Article Title

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December 20, 2017

Abstract

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I. INTRODUCTION

Patellofemoral pain syndrome (PFPS) is a painful musculoskeletal condition that is presented as pain behind or around the patella [1, 2]. PFPS affects 6-7 % of adolescents, of whom two thirds are highly physically active [3]. Additionally the prevalence is more than twice as high for females than males [3, 4]. PFPS may be present over a longer period of time where a high number of individuals experience a recurrent or chronic pain [5] and may also lead to osteoarthritis [4, 6].

Patellofemoral pain (PFP) is often described as diffuse knee pain, that can be hard for individuals to explain and localize [5]. Despite the fact that individuals feel pain in the knee, there is no structural changes in the knee such as significant chondral damage or increased Q-angle. Because of this there is no definitive clinical test to diagnose PFPS and it is thereby often diagnosed based on exclusion criterias [4] to which PFPS is also described as an orthopaedic enigma, and is one of the most challenging pathologies to manage [7]. To assist diagnosis of PFPS, pain maps may be used as a helpful tool for the individuals to communicate their pain by drawing pain areas on a body outline [8].

Another method to measure pain is visual analog scale (VAS), that scores pain intensity between no-pain to the worst pain imaginable [10]. A study by Boudreau et al. shows that through the use of pain maps it is possible to find a correlation between the symptom duration and the size as well as morphology of pain area in individuals with a symptom duration longer than five years. Furthermore a correlation between pain intensity and the size of the pain was found.[9] It is a known problem that chronic pain is considered as multidimensional, because the perceived pain of an individual is influenced by biomedical, psychosocial and behavioral factors [?].

Because there is a lack of knowledge in the area of PFP, and it has been shown that there is a correlation between pain maps and symptom duration as well as pain intensity, it is interesting to investigate if pain maps can be used to classify and predict PFP related information.

A method that has not been found used in this context before is deep learning. The deep learning method is chosen for this study because it is a state-of-the-art method, that has shown greater performance in specific computation fields, compared to other ma-

chine learning methods [11]. Furthermore, the method is chosen because of its ability to find non-linear connections between input and output data [11], which is found relevant for this study mainly based on the fact that pain is subjective and may be affected by the multidimensionality of chronic pain.

The goals of this project is to explore how accurate a deep learning model can classify pain maps according to symptom duration and pain intensity by using a limited dataset. Because of the imbalance in prevalence between females and males, the gender is included as a feature in the deep learning model. Furthermore, morphology of the pain is considered to be relevant, based on the indication that morphology and size of pain area increase with prolonged symptom duration. To accommodate the difficulty of localizing pain related to PFP, the pain is divided into different knee regions. This might indicate whether regions has a relation to either symptom duration or pain intensity. To investigate the influence of morphology and location of the pain, three types of pain map representations are created: a binary representation which reflect the morphology, a simplified representation of morphology based on knee regions that give information about the pain location, and a combined representation that contains the morphology divided into knee regions.

The aim of this study is to explore classification performance of a deep learning model, using PFP pain maps and gender as input to classify either symptom duration or pain intensity.

It is hypothesized that a deep learning model that uses pain maps and gender as input parameter has a higher performance when classifying according to symptom duration than pain intensity.

The secondary aim is to investigate if multiple pain map representations, which reflect the morphology and location of the pain, affect the deep learning model classification performance.

It is hypothesized that different data representations of pain maps, reflecting morphology and

location of pain, affect the performance accuracy of a deep learning model when classifying according to symptom duration or pain intensity.

II. Methods

Data and manual data handling
Data used in this study were collected beforehand from an on-going FOXH trial which is conducted in collaboration with Danish and Australian universities. The data consists of pain maps which were drawn by individuals with PFPS through the use of an application, Navigate Pain, in a clinical setting. The pain maps are both from individuals with uni- and bilateral PFP, an example of these are shown in figure 1.
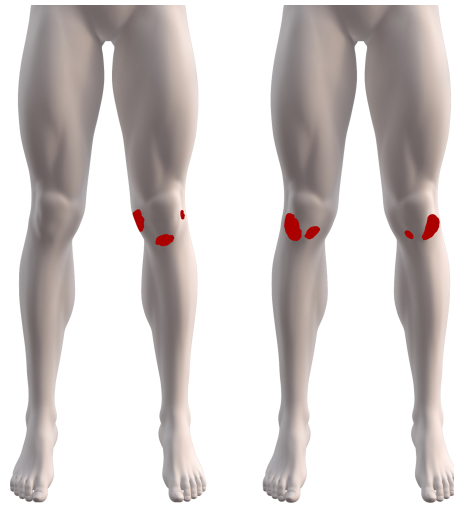

Figure 1: *Pain maps of the lower extremities from individuals with uni- and bilateral PFP. The red markings indicate the area of pain perceived by the individuals.*

In addition to the pain maps appurtenant information was available, which contained information regarding the individuals. Before using the data in the deep learning models, a manual data handling was necessary. This incorporated matching the given pain maps and appertaining ID regarding the individuals, which resulted in 217 available pain maps. Furthermore, specific information like gender, symptom duration and pain intensity were

collected from the appurtenant information. The number of pain maps with associated information, gender and symptom duration, was 205. Additionally, there were 197 pain maps with associated information, gender and pain intensity.

Software application: Navigate Pain

Navigate Pain is a software application that is used to visualise the location, shape and spatial distribution of pain from individuals to healthcare personnel. The application permits individuals to draw their pain into a body outline with different colors and line thickness. Navigate Pain android was developed at Aalborg University and a commercial web application is available at Aglance Solutions (Denmark).[12]

Data representations

It is presumed that different representations of the pain maps affect the performance accuracy of a deep learning models, which is why different data representations are created. A study by Boudreau et al. found a correlation between a prolonged symptom duration and the size of the pain area. It was shown that the pain area increased for individuals that have a symptom duration for longer than five years compared to those with a symptom duration below. Likewise, pain intensity had a correlation with the size of pain area for individuals. Furthermore, the morphology of the pain developed from a U-shape to an O-shape for individuals with a symptom duration above five years.[9]
Based on this study the morphology of PFP is considered to be relevant to investigate, and therefore the morphology constitutes a data representation.
The PFP is often described as diffuse pain and therefore difficult to describe and localise [5]. To accommodate this is it chosen to divide the pain into different knee regions, which may indicate whether a specific region of the knee influence the PFP. This is converted to a simplified data representation that indicate active pain regions. A combination of the morphology and location of the pain constitutes third

data representation. Furthermore, gender is an interesting parameter to use as an input, because the prevalence is more than twice as high for females than males. Thereto, perceived pain is subjective and depends on the individual's character and personality. The distribution of gender is investigated by creating a histogram, which showed that the prevalence is higher for females than males, given that females constitute 156 of the 206 individuals.
It is chosen to classify the three data representation in proportion to symptom duration, based on the study by Boudreau et al. which indicated that symptom duration seems to affect the size and morphology of the pain area. Furthermore the study showed that there was a correlation between pain intensity and size of pain area, which is why it is chosen to classify pain maps according to pain intensity. The three data representations are referred to as morphology-, regions- and combined-representation.

Knee regions

Patients with PFPS 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, where the division of the left and right anterior knees are illustrated.
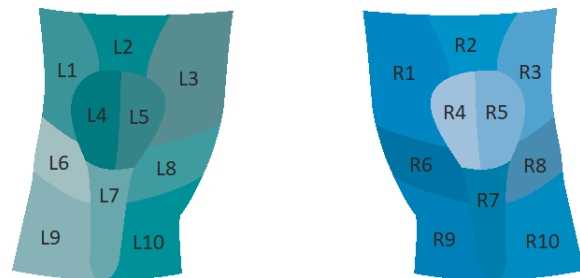

Figure 2: *The regions of the left and right knees, where each knee is split into ten regions.*

The divisions is inspired by Photographic Knee Pain Map (PKPM) which is designed to cate-

gories location of knee pain, diagnostic and research purposes. PKPM represent both knees that makes it possible to identify unilateral and bilateral pain.[13]

The regions are based on the anatomic structures according to the areas where individuals often indicate pain. There is ten regions, where region 1 and 3 represent the superior lateral and superior medial areas for patella. Region 2 refers to quadriceps tendon. The patella is divided into lateral and medial regions, which are region 4 and 5. Region 6 and 8 are lateral and medial joint line areas. Patella tendor is region 7 and the two last regions, 9 and 10, are tibia lateral and medial.[13]

In relation to the regions-representation, it is necessary to find a threshold that decides when a knee region contains enough pain pixels to be considered active. A threshold is required to increase the confidence of an active pain region by avoiding minimal contributions e.g. small pain areas in the associated regions. Simultaneously the threshold may not be too large so that potential pain regions will not be incorporated. The threshold to indicate active pain regions is decided based on an analysis, where threshold values of 0, 5, 10 and 15 percent are tested. The analysis of the threshold is tested on five random pain maps to get a general impression of the data. Based on analysis of the five pain maps is 5 percent chosen as the threshold, that defines when a pain region is active.

Pre-processing of data
The data is pre-processed in MatLab to prepare it to the three different deep learning models. Each model has an appurtenant data representation which are prepared in three different ways. In general are the pain maps resized, since it was collected at different resolutions (screen sizes) and cropped to sort out unnecessary data like the areas inferior and superior to the knee. Each data representation is reflected in a matrix consisting of the pain maps, gender and the output, symptom duration and pain intensity. The morphology-representation

is not further processed before using it in the models. The regions-representation is a simplified representation of morphology of the pain and reflects only the active pain regions. Thereto is a threshold used to define when a region is active. The third data representation is a combination of morphology- and regions-representations, which means that the matrix reflects the morphology of the pain in each region.

III. Results

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IV. Discussion

Discussss

V. Conclusion

conclusionnnnn

References

[1] Liam R. Maclachlan, Natalie J. Collins, and Et.al. The psychological features of patellofemoral pain: a systematic review. 2017. doi: 10.1136-bjsports-2016-096705.

[2] T.O. Smith, B.T. Drew, and Et.al. Knee orthoses for treating patellofemoral pain syndrome (review). 2015. doi: 10.1002/14651858.CD010513.pub2.

[3] M. S. Rathleff, B. Vicenzino, and Et.al. Patellofemoral Pain in Adolescents and adulthood: same same, but different? 2015. doi: 10.1007/s40279-015-0364-1.

[4] Wolf Petersen, Andree Ellermann, and Et.al. Patellofemoral Pain Syndrome. *Clinical Orthopaedics and Related Research*, 2013. doi: 10.1097/01.blo.0000229284.45485.6c.

[5] Erik Witvrouw, Michael J. Callaghan, and Et.at. Patellofemoral Pain: consensus statement from the 3rd International

Patellofemoral Pain Research Retreat held in Vancouver, September 2013. 2014. doi: 10.1136/bjsports-2014-093450.

[6] Kay M. Crossley, Michael J. Callaghan, and Et.al. Patellofemoral pain. 2016. doi: 10.1136/bjsports-2015-h3939rep.

[7] Scott F Dye. Patellofemoral Pain Current Concepts: An Overview. *Sports Medicine and Arthroscopy Review*, 2001.

[8] Shellie A. Boudreau and Susanne et.al Badsberg. Digital pain drawings: Assessing Touch-Screen Technology and 3D Body Schemas. 2016. doi: 10.1097/AJP.0000000000000230.

[9] Shellie A. Boudreau, E. N. Kamavuako, and Et.al. Distribution and symmetrical patellofemoral pain patterns as revealed by high-resolution 3D body mapping: a cross-sectional study. 2017. doi: 10.1186/s12891-017-1521-5.

[10] Mathias Haefeli and Achim Elfering. Pain assessment. 2005. doi: 10.1007/s00586-005-1044-x.

[11] Yann LeCun, Yoshua Bengio, and Geoffrey Hinton. Deep Learning. *Nature Insight Review*, pages 436–444, 2015. doi: 10.1038/nature14539. URL `https://www.nature.com/nature/journal/v521/n7553/pdf/nature14539.pdf`.

[12] Aglance Solutions. Visual insight for clinical reasoning – Navigate Pain, 2015. URL `http://www.navigatepain.com/`.

[13] D. W. Elson, S. Jones, and Et.al. The photographic knee pain map: Locating knee pain with an instrument developed for diagnostic, communcation and research purposes. 2010. doi: 10.1016/j.knee.2010.08.012.