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Written by
Group 17gr7402

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STUDENT REPORT

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School of Medicine and Health
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Fredrik Bajers Vej 7
9220 Aalborg

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Participants:
Birgithe Kleemann Rasmussen
Ignas Kupcikevičius
Linette Helena Poulsen
Mads Kristensen

Supervisor(s)
Shellie Boudreau
Lasse Riis Østergaard

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Abstract

Preface

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Contents

Chapter 1

Methodology

This chapter is an overview of the worksheet's structure and will describe how literature is found. The purpose of the worksheet is to list the fundamental understanding and the findings from which the scientific article is formed.

1.1 Structure of the worksheet

The worksheet is divided into different chapters: Background, Aim of the project, Materials, Data processing and results. The Background chapter contains anatomy of the knee, description of pain and pain maps, knee regions, machine learning and deep learning. The knowledge of the anatomy of the knee, pain and pain maps support the understanding of patellofemoral pain and the given pain maps. Machine learning and deep learning is necessary for development of the model to process the data.

The aim of the project is presented and contains the formulated hypothesis. The description of the data and program for developing the deep learning model is written in the Materials chapter. The pre-processing is elaborated followed by the data processing and results.

1.2 Literature

The literature search has been both unstructured and structured. The unstructured searching is primary used in the beginning of the project, where the approach to the literature was wide and nonspecific. This was used to get an overall understanding of the different aspects of the project and to gather keywords which later is used in the structured searching. The structured searching is used to develop the worksheet and the scientific article. Literature is primarily peer reviewed articles or textbooks.

Chapter 2

Background

This chapter contains the background knowledge to optimise the understanding of patellofemoral pain and deep learning. The chapter is divided into the following sections: Anatomy of the knee, Pain, Pain mapping and Knee regions. Futhermore, machine learning and deep learning are specified.

2.1 Anatomy of the Knee

The knee is the largest synovial joint in the body and consists of a hinge and a gliding joint. The hinge joint is placed between the lateral and medial femoral condyles and the lateral and medial tibial condyles. The gliding joint is formed between the patella and femur. The structure of the knee is illustrated in figure 2.1.[1]

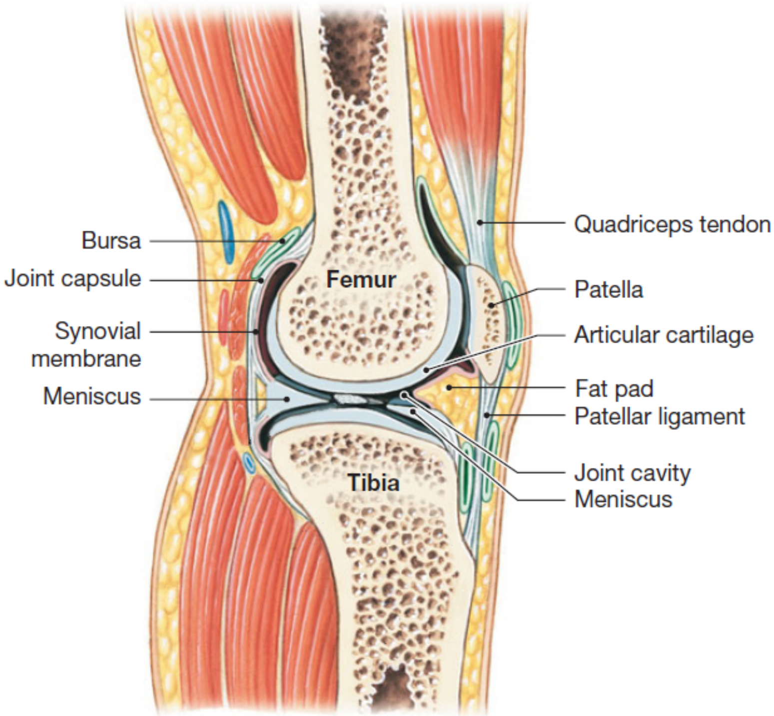

Figure 2.1: *The figure illustrates the anatomy of the knee. Edited from [1].*

It is shown in figure 2.1 that the patella is a sesamoid bone. At birth the patella consists of cartilaginous and ossifies when the child's extremities gets stronger, which typically proceeds between age two or three and the beginning of puberty.
The patella is surrounded by the tendon of the quadriceps femoris. Quadriceps femoris is the muscles which controls the extending of the knee. The quadriceps tendon is combined to the

surface anterior and superior of patella. Tibia is combined to the anterior and inferior surface of the patella by the patellar ligament. The bones, tibia and femur, are covered by articular cartilage with the purpose of protecting the bones from friction. The articular cartilage on the two bones are separated from one another by synovial membranes that contains synovial fluid, that further reduce the friction. The primary functions of the synovial fluid is to lubricate, distribution of nutrient and absorption of shock.[1]

The fat pads and menisci are placed between the articular cartilages. The fat pads' function is to protect the cartilage and fill out space as result of the joint cavity changes. The menisci stabilize the knee and acts like pads, that conform shape when femur moves. In addition to fat pads and menisci the bursa acts as friction minimization between patella and tissues.[1]
There are three separate articulations in the knee joint. The first is between the patella and the patellar surface of the femur and the rest are between the femoral and tibial condyles. Additionally, the knee consist of seven major ligaments that stabilize the knee joint, which is shown in figure 2.2.[1]

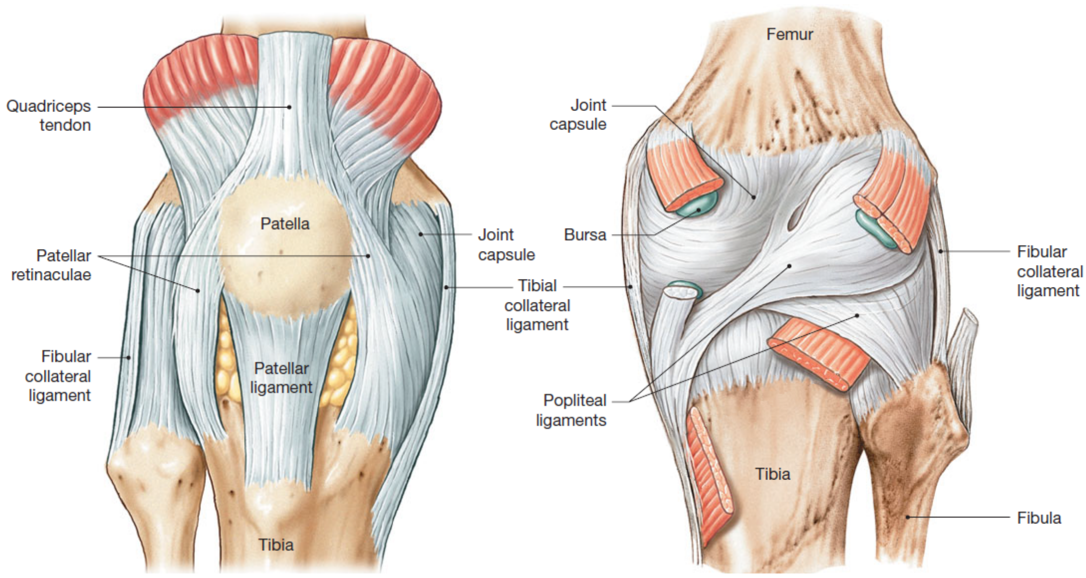

Figure 2.2: *The figure illustrates the anatomy of the knee with focus on the ligaments. Edited from [1].*

The ligaments patellar retinaculae and patellar ligament support the anterior surface of the knee. When the knee is fully extended, the tibial and fibular collateral ligament are responsible for stabilizing the joint. Between femur and the two lower bones in the leg, tibia and fibula, is the location of the two popliteal ligaments, which stabilize the posterior surface of the joint. In addition to the visible ligaments in figure 2.2 there are the anterior cruciate ligament (ACI) and posterior cruciate ligament (PCL) in the joint capsule. The two ligaments cross each other and are connected to the tibial and femoral condyles. They reduce the movement, anterior and posterior.[1]

As previously mentioned the gliding joint is formed between the patella and femur, so that during knee movement patella is gliding up and down at the femoral condyle. A condition associated with incorrect movement of the patella, is patellofemoral pain syndrome (PFPS), that occurs when the patella moves outside of its ordinary track, which for instance can be movement in lateral direction.[1]

2.2 Pain

The International Association for the Study of Pain (IASP) has defined pain as being "an unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage" [2, 3].
Humans are aware of the surroundings and threats to their bodies because of the possibility of feeling pain. The pain indicates that there might be a risk for permanent damage on the body, which refrain humans from danger and therefore increases the chances of survival. Pain can be either nociceptive or neuropathic. Nociceptive pain is associated with tissue damage. This type of pain is associated with the nociceptors, which are receptors with a high threshold that when stimulated gives the perception of pain in tissue [4]. Neuropathic is associated with damage to the nervous system. Furthermore, pain can be divided into three categories: acute pain (less than three months), persistent or chronic pain and cancer pain. [5] Additionally, the sense of pain can be divided into some qualities, which is shown in figure 2.3.

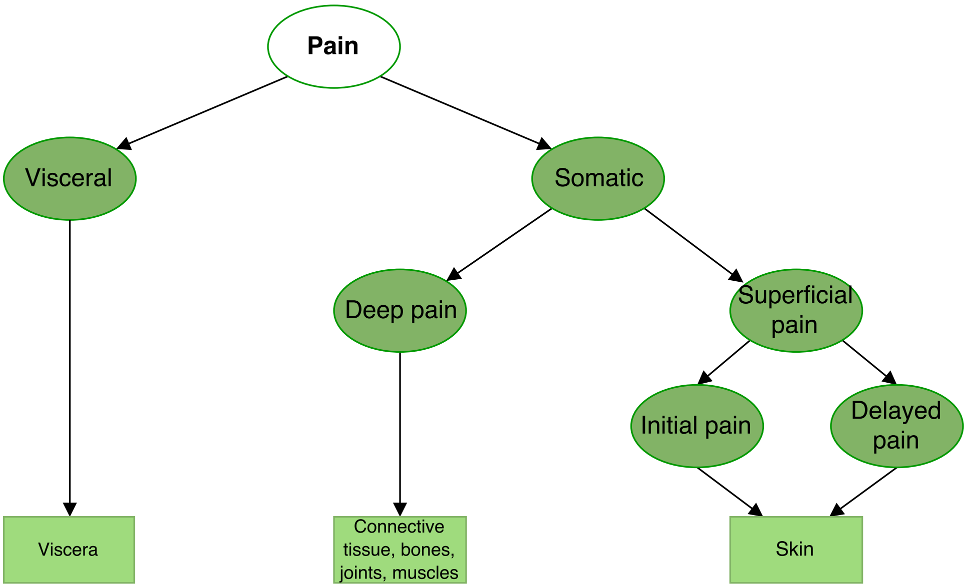

Figure 2.3: *Model of pain qualities. Ovals with green background represent qualities of pain. The rectangles show where the pain is. Edited from [4].*

The pain is divided into two qualities; visceral and somatic pain. Visceral pain is associated with e.g. gallstone pain and appendicitis. This pain can be characterised as dull or diffuse. Somatic pain is subdivided into superficial pain and deep pain. If the pain derives from the skin it is superficial pain, which furthermore is divided into initial pain and delayed pain. The initial pain is the first pain that is received, and this pain is characterised as sharp and localizable. The delayed pain, also known as the second pain, is sensed as a dull or burning pain that occur after a half to one second. This pain is more difficult to localise than the initial pain and lasts longer. [4, 3] The deep pain is associated with pain from the muscles, bones, joints and connective tissue. This pain is described as a dull pain and it radiates into the surrounding tissue, which makes the exact pain area hard to point out. [4, 3]
Since the aetiology of PFPS still remains unclear [6], is it hard to place this type of pain in addition to nociceptive and neuropathic pain. But PFPS can be divided into deep pain and acute or chronic pain. Since the PFPS often is longer than six month is it described as a chronic deep pain.

2.3 Pain measurement

There are many ways of measuring pain, but none of them are valid or reliable in terms of objectively quantifying a subjects experienced pain [7]. There is both subjective and objective methods to measure and identify pain. The subjective method is used to collect knowledge of the subjects pain intensity, behavior and how it is experienced. Whereas the objective method is used to identify the pain and find some physical damage in tissue or bones.

2.3.1 Subjective pain measurement

Pain is experienced and perceived subjectively [2, 7] and is dependent on personality and character [4], which is why it is important to measure the pain from the subject's perspective. On of the subjective methods used to measure knee pain is Knee injury and Osteoarthritis Outcome Score (KOOS), which is a questionnaire about symptoms, stiffness, pain, function daily living, function, sports and recreational activities and quality of life. When the subjects fill the scheme a score between zero and one hundred is achieved. A score at zero represent extreme knee problems, whereas a score at one hundred represent no knee problems.[8] The questionnaire can be seen in Appendix A.1.

2.3.2 Objective pain measurement

When a subject experience knee pain is the first part often a clinical examination of the knee. This examination involves i.a. provocative tests, whereas anterior and posterior drawer test, Lachman's test and pivot test examines the integrity of the ACL and PCL. Furthermore is McMurray test which test for meniscal tear.[9] Illustrations of the tests are shown in figure 2.4.

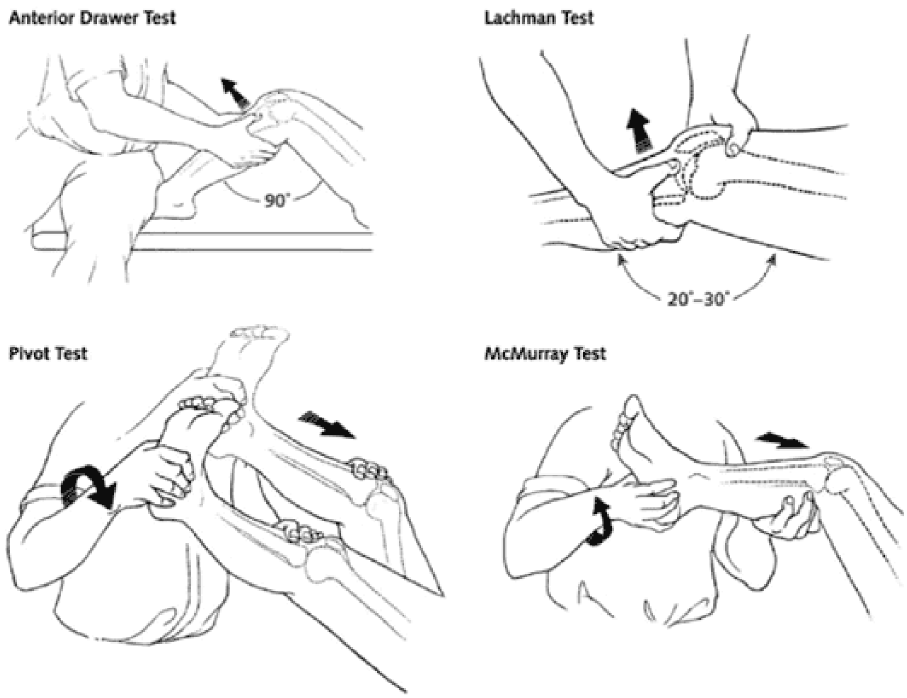

Figure 2.4: *Clinical examination with provocative tests; Anterior Drawer Test, Lachman Test, Pivot Test and McMurray Test.[9]*

In addition to clinical test is there some paraclinical test such as x-ray and MR, but PFPS does not show any structural changes in the knee [10] which makes it difficult for the healthcare personnel to treat the subjects. A method that makes it possible for subjects to describe their pain is pain mapping, which is described in the following section.

2.3.3 Pain mapping

Pain mapping is a technique, that Harold Palmer introduced in 1949 [11], which is used to transfer a patient's perceived pain into an objective graph or map by drawing the pain area. Pain drawings can be made by the patients who draw their pain areas on a display on which a body outline is shown, or it can be made by observers who observe the patients and then draw from the signs the patients are showing. An example of a body outline is shown at figure 2.5. Sometimes a questionnaire is added to the pain drawings to get a more detailed overview of the pain.[12]

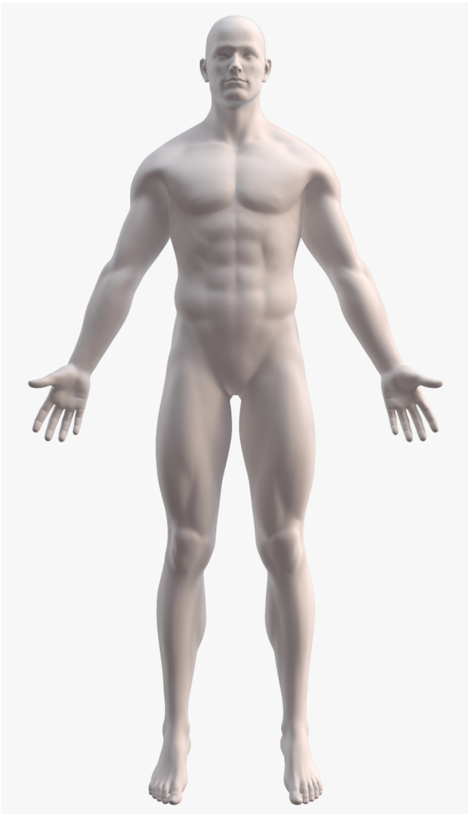

Figure 2.5: *The figure illustrates an anterior body outline for pain drawing. The figure is a screenshot from the application Navigate Pain.*

Pain mapping are commonly used in clinical practice [12], and can be useful for patients when they try to describe their pain. Pain maps may also be helpful in diagnosing patients and follow-ups during or after treatment to get an indicator of the patient's response to the treatment.[13] According to Schott there are some issues with the graphical representations of pain, some of which are problems with drawing a three-dimensional feeling of pain on a two-dimensional surface, and distinguishing between internal and external perceived pain on a map.[12]

2.4 Knee regions

Patients with PFP often describe the knee pain as a diffuse pain, and when looking at pain drawing samples from multiple patients it is also evident that there is a high variability in the distribution of pain patterns across different areas of the knee. To distinguish between different pain areas, the knee can be divided into various regions as seen in figure 2.6, where atlases of the left and right anterior knees are illustrated. The atlases has been provided by Shellie Boudreau.

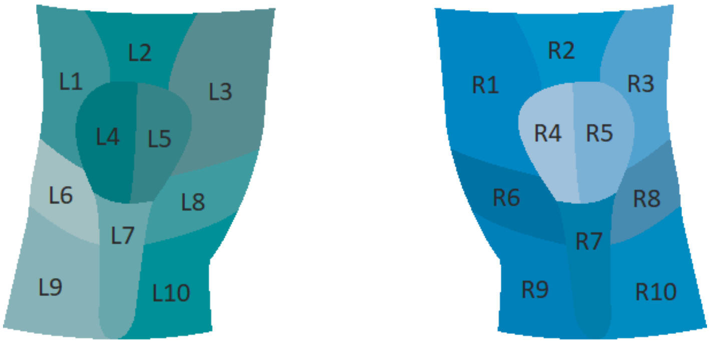

Figure 2.6: *The figure illustrates atlases of the left and right knees, where each knee is split into ten regions.*

2.5 Machine learning

Machine learning describes the use of algorithms to make a system able to identify different data types, like images or text, for transcription of speech into text, matching news items, posts or selection of relevant results of search [14]. Machine learning is a method that uses inductive inference in order to identify rules in a dataset from given input and output [15]. If the computer learns this feature, it can be used to make intelligent decisions and predict specific outcomes.[15] It is a field that has seen a lot of progress over the past decades, partially because developers recognize the ease in training a system only using examples of the desired in- and output behavior. This is simply easier than trying to manually write a piece of code that anticipate different scenarios from different input types.[16]

2.5.1 Deep Learning

Deep learning is a branch of machine learning. The main difference between the use of machine learning and deep learning, is that machine learning is not suitable for handling raw data form. Instead a machine learning system often needs a feature extractor, that will generate a feature vector from the data that can be used as an input for the machine learning system. Deep learning is based on different techniques that makes it able to handle that data in its raw form, mainly because of its structure.[14, 17] Because of this the system will automatically detect the necessary representations needed for classification and detection. Neural network is a structure of deep learning which consists of different layers, that can be divided into a input-layer and an output-layer, with one or more hidden layers in between [17]. The key aspect of these layers is that the features are not defined by programmers, but they are found and learned from raw data using a general–purpose learning procedure.[14] An example of the structure can be seen in figure 2.7.

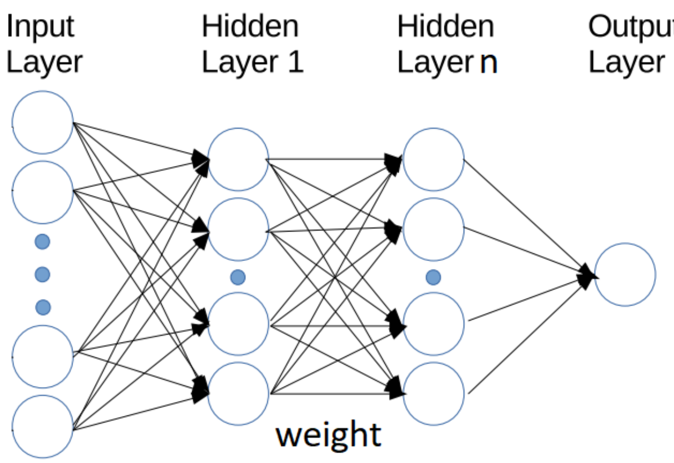

Figure 2.7: *Example of the neural network with possible layers[18].*

The different layers consist of a series of nodes, where each node is connected by weights to one or several other nodes from a different layer. In the input-layer the nodes are fed with the data that the system is given. The second layer will then receive the output from the previous layer, and this process continues through the layers until the output-layer is reached.[17] An example of how the hidden layers affect an image can be explained as follows: Firstly, the system detects minor changes like edges. Secondly, the edges are compared and put together to make up different kind of shapes. In the third hidden layer, it will be further combined to make up an object that can be identified.[14]

Learning scenarios

There are three main learning scenarios: supervised, unsupervised and semi-supervised learnings.

Supervised learning is the most common way of training in machine learning [14]. When using this method the system is trained with labeled data, where the generated output can be compared with an expected output, and thereby see how accurate the system is. The weights are interconnection between two layers and they work as a set of coefficients, defining an image feature.[19] By adjusting weights in the neural network it is possible to fit the model better to the training data, and thereby increase its accuracy and reduce error [14]. Supervised learning is mostly associated with classification, regression, and ranking problems [20]. Differently from supervised learning the input in unsupervised learning is received with unlabeled data and the predictions. Then the system organizes the data by searching for common characteristics [20]. An example of an unsupervised learning algorithm is clustering, where the unlabeled dataset goes through a classification, and split into different classes.[21] In semi-supervised learning the learner is receiving both labeled, unlabeled data and then it searches for common characteristics in data. It is used mainly when the labeled data is hardly collected and unlabeled data is easily reachable.[20]

2.5.2 Convolutional Neural Networks

Convolutional neural networks (CNNs) perform highly in several tasks, including digit recognition, image classification and face recognition. The key aspect of CNNs is to automatically learn a complex model by extracting visual features from the pixel-level content. CNNs are feed–forward models that map input data with a set of suitable outputs. Accuracy and performance rely on large training datasets and training procedure based on back-propagation with optimization algorithm such as gradient descent which is used for finding minimum value of the function.[18]

Back-propagation

Back–propagation is a popular learning algorithm in CNN. It is valuable because of the simplicity and computationally efficient [22]. The basic idea behind it is to minimize the overall output error as much as possible during the learning stage. This algorithm process is divided in two main stages: forward and backward. In the first process (forward), the back-propagation architecture is described as the inputs and weights multiplication of each node (separate input) summed with additional coefficients called biases.[19]

In the backward process, weights will be updated to minimize the error between input and output layers. This process will be applied until optimal weights with minimum error is reached.[19]

Chapter 3

Aim of the project

In this project the focus is patellofemoral pain and how accurate the duration of the pain can be predicted by using different methods. PFP occurs as diffuse knee pain which makes it hard for patients to explain and point out the precise pain area. Furthermore it is hard for healthcare personnel to interpret and give a treatment for the condition. Since the pain is perceived as diffuse and seems very different from subject to subject, it is assumed that the data is non-linear. To compensate for the differences in pain maps it is chosen to superimpose an atlas of the knees to the pain maps to help define the different pain regions with labels. Here it is believed that a better prediction, regarding duration of the syndrome, can be made with the use of a neural network than the use of a more ordinary methods. The reason for this belief is because of the subjective element in the data, where patterns may be best discovered by trying to let the system itself extract the nessesary features from which the predictions is made. Based on this the following hypothesis is formulated.

Hypothesis: *It is hypothesized that deep neural network performs more accurate than a simple correlation, when predicting the duration of patellofemoral pain from active pain regions.*

Chapter 4

Materials

Materials contains a describtion of the given data of PFP subjects and which program is used to form the deep learning model to predict the duration of the PFP.

4.1 Data

Data used in this project were collected beforehand. The data consists of pain maps which were drawn by subjects with PFP through the use of an application Navigate Pain in a clinical setting. The data contained information regarding the subjects in terms of i.a. age, gender, height and weight. For each individual subject information related to the PFPS was also collected, regarding the duration of PFP and which knee was the most prominent for pain. The number of samples available during this study was collected from ??? subjects with PFP. An example of a pain drawing can be seen in figure 4.1.

Figure 4.1: *Pain drawings of the lower extremities. The red markings indicate the area of pain perceived by the individual subject. In this case the PFP is bilateral (on both knees).*

4.1.1 Navigate Pain

Navigate Pain is an application that is used to visualise the location, shape and spatial distribution of pain from patient to healthcare personnel. The application permits subjects to draw their pain into a body outline with different colors and line thickness. Navigate Pain is developed by Algance Solutions within Aalborg University in Denmark.[23] Figure 4.2 illustrate the process using the application.

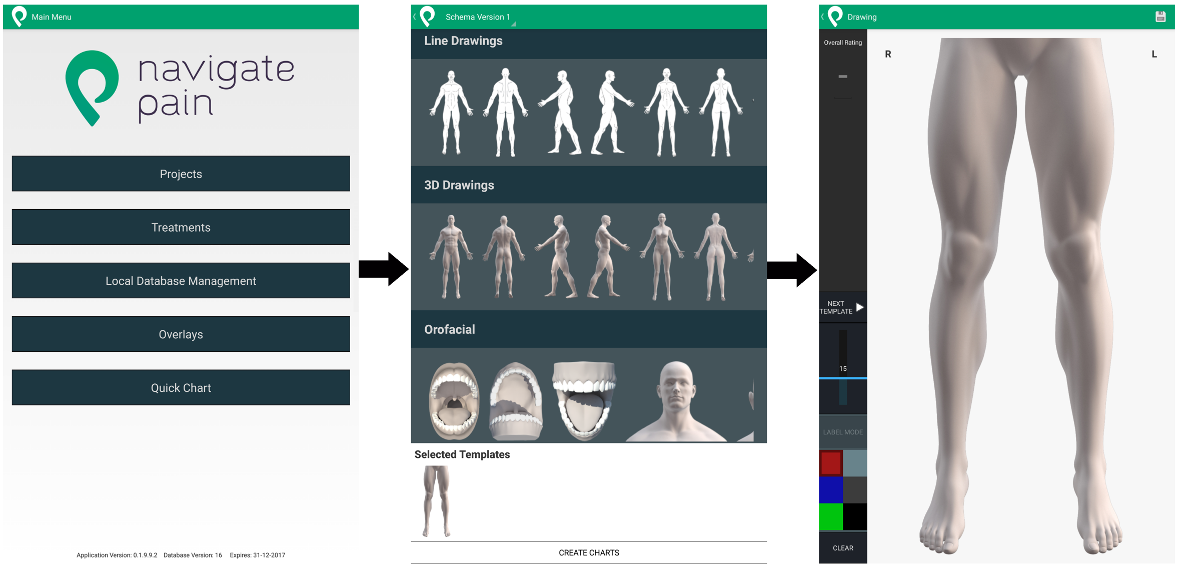

Figure 4.2: *The figure illustrates the process for making a pain map with Navigate Pain. There is three screenshots of the application.*

The left screen in figure 4.2 is the main screen. By clicking on "Project" a folder with subjects is created. From each subject information like name, age, height is saved. Before the subject can draw their pain areas, the body outline has to be chosen, which illustrates the screen in the middle. The body outlines is divided into five categories: Line Drawings, 3D Drawings, Orofacial, Special Zooms and Knee Pain. In the bottom the seleceted templates is shown. When clicking on "CREATE CHARTS" the right screen is shown. Here it is possible to draw the pain areas with different colors and line thickness, which can be seen in the left side of the screen. Afterwards the pain map can be saved.

4.2 Programs

In this project it is chosen to use Python v3.6.3 for development of the neural network. Python is an object-oriented and general-purpose programming and scripting language. Python is among other things used for programming websites, mobile applications, desktop GUI's, but also used for machine learning programming. When developing a machine learning application, there are different libraries that can be used, where some of the most popular is the Theano and the TensorFlow libraries.[24]

In this project the TensorFlow v1.3.0 library has been used. TensorFlow is an open source library for development of machine learning applications, that has been released by Google [24].

maybe something about keras... if we are gonna use it. Keras is a high-level neural network library, that runs on top of either TensorFlow or Theano. Keras is a simplified version of the two libraries, which makes it easier to program in Python, but still allows for building complex models.[24]

Chapter 5

Data Processing

** REMEMBER TEXT! **

5.1 Pre-processing

The data is pre-processed in MatLab, where pain maps are superimposed onto the knee regions. When importing pictures into MatLab a matrix is created. The pain map is converted into a matrix consisting of zeroes and ones, where the pain is symbolised with ones. Since the knee regions shown in figure 2.6 is a picture with three layers consisting of RGB colors, the picture is divided into three matrices, that enables the regions to be labeled in a new matrix. The two matrices, pain map and the labeled knee regions, are superimposed, which results in a matrix with only zeroes and the regions with pain. An illustration of the pre-processing step is shown in figure 5.1.

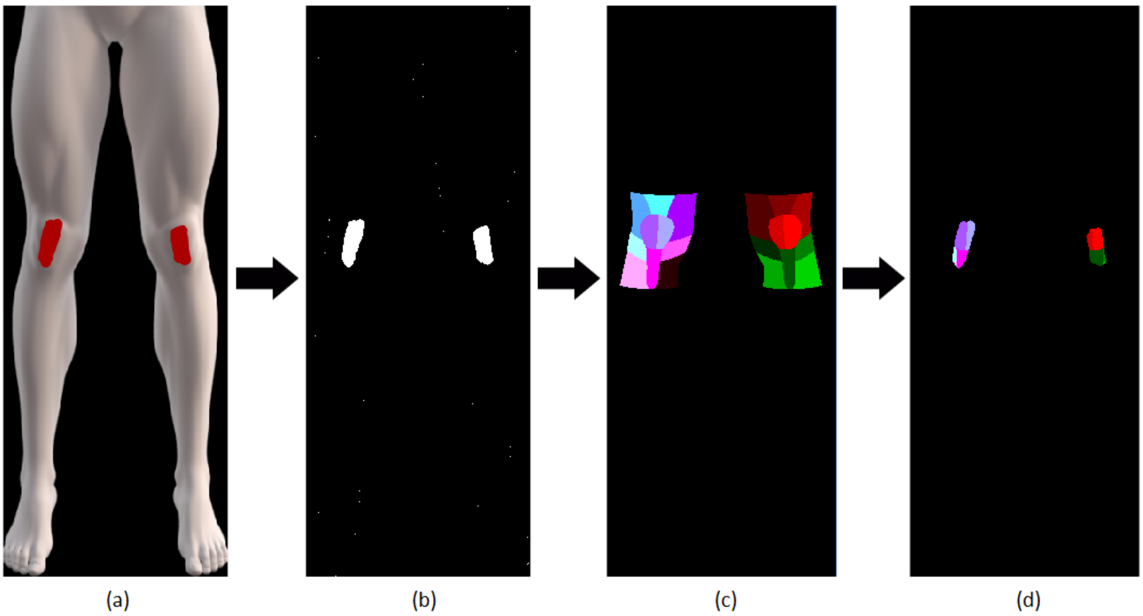

Figure 5.1: *The figure illustrates the pre-processing step. (a) is the raw pain map, (b) is the matrix of pain, (c) is the pain regions and (d) is the active pain regions.*

Figure 5.1(a) is the raw pain map, and (b) is the pain transferred to a matrix consisting of zeroes and ones, which is shown as black and white, where white areas are ones in the matrix. In figure 5.1(b) is there white spots, these spots is removed with a filter. Figure 5.1(c) illustrates the pain regions, each region is colored in relate to the set label, which permits the comparison of the pain and regions, that is shown in figure 5.1(d).

Chapter 6

Results

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Appendix A

Appendix

A.1 Appendix I