyrimo metu tiriamasis nepatirs. Finansinis kompensavimas nėra numatytas.

14. Ar galėsite nutraukti dalyvavimą tyrime?

Jei nuspręsite pasitraukti iš tyrimo šiam nepasibaigus, tyrėjas pateiks ir paprašys parašyti laisvos formos atsisakymo prašymą.

Norėtume atkreipti dėmesį, kad šio tyrimo rezultatai, t. y. tyrimo dokumentuose iki Jūsų sutikimo dalyvauti biomedicininiame tyrime atšaukimo įrašyti duomenys nebus sunaikinti, nes jie bus reikalingi tolimesniam duomenų apdorojimui ir išvadų atlikimui, dėl bendros imties dydžio negalėsime šių duomenų sunaikinti.

Jeigu dėl pablogėjusios sveikatos būklės negalėsite spręsti apie tolesnes galimybes dalyvauti tyrime, į Jūsų norą atšaukti sutikimą dalyvauti tyrime bus atsižvelgta, bet teisiškai šį sprendimą priims sutuoktinis, jeigu jo nėra – vienas iš tėvų, pilnamečių vaikų arba kitas teisėtas (Jūsų) atstovas.

Jūs turite teisę nesutikti, kad biomedicininio tyrimo tikslu toliau būtų naudojama Jūsų sveikatos informacija, gauta šio biomedicininio tyrimo metu, nenurodant priežasčių ir motyvų.

15. Jūsų dalyvavimo tyrime nutraukimo aplinkybės ir kriterijai

Jei nesilaikysite tyrėjo nurodymų ar dalyvaujant tyrime smarkiai pablogės Jūsų sveikatos būklė, Jūs daugiau nebegalėsite dalyvauti tyrime.

Tyrimo tyrėjas ar užsakovas turi teisę bet kuriuo metu sustabdyti tyrimą ar Jūsų dalyvavimą jame. Jūs nebegalėsite dalyvauti tyrime, jei neatvyksite į suplanuotus vizitus ar nesilaikysite kitų tyrėjų nurodymų.

16. Kokias pasirinkimo galimybes turėsite, jeigu nesutiksite dalyvauti šiame tyrime arba atšauksite sutikimą jame dalyvauti?

Tyrime dalyvaujate savanoriškai, todėl turite teisę atsisakyti, o pradėjęs galite bet kada iš jo pasitraukti, nenurodant priežasčių ar motyvų.

Jei sprendimas nedalyvauti tyrime Jūsų sveikatai keltų pavojų, tyrėjas paaiškins, kaip tokiu atveju geriausia elgtis.

Jūsų sprendimas atsisakyti dalyvauti ar nutraukti dalyvavimą tyrime nedarys jokios įtakos teikiamai įprastinei sveikatos priežiūrai.

17. Ar dalyvaudami šiame tyrime patirsite kokių nors išlaidų?

Už dalyvavimą biomedicininiuose tyrimuose atlygis nėra mokamas, taip pat, nebus galimybės gauti kompensaciją už patirtas išlaidas ar sugaištą laiką.

Dalyvaudami šiame tyrime negausite finansinės naudos.

18. Ar Jūsų asmens duomenys bus konfidencialūs?

Biomedicininį tyrimą atliekant gauta sveikatos informacija, leidžianti nustatyti asmens tapatybę (vardas, pavardė, gimimo data, elektroninis paštas), yra konfidenciali ir gali būti teikiama tik pacientų teises ir asmens duomenų apsaugą reglamentuojančių įstatymų nustatyta tvarka. Bus renkami Jūsų asmens duomenys: vardas, pavardė, gimimo data, elektroninio pašto adresas. Asmens duomenų valdytojas Kauno technologijos universitetas 111950581, K. Donelaičio g. 73.

Siekiant apsaugoti duomenų konfidencialumą, Jums bus suteiktas specialus kodas, kuris bus nurodomas visuose dokumentuose, išskyrus sutikimo formą. Sąrašą, kuriame Jūsų vardas ir pavardė susiejami su kodu, saugos pagrindinis tyrėjas seife, į kurį prieigą turi tik jis ir įgaliotas tyrėjas.

Kompiuteriai, kuriuose saugomi elektroniniai tyrimo dokumentai ir duomenys, apsaugoti slaptažodžiu. Prisijungimo kodus žino tik tyrėjai, šie duomenys atnaujinami kas mėnesį.

Dokumentai saugomi rakinamoje spintoje, kurios raktą turi tik tyrėjai.

Jei sutiksite dalyvauti šiame tyrime, tyrėjas ir tyrimo darbuotojai naudos tyrimui atlikti reikalingus Jūsų asmeninius duomenis. Duomenys bus renkami remiantis Jūsų pateikta informacija. . Pagrindiniai duomenys, kuriuos sieksime sužinoti jūsų vizito metu tai bus: kaip ilgai sėdite darbe, ar naudojate ergonomines darbo priemones (kėdė, stalas ir t.t.), ar jaučiate darbo metu nugaros skausmą ir kada dažniausiai pasireiškia nugaros skausmas, kaip jį įvertinate pagal skaičių skausmo skalę (SAS), koks Jūsų fizinis aktyvumas per savaitę ir kiek minučių trunka.

Atliekant šį tyrimą gauta sveikatos informacija nelaikoma konfidencialia ir gali būti paskelbta be Jūsų sutikimo, jeigu ją paskelbus nebus galima tiesiogiai ar netiesiogiai nustatyti Jūsų tapatybės.

19. Kas ir kokiu tikslu galės susipažinti su Jūsų asmens duomenimis?

Pasirašydami šią formą sutinkate, kad tyrimo centro tyrėjai, tyrimus kontroliuojančios institucijos (tokios etikos komitetai) ir įgalioti tyrimo užsakovo (Kauno technologijos universiteto) tyrimą prižiūrintys asmenys galės susipažinti su visa šio tyrimo tikslais apie Jus surinkta informacija. Kitiems asmenims ar įmonėms bus teikiami tik užkoduoti sveikatos duomenys, neleidžiantys tiesiogiai nustatyti Jūsų tapatybės. („Užkoduoti" reiškia, kad dokumentuose bus nurodomas ne Jūsų vardas ir pavardė, o specialus numeris, kurį susieti su Jūsų asmeniu galės tik tyrėjas).

Surinktus duomenis tyrėjai naudos tik šio biomedicininio tyrimo tikslais. Užsakovas užkoduotus sveikatos duomenis gali naudoti atlikdamas tyrimą, pateikdamas prašymus dėl mokslinio tyrimo, diagnostikos.

Jūs turite teisę sužinoti, kokie asmens duomenys buvo surinkti, taip pat, galite reikalauti juos ištaisyti. Bus renkami Jūsų asmens duomenys: vardas, pavardė, gimimo data, elektroninio pašto adresas. Jei nuspręsite pasitraukti iš tyrimo anksčiau numatyto laiko, tada tyrėjai apie Jus neberinks naujos informacijos, bet negalės sunaikinti iki tol surinktų duomenų, kurie svarbūs statistiniams duomenims.

20. Kiek laiko bus saugomi tyrimo metu surinkti duomenys ir kas už tai bus atsakingas?

Visa informacija bus užrašoma specialiai biomedicininiam tyrimui sudaromuose elektroniniuose ir popieriniuose dokumentuose ir tyrimo centre saugoma 10 metų pasibaigus tyrimui. Vėliau Jūsų asmens duomenys bus sunaikinti tyrimo centro nustatyta tvarka. Už dokumentų saugojimą tyrimo centre bus atsakingas pagrindinis tyrėjas.

21. Kas įvertino šį biomedicininį tyrimą? / Į ką kreiptis, jeigu iškiltų klausimų?

Dėl savo kaip tyrimo dalyvio teisių galite kreiptis į leidimą atlikti šį biomedicininį tyrimą išdavusį Kauno regioninį biomedicininių tyrimų etikos komitetą, Lietuvos Sveikatos mokslų universitetas, Mickevičiaus g. 9, LT-44307, Kaunas, tel. (8-37) 326889,el. paštas: kaunorbtek@lsmuni.lt.

Dėl savo kaip tyrimo dalyvio teisių galite kreiptis į Valstybinės duomenų apsaugos inspekcija. L. Sapiegos g. 17, Vilnius (Įėjimas iš kairės pusės) Tel. (8 5) 271 28 04, (8 5) 279 1445; Faks. (8 5) 261 94 94; El. paštas ada@ada.lt

Jei iškiltų klausimų, galite kreiptis į pagrindinį tyrėją: Dr. Aurelijus Domeika, Studentų g. 56 – 124, Kaunas, tel. +370 68630863, el. paštas: aurelijus.domeika@ktu.lt

22. Kita svarbi informacija, kuri gali turėti įtakos Jūsų apsisprendimui sutikti ar atsisakyti dalyvauti biomedicininiame tyrime.

Visa aukščiau išvardinta informacija yra svarbi, prašome ją perskaityti atidžiai, nes tai gali turėti įtakos Jūsų apsisprendimui dalyvauti biomedicininiame tyrime.

SUTIKIMAS DALYVAUTI BIOMEDICININIAME TYRIME

Aš perskaičiau šią Informuoto asmens sutikimo formą ir supratau man pateiktą informaciją.

Man buvo suteikta galimybė užduoti klausimus ir gavau mane tenkinančius atsakymus.

Supratau, kad galiu bet kada pasitraukti iš tyrimo, nenurodydama(s) priežasčių[2].

Supratau, kad asmuo, dėl kurio dalyvavimo biomedicininiame tyrime aš duodu sutikimą, gali bet kada pasitraukti iš tyrimo, nenurodydamas priežasčių.[3]

Supratau, kad norėdama(s) atšaukti sutikimą dalyvauti biomedicininiame tyrime, raštu turiu apie tai informuoti tyrėją/kitą jo įgaliotą biomedicininį tyrimą atliekantį asmenį.

Patvirtinu, kad turėjau užtektinai laiko apsvarstyti man suteiktą informaciją apie biomedicininį tyrimą.

Supratau, kad dalyvavimas šiame tyrime yra savanoriškas.

Patvirtinu, kad sutikimą dalyvauti šiame biomedicininiame tyrime duodu laisva valia.

Leidžiu naudoti asmens duomenis ta apimtimi ir būdu, kaip nurodyta Informuoto asmens sutikimo formoje.

Patvirtinu, kad gavau Informuoto asmens sutikimo formos egzempliorių, pasirašytą tyrėjo/ kito jo įgalioto biomedicininį tyrimą atliekančio asmens.

Asmuo (ar kitas sutikimą turintis teisę duoti asmuo)

					_:_
vardas	pavardė	atstovavimo pagrindas	parašas	pasirašymo data	pasirašymo laikas

Patvirtinu, kad suteikiau informaciją apie biomedicininį tyrimą aukščiau nurodytam asmeniui.

Patvirtinu, kad asmeniui (ar kitam sutikimą duoti turinčiam teisę asmeniui) buvo skirta pakankamai laiko apsispręsti dalyvauti biomedicininiame tyrime, atsižvelgiant į biomedicininio tyrimo pobūdį, taip pat įvertinus kitas aplinkybes, galinčias daryti įtaką priimamam sprendimui.

Aš skatinau asmenį (ar kitą sutikimą turintį teisę duoti asmenį) užduoti klausimus ir į juos atsakiau.

Tyrėjas ar kitas jo įgaliotą biomedicininį tyrimą atliekantis asmuo

					_:_
vardas	pavardė	pareigos tyrime	parašas	pasirašymo data	pasirašymo laikas

[2] Jei sutikimą dalyvauti tyrime duoda pats asmuo
[3] Jei sutikimą dalyvauti tyrime duoda kitas asmuo

Annex 3

Klausimynas

Prašome Jūsų užpildyti šį klausimyną. Šio tyrimo tikslas – nustatyti ir įvertinti sėdimą darbą dirbančių asmenų elektrinį smegenų ir raumenų ląstelių aktyvumą, atliekant statines ir dinamines pusiausvyros užduotis. Šį biomedicininį tyrimą atlieka Kauno technologijos universiteto doktorantė Ieva Aleknaitė-Dambrauskienė, pagrindinis tyrėjas – doc. dr. Aurelijus Domeika. Tyrimo užsakovas Kauno technologijos universitetas, jo įgaliotas atstovas doc. dr. Leonas Balaševičius.

Kodas: ____________

Gimimo data: _________m._____mėn.____d.

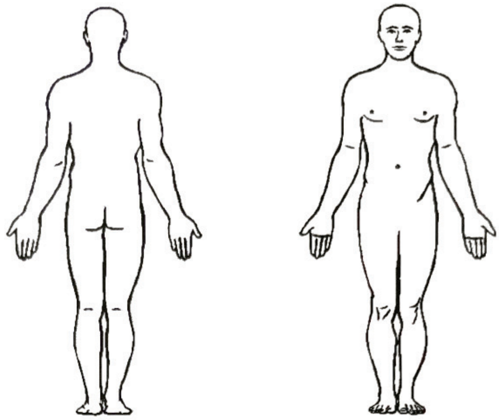
3. Ūgis _______

4. Svoris_______

5. Kiek laiko praleidžiate sėdėdami darbe?

6. Ar darbo vietoje naudojate ergonomines darbo priemones (kėdė, stalas ir t.t.), jei taip, kokias?

7. Ar jaučiate darbo metu nugaros skausmą, jei taip žmogaus kūno diagramoje užtušuokite skausmo vietą (-as) ir plotą,?



8.Kada dažniausiai pasireiškia nugaros skausmas?

9. Kaip pasireiškiantį nugaros skausmą vertinate pagal skaičių skausmo skalę (SAS)?

neskauda 0.....1.....2.....3.....4.....5.....6.....7.....8.....9.....10 stipriausias skausmas, kokį galima įsivaizduoti

10. Ar Jūs užsiimate aktyvia fizine veikla (mankšta, važinėjimas dviračiais, Pilatesas ir t.t.), jei taip, kiek kartų per savaitę tuo užsiimate?

11. Kiek minučių per dieną ir per savaitę trunka Jūsų fizinis aktyvumas?

UDK 684.434+331.101.1](043.3)

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