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Design, implementation and evaluation of a fitness application to aid in compliance and correctness of home exercises for back pain using PoseNet

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Abstract

Background: Back pain has a high prevalence. It is costly for both the patient and the health system. Exercise therapy is the most prescribed treatment for back pain. Compliance is a serious issue with back pain exercises performed at home. This paper aims to design, evaluate and implement a web application to help with the compliance and correctness of back pain using the machine learning model PoseNet. **Methods:** A Google search was completed to identify which exercises are most prescribed by physiotherapists. 20 programs were studied and the most commonly used exercises were tabulated. PoseNet was tested for 4 outfits, 11 poses, 3 brightness levels and 6 different backgrounds. 105 images were taken and fed into PoseNet to evaluate its ability to correctly locate 17 body parts. The application was developed using web technologies: HTML, CSS, JavaScript, PHP, MySQL and several libraries. **Results:** The exercises found in more than 5 programs were: Bridge, Arm and Leg Lift, Back extension, Plank, Crunch, Side Plank and Squat. In the PoseNet evaluation it became clear that the model is extremely robust towards clothes, backgrounds and brightness. However, camera quality and body poses have a big effect on the pose estimation. A prototype web application using the squat as an exercise was implemented. The application provides the user with an index page, exercise program page, how to page, start exercise page, history page and logout. Once in the exercise, the application uses the coordinates of the body parts, calculates angles and displays guidelines and an avatar which change colour and position according to the correctness of the execution. All the critical information obtained during the exercise is saved automatically and displayed in a graph in a history page. **Conclusion:** PoseNet needs to be retrained or another model needs to be used to include exercises which are executed on the floor. Otherwise the application provides a promising step towards improving the correctness of exercise execution and solving the compliance problems encountered in back pain treatment, without the cost and hassle of some of the currently available solutions.

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List of Abbreviations

2D	2-dimensional
3D	3-dimensional
AGR	Aktion Gesunder Rücken
ANN	Artificial neural networks
API	Application programming interface
BdR	Bundesverband deutscher Rückenschulen
CNN	Convolutional neural networks
CPU	Central processing unit
CSS	Cascading style sheets
DAC	Directed acyclic graph
DBMS	Database Management System
DEGAM	Deutsche Gesellschaft für Allgemeinmedizin und Familienmedizin
FTP	File Transfer Protocol
GIMP	GNU Image Manipulation Program
GPU	Graphics processing unit
HTML	Hyper Text Markup Language
IP	Internet Protocol
LBP	Lower Back Pain
NHS	National Health Service
NN	Neural networks
PHP	PHP Hypertext Pre-processor
RGB	Red, Green, Blue
UI	User Interface

1 Introduction

Back pain has a high prevalence.[1] Results from a statistical questionnaire about the frequency of back pain in Germany from 2017, showed more than 83% of the population having back pain at least once a year and 10% of the population complaining about daily back problems.[2] It is expensive for both the individual and the health system,[3] costing Germany 4.494 Billion euro in 2015 according to Destatis.[4] Back pain affects families, causes disability, participation restriction and is a career burden.[3] In 2018 back pain constituted to 5,3% of the sick days in Germany, an average of nearly 0,8 sick days are taken per person per year due to back pain.[5] Back pain is a multifactorial problem, having many influencing factors including genes, lifestyle and environmental factors. The exact causes of individual cases are often unknown, making the correct treatment for back pain difficult to select.[6,7]

When comparing exercise to other types of treatment it is shown to improve back pain more effectively in terms of pain and function.[8,9] As a result, patients are often given exercise plans to carry out at home.[10] Exercise plans which are personalised and have regular follow ups appear to be most effective.[11] Compliance plays a huge role in the effectiveness of an exercise plan.[11,12] Unfortunately, in a review paper by Beinart et al it was found that between 50% and 70% of patients do not comply to their given exercise plans. Compliance was defined as ”the extent to which a person’s behaviour corresponds with agreed recommendations from a healthcare provider”.[11]

Compliance in home exercise plans is difficult to monitor and control.[11,13,14] More than 90% of Germans are internet users.[15] As a result, web applications and cell phone applications have become more and more part of healthcare and are shown to improve compliance and result in greater functional improvements when compared to paper handouts.[16] The success of such applications could be due to the use of a mobile phone or laptop being more convenient and motivating and that a history of the completed exercises and the knowledge that the patient’s personal trainer can monitor his progress could increase compliance.[16,17] Due to the large number of people having access to computers and the internet, these applications have great potential to reach a large population, especially those with limited access to healthcare information and interventions.[17] Most applications however require the user to input the exercises which he has completed, this is not only time consuming but can also result in incorrect data.

Pose estimation, estimating the position of the human body parts in an image or video, is a subcategory of machine learning artificial intelligence and has been studied for the past few decades. It is a crucial step towards understanding people in images and videos and using this in medical applications.[18] Through machine learning one can produce applications that use everyday cameras, from laptops or cell phones, to obtain information about the exercises that a user completes in terms of frequency and correctness. This eliminates the somewhat biased step of the user filling this information out. PoseNet is a machine learning model which allows for real-time human pose estimation in the browser. PoseNet runs on tensorflow.js, which enables on-device machine learning inference with low latency and a small binary size. It can therefore work in the browser. PoseNet uses an RGB image as its input. This is fed through a convolutional neural network and in the single pose decoding algorithm outputs the 2-dimensional (2D) positions of 17 body parts as well as corresponding certainties.[19]

1.1 Research Goal

This master thesis aims, using PoseNet and user interface guidelines, to design a web application to help with compliance and correctness of home exercises for back pain. The positions of the body parts are used to calculate the correctness of an exercise. The application is then able to guide the user to perform his exercises correctly, in terms of posture and frequency. The application stores and displays this information in order to see how often the user is exercising and where the user is going wrong in his program.

2 Background

2.1 Medical background - Back pain

Back pain is one of the biggest health problems in Germany in terms of prevalence and cost.[1,4] It is found in all genders, in all age groups and in all social classes. Back pain is the term used to describe pain in all areas of the back regardless of the pain intensity and cause. There are different names given to back pain depending on its location: neck pain, middle back pain and lower back pain (LBP). Neck pain is found in the cervical spine region, middle back pain is found in the thoracic spine region, and LBP is found in the lumbar spine region. LBP is the most common type of back pain. There are many classifications of the severity of the pain, the Deutsche Gesellschaft für Allgemeinmedizin und Familienmedizin (DEGAM) uses the following criteria: Acute back pain occurs after at least six months without symptoms and lasts for no longer than 3 months. Acute back pain that lasts for longer than 6 weeks is named subacute. Finally, chronic back pain lasts for longer than 3 months.[20]

2.1.1 Aetiology of back pain

The cause of back pain is extremely complex and only partially understood. It is commonly separated into two groups, specific and non-specific. Specific back pain means that the cause is medically diagnosable. Examples of such causes include root compressions, vertebral fractures, spinal stenosis, tumours and inflammatory diseases. Specific back pain only accounts for roughly 10-15% of cases of people with back pain. The rest of the back pain cases are non-specific, accounting for roughly 85-90%. Non-specific, as the name suggests, means no specific cause is found. Not being able to identify the cause makes it extremely difficult to find or prescribe general preventative and therapeutic treatments that work for everybody.[20]

2.1.2 Treatment for back pain

There are many treatments prescribed for back pain, they include the following: exercise therapy, manual therapy such as spinal manipulation/mobilisation, massage, back schools and brief educational interventions/advice to promote self-care, cognitive-behavioural treatment methods, multidisciplinary interventions, pharmacological procedures such as antidepressants, muscle relaxants, opioids, invasive procedures such as acupuncture, injections and nerve blocks, epidural corticosteroids and spinal nerve root blocks with steroids, facet injections, intradiscal injections, trigger point injections and surgery.

Exercise therapy is the most common and it is the recommended treatment according to the European guidelines for the management of chronic nonspecific low back pain. The guideline does not however recommend a specific exercise. According to the guideline the exercise should be decided on by both the therapist and patient together, depending on preferences, abilities and expectations.[21,22,23]

2.1.3 Exercise therapy

Exercise programs which are deemed to be beneficial for the treatment of back pain include strength exercises, flexibility or aerobic exercises and stabilization exercises. These exercises can take place in a standing, sitting or lying position.[24]

It is difficult to say what the most beneficial exercise is. Several randomized control trials failed to find evidence that any one exercise in either of the categories stability, strength or stretching is more beneficial than another in the long run.[22] A review by Smith et. al. notes that the high variability, i.e. differences in the duration of the exercises, methods of measuring pain intensity, scale of pain intensity, progression criteria, duration of treatment and follow-ups, prevent comparison of the effectiveness of different exercises. A unified terminology for all the variables being evaluated is required.[25]

Until better randomized control trials are available, personalised training plans agreed on by both the therapist and the patient work best. These training plans should take the preferences, expectations and abilities of the patient into account.[22, 24, 25, 26, 27]

2.1.4 Home training and Patient compliance

Personalised exercise plans are usually introduced by the trainer or physiotherapist in his office where the trainer shows the patient the exercises and explains how they need to be executed. This can take place in one or several sessions. The patient should then be able to do the exercises alone by the end of the session/s so that he can continue them at home.[28]

Compliance refers to the degree to which the patient follows healthcare instructions.[11,12] Compliance to exercise plans is unfortunately a very big problem worldwide. A lack of compliance usually means that the treatment is not successful which is both a health and a cost problem. Studies show that it would be far more effective to focus on improving the compliance of patients as opposed to trying to improve the prescribed treatment. In order to ensure that compliance is maintained or even improved, regular follow ups and trainer supervision are necessary, which cost time and money.[12, 22]

It is difficult to find out why patients are not compliant. There are many variables that are not necessarily comparable and research often lacks important information about how the intervention was executed. A randomised control trial (RCT) is needed where a validated measure of compliance is defined.[11] To add to this, studies on compliance often rely on the patient himself to provide information on how often the patient did his exercises and his opinion of how well the exercises go. This is unfortunately often biased. Important information on the treatment of back pain could be learnt if compliance was better understood.[27,28]

2.1.5 Technology helping with compliance of home exercises

Technology e.g. in the form of sensors or software applications, that gather unbiased data and provide history summaries could help the therapist encourage and supervise the patient more closely. Additionally, researchers could incorporate such applications into randomised control trials to determine compliance problems and exercise effectiveness.[16,17]

2.2 Technical Background - Web application

Web applications do not require installation. They run on internet browsers and can run on all devices that have an internet connection such as laptops, computers, tablets, cell phones and smart televisions. The application provides the user with an interface, the frontend, through which the user can submit data to a webserver, the backend. The application can store and process this data on the webserver and return processed data to the frontend. There are several languages and programs that can be used to create a web application.[29]

2.2.1 HTML

HTML is the standard language used to create the structure and content of webpages and stands for Hyper Text Markup Language. Hyper Texts are links that connect web pages to one another and a Markup language is human readable, using words and not programming syntax. It uses tags to describe its elements. These tags define the structure and content of the webpage. They are used by the browser to display the content and are themselves not visible.[29,30]

2.2.2 CSS, Bootstrap and Font Awesome

CSS is the standard language used to describe the appearance of a structured webpage written in HTML and stands for Cascading Style Sheets. It is a stylesheet language, which means it describes how the elements of HTML are positioned and how they look. It is included in an HTML document using the style tag.

Bootstrap is a free front-end library consisting of JavaScript and CSS based design templates. These templates provide faster and easier web development. Bootstrap's grid system enables easily made responsive designs.

FontAwesome is a font and icon library. Font awesome was originally designed for Bootstrap and therefore is easily included as a Bootstrap class.[29,30]

2.2.3 Javascript and jQuery

JavaScript completes the three standard languages necessary for web development. It allows websites to be interactive. It is a high-level, interpreted scripting language, which means it is interpreted and does not need a compilation step. This interpretation is done by the browser, which understands the code and then performs the corresponding commands. Javascript is included in HTML using the script tag.

jQuery is a JavaScript library that simplifies various things such as HTML document traversal and manipulation, event handling and animation.[30]

2.2.4 PHP

PHP is the most common server-side language in the world. PHP was originally an abbreviation for „Personal Home Page Tools“, but later for „Hypertext Pre-processor“. PHP is a server-side scripting language, which means that a webserver is needed to run the code. PHP can be used to dynamically generate HTML documents and interact with a database or file system. It can be embedded in an HTML document, where it is removed from the file before sending it to the client. This means that no PHP code is visible in the frontend.[30, 31]

2.2.5 Webserver

A webserver usually acts as a host for all resources of the webpage, as an interpreter for PHP and as a database server, which holds the Database Management System (DBMS) and the databases for a website to store and maintain its information.

The browser knows which webserver to contact using the domain name, the link that is entered into the browser. Domain names are text based aliases that are easier to remember then the numbers they represent: Internet Protocol (IP) addresses.

Webservers often make use of a database to store and maintain dynamic content for the website. A database is a collection of data that is logically related making it easy to access, update and maintain the data. A database is maintained by a DBMS. It is only possible to access the data in a database through the logical interface of the DBMS. One of the most common database interface languages is SQL. SQL stands for Structured Query Language and is a programming language that is exclusively used to interact with database systems.[30, 31]

2.2.6 Internet hosting service provider

Webservers can be hosted by any computer, but for websites that need to be accessible around the clock, that computer needs to always be online. An internet hosting service provider is the most economical solution. They provide the client with a webspace, a storage space for files on a server, a webserver and a database server.[31]

2.2.7 User Interface (UI) of website

A user interface should not only be aesthetically pleasing and capturing but should be effective, efficient, ergonomic and risk free so that the user can achieve his goals with contentment and satisfaction.[32]

There are many guidelines and studies on what the best practices for designing a user interface are. According to Shneiderman there are eight “Golden Rules” when designing the user interface of an interactive system. Shneiderman makes it clear that these rules are a good starting point and should be adapted for each application as the rules have their limitations.

1. Strive for consistency

The application should be consistent in terms of colour, layout and terminology. As well as, in similar situations, similar actions should lead to similar results.

2. Cater to versatility

The application should take into account factors such as age, disabilities, technical ability of the user, new users (explanations and guidance) and old users (shortcuts, reduction of the number of interactions), personal differences (user settings to suit different tastes), physical abilities, hardware differences (the application should work on all devices).

3. Offer informative feedback

The application should provide informative feedback for each action that the user does. How this feedback is displayed should be dependent on the importance of the action. Users like awards for actions when something was done well and correctly. The application should run quickly, the user should not have to wait too long for anything.

4. Design dialogues to yield closure

Actions should have a beginning, middle and end. The user should be congratulated on completing a set of actions. This gives the user satisfaction and a relief that he is doing everything right.

5. Prevent errors

The application should, as far as possible make it impossible for a user to make serious errors. This can be done by disabling buttons which should not be pressed, validating inputs, ensuring that there are only numbers in a number field. Nothing potentially harmful should be triggered by too simple an operation.

6. Permit easy reversal of actions

If it is impossible to avoid errors, the application should make it clear that the user has made an error and should make it easy for the user to correct the error e.g. when entering the wrong password the user should not have to input his username again. Making errors easily reversible ensures that the user never feels stressed about making mistakes and using the product.

7. Support internal locus of control

The application should respond to actions of the user and not the other way around. Users like to be in charge of the application, unless the application is designed for the user to respond to it.

8. Reduce short-term memory load

Much unlike a computer the human has a very limited information processing capacity, only being able to maintain between five and nine things in his short-term memory. Therefore, it is important not to make the user need to remember too many things. Recognising is much easier than remembering. Incorporating recognising instead of memory can be done by making objects and options available. It is also a good idea to make sure all information relating to one topic is on one page and not scattered over several pages.[33, 34]

2.2.8 Limitation of web applications without machine learning

A problem with most of the available applications for back pain is that the user must input the duration and type of exercise completed. This can be tedious, causing the user to forget to write this down or doing it later and not being able to remember what he did correctly. This is where artificial intelligence and more specifically pose estimation could play an important role.

2.3 Technical Background - Artificial Intelligence and PoseNet

Artificial Intelligence (AI) aims to create computers that can act like human minds, with skills such as reasoning, vision interpretation, perception, association, prediction, planning and motor control.[35] AI is a very broad subject comprising of many subcategories which are described in the diagram seen in Figure 1 below.

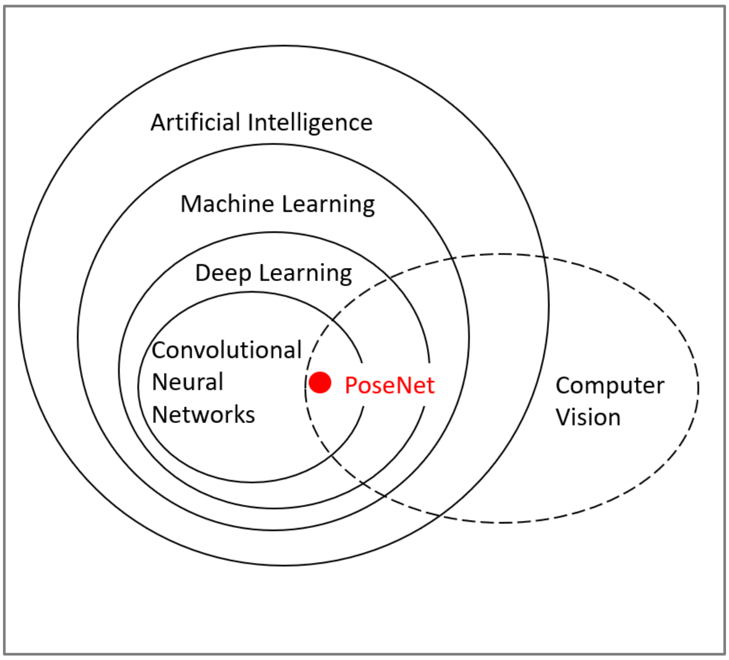

Figure 1: Categories that fall under Artificial Intelligence adapted from Journalism AI [36]

2.3.1 Machine learning

We are living in the information age, where everyone from small start-ups to large international companies gather large amounts of data and use machine learning to work through this data to generate knowledge. In 1958 Arthur Samuel said that Machine learning is the ability of computers to learn, without being explicitly programmed.

The two most important aspects in machine learning are choosing the best suited machine learning algorithm and obtaining enough high-quality data to train it. For image recognition it is sometimes necessary to have millions of datasets. The complexity of the algorithm must be chosen according to the available data.

Overfitting occurs when there is too little data and there is too much noise for the complexity of the model, i.e the model is too complex for the available data. Underfitting of data is the exact opposite of overfitting, the model is too simple.

For complex problems the data is often more important than the algorithm. Common data quality issues include bias, when the training data is not representative for the testing data, poor quality, when the data is full of errors, outliers and noise, from measuring mistakes and irrelevant characteristics, when characteristics that are necessary are absent from the data set or unnecessary characteristics are too prominent.

Once the model has been trained, it needs to be tested and validated. This is done by testing the model with new data, i.e. data that was not part of the learning data. It is common to use about 80% of the data for training and 20% of the data for testing.[37, 38]

2.3.2 Computer Vision

Computer vision draws its methods from computer science, physics, mathematics and biology making it a rather complex field. Computer vision has come a long way since machine learning methods have been introduced. The human brain does an impressive job at recognizing faces in images and telling one object apart from another, especially when the boundaries are not very clear. The computer on the other hand sees images only as an array of Red, Green, Blue (RGB) elements. According to Planche and Andreas, the aim of computer vision is to "teach computers how to make sense of pixels the way humans do" and computer vision is in some tasks, such as face identification or handwriting identification, able to surpass the ability of humans. The idea of computer vision is to detect features from the array of pixels and then to determine which of the known, labelled features is most similar to this detected feature and thereby achieve recognition.

Examples of computer vision are object classification (the assignment of labels to images), object detection (e.g. the detection of cancerous cells in medical images), segmentation (the selection of all the pixels relating to a searched object) and pose estimation. Pose estimation uses the 2D information of an image to estimate the actual position and orientation of a 3-dimensional (3D) object. The tool that computer vision uses to do this is machine learning, and more specifically deep learning. Deep learning has had an impressive influence on computer vision.[37,39]

2.3.3 Deep learning

Deep learning is used to obtain information from and to understand the content in images, text and audio recordings. It has a very broad field of possible applications, from cell phone applications to automobile cars. In deep learning huge amounts of raw data are fed into neural networks and with the help of labels in the data, the network learns how to identify patterns in the data. In images this raw data is usually the pixel values of the image. This teaching usually requires a lot of time, resources and energy. Networks are powerful tools used by machine learning/deep learning. A network type used often in deep learning is artificial neural networks (ANN) or neural networks (NN).[37,39]

2.3.4 Artificial neural networks

ANN or NN are used to process large amounts of information, detect known or new patterns, or to estimate processes. NN are built off how the brain works. The brain is made up of a network of neurons. Each neuron is similar to a signal processing unit, transmitting signals to the next neuron when the signal is stronger than a certain threshold. These neurons stacked together are how we think. Much like our brains, the mathematical model of a NN will usually take in the weighted sum of a number of inputs and apply some activation function to them to produce an output. This output signal is then the input signal for the next row of neurons, the signal is fed forward to the next neuron. Each of the input weights can be tuned when training the model. It is also common to add an offset or bias. This too is a parameter that can be varied during training. Equation 1 describes the weighted summation of the inputs with an added bias:

$$z = x.w + b \qquad \textit{Equation 1}$$

Where z is the weighted summation of the inputs with an added bias, x is the input values: $x = (x0 \;\; x1)$, w is the weights: $w = \binom{w0}{w1}$ and b is the bias.

The weighted inputs with bias then have an activation function applied to them, similar to the threshold in the brain, determining whether a signal is fired or not. The Rectified Linear Unit is one of the most used activation functions. It is shown in Equation 2 below:

$$ReLU(z) = max(0, z) = \begin{cases} 0 \; if \; z < 0 \\ z \; if \; z \geq 0 \end{cases} \qquad \textit{Equation 2}$$

This is a very basic model of an artificial neuron. It receives an input, processes it, and depending on the threshold, outputs the value to the next layer of neurons. Networks are built by layering neurons together.[39] A model of an artificial neuron and of an artificial neural network can be seen below in Figure 2.

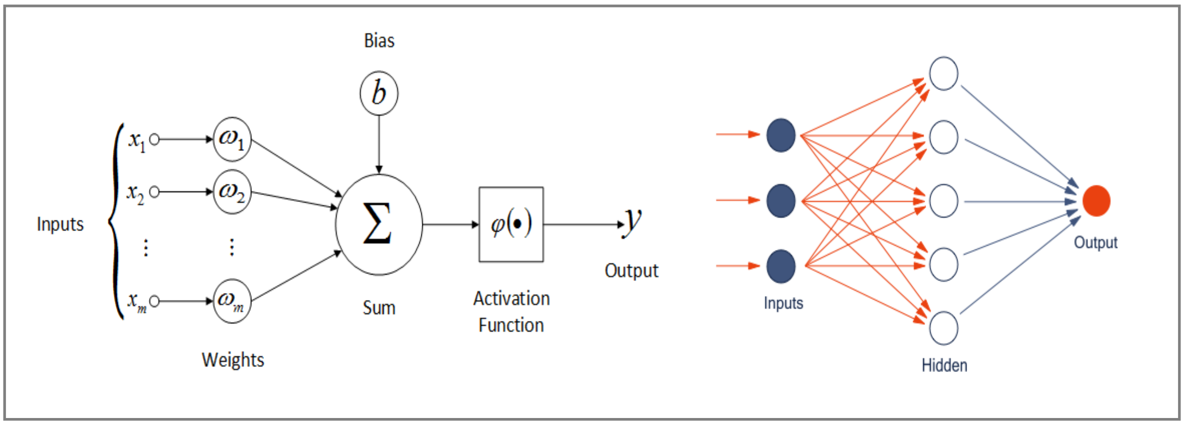

Figure 2: On the left: A model of an artificial neuron.[40] On the right: An artificial neural network.[41]

2.3.5 Training of networks

Each network needs to be trained before it can perform the required task. This training includes tuning the parameters so that the network is optimised for that specific task. As already mentioned, training comprises of huge amounts of labelled data being fed into the network. Labelled data is for example, when training for a pose estimation model, images that have the coordinates and the name for each body part. The network estimates where it thinks the coordinates are and this is compared to where the actual coordinates are using a cost or loss function. The cost function enables the computer to judge the impact of changing each of the networks parameters with regards to minimising the error between its own prediction and the labelled data. It indicates which parameters have the biggest influence in minimizing the cost function. Planche et al. describe the cost function as showing the "quality of the predictions as a function of the network's parameters". This is an iterative process and is computed until the parameters cannot be optimised further. A common cost function is the sum of squares function. Adding all the results costs of each training and averaging them gives the total cost of the network.[39]

2.3.6 Minimizing the cost function of networks

In order to find the minimum of a function, one needs to find the derivative, with negative coefficient, of that function. More complex functions have more than one minimum and a process known as gradient descent is used to find the minimum, i.e. moving down the slope of the cost function with respect to each parameter. In neural networks this means that for each parameter the derivative of that parameter relative to the cost function is computed. These derivatives show to what degree the parameters need to be changed to minimise the cost function. All these derivatives are computed using the chain rule, starting at the last layer moving from layer to layer backwards through the network. This is known as back propagation. The parameters are then updated according to the derivatives found, and this process is reiterated until the cost function is minimized and the parameters cannot be optimized further. Stochastic gradient descent is often used, which takes batches of data instead of all the data and thus speeds up the computation time.[39]

2.3.7 Convolutional neural network

Basic neural networks have two major problems, they have an explosive number of parameters and they have no spatial reasoning. Convolutional neural networks (CNNs) were introduced to solve these problems. In CNNs, unlike in NN, the neurons are not connected to all neurons from the previous layer. Instead each neuron is connected to some neurons in the neighbouring region in the previous layer. This region is known as the receptive field. Through receptive fields, CNNs reduce the number of training parameters and maintain the location of image features.

CNNs are given their name as they have convolutional layers. In image processing convolution is a mathematical operation that is used to for example blur, sharpen or detect edges of the original image (in CNN this result is known as a feature map). It is computed by sliding a filter, kernel or convolutional matrix over an input image. At every point element-wise matrix multiplication is computed and the result is summed. This is what makes up the feature map.

In CNNs the neurons that are connected to the same output, the neurons in the receptive field, are like one of these filters. Looking at the description of a neural network already given thus far, the filter is made up of a matrix of numbers which are the weights and parameters, and the filter is a neuron. Figure 3 shows an example of a convolutional neural network, with the green area being the receptive field.

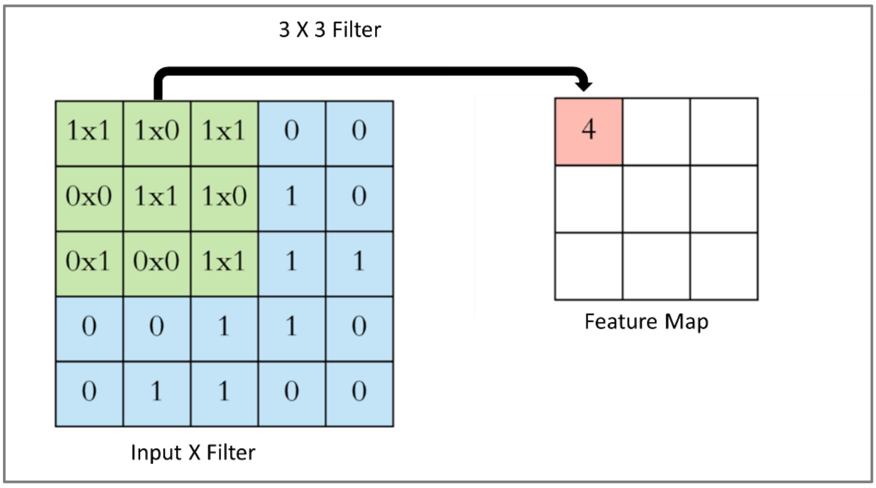

Figure 3: Convolutional neural network [42]

When looking at inputs with more than 1 channel, RGB images have 3, the convolutional layer will have 3 sets of different filters, i.e. 3 different weight matrices. Extending this to the Nth dimension, a layer with N different neurons has N weight matrices. This layer will also therefore produce N feature maps, these maps each find specific features. All the feature maps from one layer are called a feature volume.

Training the network means finding different values for the filters so that they become better at finding specific features such as, at the first layer, line orientation or colour gradient and at deeper layers, contours of specific shapes such as shoulder or the shapes of eyes. A layer with N filters translates to a layer being able to find N different specific features. An important aspect is that filters look for a specific image feature and the orientation (a translation) is not important.[38, 39] There are many libraries and languages in place to help one program these networks.

2.3.8 TensorFlow

TensorFlow is an open source deep learning library by Google, consisting of several tools that help with developing a convolutional neural network. TensorFlow was designed to be extremely portable, enabling the deployment of machine learning on several platforms, central processing unit (CPU), graphics processing unit (GPU), mobile devices and in the browser.

The architecture of TensorFlow consists of three layers. A C++ layer, a low-level application programming interface (API) layer and a high-level API layer. C++ is used to code the majority of the deep learning computations. Python is used in the low-level API layer to wrap around the C++ code. Python is considered an easier language allowing easier, quicker use and does not need to be compiled. The top layer is made up of Keras, an interface designed for quick experimentation with neural networks and the Estimator, which is a set of templates.

In mathematics, tensors are arrays with N-dimensions and include scalars i.e. 2D arrays, 3D arrays and N dimensional matrices. In TensorFlow a tensor is an object that can store either constants or variables. Tensors are used as both inputs and outputs in TensorFlow. TensorFlow therefore refers to tensors flowing from the input layer to the output layer.

In TensorFlow the activation functions are depicted using a directed acyclic graph (DAC), or just a graph. These graphs represent the different layers of the model and have several benefits, one being that they allow TensorFlow to run on several devices, i.e. they allow different parts of the functions to be run on the CPU and different parts on the GPU.[37,38,39]

The flexibility and portability of TensorFlow make it very easy for users that are not machine learning experts to use and implement these models in real world applications. TensorFlow comes with several already trained models. These models have been trained using enormous amounts of data and using computers with large computing power. They can be easily adapted for what one needs. One such model is PoseNet.[37,39]

2.3.9 PoseNet

PoseNet is a pose estimation model that can run in Javascript, which enables the model to run on the browser of any device with an internet connection and a web camera. There is no system setup or 3D cameras needed. PoseNet takes in an RGB image as input and sends it through a convolutional neural network. It offers two algorithms: single pose for one person and multipose for several people. PoseNet then outputs the pose of the person or the people. The single pose algorithm is more basic and quicker. Only the single pose algorithm will be looked at in this work.[43,44]

Inputs for the model:

- Image element — An html image or video element.
- Image scale factor — Scales the image. It is a number between 0.2 and 1, the lower the number the smaller the image and the faster and less accurate the network. Defaults to 0.5.
- Flip horizontal — This is for when the image/video is flipped horizontally, i.e. when a web camera is used, setting this parameter to true flips the images back. Defaults to false.
- Output stride — This influences the height and width of the layers in the neural network. It affects the accuracy and speed of the network. The three options are 32, 16 or 8. The lower the number the better the accuracy but slower, the higher the number the worse the accuracy but faster. Defaults to 16.

For each image, the model outputs a pose. This pose is an array which consists of a confidence score, i.e. a number between 0 and 1 of how confident the estimation is, and an array of 17 keypoints, i.e. 17 body parts. This pose array is highlighted by the blue box in Figure 4. Posenet currently estimates 17 keypoints: nose, right eye, left eye, right ear, left ear, right shoulder, left shoulder, right wrist, left wrist, right elbow, left elbow, right hip, left hip, right knee, left knee, right foot, left foot. The keypoint array is highlighted by the green box in Figure 4. Each keypoint array consists of the body part, its position and a confidence score. The positions are the x and y coordinates of the keypoints in the original image and the score is again a number between 0 and 1 of how confident the estimation is. An example of a body part is highlighted by an orange box in Figure 4. The pose shown in Figure 4 is one of just the face and shoulders, hence only these body parts have a high confidence score.[43,44]

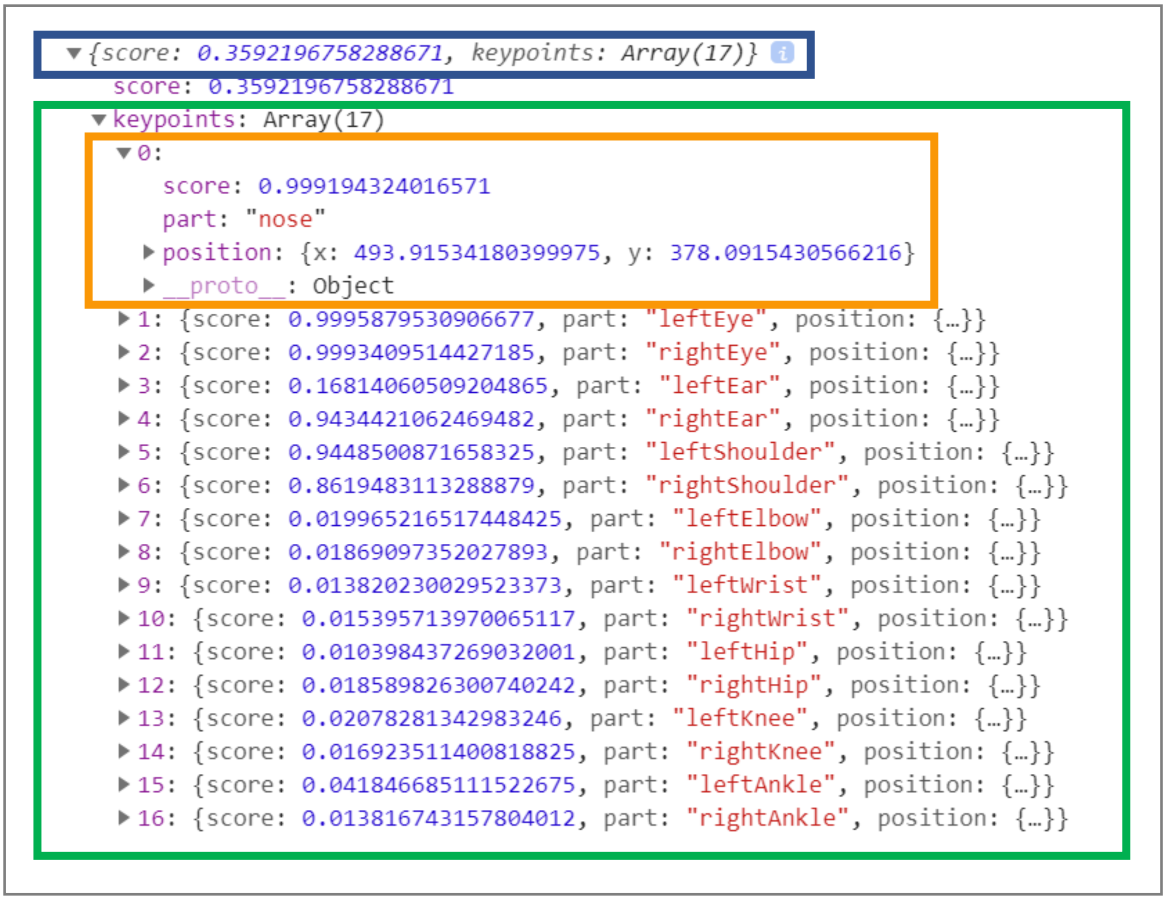

Figure 4: Output pose array from PoseNet

2.4 State of the art

There are many companies producing software solutions to medical problems. Two companies were found that have produced similar products. MIRA and VAY fitness Coach. MIRA is a medical device that uses motion tracking sensors to gamify physical therapy and increase patient compliance. The device is used for orthopaedic and neurological therapy for both children and adults and in programs to help elderly people from falling. The device has been shown to improve compliance.[45] VAY Fitness Coach is a general fitness cell phone application which uses machine learning and professional trainers to motivate the user to do his exercises and stay fit. It was released in 2019. The application asks the user to choose from three options: muscle building, weight loss or better body tone. It then asks for weight, height, age, sex and requests to select a trainer before presenting a training plan. The application has a rating of 3.3 on Google Play with several people complaining that the image recognition does not work properly.[46]

3 Methods

3.1 Identification of back pain exercises

Two methods were employed in order to identify exercises most commonly used for back pain: direct email and a Google search. For the direct email, recipients were selected through Google Maps using the search term “Physiotherapie Hamburg” and sorted by rating. The first 30 doctors and therapists with an email address or contact form were emailed. Additionally, two German back pain societies were emailed. In the email the purpose of this master thesis was briefly explained, and the recipients were asked if they have a training program or a set of home exercises which they find particularly effective for back pain. The email can be found in Appendix A.

The Google search used the search term ‘Rückenübungen Physiotherapie pdf”. The first 20 results were examined for back pain related exercise programs. Results were excluded if they provided no program at all or if the program was not specifically written for back pain. The back pain program from the National Health Service (NHS) was also included. The names for each exercise are not unified and vary from exercise program to exercise program. As all exercises were found in Physiotools, a commercial online library of exercises for Physiotherapists, the names from this library were used in this thesis. Similar exercises were grouped together. To obtain the most commonly recommended exercises, all exercises from each program were entered into a table and the total number each exercise appeared over all programs found was computed.

3.2 Evaluation of PoseNet

The confidence score of PoseNet in settings of home-based back pain exercises was evaluated through images of different poses, outfits, backgrounds and brightnesses. The images were taken with the Huawei P20 rear camera and Acer Swift 12 front camera. The Huawei P20 has a dual rear camera with a 12MP RGB sensor and a 20MP monochrome sensor. The Acer Swift 12 has a 2MP HD front camera.

A dedicated evaluation page was programmed for this purpose. This page feeds the image being evaluated into PoseNet, draws blue points onto a canvas at the coordinates of the body parts delivered by PoseNet, and displays the image with the blue points overlaid. Furthermore, the page displays a table with the numerical confidence score for each body part. Only body part coordinates with a confidence score of more than 0.5 were drawn. The Canvas API, a web API which allows drawing graphics in the browser with JavaScript and HTML, was used to draw the blue points. The following PoseNet input parameters were used:

- Image element: A HTML image element.
- Flip horizontal: True
- Image scale factor: 1
- Output stride: 32

The highest accuracy parameters for Image scale factor and Output stride were used, as execution speed did not matter for this evaluation.

3.2.1 Different poses and outfits

Ten poses from section 3.1, were selected to be evaluated. Additionally, the normal standing pose was included, as it appears this pose was used to train the PoseNet model. All images were taken with the Huawei P20 with good lighting in front of a white wall. The four different outfits used were: short, black, colourful and baggy. The short outfit consisted of short black pants, a dark blue T-shirt and no shoes. The black outfit consisted of long and tight all black clothes and black socks. The colourful outfit consisted of long purple, pink, blue and white patterned tights, a yellow long sleeve top and white shoes. Finally, the baggy outfit consisted of long pants and a pullover, both grey and loose fitting and grey socks. For each combination of pose and outfit two images were taken: the first at a 90-degree angle to the camera, the second at a 45-degree angle to the camera. The average confidence score for all the body parts of each of the eleven poses was taken and a bar graph was plotted showing the difference between each outfit for each pose and showing which poses are detected well by PoseNet and which are not.

3.2.2 Different brightnesses

Images of squats in front of a white wall in three different lighting levels were taken. The brightness of the images was defined by their light intensity. The light intensity of the images was calculated by adding the red, green and blue values for each pixel and dividing by three, i.e. finding the grey value of the image. The grey value was then divided by the size of the image resulting in a light intensity between 0 and 255 where 0 is black and 255 is white. The images were taken with both a Huawei P20 and with the front camera of the Acer Swift 12. Different cameras were used, because camera behaviour with decreased lighting depends heavily on the camera hardware and software. The lighting was changed using a blind. Due to the post processing of the Huawei, the images were much brighter than those of the Acer. To obtain similar light intensity levels in the final images, the Huawei images were digitally darkened. The average confidence score for all the body parts was plotted against the light intensity values for both the Huawei and the Acer camera.

3.2.3 Different backgrounds

Six representative home environment backgrounds were selected to be evaluated: a bedroom, a lounge with a couch, a grey wall, a kitchen with fridge and oven, plants and a white wall. A squat was done in front of all backgrounds wearing grey clothes. Images were taken using the Huawei P20 camera. The average confidence score for all the body parts was plotted against the backgrounds.

3.3 Implementation of the web application

Strato was selected as the internet hosting service provider. A contract with 3 domains, 50 GB of webspace and 2 MySQL databases was obtained from Strato. Notepad++ was used to write HTML, CSS, Javascript, PHP and MySQL code. The source files were uploaded to the Strato webserver using FileZilla, a File Transfer Protocol (FTP) interface. The domain name everywheretrainer.com was selected. The user can use the web application by entering this domain name into his browser. In response, the PHP code is run by the webserver to access data from the database using MySQL. PHP dynamically generates HTML documents which are sent to the user. Frontend languages are executed in the browser to create the GUI that is visible to the user. Figure 5 shows the tools and setup of the web application. GitHub, a development platform, was used for version control and source code management. The source code was documented using Natural Docs, an open source software which allows for easy and neat source code documentation.

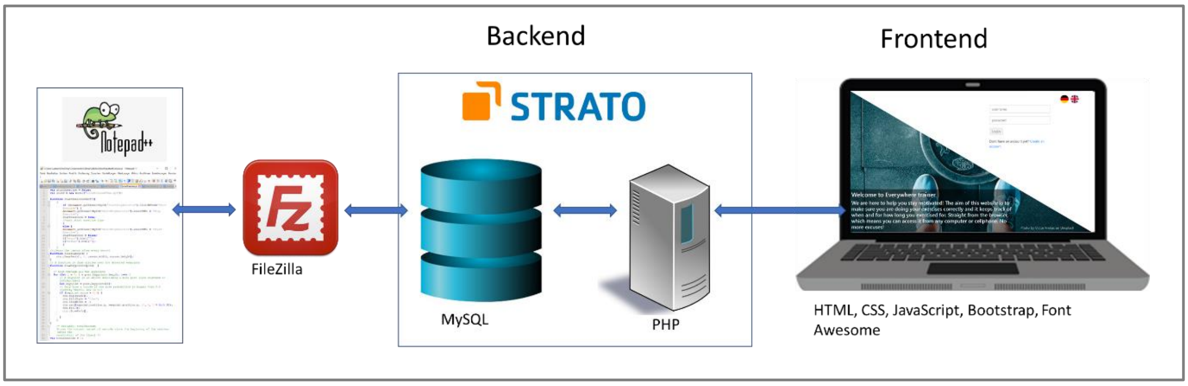

Figure 5: Tools and setup of the web application [47,48,49,50,51,52]

The GUI was developed by following, as far as possible, Shneiderman's eight golden rules for user interface. All images on the website were either taken personally with a camera or downloaded from Unsplash, a website which provides freely usable images. Bootstrap was used to achieve a responsive layout, meaning the application adapts its layout to fit the screen size being used.

PoseNet requires an image as input. For this input a video stream of the user is obtained using the MediaDevices interface, a web API which provides access to a user's hardware. SSL/https is needed for MediaDevices to run on all browsers. SSL/https is a licence which allows safe and secure connections between the browser and webserver. A corresponding license was obtained from Strato. The video stream is treated as individual images when input into PoseNet, the PoseNet function is called every second. The coordinates received from PoseNet for the body parts are used to draw blue circles and coloured lines onto a canvas using the Canvas API. This canvas is layered on top of the video stream element, so that the blue dots and coloured lines are visible and align with the body parts in the video stream. Basic geometry and trigonometry were used to calculate the angles of body parts relative to the coordinate system. Using the example of the thigh, seen in Figure 6, first the distance between hip and knee in x and y direction is calculated. These constitute to the opposite and adjacent side of a right-angled triangle. The arctan function is then used to calculate the angle of the thigh relative to the x-axis. This computed angle is used to colour the body parts and assess how "correct" the exercise is executed.

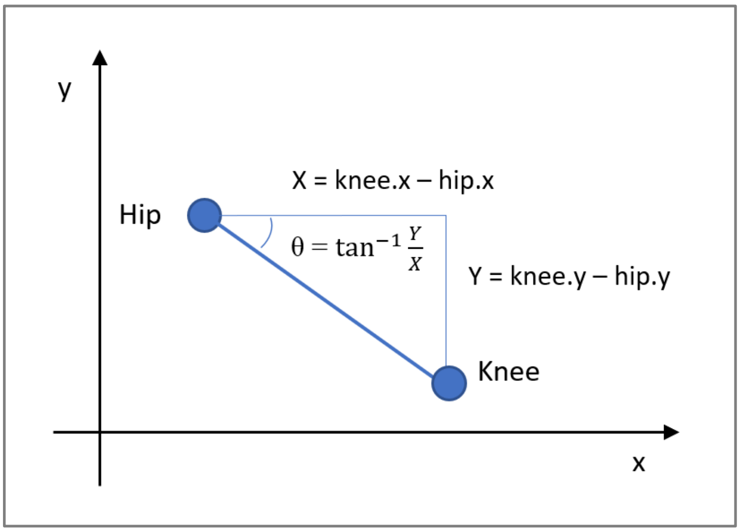

Figure 6: Calculation of the angle of the thigh relative to the x-axis

For additional visual guidance for the user, an avatar was created using a photo which was made into a silhouette using GIMP. GIMP stands for GNU Image Manipulation Program and is a free graphics editor. The image was then cut, using Microsoft Paint, into individual pieces which can move independently of each other: the foot, the lower leg, the upper leg and the upper body. Each body part is rotated and translated according to the received angles calculated using geometry and trigonometry as explained above. To change the colour of the avatar the image itself is exchanged i.e. both the lower and upper leg have four images, one in black, green, orange and red. The bell noise for the break was downloaded from Zapsplat, a sound effects music library. To display the results from the exercise Plotly, a JavaScript visualization library, was used.

A database was created in Strato to store data that needs to be kept for longer than one user session, such as individual exercise plans and exercise history. The tables were managed using phpMyAdmin, the administration tool for the DBMS which provides a frontend to manage tables in the database, and mySQL.

4 Results

4.1 Identification of back pain exercises

Of the 30 doctors and physiotherapists, as well as the two societies contacted through direct email, only the two societies responded. The Bundesverband deutscher Rückenschulen (BdR) and the Aktion Gesunder Rücken (AGR). The BdR stated that doctors tend not to prescribe specific exercises, but instead point out existing muscular imbalances etc. which are noted on the prescription, whereas therapists (sports or physio) do prescribe specific exercise plans. Similar to doctors, therapists determine, where and to what extent pain occurs before recommending a set of exercises. The AGR suggested to look at their website for generally appropriate exercises. However, they make a note that individuals with existing severe pain, especially if it is long-lasting, should consult a doctor or therapist beforehand. These can then rule out exercises that are not suitable for the patient. The email responses from BdR and AGR can be found in Appendix B.

Table 1 shows the first 20 results of the Google search using the search term ‘Rückenübungen Physiotherapie pdf”. The table indicates for each result, the organization and if a back pain specific exercise program was found or not.

Table 1: First 20 results of Google search using the search term ‘Rückenübungen Physiotherapie pdf”

Organization	Back pain specific exercise program
Wirbelsäulenzentrum [53]	Yes
Dr. Kade [54]	Yes
Regensburger Orthopädengemeinschaft [55]	Yes
Physiotherapie Frank Zwetsloot [56]	Yes
AGR Aktion Gesunder Rücken e.V.[57]	Yes
Novartis Pharmaceuticals [58]	No, Not back pain specific exercise program
Deutsche Rheuma-Liga Bundesverband e.V. [59]	Yes
Praxis für physiotherapie Dietmar Linsler (Köln) [60]	Yes
Voltaren [61]	Yes
Ikk-classic [62]	Yes
Pain Education [63]	Yes
Barmer [64]	Yes
Hirslanden klink Birshof [65]	Yes
Physikalische-medizin [66]	Yes
bGw (Berufsgenossenschaft für Gesundheitsdienst und Wohlfahrtspflege)[67]	Yes
Physiowissen [68]	No, No program
Deutsche Gesellschaft für Unfallchirurgie (DGU) [69]	No, Not back pain specific exercise program
Gesundes Bayern [70]	Yes
Orthopaedie-Zentrum [71,72]	Yes
Rehazentrum-bb [73]	Yes

The Google search results yielded 17 programs. Including the additional NHS program [74], 18 programs were examined. Two tables were created: Table 2 shows exercises that are designed for strengthening and stability and Table 3 shows exercises which were designed for stretching. Both tables were separated into where the exercise is performed i.e. on the floor or in a standing/sitting position. It is important to note that the Cat and Dog stretch and Trunk Rotation stretch can be performed both on the floor and in a standing position, they are however only included in the standing/sitting position in Table 3.

From Table 2, it can be seen that, for exercises on the floor the Bridge, Arm and Leg lift, back extension and the Plank are most commonly recommended. For exercises in a standing position the Squat is most commonly recommended. A table containing the name and an illustration for each of the exercises in Table 2 can be found in Appendix C.1.

Table 2: Strengthening and Stability exercises

Position	Exercise Name	Wirbelsäulenzentrum	Dr Kade Pharma	Regensburger Orthopädengemeinschaft	Physiotherapie Frank Zwetsloot	AGR Aktion Gesunder Rücken e.V.	Deutsche Rheuma-Liga Bundesverband e.V.	Praxis für physiotherapie Dietmar Linsler	Voltaren	ikk-classic	Pain Education	Barmer	Hirslanden klink Birshof	Physikalische-medizin	bGw	Gesundes Bayern	Orthopaedie-Zentrum	Rehazentrum-bb	NHS	Total
Floor	Bridge	x	x	x	x	x		x	x	x	x	x	x	x		x	x	x	x	16
	Arm and Leg lift	x	x	x	x	x	x	x	x	x	x	x		x		x	x	x		15
	Back extension	x	x	x		x	x	x	x		x			x		x	x			11
	Plank	x				x	x	x	x	x		x					x		x	9
	Crunch	x	x	x	x				x		x	x				x	x			9
	Side Plank		x		x	x			x	x		x				x				7
	Side Lying leg lifts	x			x							x								3
	Air Bike		x				x													2
	Bent leg hip extension			x		x														2
	Arm circles															x				1
Standing/Sitting	Squat	x	x		x	x						x				x		x	x	8
	Lunge	x											x							2
	Knee Lift		x																	1

From Table 3 it can be seen that for stretches on the floor the Resting Pose, Child's Pose, and Knee to chest are most commonly recommended. For stretches in a standing position the Cat and Dog stretch, Thoracic extension and Trunk side bending are most commonly recommended. A table containing the name and an illustration for each of the exercises in Table 3 can be found in Appendix C.2.

Table 3: Stretching Exercises

Position	Exercise Name	Wirbelsäulenzentrum	Dr Kade Pharma	Regensburger Orthopädengemeinschaft	Physiotherapie Frank Zwetsloot	AGR Aktion Gesunder Rücken e.V.	Deutsche Rheuma-Liga Bundesverband e.V.	Praxis für physiotherapie Dietmar Linsler	Voltaren	ikk-classic	Pain Education	Barmer	Hirslanden klink Birshof	Physikalische-medizin	bGw	Gesundes Bayern	Orthopaedie-Zentrum	Rehazentrum-bb	NHS	Total
Floor	Resting Pose	x		x	x		x				x	x			x		x			8
	Child's pose		x			x						x		x					x	5
	Knee to chest				x						x			x			x		x	5
	Knees to Sides				x									x					x	3
	Posterior Pelvic Tilt								x				x						x	3
	Cobra														x				x	2
	Downward facing dog					x		x												2
	Clam (sidelying)												x							1
	Hip Adductor								x											1
	Gluteus Stretch		x																	1
Standing/Sitting	Cat stretch		x	x		x	x		x		x	x	x			x	x		x	11
	Dog Stretch		x	x		x	x		x		x	x	x			x	x		x	11
	Thoracic Extension with shoulder flex	x		x	x		x		x			x						x		7
	Trunk Side Bending Stretch		x	x		x			x			x								5
	Trunk Rotation				x	x			x			x				x				5
	Crossbody Stretch			x	x	x			x											4
	Trapezius Stretch			x		x			x											3
	Triceps Stretch				x	x			x											3
	Wrist Flexors Stretch				x	x														2
	Standing Quad Stretch	x			x															2
	Forward Bend								x											1

From Table 2 and Table 3 ten of the most commonly recommended exercises for back pain were selected to evaluate PoseNet with. Each of these exercises can be seen in Figure 7. From top left to bottom right the exercises are: Child's Pose, Squat, Arm and Leg Lift, Bridge, Thoracic Extension, Cat and Dog stretch, Trunk Side Bending, Plank, Resting Pose.

Figure 7: Ten most commonly recommended exercises for back pain. From top left to bottom right: Child's Pose, Squat, Arm and Leg Lift, Bridge, Thoracic Extension, Cat and Dog stretch, Trunk Side Bending, Plank, Resting Pose

4.2 Evaluation of PoseNet

4.2.1 Different poses and outfits

The average confidence score for different poses and outfits for images facing the camera at 90-degrees can be seen in Figure 8 and Table 4 and those for images facing the camera at 45-degrees can be seen in Figure 9 and Table 5. Images from both evaluations can be found in Appendix D.1.

From Figure 8 and Table 4 it can be seen that there are three poses with an average confidence score greater than 0.8: Standing, Thoracic Extension and Trunk Side Bending, there are four poses with an average confidence score between 0.6 and 0.8: Squat, Arm and Leg Lift, Plank and Dog stretch and finally there are four poses with an average confidence score between 0.2 and 0.6: Cat stretch, Resting pose, Bridge and Child's pose. There is no notable difference between the different outfits, no outfit is consistently better than another outfit. Excluding standing, the pose with the highest average confidence score is the Thoracic Extension (0.88).

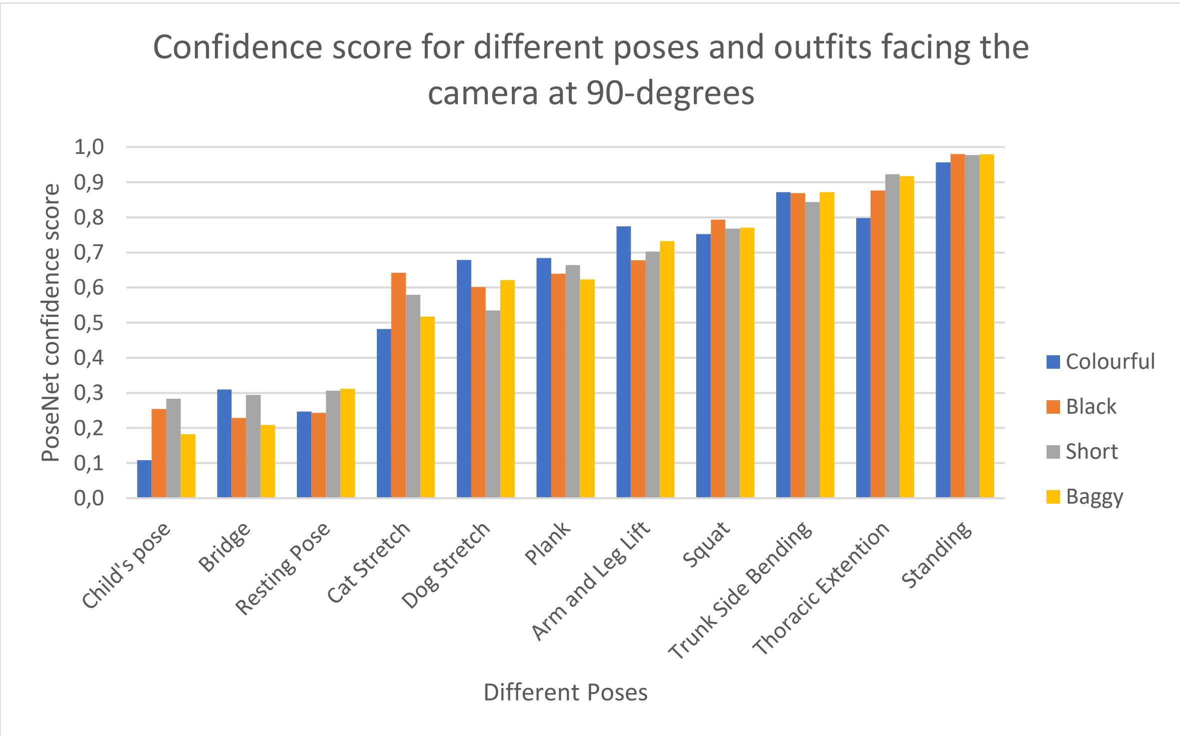

Figure 8: Average confidence score for different poses and outfits facing the camera at 90-degrees

Table 4: Average confidence score for different poses and outfits facing the camera at 90-degrees

Outfit	Child's pose	Bridge	Resting Pose	Cat Stretch	Dog Stretch	Plank	Arm and Leg Lift	Squat	Trunk Side Bending	Thoracic Extention	Standing
Colourful	0,109	0,310	0,247	0,482	0,678	0,684	0,775	0,753	0,872	0,798	0,957
Black	0,254	0,229	0,243	0,642	0,601	0,640	0,678	0,793	0,869	0,876	0,980
Short	0,283	0,294	0,306	0,580	0,535	0,664	0,702	0,768	0,844	0,923	0,978
Baggy	0,182	0,209	0,312	0,518	0,621	0,623	0,733	0,771	0,871	0,918	0,979
Average	0,207	0,260	0,277	0,555	0,609	0,653	0,722	0,771	0,864	0,879	0,973

From Figure 9 and Table 5 it can be seen that there are four poses with an average confidence score greater than 0.8: Standing, Squat, Thoracic Extension and Dog stretch, there are three poses with an average confidence score between 0.6 and 0.8: Trunk Side Bending, Arm and Leg Lift, Plank and Cat Stretch and finally there are three poses with an average confidence score between 0.2 and 0.6: Resting pose, Bridge and finally Child's pose. There is no notable difference between the different set of outfits, no outfit is consistently better than another outfit. Excluding standing, the pose with the highest average confidence score is the Squat (0.87).

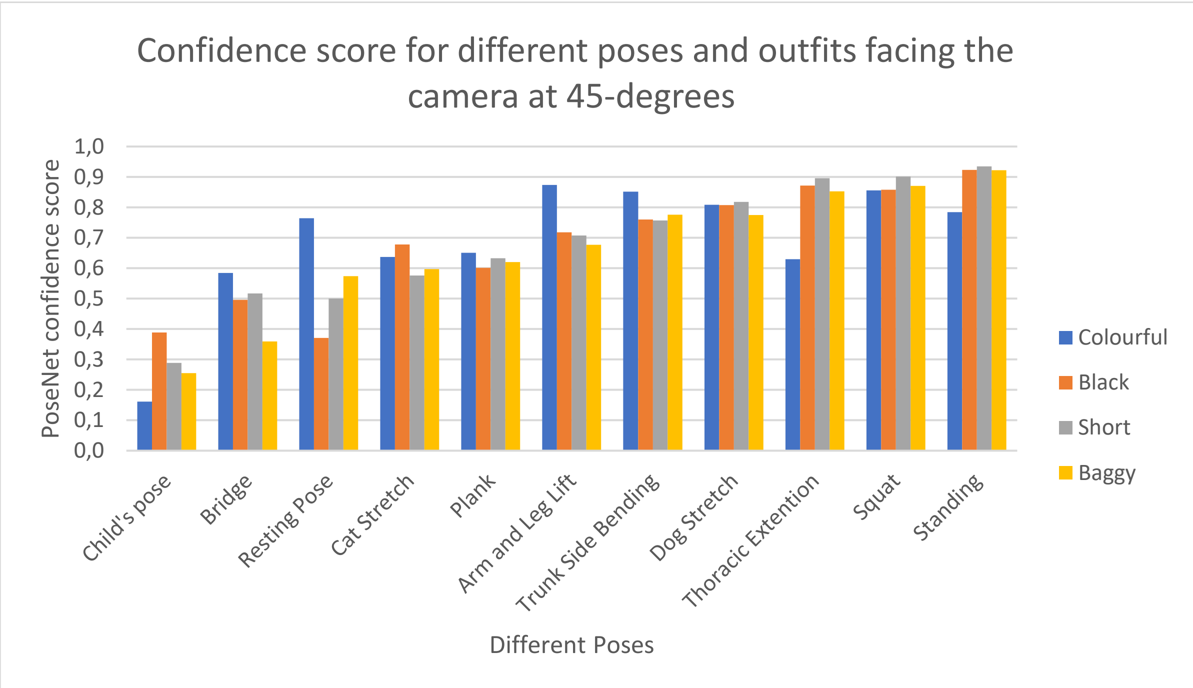

Figure 9: Average confidence score for different poses and outfits facing the camera at 45-degrees

Table 5: Average confidence score for different poses and outfits facing the camera at 45-degrees

Outfit	Child's pose	Bridge	Resting Pose	Cat Stretch	Plank	Arm and Leg Lift	Trunk Side Bending	Dog Stretch	Thoracic Extention	Squat	Standing
Colourful	0,161	0,584	0,764	0,637	0,650	0,873	0,852	0,809	0,629	0,855	0,784
Black	0,389	0,496	0,371	0,678	0,601	0,718	0,760	0,807	0,871	0,857	0,924
Short	0,288	0,517	0,501	0,576	0,633	0,707	0,757	0,818	0,896	0,901	0,934
Baggy	0,255	0,359	0,573	0,597	0,620	0,677	0,776	0,775	0,853	0,870	0,922
Average	0,273	0,489	0,552	0,622	0,626	0,744	0,786	0,802	0,812	0,871	0,891

4.2.2 Different brightnesses

The results of the brightness evaluation are shown in Figure 10 and Table 6. Images from the evaluation can be found in Appendix D.2. From Figure 10 and Table 6 it can be seen that the confidence score decreases with decreasing light intensity. At a light intensity of 40 the Huawei has a confidence score of 0.78 and at the same light intensity the Acer Swift has a confidence score of 0.456.

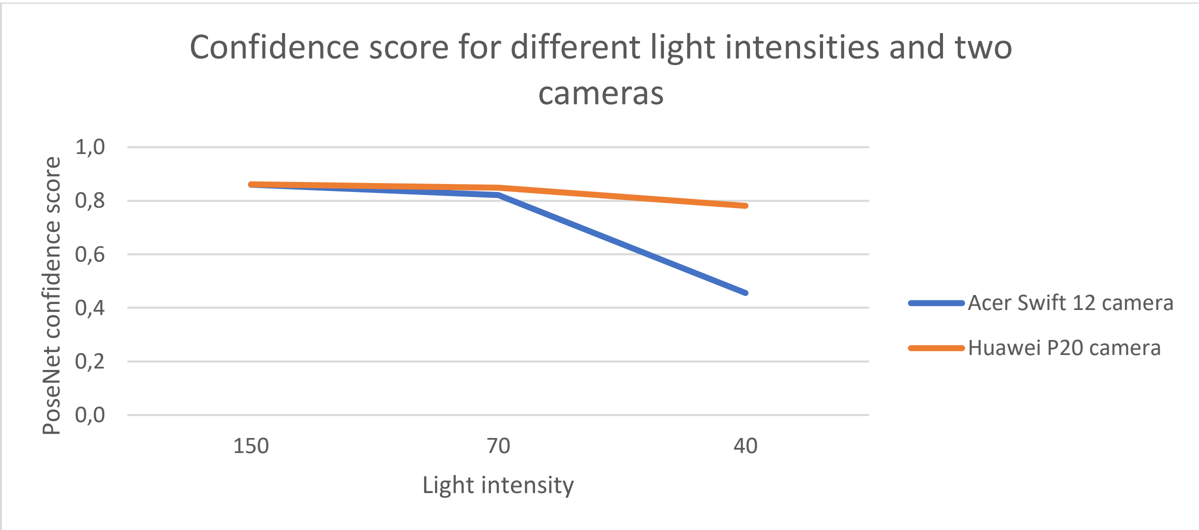

Figure 10: Average confidence score for different light intensities and two cameras

Table 6: Average confidence scores for different image light intensities for two cameras

Camera	150	70	40
Acer Swift 12 camera	0,860	0,821	0,456
Huawei P20 camera	0,861	0,849	0,781

4.2.3 Different backgrounds

The results of the background evaluation are seen in Figure 11 and Table 7. Images from the evaluation can be found in Appendix D.3. From Figure 11 and Table 7 there is no significant difference in the confidence score between each background, for all the backgrounds evaluated the confidence score for the squat is above 0.78.

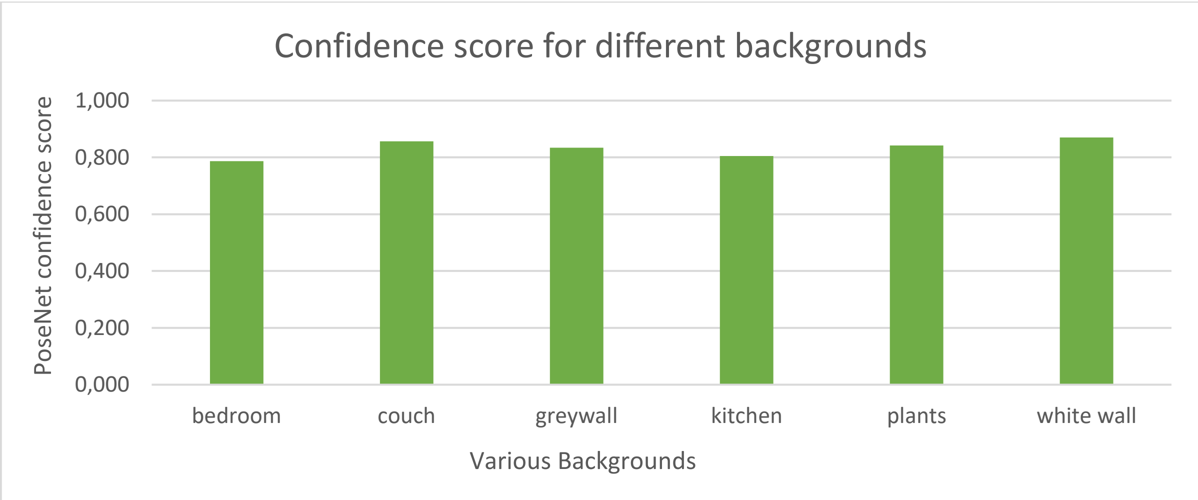

Figure 11: Average confidence score for different backgrounds

Table 7: Average confidence score for different backgrounds

Background	bedroom	couch	greywall	kitchen	plants	white wall
Average Score	0,786	0,856	0,835	0,805	0,842	0,870

4.3 Web application

The application consists of five main pages: Index, Exercise program, How to, Start exercise and History. The application is responsive, allowing users to open it on devices with various screen sizes. The application is bilingual, all functions are available in both English and German. The user can change the language by pressing on the English flag or the German flag.

The structure and makeup of the website is as follows: from the Index page the user can either create a new account or login with an existing account. Once logged in the user is directed to the Exercise program page, from here he has access to all further pages. To perform an exercise, the user can choose between one of two paths. He can either open the Start exercise page directly or visit the How to page first. From the Start exercise page the user can either exit and return to the Exercise program page or once finished with his exercises, continue to the History page. The user is able to logout from three pages, the History page, the Exercise Program Page and the How to Page. A sitemap of the web application can be seen in Figure 12. Large images of each page can be found in Appendix E.1.

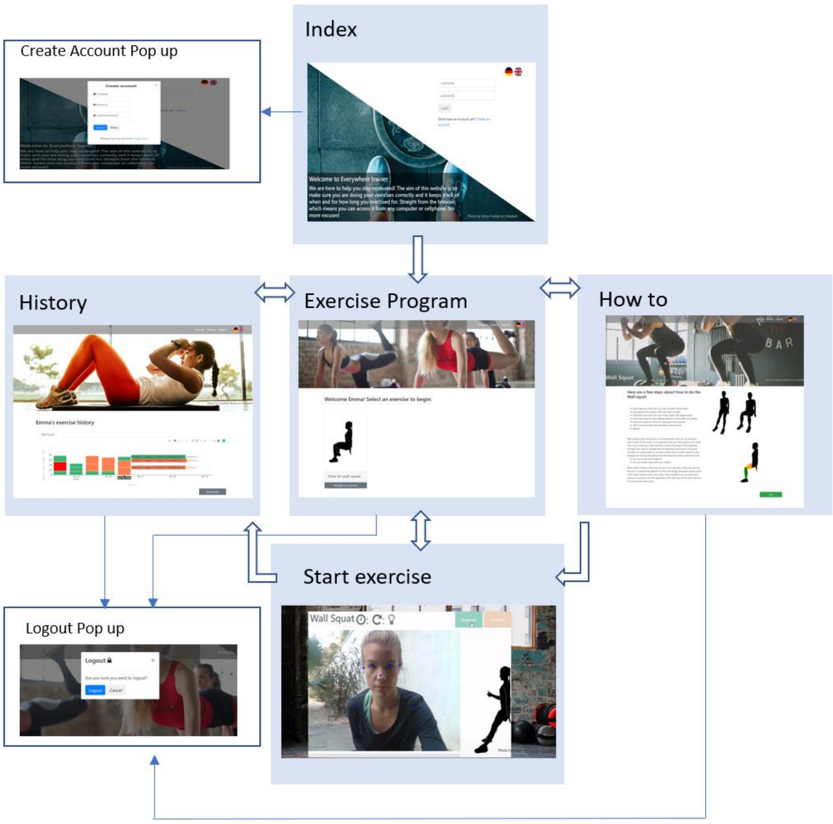

Figure 12: Sitemap of the web application

4.3.1 Frontend

The Index page welcomes the user with a short motivation and description of what the application does. Here the user is required to enter his username and password to use the application. If the user does not have an account, he needs to register himself with a new username and password. This is done by pressing on the ”create an account“ link which makes the create an account pop up appear. The login is designed to be error friendly meaning on entry of a false password, the username does not need to be re-entered. The login is required to provide the user with his individual exercise plan and history page.

The Exercise program page shows all the exercises available to the user. For each exercise the user can choose to either start doing the exercise directly or to first visit the corresponding How to page. New users should go through the How to page first, while experienced users can go directly to the exercise. The How to page explains how to do the exercise correctly, what angles and positions the application is monitoring and how the application will indicate pose errors and breaks. The exercise is illustrated by an MP4 video of an avatar moving through the different exercise positions.

Using the results from section 4.1 and 4.2, the wall squat exercise was chosen for the application prototype. Once the user has opened the Start exercise page for the squat, he must accept a permission request for the application to use the camera. The application cannot work without this permission. The video stream from the camera is displayed in the middle of the screen. PoseNet needs a few seconds for the initial setup. During this time a loading circle is shown until the first coordinates for the body parts are received from PoseNet and the blue points can be drawn.

Above the video stream are the name of the exercise, a clock icon for the number of seconds that the exercise has been held, a repeat icon for the number of repetitions completed, a light bulb icon which indicates when the room is insufficiently lit by turning orange, a start exercise button and an exit exercise button. On the right side of the page is an avatar which updates itself corresponding to the movements of the user.

After pressing the start button, the user must step backwards so that all the necessary body parts are visible. This is indicated by a bar at the bottom of the screen and by text on the screen. Once the user is completely visible, the application shows the correctness of his squat indicated by the colour of lines tracing the body parts in the video stream. For the squat, correctness depends on the angle the calf makes with the y-axis and the angle the thigh makes with the x-axis. This angle should be zero for both thigh and calf for the perfect squat. Depending on the deviation from the zero angle, the colour of the corresponding lines is changed. Furthermore, the colour of the relevant body parts of the avatar are changed. For the colours, the traffic light system is used: green when the pose is correct, orange when the pose is slightly incorrect and red when the pose is very incorrect.

The timer starts as soon as the user is in the correct pose for the first time, i.e. all relevant body parts are shown in green. It keeps running as long as the position is held but interrupts when the user deviates from the correct position. The number of repetitions is increased by one once the timer reaches the target duration for one repetition. At the end of each repetition, the information gathered during the exercise is saved into the exercise_holding table in the database. In between each repetition the user is prompted to take a small break, the start and end of the break are indicated with the sound of a bell and text on the screen. The application counts the number of repetitions and once the required number is completed the user is informed of this and has the option to continue the same exercise, move on to the next exercise or go to the History page where he can see the results from the exercise.

The sequence of events for the execution of a wall squat in the application can be seen below in Figure 13. Large images of this sequence can be found in Appendix E.2.

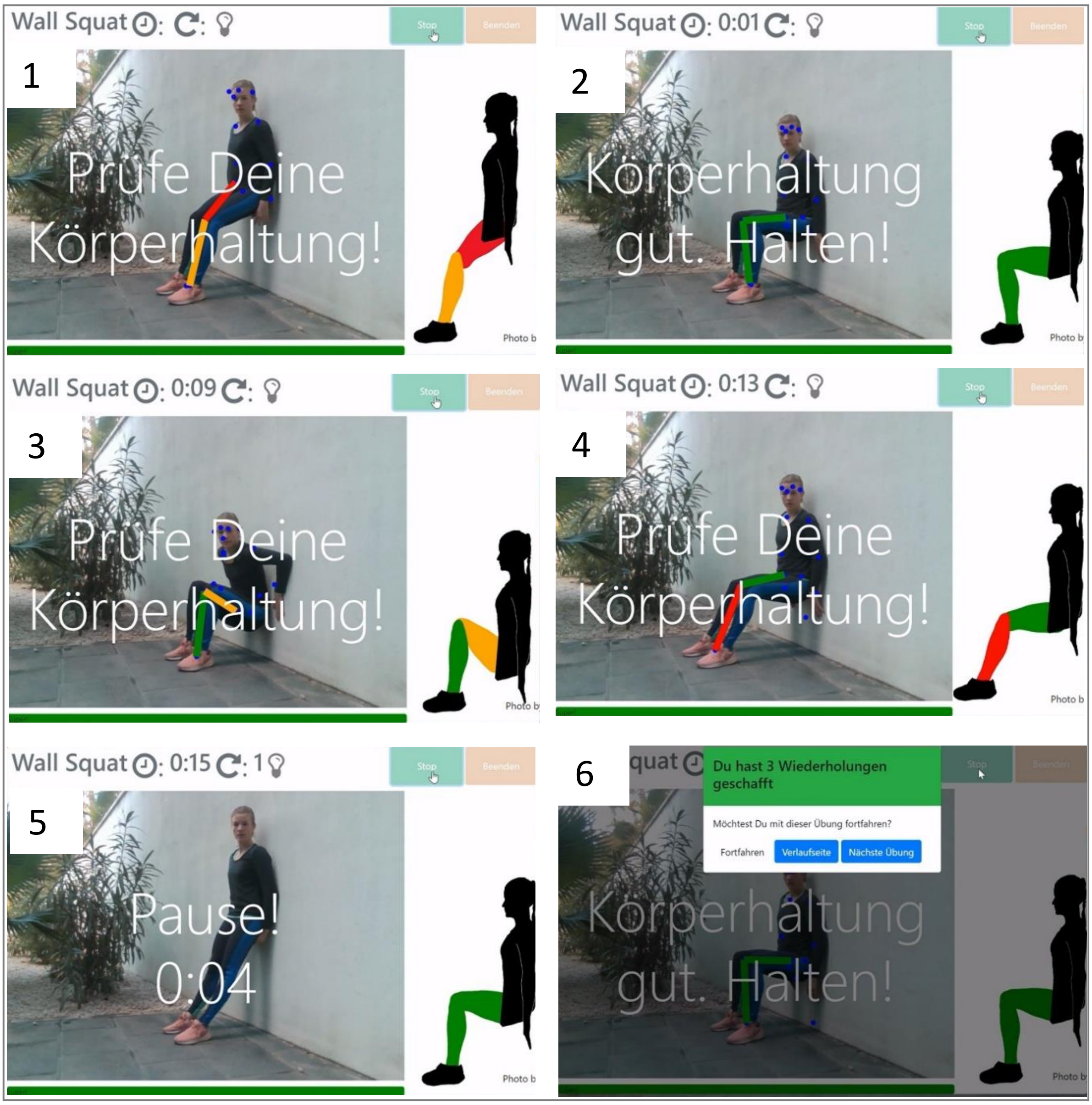

Figure 13: Sequence of events for the execution of a wall squat in the application

The History page displays a stacked graph of the time taken in seconds for each repetition versus the day on which the exercise was completed. The stacked graph starts with the first repetition, then second and so on. Again, the traffic light system is used. Each repetition is coloured in green, orange or red depending on the length of the repetition. The graph gives an overview of the user's compliance and the correctness of the exercise. The graph begins with the date that the user created his account. Hovering the mouse pointer over one of the bars will bring up a text box with detailed information on errors made during each repetition. The graph provides the user with several additional functions such as download plot as png, zoom and pan. One chart is created for each exercise type. At the top of the graph is a menu to change between the different exercises. At the bottom of the graph is a download button, which enables the user to obtain the data from the graph in table format as a .csv file. An example of a user's exercise history can be seen in Figure 14.

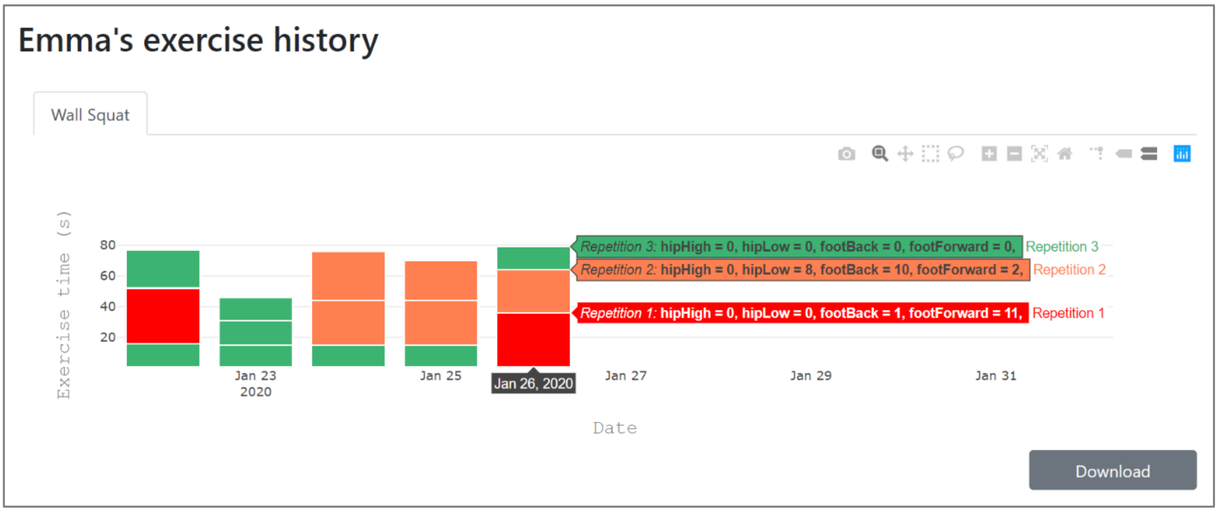

Figure 14: Example of a user's exercise history. The image illustrates the onhover event for the 26th Jan 2020

4.3.2 Backend

Three tables were created: users, holding_exercises and alldates. The user table allows the website to be personalized, the user is greeted by name and the History page displays only information from the currently logged in user. The user table was created with four columns having the following names and data types: id (int), username (varchar), password (varchar) and created_at (timestamp). The id was set as the table's primary key and is a number given automatically to the user upon account creation. The username and password are chosen by the user. The password is saved using a strong one-way hashing algorithm, which means it is not possible to read the password from the database. Finally, created_at is the time and date when the user created his account. An image of the user table structure can be seen in Figure 15.

#	Name	Type	Collation	Attributes	Null	Default
1	**id**	int(11)			No	*None*
2	**username**	varchar(50)	latin1_german1_ci		No	*None*
3	**password**	varchar(255)	latin1_german1_ci		No	*None*
4	**created_at**	timestamp			No	CURRENT_TIMESTAMP

Figure 15: Structure of the table: users

The holding_exercises table was created to store all the valuable information that occurs while a user is exercising. The data is relevant for the History page, enabling the user to evaluate his correctness and compliance with the exercise program. The holding_exercises table has seven columns with the following names and types: user_id (int), exercise (varchar), time (timestamp), exe_time (int), reps (int), corrections (varchar) and reps_duration (int). User_id corresponds to the id in the user table. Exercise is the name of the exercise completed, i.e Wall Squat or Plank. Time is the time and date the repetition was completed. The exe_time, is the time requested by the trainer that the user should hold for one repetition. Reps is the number of repetitions completed, i.e. 1, 2 or 3. Corrections is an array which is saved as a string, it contains all the textual information related to mistakes made by the user during the exercises. Finally, the last column, reps_duration is the actual time the user took to complete a repetition including the errors. The user_id and time were set as a primary key together. An image of the holding_exercises table structure can be seen in Figure 16.

#	Name	Type	Collation	Attributes	Null	Default
1	**user_id**	int(11)			No	*None*
2	**exercise**	varchar(50)	latin1_german1_ci		No	*None*
3	**time**	timestamp			No	CURRENT_TIMESTAMP
4	**exe_time**	int(11)			No	*None*
5	**reps**	int(11)			No	*None*
6	**corrections**	varchar(1000)	latin1_german1_ci		No	*None*
7	**reps_duration**	int(11)			No	*None*

Figure 16: Structure of the table: holding_exercises

To ensure that the chart on the History page has a continuous time axis, i.e. all dates are shown and not just the dates where the user exercised, a table with all dates is needed. The alldates table fills this purpose and was created with one column having the following name and type: all_dates(date). The table was filled with all dates between the 01.08.2019 and the 31.12.2020. An image of the alldates table structure can be seen in Figure 17.

	#	Name	Type	Collation	Attributes	Null	Default
☐	1	**all_dates**	date			Yes	*NULL*

Figure 17: Structure of the table: alldates

5 Discussion

The aim of this thesis was to design, implement and evaluate a fitness application that employs PoseNet to improve compliance and correctness of home exercises for back pain. Such an application was successfully developed. It guides the user on the correctness of his posture and documents the execution. The user uses a webcam to obtain a video stream of himself. The application shows how to achieve the correct posture through an overlay of coloured lines on the video stream. Additionally, an avatar mirrors the user's movement and shows which body parts are not in the correct position. The application aids the user with compliance by storing and displaying information on how often an exercise was completed and where the user made posture errors. The design, evaluation and implementation processes and results are discussed in the following sections.

5.1 Medical

Several papers [22, 25, 26] suggest that there is no single best practice program against back pain, it was however found that physiotherapists prescribe certain exercises more often than others. An email survey and a Google search were employed to identify the most important home exercises. The programs obtained in this way were summarized into a single list of exercises. As the application would mostly be used by a physiotherapist, it was these exercises that were used for the prototypical implementation and the evaluation of PoseNet.

5.1.1 Methods

None of the 30 physiotherapists replied to the email survey. This shows that the number of recipients was too low and that follow ups in the form of phone calls and second emails are necessary. As an alternative, personal visits to physiotherapy practices, while necessitating much more time, could be more successful.

From the Google search, the most common exercises prescribed by physiotherapists were identified by including the top twenty search results. This number was considered sufficiently large to see a pattern in back pain exercises and to choose an exercise to be implemented into the prototype. It must be noted that these exercises are not necessarily the best in terms of pain relief. Physiotherapists simply suggest them most commonly. For future development more time could be spent on the selection of exercises.

When looking through the back pain programs and sorting the exercises, some exercises were placed in the category for standing position although they could also be executed on the floor. The difference in effectiveness of doing an exercise standing and on the floor should be examined. Furthermore, the difference between similar exercises which were grouped together should be better analysed to ensure these exercises can be grouped together. Finally exercises that require additional equipment to be executed were excluded. These could potentially be added at a later stage as another exercise category.

5.1.2 Results

The results provided a list of exercises which would be plausible to include in the application in the future. The exercises found in more than 5 programs were: Bridge, Arm and Leg Lift, Back extension, Plank, Crunch, Side Plank and Squat. For the stretches: Resting Pose, Child's Pose, Knee to chest, Cat and Dog stretch, Thoracis Extension and Trunk Rotation. These exercises and stretches contain both holding exercises, like the plank and repetition exercises, like crunches and are often executed on the ground.

5.2 PoseNet

PoseNet is an extremely robust model which is easy to use and runs in the browser. This makes it possible to build an application that can observe the user in a similar fashion as a real trainer or therapist would. However, PoseNet was not developed for back pain exercises in particular. The suitability of the model for this purpose was therefore evaluated in a number of tests.

5.2.1 Methods

For all of the PoseNet evaluations, the confidence scores of the body parts were taken as the measure for correctness of the pose estimation. This assumes that the coordinates of the body parts are correct when PoseNet delivers these with a high confidence score, i.e. the location of the knee coordinate is in fact on the knee. This is unfortunately not always the case and it does happen that PoseNet is confident about the coordinates of a body part without them being correct. For example, when doing the plank or the arm and leg lift PoseNet often mistook hands for feet. While the actual reasoning of PoseNet is unknown, it appeared that hands were mistaken for feet when they were located directly beneath the head. PoseNet increasingly struggles when the pose is different from a standing position, probably because it has been trained mainly on images of the latter. For example, PoseNet has high confidence scores for a few body parts of the resting childs pose, but the coordinates are incorrect. Fur future developments, it would probably be necessary to train PoseNet specifically on the poses seen in back pain exercises. For poses where the user is standing with his face towards the camera PoseNet already works very well.

When doing the brightness tests, the brightness of the room was changed 5 times. However, on closer inspection, the first three brightness levels were almost identical and for this reason two of these were discarded leaving only three different levels in the end. In order to determine the detailed behaviour of the curve for low brightness levels, one would need more points towards the darker end of the axis. The quality of the image for the Acer Swift is noticeably worse when changing the lighting in real life as opposed to changing it digitally. The brightness was reduced artificially for the Huawei P20. Obtaining two images of the same brightness naturally from both cameras was very difficult, as the Huawei P20 changed its settings to compensate for the dim light.

The quality of the camera used influences the correctness of PoseNet's results. Unfortunately, only two devices were available for the evaluation. It could be necessary to repeat these evaluations with several cameras to determine limitations specifically for different camera specifications.

A 26-year-old white female was used for all of the evaluations. The evaluation results are therefore biased towards this user group. Results for users of different races, age groups and sexes could deviate from the results obtained in this work.

All evaluations were done with still images that were taken separately. In the application PoseNet is taking an image from the video stream every second. It could happen that the person is moving at the moment that the PoseNet function is called, which would send a potentially blurry image. The effect of this blurriness was not investigated further in this thesis.

With poses, clothes, backgrounds, lighting and cameras, the evaluation conducted in this thesis covers a wide range of possible factors influencing the suitability of PoseNet for monitoring home based back pain exercises. 105 images were taken and evaluated.

5.2.2 Results

PoseNet seems to be largely independent of the outfits worn by the user. Contrary to expectation, baggy clothes do not perform worse than a tighter outfit consisting of shorts and a T-Shirt. Similarly, PoseNet appears to have no problem with objects being in the background or with the background being of a similar colour as the clothes being worn. A natural exception is of course having another person in the background. With the single pose algorithm, the algorithm selected for this thesis, PoseNet will select body parts from every person in the image at random. For monitoring of more than one person, the multipose algorithm should be selected. Through this evaluation however, it became clear that PoseNet is not suited for poses where the user is on the floor or where the user is covering his face. Certain crossing movements are also not recognised well. Therefore, in order to use PoseNet for exercises that occur on the floor, one would either need to train the model further or find a different, more suitable model.

Having a PoseNet confidence score above 0.7 for all relevant body parts was sufficient to be able to compute an exercise effectively. It must be noted that the face was included in all of the average numbers for the certainty score. Although the face coordinates are not necessarily needed for any exercise, PoseNet seems to perform better when the face coordinates are visible. It was found that PoseNet is really only suited for poses where the person is standing relatively upright and with the face being visible. This is highlighted by the Plank: when the image of the

Plank is fed into PoseNet horizontally the average confidence score is low, at only 0.609. After rotating the image of the plank, such that the person appears to be standing, the score increased by 0.154 to a score of 0.763.

From the brightness tests it can be concluded that brightness itself is not necessarily a problem on its own, but rather the quality of the camera used. Low light levels can cause the camera to produce pixelated images, which then cause PoseNet to show low confidence scores for the body parts. The Huawei performed far better than the Acer Swift. At a lightness intensity of 40, images from the Acer swift had an average confidence score of 0.456, barely yielding any body parts correctly. The same images taken with the Huawei had an average confidence score of 0.781, which means that PoseNet was still able to estimate most of the body parts accurately. More research needs to be conducted to explore what exactly provides the difference between the cameras; the hardware, software or both. It is therefore difficult to select a minimum brightness level that works for all cameras. For the prototype, a lower intensity limit of 70 was implemented which works with both cameras employed in this thesis.

5.3 The Application

The application provides an easy way to visually monitor patients while they do their exercises. It replaces the need to fill out forms, as is the case in some applications, with all the necessary information being saved automatically. It gives people who already have a cell phone, laptop or smart TV the opportunity to improve their back pain, without having to spend money on equipment or needing to find the time for appointments at a physiotherapist.

Based on the outcome of the several tests performed, this application prototype may be a promising candidate for the solution of standardising the many variables that make it difficult to compare exercises and compliance tests in back pain studies. It could help define randomised control trials for both back pain exercises and compliance.

5.3.1 Methods

The application effectively takes an image from the video stream once every second and sends this to PoseNet, which works well in good lighting. However, when the lighting is not sufficient especially if the camera specifications are low, the recognition quality declines with some body parts intermittently jumping to objects in the room. Therefore, if one were to include cameras that have low specifications, a more effective method than just studying each frame separately i.e. without taking previous images into account, is needed at low light. Such a method could be to take into account the deductions from previous images to guide the process on new frames or take the complete image sequences as inputs for their predictions. By taking into account the temporal relationship between images or video frames, PoseNet might do a better job at recognising the knee for an example in the next frame. However, this would necessitate changes in PoseNet itself and cannot be enforced externally through the API.

Futhermore, some information is lost when one takes an image in 3D and projects its points onto a 2D plane. The 3D image becomes flat and one is not able to 'estimate' all angles correctly. Different perspectives can cause the points to appear in angles that they are not really building in 3D. To minimise this problem, one needs to suggest specific, well working angles between the user and the camera.

Some important notes about the application in its current state. The application needs a good internet connection to load the website, the worse the connection the longer it takes for PoseNet to load. Once the website is loaded it can be seen in the developer tools that there is no network activity, nothing is being sent or received. This means that no image is being sent to Google and the user‘s video stream remains private.

The time interval to update the coordinates, i.e. the time interval that images are sent to PoseNet was set to 1000 milliseconds. This ensured that the coordinates were accurate enough for the holding exercise without there being delays from PoseNet. For a seamless update of coordinates, i.e. where the coordinates do not flash once a second, the time interval could be decreased. However, this has an immediate effect on the performance of the application. The computing power of both the Acer Swift and Huawei P20 were not sufficient to return the coordinates without lagging or overheating at intervals smaller than 200 milliseconds. Reducing the time interval further could be necessary to implement repetition exercises.

5.3.2 Results

The application that was developed is a Hybrid app, which means it is a web-based app that is designed to also work on a smart phone. The application requires no installation but necessitates a large amount of testing before it can run problem free on all common browsers and screen sizes: i.e. on a phone, laptop and computer. This testing has only been done on a handful of devices.

The application is easy to use. One just needs to enter the domain name into a browser to begin exercising. It is made for all screen sizes, meaning the user can use his cell phone or computer TV screen, whichever is currently available. A bigger screen obviously has the advantage, especially for elderly, of being able to see oneself and the corrections better.

As described in the results, the application uses the coordinates of the body, calculates angles and displays guidelines and an avatar which change colour and position according to the correctness of the execution. The framework for one exercise, the wall squat, has been completed and the application was developed with more than one exercise in mind, meaning that the implementation of other exercises in the future would be easy. The user is guided through the exercise with a written text across the screen. This could be supported or replaced with voice prompts in the future so that the experienced users do not necessarily need to look at the screen all the time and can complete their exercises from voice prompts. The application was programmed with usability in mind and followed Shneiderman's 8 rules, however usability tests still would need to be completed.

Currently the application is set up only for holding exercises. Stretches and repetition exercises would require adjustments and expansion of the current application. Technically, this should not be difficult to implement as all necessary components exist.

The application was programmed at every stage with the intention of adding a trainer's page. This page would enable the trainer to design an individual training program for the trainee. The trainer would do an analysis of the patient and, according to the analysis, select appropriate exercises, their duration and frequency, as well as the angles which the patient should meet. These angles would be different for everyone, an elderly person might not be able to squat at

90 degrees initially. These values are currently all saved in variables but are assigned a fixed value.

An application like this could help trainers or physiotherapists reduce costs and help with compliance of patients as it enables the trainer to supervise without seeing the patient. The patient would only be required to come in when the trainer sees that the user is not doing his exercises or if the exercises are done incorrectly. The application will also provide more insights as to why the user is not compliant. Was the patient insufficiently prepared before going home; i.e. he doesn’t know or has forgotten how to do his exercises? Or is the patient not taking time for exercises at all? Either the patient is not complying to his exercise programs, he is not executing his exercises correctly or the chosen exercises are not beneficial to his recovery, all not leading to a healthy patient and needing different solutions.

5.4 State of the art

Comparing the application created in this thesis to that of VAY [46] one can see that with VAY no correctness is saved. The application simply counts the number of repetitions the user has completed for a certain exercise but it does not monitor or record what was done well and what can be improved. Everything is audio related and there is no visual feedback. Furthermore, the work of this thesis focuses on patients who have back problems and not just patients looking to get fit, like VAY. Finally, VAY is a commercial product that requires a subscription.

MIRA [45] has produced a physiotherapy tool that through games helps increase the patient’s movements and records his compliance. MIRA however uses motion tracking sensors to perform this task. Although the accuracy of MIRA may be better than that of this thesis, this thesis uses no additional device besides a camera from a device that a user already has, making it much more available but not as accurate. Machine learning is still new and with more progress, has the ability to be as accurate as motion tracking sensors in the future.

5.5 Outlook

There is a big need in the world for an application such as the one presented in this work. An application with the potential to get behind the treatment programs and compliance problems faced in back pain, without the cost and hassle of some of the currently available solutions.

There are several ways forward for this project depending on how the application is developed further. One possibility would be to include a trainer page. If a trainer page is to be included, physiotherapists should be consulted to find out which exercises to include and what variables, such as deviation angle and duration, they would want to set and monitor in the final application. With a physiotherapist behind the treatment plans, these plans could be personalised perfectly instead of having more general treatment plans. An increase in compliance could also be the result of the patient just knowing that he is being monitored by his physiotherapist.

Another option would be to not include physiotherapists and use a general set of exercises instead. The user could then set variables and a plan themselves or the application would suggest a program based on user characteristics, best practice and even the user's historic performance.

Finally, a combination of both approaches is thinkable, i.e. having a trainer page for those users that want to collaborate with a physiotherapist, but not enforcing this collaboration for every user. This approach would also enable a comparative for compliance between users with and without a trainer.

More exercises need to be added. If the further development of the application is to maintain PoseNet as the machine learning model behind the application, the model would need to be retrained so as to enable back pain exercises which are performed on the floor. PoseNet would also need to be tested with a range of different cameras and it might be necessary to establish minimum requirements for the hardware.

If it was decided not to continue with PoseNet, it would be necessary to find another system which provides the coordinates of the body parts being examined. The author believes that the adaptations of the application to another such system would be minimal.

6 Conclusion

This thesis successfully designed, implemented and evaluated a prototype web application that helps with compliance and correctness of home exercises in back pain. This was achieved through the study of compliance and back pain exercises, the evaluation of PoseNet capabilities and the implementation of web technologies.

Several back pain exercises are used by physiotherapists to fight back pain, there is however no exercise proven to be the best. On top of this, compliance is a serious problem in home exercise plans. Back pain exercises are often executed on the floor. In the PoseNet evaluation it became clear that the model is extremely robust towards clothes, backgrounds and brightness. However, camera quality and body poses do have a big effect on the pose estimation. More research needs to be done as to the limitations of the cameras and either PoseNet needs to be retrained or another model needs to be used to allow for the addition of exercises which are executed on the floor. Otherwise the application provides a promising step towards improving the correctness of exercise execution and solving the compliance problems encountered in back pain treatment, without the cost and hassle of some of the currently available solutions.

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Erklärung

Ich versichere, dass ich die vorliegende Arbeit ohne fremde Hilfe selbständig verfasst und nur die angegebenen Quellen und Hilfsmittel benutzt habe. Wörtlich oder dem Sinn nach aus anderen Werken entnommene Stellen sind unter Angabe der Quelle kenntlich gemacht.

Ich erkläre mich damit einverstanden, dass ein Exemplar meiner Bachelor- (Master-) Thesis in die Bibliothek des Fachbereichs aufgenommen wird; Rechte Dritter werden dadurch nicht verletzt.

Ort, Datum (Unterschrift der/des Studierenden)

Table of Contents for Appendix

Appendix A: E-mail sent to doctors, therapists and back pain societies

Liebe(r) [persönliche Anrede],

ich bin eine Medizintechnik Masterstudentin an der Hochschule für Angewandte Wissenschaften Hamburg. Derzeit schreibe ich meine Masterarbeit, in der es um die Entwicklung einer Fitness Applikation geht. Die Applikation soll mit Compliance und Korrektheit von zuhause ausgeführten Übungen helfen.

Eine Kamera (Handy oder Rechner) beobachtet den Patienten während der Übungen und rechnet die Koordinaten der Gelenke aus. Mit diesen Koordinaten kann man z.B. bestimmen ob die Knie zu weit vorne oder die Hüfte nicht tief genug sind. Die Applikation speichert Zeitpunkt, Dauer/Anzahl Wiederholungen und Qualität aller Übungen und stellt diese Information in grafischer Form auf einer 'Geschichte' Seite da.

Die Idee ist, dass der Trainer/Physiotherapeut Zugriff auf diese 'Geschichte' Seite hat und dementsprechend einfach Compliance, Fortschritte und Probleme einsehen und bewerten kann.

Die Applikation soll zuerst auf Rückenschmerzen fokussieren. Dafür brauche ich Übungen die häufig für Rückenschmerzen verschrieben werden.

Haben Sie vielleicht ein Trainingsprogramm für Zuhause mit Übungen, die Sie ihren Patienten mit Rückenschmerzen geben? Oder gibt es einzelne Übungen, die Sie für besonders effektiv erachten?

Wäre es möglich mir dieses Trainingsprogramm oder einzelne Übungen zu schicken?

Ich wäre sehr dankbar für ihre Hilfe.

Mit freundlichen Grüßen,

Serena Glass

Appendix B: E-mail responses from BdR and AGR

Sehr geehrte Frau Glass,

vielen Dank für Ihre Anfrage. Ihr Plan klingt interessant und umfangreich. Unsere hier hinterlegten Programme beziehen sich zurzeit auf Prävention, auch wenn einige Übungen sicherlich hilfreicher als andere gegen Schmerzen sind und auf jeden Fall der Chronifizierung von Schmerzen entgegen wirken. Ärzte verschreiben eher nicht konkrete Übungen, sondern weisen ggf. auf bestehende muskuläre Dysbalancen usw. hin, welches dann auf dem Rezept/Verordnung vermerkt wird, woraufhin tatsächlich der Therapeut (Sport oder Physio) die Übungsauswahl und deren Dosierung/Belastungsnormative festlegt. Die Schmerzen müssen differenziert werden, wo und in welcher Stärke diese auftreten um konkrete Übungen anzuraten. Wir möchten Ihnen daher empfehlen, gezielt z.B. Physiotherapeuten anzusprechen um hier die entsprechenden Übungen herauszufinden, die geeignet sind.

Mit freundlichen Grüßen

Gudrun Ruggeri

Geschäftsstelle des BdR e.V.

Bundesverband deutscher Rückenschulen (BdR) e. V.

Sehr geehrte Frau Glass,

zunächst entschuldigen Sie bitte, dass wir bis jetzt noch nicht von uns haben hören lassen. Das ist nicht unser Stil, nur leider haben wir gerade wieder sehr viel Anfragen die beantwortet werden wollen. Sorry - für die Verzögerung. Nun zu Ihrer Frage. Unter www.agr-ev.de/uebungen finden Sie eine Auswahl von verschiedensten Übungen. Hierbei handelt es sich um einfache Übungen die prophylaktisch durchgeführt werden können. Liegen bereits stärkere schmerzen, gerade wenn diese bereits länger anhaltend sind, vor, empfiehlt es sich vorher einen Arzt oder Therapeuten zu konsultieren. Dieser kann dann evtl. Übungen ausschließen, die für den Patienten nicht geeignet sind. Auch empfehlenswerte Onlinetrainingsprogramme gibt es. Diese wurden bereits von unserem unabhängigen Expertengremium mit dem AGR-Gütesiegel ausgezeichnet. Um welche es sich genau dabei handelt und was die Voraussetzungen für eine erfolgreiche Prüfung sind, können Sie hier nachlesen: www.agr-ev.de/trainingsprogramme

Ich hoffe, ich konnte Ihre Fragen ausreichend beantworten, ansonsten melden Sie sich gern noch einmal.

Freundliche Grüße

Jens Löhn

stv. Geschäftsführer

Aktion Gesunder Rücken e. V.

Appendix C: Illustrations of back pain exercises

C.1 Strengthening and stability exercises

PHYSIOTOOLS

Personal exercise program

PhysioTools Trial.

Provided by Serena Glass
Provided for

Bridge

Arm and Leg Lift

Back Extension

Plank

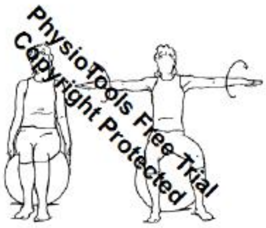
Crunch

Side Plank

Side lying Leg Lifts

Air Bike / Air Cycling

Bent Leg Hip Extension



Arm Circles

Wall Squat

Forward Lunges

Knee Lift

C.2 Stretching exercises

PT PHYSIOTOOLS

Personal exercise program

PhysioTools Trial.

Provided by Serena Glass

Provided for

©Physiotools

Resting Pose

©Physiotools

Child's Pose

©The Saunders Group Inc.

Knee to chest / Lower Trunk Flexion

©Physiotools

Knees to Sides

©Physiotools

Posterior Pelvic Tilt

©Physiotools

Cobra

©Physiotools

Downward Facing Dog

©Physiotools

Clam (sidelying)

 ©Physiotools	Hip Adductor / Frog Stretch	 ©Physiotools	Gluteus Stretch
 ©Physiotools	Cat Dog / Mid Back Stretch	 ©Physiotools	Thoracic Extension with shoulder flex
 ©Physiotools	Trunk Side Bending Stretch	 ©Joanne Elphinston	Body / Trunk Rotation
 ©Physiotools	Crossbody / Shoulder Stretch	 ©Physiotools	Trapezius / Neck Stretch
 ©Physiotools	Triceps Stretch	 ©Physiotools	Wrist Flexors Stretch

Standing Quad Stretch

Forward Bend

Appendix D: Images from PoseNet Evaluation

D.1 Different poses and outfits

The images are ordered as following in terms of outfits: colourful, black, short and baggy. In each outfit group the poses are ordered as follows: Arm and Leg Lift, Resting Pose Bridge, Cat and Dog stretch, Child's Pose, Trunk Side Bending, Plank, Squat, Standing, Thoracic Extension.

Image:	armandlegliftcolour1
Brightness:	225
Nose:	0.9770283699035645
RightEye:	0.9553978443145752
LeftEye:	0.5402591824531555
EarRight:	0.9755109548568726
EarLeft:	0.3555300235748291
ShoulderRight:	0.9839425683021545
ShoulderLeft:	0.9275428056716919
ElbowRight:	0.8323556780815125
ElbowLeft:	0.7000769376754761
WristRight:	0.4904751479625702
WristLeft:	0.8445228934288025
HipRight:	0.873404860496521
HipLeft:	0.8531632423400879
KneeRight:	0.6487501263618469
KneeLeft:	0.6975283026695251
AnkleRight:	0.7125290036201477
AnkleLeft:	0.7999727129936218

Image:	armandlegliftcolour2
Brightness:	207
Nose:	0.9970201253890991
RightEye:	0.9963196516036987
LeftEye:	0.7586430907249451
EarRight:	0.995003879070282
EarLeft:	0.05011877045035362
ShoulderRight:	0.9714831113815308
ShoulderLeft:	0.9562243223190308
ElbowRight:	0.7652704119682312
ElbowLeft:	0.9189561009407043
WristRight:	0.7892854809761047
WristLeft:	0.9023215174674988
HipRight:	0.5816124677658081
HipLeft:	0.722343921661377
KneeRight:	0.6866103410720825
KneeLeft:	0.7656810283660889
AnkleRight:	0.6709208488464355
AnkleLeft:	0.4575071632862091

Image:	restingposecolourful1
Brightness:	216
Nose:	0.19445087015628815
RightEye:	0.0814913809299469
LeftEye:	0.18842379748821259
EarRight:	0.06285954266786575
EarLeft:	0.0543944351375103
ShoulderRight:	0.3321058452129364
ShoulderLeft:	0.2500970661640167
ElbowRight:	0.21191895008087158
ElbowLeft:	0.3402436077594757
WristRight:	0.5567828416824341
WristLeft:	0.5723392963409424
HipRight:	0.1966819018125534
HipLeft:	0.2771502435207367
KneeRight:	0.15295982360839844
KneeLeft:	0.13684041798114777
AnkleRight:	0.2920502722263336
AnkleLeft:	0.3009197413921356

Image:	restingposecolourful2
Brightness:	221
Nose:	0.7509821653366089
RightEye:	0.6275971531867981
LeftEye:	0.6500328779220581
EarRight:	0.7174909114837646
EarLeft:	0.5477961301803589
ShoulderRight:	0.9060671925544739
ShoulderLeft:	0.8272108435630798
ElbowRight:	0.6818367838859558
ElbowLeft:	0.5820155739784241
WristRight:	0.7571488618850708
WristLeft:	0.5942888259887695
HipRight:	0.8501402735710144
HipLeft:	0.8671202659606934
KneeRight:	0.38428738713264465
KneeLeft:	0.4137376844882965
AnkleRight:	0.31250959634780884
AnkleLeft:	0.23120975494384766

Image:	BridgeColourful
Brightness:	224
Nose:	0.2457621544599533
RightEye:	0.16185075044631958
LeftEye:	0.17616955935955048
EarRight:	0.16833044588565826
EarLeft:	0.14318646490573883
ShoulderRight:	0.22167880833148956
ShoulderLeft:	0.4657192528247833
ElbowRight:	0.19684718549251556
ElbowLeft:	0.19853471219539642
WristRight:	0.3706578314304352
WristLeft:	0.19519241154193878
HipRight:	0.3958192467689514
HipLeft:	0.37375912070274353
KneeRight:	0.4630305767059326
KneeLeft:	0.4350539743900299
AnkleRight:	0.39368483424186707
AnkleLeft:	0.6647210121154785

Image:	BridgeColourful3
Brightness:	230
Nose:	0.7931624054908752
RightEye:	0.7811002731323242
LeftEye:	0.6561515927314758
EarRight:	0.5778469443321228
EarLeft:	0.4535886347293854
ShoulderRight:	0.7228484749794006
ShoulderLeft:	0.6626124978065491
ElbowRight:	0.6786045432090759
ElbowLeft:	0.4743918180465698
WristRight:	0.6228143572807312
WristLeft:	0.41034379601478577
HipRight:	0.6641546487808228
HipLeft:	0.5837426781654358
KneeRight:	0.4355550706386566
KneeLeft:	0.38766583800315857
AnkleRight:	0.5060057640075684
AnkleLeft:	0.524114727973938

Image:	CatStretchColourful
Brightness:	221
Nose:	0.04866057261824608
RightEye:	0.053297556936740875
LeftEye:	0.03791811317205429
EarRight:	0.1224842295050621
EarLeft:	0.02563956193625927
ShoulderRight:	0.5396220684051514
ShoulderLeft:	0.36950215697288513
ElbowRight:	0.4999595880508423
ElbowLeft:	0.4423879384994507
WristRight:	0.7186520099639893
WristLeft:	0.7197849750518799
HipRight:	0.8280898928642273
HipLeft:	0.8030499219894409
KneeRight:	0.7912585139274597
KneeLeft:	0.7850269675254822
AnkleRight:	0.760509192943573
AnkleLeft:	0.6532251238822937

Image:	CatStretchColourful2
Brightness:	223
Nose:	0.23969168961048126
RightEye:	0.30551856756210327
LeftEye:	0.05487094074487686
EarRight:	0.7827450037002563
EarLeft:	0.08036593347787857
ShoulderRight:	0.9391381144523621
ShoulderLeft:	0.5644896626472473
ElbowRight:	0.6226491928100586
ElbowLeft:	0.4620630145072937
WristRight:	0.9102962613105774
WristLeft:	0.6985602378845215
HipRight:	0.9121411442756653
HipLeft:	0.8437212109565735
KneeRight:	0.9381280541419983
KneeLeft:	0.8494452238082886
AnkleRight:	0.8515207171440125
AnkleLeft:	0.7804003953933716

Image:	CowStretchColourful
Brightness:	224
Nose:	0.9002982378005981
RightEye:	0.9205383062362671
LeftEye:	0.5403800010681152
EarRight:	0.9212242364883423
EarLeft:	0.24685880541801453
ShoulderRight:	0.8386502265930176
ShoulderLeft:	0.773145854473114
ElbowRight:	0.2899119257926941
ElbowLeft:	0.17934516072273254
WristRight:	0.6651855111122131
WristLeft:	0.4275832176208496
HipRight:	0.9162958860397339
HipLeft:	0.9104823470115662
KneeRight:	0.7034773826599121
KneeLeft:	0.7537362575531006
AnkleRight:	0.7331523895263672
AnkleLeft:	0.8123764991760254

Image:	CowStretchColourful2
Brightness:	227
Nose:	0.9989990592002869
RightEye:	0.9983532428741455
LeftEye:	0.9835138916969299
EarRight:	0.9847198724746704
EarLeft:	0.15330608189105988
ShoulderRight:	0.9356932640075684
ShoulderLeft:	0.9852229356765747
ElbowRight:	0.8991056680679321
ElbowLeft:	0.7229053974151611
WristRight:	0.1901438981294632
WristLeft:	0.3297622799873352
HipRight:	0.9892595410346985
HipLeft:	0.9838233590126038
KneeRight:	0.9201886057853699
KneeLeft:	0.913120687007904
AnkleRight:	0.8833515048027039
AnkleLeft:	0.8756750822067261

Image:	LowerbackStretchColourful
Brightness:	225
Nose:	0.0512055866420269
RightEye:	0.037464603781700134
LeftEye:	0.06458979099988937
EarRight:	0.07303943485021591
EarLeft:	0.14027659595012665
ShoulderRight:	0.33977723121643066
ShoulderLeft:	0.21697956323623657
ElbowRight:	0.11793376505374908
ElbowLeft:	0.08279001712799072
WristRight:	0.08581066876649857
WristLeft:	0.06597352772951126
HipRight:	0.1382083296775818
HipLeft:	0.10428421199321747
KneeRight:	0.08852863311767578
KneeLeft:	0.08673962950706482
AnkleRight:	0.07953993231058121
AnkleLeft:	0.07341846078634262

Image:	LowerbackStretchColourful2
Brightness:	224
Nose:	0.13993851840496063
RightEye:	0.10290016978979111
LeftEye:	0.16363216936588287
EarRight:	0.09816023707389832
EarLeft:	0.2578776776790619
ShoulderRight:	0.19286289811134338
ShoulderLeft:	0.2989180386066437
ElbowRight:	0.1327883005142212
ElbowLeft:	0.205943301320076
WristRight:	0.13454729318618774
WristLeft:	0.08380170166492462
HipRight:	0.31794124841690063
HipLeft:	0.17798595130443573
KneeRight:	0.14987130463123322
KneeLeft:	0.1620650291442871
AnkleRight:	0.06810172647237778
AnkleLeft:	0.05745347961783409

Image:	ObliqueStretchColourful
Brightness:	225
Nose:	0.9896904230117798
RightEye:	0.9507542252540588
LeftEye:	0.9701324701309204
EarRight:	0.39586248993873596
EarLeft:	0.8407678604125977
ShoulderRight:	0.946179211139679
ShoulderLeft:	0.9354519248008728
ElbowRight:	0.7584654092788696
ElbowLeft:	0.6810784935951233
WristRight:	0.926813542842865
WristLeft:	0.766692042350769
HipRight:	0.9946579337120056
HipLeft:	0.995586633682251
KneeRight:	0.9501539468765259
KneeLeft:	0.9600806832313538
AnkleRight:	0.8858391642570496
AnkleLeft:	0.8786473274230957

Image:	ObliqueStretchColourful2
Brightness:	215
Nose:	0.9547932147979736
RightEye:	0.9387839436531067
LeftEye:	0.924553394317627
EarRight:	0.560194730758667
EarLeft:	0.8671327829360962
ShoulderRight:	0.8160915374755859
ShoulderLeft:	0.9150561690330505
ElbowRight:	0.8724561333656311
ElbowLeft:	0.6959000825881958
WristRight:	0.9607092142105103
WristLeft:	0.7830028533935547
HipRight:	0.9003193974494934
HipLeft:	0.9284207224845886
KneeRight:	0.7972881197929382
KneeLeft:	0.7616797089576721
AnkleRight:	0.8847361207008362
AnkleLeft:	0.9176101088523865

Image:	PlankColourful
Brightness:	220
Nose:	0.9025291800498962
RightEye:	0.8414332270622253
LeftEye:	0.5750784277915955
EarRight:	0.9443621039390564
EarLeft:	0.37536272406578064
ShoulderRight:	0.9883221983909607
ShoulderLeft:	0.7333311438560486
ElbowRight:	0.9496994614601135
ElbowLeft:	0.7531809210777283
WristRight:	0.8846451640129089
WristLeft:	0.6788278222084045
HipRight:	0.5836832523345947
HipLeft:	0.5370931029319763
KneeRight:	0.5019863843917847
KneeLeft:	0.3929136395454407
AnkleRight:	0.5684465765953064
AnkleLeft:	0.42035847902297974

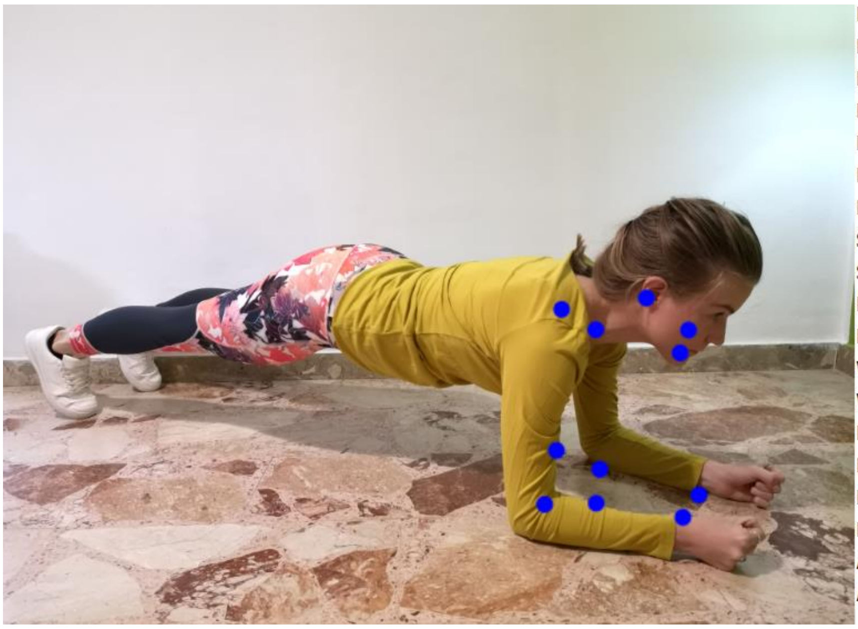


Image:	PlankColourful2
Brightness:	224
Nose:	0.8849075436592102
RightEye:	0.9641295671463013
LeftEye:	0.42224690318107605
EarRight:	0.9748753309249878
EarLeft:	0.08443626016378403
ShoulderRight:	0.9570949077606201
ShoulderLeft:	0.72378009557724
ElbowRight:	0.9073253273963928
ElbowLeft:	0.6270232796669006
WristRight:	0.8810977935791016
WristLeft:	0.8711323738098145
HipRight:	0.45284777879714966
HipLeft:	0.5575085878372192
KneeRight:	0.49489742517471313
KneeLeft:	0.5654503107070923
AnkleRight:	0.29193446040153503
AnkleLeft:	0.39151710271835327

Image:	PlankColourful
Brightness:	151
Nose:	0.8814506530761719
RightEye:	0.7226691246032715
LeftEye:	0.8526284694671631
EarRight:	0.35450679063796997
EarLeft:	0.8631194829940796
ShoulderRight:	0.8775779604911804
ShoulderLeft:	0.9530657529830933
ElbowRight:	0.7119899392127991
ElbowLeft:	0.8099512457847595
WristRight:	0.4255054295063019
WristLeft:	0.5548684597015381
HipRight:	0.9023762941360474
HipLeft:	0.9267178177833557
KneeRight:	0.8977673649787903
KneeLeft:	0.7830951809883118
AnkleRight:	0.8604065775871277
AnkleLeft:	0.8504049777984619

Image:	SquatColourful
Brightness:	224
Nose:	0.8442484736442566
RightEye:	0.895405113697052
LeftEye:	0.30170390009880066
EarRight:	0.9760167598724365
EarLeft:	0.23629190027713776
ShoulderRight:	0.9825236797332764
ShoulderLeft:	0.9443936944007874
ElbowRight:	0.533292829990387
ElbowLeft:	0.7652763724327087
WristRight:	0.7856977581977844
WristLeft:	0.6988239884376526
HipRight:	0.93461674451828
HipLeft:	0.9000842571258545
KneeRight:	0.8096224069595337
KneeLeft:	0.7799235582351685
AnkleRight:	0.7041118144989014
AnkleLeft:	0.7065220475196838

Image:	SquatColourful2
Brightness:	229
Nose:	0.9982452392578125
RightEye:	0.997909665107727
LeftEye:	0.9862322807312012
EarRight:	0.9845032095909119
EarLeft:	0.13604217767715454
ShoulderRight:	0.9909566044807434
ShoulderLeft:	0.9784817099571228
ElbowRight:	0.39442941546440125
ElbowLeft:	0.9693147540092468
WristRight:	0.5352193713188171
WristLeft:	0.9893348813056946
HipRight:	0.993744432926178
HipLeft:	0.939493715763092
KneeRight:	0.8910982012748718
KneeLeft:	0.8906642198562622
AnkleRight:	0.9471873044967651
AnkleLeft:	0.9192768335342407


Image: BlueShirtColourfulTightPants
Brightness: 215
Nose: 0.997735857963562
RightEye: 0.9935698509216309
LeftEye: 0.995793342590332
EarRight: 0.922096312046051
EarLeft: 0.8313154578208923
ShoulderRight: 0.9951990842819214
ShoulderLeft: 0.9973081350326538
ElbowRight: 0.9969196319580078
ElbowLeft: 0.9933512806892395
WristRight: 0.9843859076499939
WristLeft: 0.9802746176719666
HipRight: 0.9920418858528137
HipLeft: 0.9968175292015076
KneeRight: 0.9080618023872375
KneeLeft: 0.9623625874519348
AnkleRight: 0.8399994373321533
AnkleLeft: 0.8796934485435486


Image: BlueShirtColourfulTightPants2
Brightness: 216
Nose: 0.9985454082489014
RightEye: 0.9931214451789856
LeftEye: 0.9542321562767029
EarRight: 0.9663486480712891
EarLeft: 0.23110149800777435
ShoulderRight: 0.9951286315917969
ShoulderLeft: 0.9894607067108154
ElbowRight: 0.9972223043441772
ElbowLeft: 0.7117280960083008
WristRight: 0.9912909269332886
WristLeft: 0.5254452228546143
HipRight: 0.9921203851699829
HipLeft: 0.9897956252098083
KneeRight: 0.9306225776672363
KneeLeft: 0.9150113463401794
AnkleRight: 0.8467684388160706
AnkleLeft: 0.8186787366867065

Image:	thoracicextentioncolour1
Brightness:	165
Nose:	0.9894617199897766
RightEye:	0.9857355952262878
LeftEye:	0.9791684746742249
EarRight:	0.68805992603302
EarLeft:	0.8813760280609131
ShoulderRight:	0.9361162185668945
ShoulderLeft:	0.9095782041549683
ElbowRight:	0.7589005827903748
ElbowLeft:	0.7014590501785278
WristRight:	0.833743691444397
WristLeft:	0.8082473278045654
HipRight:	0.9695417284965515
HipLeft:	0.9839916229248047
KneeRight:	0.562353789806366
KneeLeft:	0.7017796039581299
AnkleRight:	0.3809666633605957
AnkleLeft:	0.49748605489730835

Image:	thoracicextentioncolour2
Brightness:	177
Nose:	0.9895924925804138
RightEye:	0.9886910915374756
LeftEye:	0.977803647518158
EarRight:	0.9092839360237122
EarLeft:	0.6282309293746948
ShoulderRight:	0.9504969716072083
ShoulderLeft:	0.9457675218582153
ElbowRight:	0.5398131608963013
ElbowLeft:	0.7824199795722961
WristRight:	0.3925463855266571
WristLeft:	0.3645768165588379
HipRight:	0.903159499168396
HipLeft:	0.9394949078559875
KneeRight:	0.768164336681366
KneeLeft:	0.7811769247055054
AnkleRight:	0.723354697227478
AnkleLeft:	0.7384718060493469

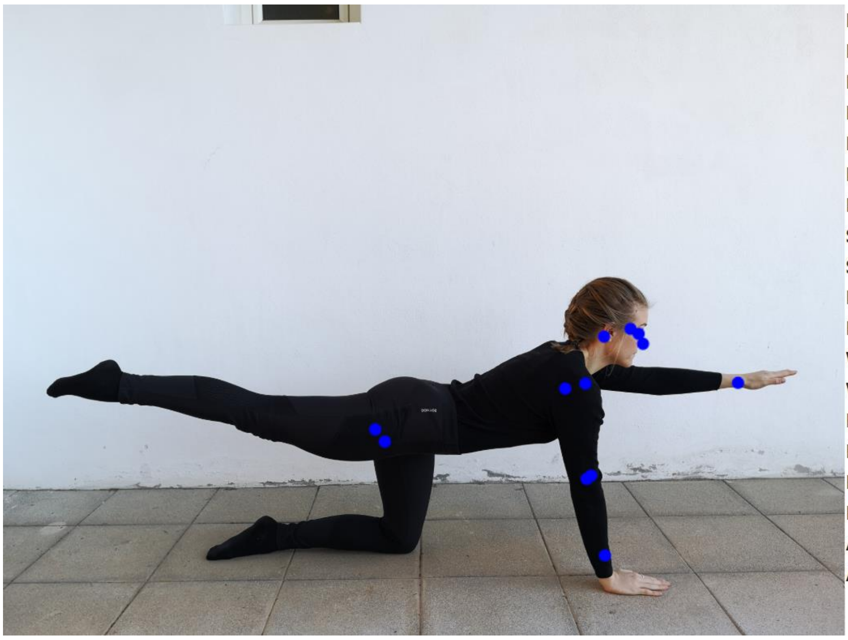


Image:	armandlegliftblack1
Brightness:	230
Nose:	0.9682103991508484
RightEye:	0.9402486681938171
LeftEye:	0.5334433317184448
EarRight:	0.9710353016853333
EarLeft:	0.2132868617773056
ShoulderRight:	0.9776995182037354
ShoulderLeft:	0.9675289988517761
ElbowRight:	0.8415650725364685
ElbowLeft:	0.627605676651001
WristRight:	0.7747955918312073
WristLeft:	0.8436936140060425
HipRight:	0.3640345335006714
HipLeft:	0.2882217764854431
KneeRight:	0.496370404958725
KneeLeft:	0.4679645001888275
AnkleRight:	0.5380540490150452
AnkleLeft:	0.709996223449707

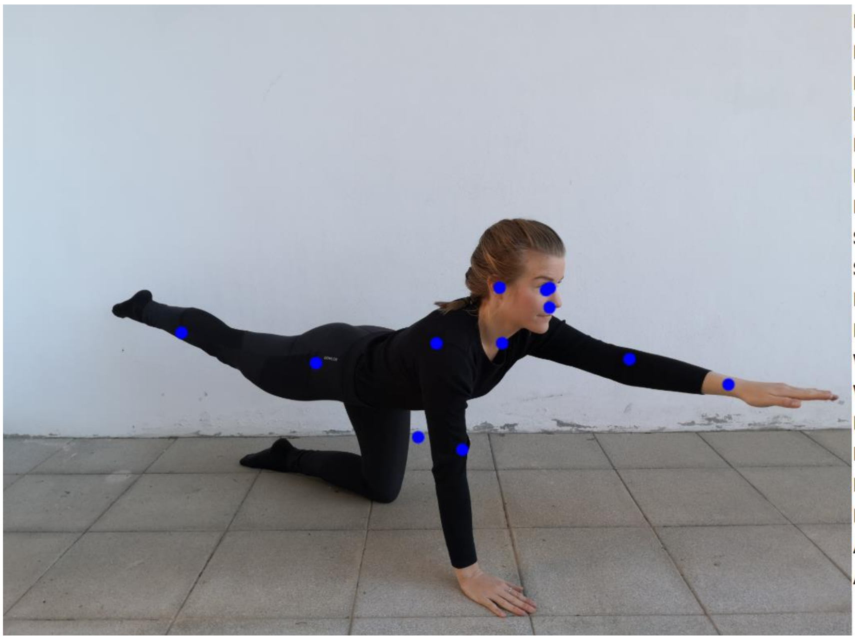


Image:	armandlegliftblack2
Brightness:	206
Nose:	0.9964015483856201
RightEye:	0.9932689070701599
LeftEye:	0.8791857957839966
EarRight:	0.9968481659889221
EarLeft:	0.05874761939048767
ShoulderRight:	0.9915856122970581
ShoulderLeft:	0.9540093541145325
ElbowRight:	0.8255022168159485
ElbowLeft:	0.9180699586868286
WristRight:	0.8818061947822571
WristLeft:	0.7804964780807495
HipRight:	0.4347212314605713
HipLeft:	0.4894220530986786
KneeRight:	0.6798146367073059
KneeLeft:	0.7212340235710144
AnkleRight:	0.2898911237716675
AnkleLeft:	0.3071376383304596

Image:	restingposeblack1
Brightness:	237
Nose:	0.24949444830417633
RightEye:	0.23787404596805573
LeftEye:	0.32755160331726074
EarRight:	0.11458731442689896
EarLeft:	0.14927442371845245
ShoulderRight:	0.21470533311367035
ShoulderLeft:	0.36194658279418945
ElbowRight:	0.11492552608251572
ElbowLeft:	0.1732008010149002
WristRight:	0.4090428948402405
WristLeft:	0.5060009956359863
HipRight:	0.2232932150363922
HipLeft:	0.28862905502319336
KneeRight:	0.16189932823181152
KneeLeft:	0.2237638533115387
AnkleRight:	0.17943018674850464
AnkleLeft:	0.1959305703639984

Image:	restingposeblack2
Brightness:	231
Nose:	0.5361448526382446
RightEye:	0.49607613682746887
LeftEye:	0.2629695236682892
EarRight:	0.23268766701221466
EarLeft:	0.2136232554912567
ShoulderRight:	0.4845614731311798
ShoulderLeft:	0.5661569237709045
ElbowRight:	0.3925940692424774
ElbowLeft:	0.22508780658245087
WristRight:	0.6294812560081482
WristLeft:	0.3472687900066376
HipRight:	0.2614423632621765
HipLeft:	0.21246276795864105
KneeRight:	0.40773841738700867
KneeLeft:	0.3636651337146759
AnkleRight:	0.26523876190185547
AnkleLeft:	0.40952369570732117

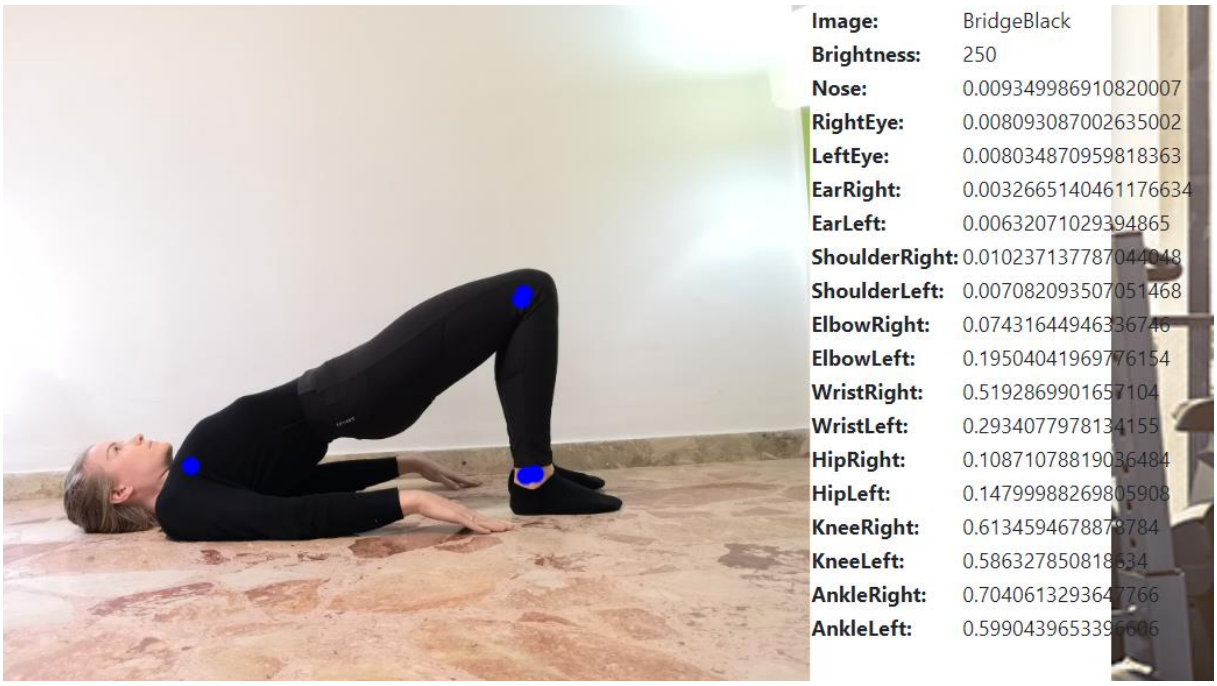


Image: BridgeBlack
Brightness: 250
Nose: 0.009349986910820007
RightEye: 0.008093087002635002
LeftEye: 0.008034870959818363
EarRight: 0.0032665140461176634
EarLeft: 0.00632071029394865
ShoulderRight: 0.010237137787044048
ShoulderLeft: 0.007082093507051468
ElbowRight: 0.07431644946336746
ElbowLeft: 0.19504041969776154
WristRight: 0.5192869901657104
WristLeft: 0.2934077978134155
HipRight: 0.10871078819036484
HipLeft: 0.14799988269805908
KneeRight: 0.6134594678878784
KneeLeft: 0.586327850818634
AnkleRight: 0.7040613293647766
AnkleLeft: 0.5990439653396606


Image: BridgeBlack3
Brightness: 225
Nose: 0.8303796648979187
RightEye: 0.47510382533073425
LeftEye: 0.763839602470398
EarRight: 0.35930925607681274
EarLeft: 0.5433809161186218
ShoulderRight: 0.8118704557418823
ShoulderLeft: 0.5749079585075378
ElbowRight: 0.2866224944591522
ElbowLeft: 0.2343045920135907
WristRight: 0.4053373038767683
WristLeft: 0.5051649212837219
HipRight: 0.29326313734054565
HipLeft: 0.19262976944446564
KneeRight: 0.5478537082672119
KneeLeft: 0.6700543761253357
AnkleRight: 0.4181651175022125
AnkleLeft: 0.5264699459075928

Image:	CatStretchBlack
Brightness:	214
Nose:	0.6650746464729309
RightEye:	0.7394297122955322
LeftEye:	0.2552977204322815
EarRight:	0.3895535171031952
EarLeft:	0.062315355986356735
ShoulderRight:	0.814791202545166
ShoulderLeft:	0.3197892904281616
ElbowRight:	0.8264406323432922
ElbowLeft:	0.5826066136360168
WristRight:	0.6600894331932068
WristLeft:	0.5848847031593323
HipRight:	0.8513838648796082
HipLeft:	0.8526231646537781
KneeRight:	0.9627885222434998
KneeLeft:	0.8923542499542236
AnkleRight:	0.735656201839447
AnkleLeft:	0.7154258489608765

Image:	CatStretchBlack2
Brightness:	219
Nose:	0.43508854508399963
RightEye:	0.5701786279678345
LeftEye:	0.20280976593494415
EarRight:	0.705282986164093
EarLeft:	0.13860619068145752
ShoulderRight:	0.9111096858978271
ShoulderLeft:	0.5695069432258606
ElbowRight:	0.40415331721305847
ElbowLeft:	0.5285970568656921
WristRight:	0.8364559412002563
WristLeft:	0.7113996148109436
HipRight:	0.9199185967445374
HipLeft:	0.7927197217941284
KneeRight:	0.9483175277709961
KneeLeft:	0.9614046216011047
AnkleRight:	0.9531792402267456
AnkleLeft:	0.9402092695236206

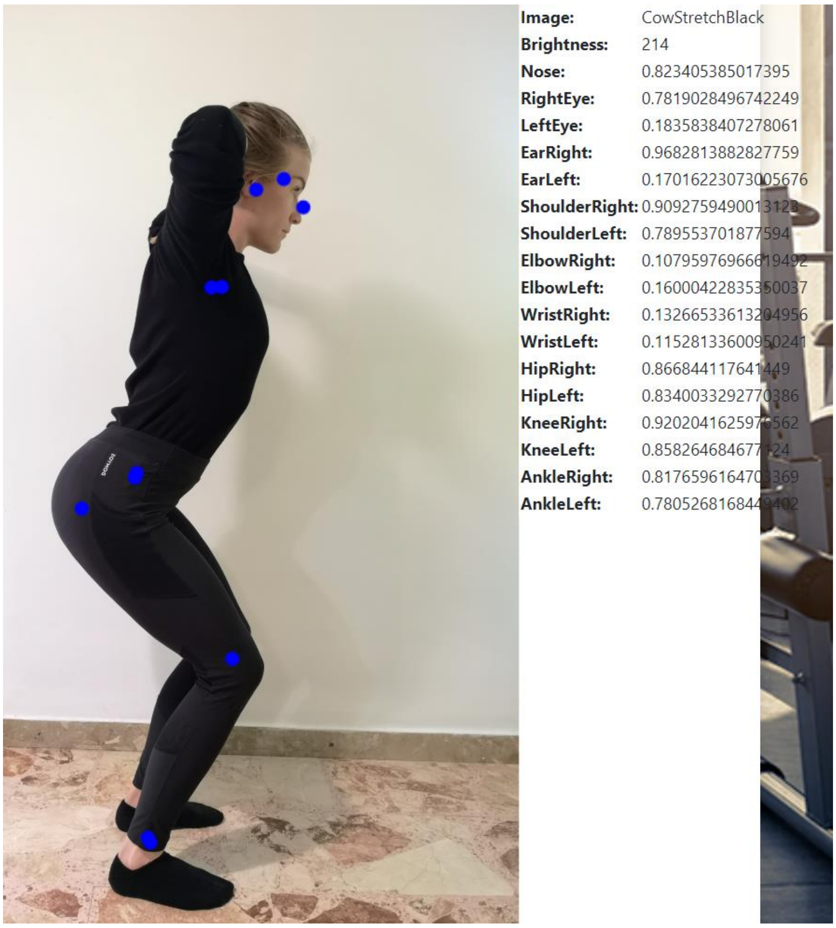


Image: CowStretchBlack
Brightness: 214
Nose: 0.823405385017395
RightEye: 0.7819028496742249
LeftEye: 0.1835838407278061
EarRight: 0.9682813882827759
EarLeft: 0.17016223073005676
ShoulderRight: 0.9092759490013123
ShoulderLeft: 0.789553701877594
ElbowRight: 0.10795976966619492
ElbowLeft: 0.16000422835350037
WristRight: 0.13266533613204956
WristLeft: 0.11528133600950241
HipRight: 0.866844117641449
HipLeft: 0.8340033292770386
KneeRight: 0.9202041625976562
KneeLeft: 0.858264684677124
AnkleRight: 0.8176596164703369
AnkleLeft: 0.7805268168449402

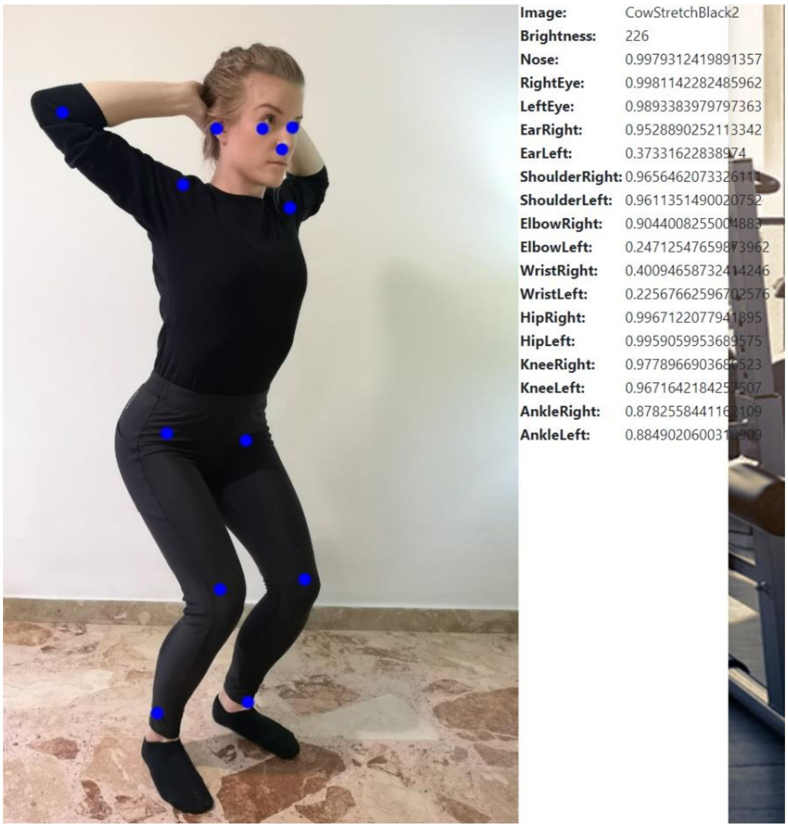


Image: CowStretchBlack2
Brightness: 226
Nose: 0.9979312419891357
RightEye: 0.9981142282485962
LeftEye: 0.9893383979797363
EarRight: 0.9528890252113342
EarLeft: 0.373316228389 74
ShoulderRight: 0.9656462073326111
ShoulderLeft: 0.9611351490020752
ElbowRight: 0.9044008255004883
ElbowLeft: 0.24712547659873962
WristRight: 0.40094658732414246
WristLeft: 0.22567662596702576
HipRight: 0.9967122077941895
HipLeft: 0.9959059953689575
KneeRight: 0.9778966903686523
KneeLeft: 0.9671642184257507
AnkleRight: 0.8782558441162109
AnkleLeft: 0.8849020600318909

Image:	LowerbackStretchBlack
Brightness:	227
Nose:	0.02462456002831459
RightEye:	0.03923983871936798
LeftEye:	0.03610312193632126
EarRight:	0.010985228233039379
EarLeft:	0.01046152226626873
ShoulderRight:	0.10490520298480988
ShoulderLeft:	0.10696137696504593
ElbowRight:	0.48652198910713196
ElbowLeft:	0.2928575277328491
WristRight:	0.3551303446292877
WristLeft:	0.6261353492736816
HipRight:	0.5507785677909851
HipLeft:	0.39013203978538513
KneeRight:	0.3396294414997101
KneeLeft:	0.37927764654159546
AnkleRight:	0.23200133442878723
AnkleLeft:	0.33927568793296814

Image:	LowerbackStretchBlack2
Brightness:	237
Nose:	0.7209054231643677
RightEye:	0.6059017181396484
LeftEye:	0.30743318796157837
EarRight:	0.5951526761054993
EarLeft:	0.10286292433738708
ShoulderRight:	0.4585321247577667
ShoulderLeft:	0.3989418148994446
ElbowRight:	0.7301737666130066
ElbowLeft:	0.47448208928108215
WristRight:	0.6338967680931091
WristLeft:	0.7302764058113098
HipRight:	0.18735946714878082
HipLeft:	0.14829732477664948
KneeRight:	0.1562550812959671
KneeLeft:	0.11516031622886658
AnkleRight:	0.1177712231874466
AnkleLeft:	0.12682956457138062

Image:	ObliqueStretchBlack
Brightness:	233
Nose:	0.9827596545219421
RightEye:	0.9129655957221985
LeftEye:	0.965579628944397
EarRight:	0.2835298776626587
EarLeft:	0.8075617551803589
ShoulderRight:	0.9121886491775513
ShoulderLeft:	0.9038367867469788
ElbowRight:	0.9256247878074646
ElbowLeft:	0.7665030360221863
WristRight:	0.7819023132324219
WristLeft:	0.7995592951774597
HipRight:	0.9970913529396057
HipLeft:	0.9965330362319946
KneeRight:	0.9527806043624878
KneeLeft:	0.9674615859985352
AnkleRight:	0.8894186615943909
AnkleLeft:	0.929286003112793

Image:	ObliqueStretchBlack2
Brightness:	223
Nose:	0.8145070672035217
RightEye:	0.7125507593154907
LeftEye:	0.5731304883956909
EarRight:	0.4058586359024048
EarLeft:	0.41367125511169434
ShoulderRight:	0.8036412000656128
ShoulderLeft:	0.6655018329620361
ElbowRight:	0.8462594747543335
ElbowLeft:	0.8470379710197449
WristRight:	0.8914541602134705
WristLeft:	0.7729886174201965
HipRight:	0.9742043018341064
HipLeft:	0.9106371998786926
KneeRight:	0.7903077602386475
KneeLeft:	0.6750831007957458
AnkleRight:	0.9081107974052429
AnkleLeft:	0.9137028455734253

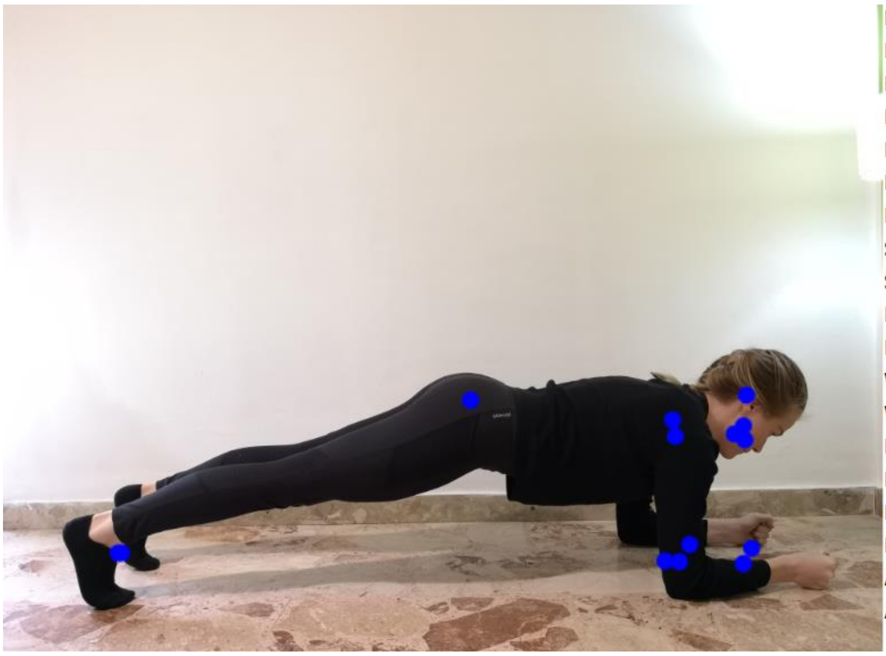


Image:	PlankBlack
Brightness:	252
Nose:	0.8852107524871826
RightEye:	0.9213424921035767
LeftEye:	0.5011325478553772
EarRight:	0.9093767404556274
EarLeft:	0.35141023993492126
ShoulderRight:	0.9545191526412964
ShoulderLeft:	0.7831287980079651
ElbowRight:	0.754828929901123
ElbowLeft:	0.691159188747406
WristRight:	0.6841810941696167
WristLeft:	0.5268904566764832
HipRight:	0.1623721718788147
HipLeft:	0.20961140096187592
KneeRight:	0.6199911832809448
KneeLeft:	0.6944244503974915
AnkleRight:	0.6356207132339478
AnkleLeft:	0.5899581909179688

Image:	PlankBlack2
Brightness:	233
Nose:	0.9710092544555664
RightEye:	0.98343825340271
LeftEye:	0.8748995661735535
EarRight:	0.9017708897590637
EarLeft:	0.07694913446903229
ShoulderRight:	0.8430594205856323
ShoulderLeft:	0.726266086101532
ElbowRight:	0.8075048327445984
ElbowLeft:	0.40979522466659546
WristRight:	0.7860034704208374
WristLeft:	0.7819467186927795
HipRight:	0.11604084819555283
HipLeft:	0.35987117886543274
KneeRight:	0.426561176776886
KneeLeft:	0.5529382824897766
AnkleRight:	0.3131980299949646
AnkleLeft:	0.2800601124763489

Image:	PlankBlack
Brightness:	170
Nose:	0.2752509117126465
RightEye:	0.21375080943107605
LeftEye:	0.35109013319015503
EarRight:	0.6381592154502869
EarLeft:	0.8862787485122681
ShoulderRight:	0.9515278935432434
ShoulderLeft:	0.9614251852035522
ElbowRight:	0.8842130303382874
ElbowLeft:	0.7753920555114746
WristRight:	0.39870312809944153
WristLeft:	0.7007098197937012
HipRight:	0.9593418836593628
HipLeft:	0.9763438105583191
KneeRight:	0.8595929741859436
KneeLeft:	0.5983970165252686
AnkleRight:	0.734096109867096
AnkleLeft:	0.6326484680175781

Image:	SquatBlack
Brightness:	240
Nose:	0.8185484409332275
RightEye:	0.8546019792556763
LeftEye:	0.33124998211860657
EarRight:	0.9819139838218689
EarLeft:	0.19254563748836517
ShoulderRight:	0.9679264426231384
ShoulderLeft:	0.9469039440155029
ElbowRight:	0.9111748933792114
ElbowLeft:	0.7903571128845215
WristRight:	0.7906805872917175
WristLeft:	0.9299935698509216
HipRight:	0.8821849226951599
HipLeft:	0.9076568484306335
KneeRight:	0.9434890151023865
KneeLeft:	0.5642421245574951
AnkleRight:	0.900251567363739
AnkleLeft:	0.7753649353981018

Image:	SquatBlack2
Brightness:	222
Nose:	0.9968078136444092
RightEye:	0.9982905983924866
LeftEye:	0.9898262619972229
EarRight:	0.9899736642837524
EarLeft:	0.1572500467300415
ShoulderRight:	0.9858283996582031
ShoulderLeft:	0.9920021295547485
ElbowRight:	0.4361696243286133
ElbowLeft:	0.9679629802703857
WristRight:	0.4346323609352112
WristLeft:	0.9807565808296204
HipRight:	0.9842778444290161
HipLeft:	0.895567774772644
KneeRight:	0.9435290098190308
KneeLeft:	0.9741625189781189
AnkleRight:	0.9073443412780762
AnkleLeft:	0.9428697824478149


Image: BlueShirtBlackBlueTightPants
Brightness: 209
Nose: 0.9972846508026123
RightEye: 0.9943869709968567
LeftEye: 0.9958330988883972
EarRight: 0.9416190981864929
EarLeft: 0.8255810141563416
ShoulderRight: 0.9959230422973633
ShoulderLeft: 0.9979460835456848
ElbowRight: 0.997252881526947
ElbowLeft: 0.9911379814147949
WristRight: 0.9912837743759155
WristLeft: 0.9911386370658875
HipRight: 0.9963634610176086
HipLeft: 0.9974944591522217
KneeRight: 0.9929965138435364
KneeLeft: 0.992074728012085
AnkleRight: 0.9855315089225769
AnkleLeft: 0.9809220433235168


Image: BlueShirtBlackBlueTightPants2
Brightness: 208
Nose: 0.9983301758766174
RightEye: 0.9909700751304626
LeftEye: 0.9203928709030151
EarRight: 0.9733596444129944
EarLeft: 0.1768608093261718
ShoulderRight: 0.9984661340713501
ShoulderLeft: 0.9955315589904785
ElbowRight: 0.9979438185691833
ElbowLeft: 0.827099621295929
WristRight: 0.9963636994361877
WristLeft: 0.9403842091560364
HipRight: 0.9981891512870789
HipLeft: 0.9965295195579529
KneeRight: 0.9884611368179321
KneeLeft: 0.9926482439041138
AnkleRight: 0.945259153842926
AnkleLeft: 0.9646229147911072

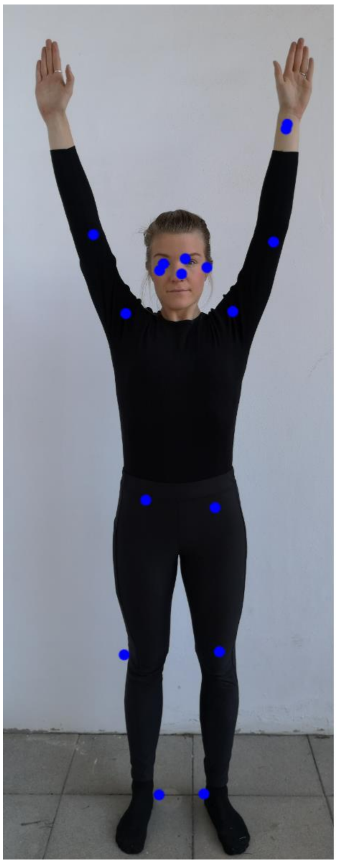


Image:	thoracicextentionblack1
Brightness:	147
Nose:	0.9835923910140991
RightEye:	0.9865542650222778
LeftEye:	0.9805731177330017
EarRight:	0.7032121419906616
EarLeft:	0.9396634101867676
ShoulderRight:	0.9676123857498169
ShoulderLeft:	0.9708200097084045
ElbowRight:	0.6243115067481995
ElbowLeft:	0.7399249076843262
WristRight:	0.7481309771537781
WristLeft:	0.7445067763328552
HipRight:	0.9931195974349976
HipLeft:	0.9966574907302856
KneeRight:	0.9534109234809875
KneeLeft:	0.9844833016395569
AnkleRight:	0.7905185222625732
AnkleLeft:	0.7846433520317078

Image:	thoracicextentionblack2
Brightness:	191
Nose:	0.9891290068626404
RightEye:	0.9842676520347595
LeftEye:	0.9408279061317444
EarRight:	0.9041491150856018
EarLeft:	0.5185336470603943
ShoulderRight:	0.9781564474105835
ShoulderLeft:	0.9810001850128174
ElbowRight:	0.5704745650291443
ElbowLeft:	0.6580415964126587
WristRight:	0.7835753560066223
WristLeft:	0.7657535672187805
HipRight:	0.9937946796417236
HipLeft:	0.9924531579017639
KneeRight:	0.9640287160873413
KneeLeft:	0.9708850383758545
AnkleRight:	0.8945725560188293
AnkleLeft:	0.9241557717323303

Image:	armandlegliftshort1
Brightness:	225
Nose:	0.9175870418548584
RightEye:	0.8307062387466431
LeftEye:	0.21167156100273132
EarRight:	0.9685196280479431
EarLeft:	0.1179996207356453
ShoulderRight:	0.9743526577949524
ShoulderLeft:	0.9171873331069946
ElbowRight:	0.8434907793998718
ElbowLeft:	0.8019970059394836
WristRight:	0.8090157508850098
WristLeft:	0.9179496765136719
HipRight:	0.6069960594177246
HipLeft:	0.5072482228279114
KneeRight:	0.49392908811569214
KneeLeft:	0.6795883178710938
AnkleRight:	0.5883832573890686
AnkleLeft:	0.7500949501991272

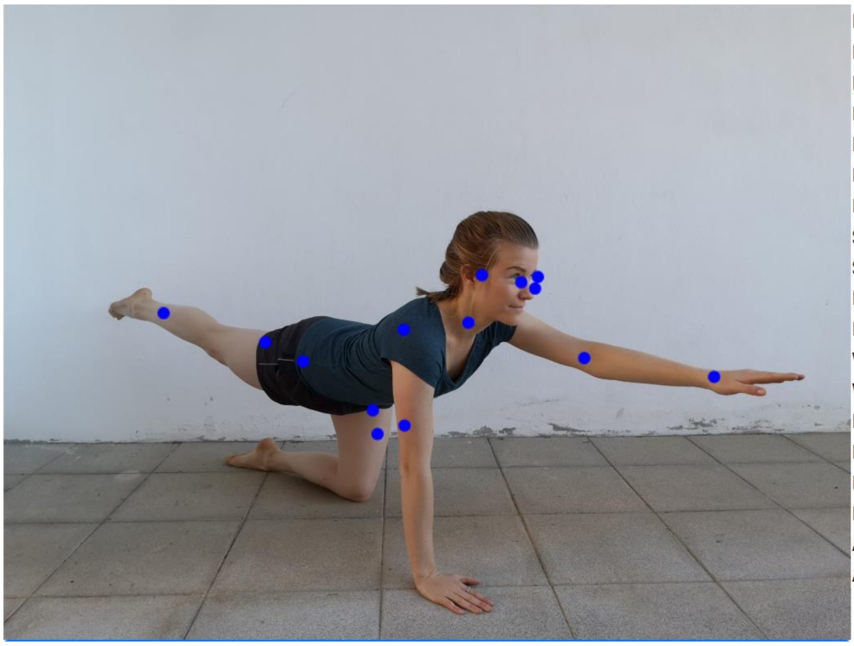


Image:	armandlegliftshort2
Brightness:	195
Nose:	0.9930204749107361
RightEye:	0.9877102971076965
LeftEye:	0.6692430377006531
EarRight:	0.9885976314544678
EarLeft:	0.06566677987575531
ShoulderRight:	0.9845784306526184
ShoulderLeft:	0.9662839770317078
ElbowRight:	0.8477952480316162
ElbowLeft:	0.8950182795524597
WristRight:	0.946460485458374
WristLeft:	0.8381516337394714
HipRight:	0.6026738882064819
HipLeft:	0.5082216262817383
KneeRight:	0.7258067727088928
KneeLeft:	0.5350633263587952
AnkleRight:	0.28704217076301575
AnkleLeft:	0.17851312458515167

Image:	restingposeshort1
Brightness:	228
Nose:	0.031156618148088455
RightEye:	0.07176416367292404
LeftEye:	0.04474533721804619
EarRight:	0.014411987736821175
EarLeft:	0.05170772969722748
ShoulderRight:	0.33690541982650757
ShoulderLeft:	0.13399305939674377
ElbowRight:	0.33568206429481506
ElbowLeft:	0.31520938873291016
WristRight:	0.4973316788673401
WristLeft:	0.6157482266426086
HipRight:	0.4272118806838989
HipLeft:	0.5693402290344238
KneeRight:	0.3388981521129608
KneeLeft:	0.4272456169128418
AnkleRight:	0.46907174587249756
AnkleLeft:	0.5160986185073853

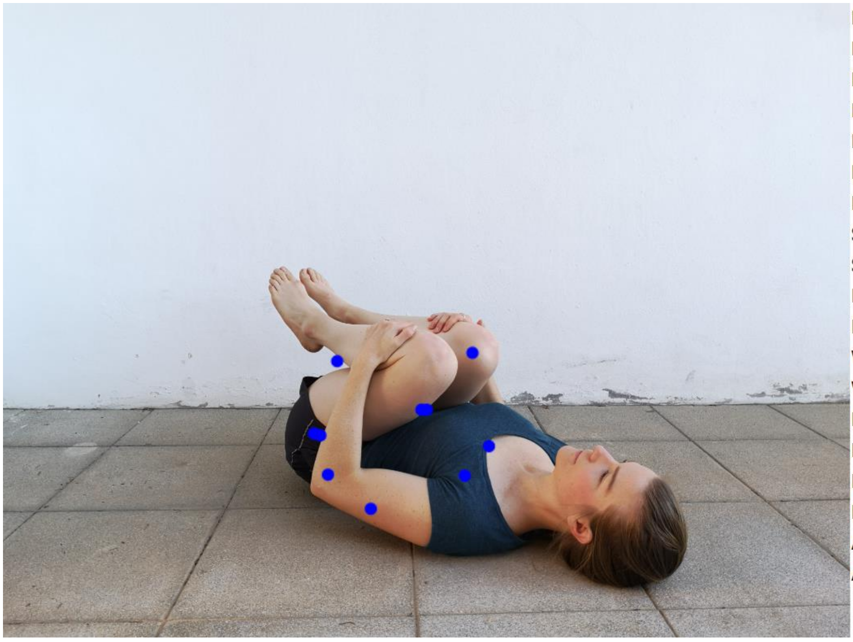


Image:	restingposeshort2
Brightness:	234
Nose:	0.2962453067302704
RightEye:	0.29183584451675415
LeftEye:	0.1321590691804886
EarRight:	0.32245275378227234
EarLeft:	0.15099981427192688
ShoulderRight:	0.6602840423583984
ShoulderLeft:	0.7513153553009033
ElbowRight:	0.5864577889442444
ElbowLeft:	0.5147346258163452
WristRight:	0.6042588353157043
WristLeft:	0.35996323823928833
HipRight:	0.735565185546875
HipLeft:	0.6710508465766907
KneeRight:	0.5453121662139893
KneeLeft:	0.46075570583343506
AnkleRight:	0.736550509929657
AnkleLeft:	0.6903504133224487

Image:	BridgeShort
Brightness:	222
Nose:	0.058315105736255646
RightEye:	0.034907031804323196
LeftEye:	0.12007515877485275
EarRight:	0.011014366522431374
EarLeft:	0.0510459840297699
ShoulderRight:	0.14237454533576965
ShoulderLeft:	0.23157794773578644
ElbowRight:	0.15496376156806946
ElbowLeft:	0.1610323190689087
WristRight:	0.2511158585548401
WristLeft:	0.4789612591266632
HipRight:	0.3394165337085724
HipLeft:	0.7040272951126099
KneeRight:	0.7308338284492493
KneeLeft:	0.778068482875824
AnkleRight:	0.3188205361366272
AnkleLeft:	0.43163496255874634

Image:	BridgeShort3
Brightness:	223
Nose:	0.7551836967468262
RightEye:	0.6123013496398926
LeftEye:	0.706950843334198
EarRight:	0.5116586685180664
EarLeft:	0.48567265272140503
ShoulderRight:	0.6593859791755676
ShoulderLeft:	0.40244030952453613
ElbowRight:	0.6863753795623779
ElbowLeft:	0.48079273104667664
WristRight:	0.5401676893234253
WristLeft:	0.47294509410858154
HipRight:	0.5155648589134216
HipLeft:	0.2949044108390808
KneeRight:	0.5338891744613647
KneeLeft:	0.48110154271125793
AnkleRight:	0.283782958984375
AnkleLeft:	0.36776259541511536

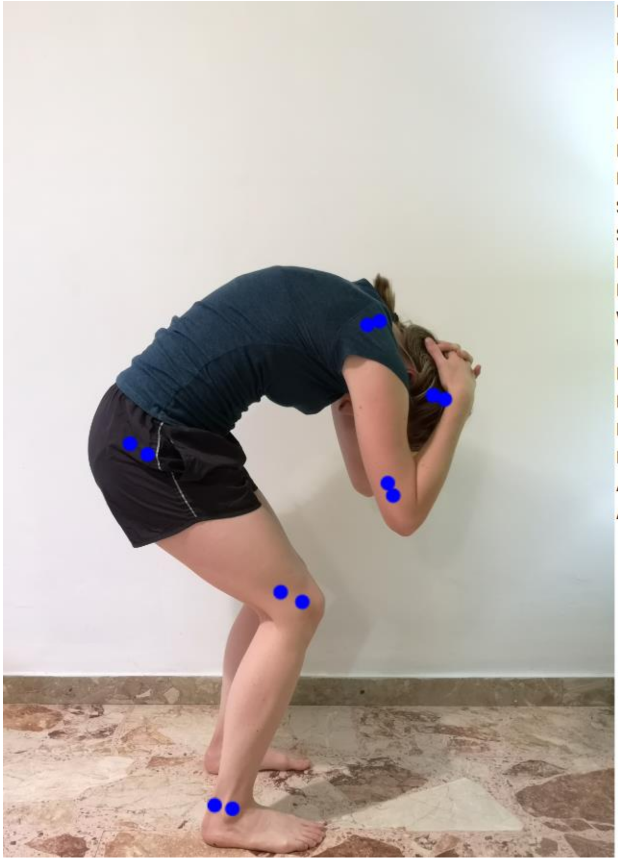


Image:	CatStretchShort
Brightness:	233
Nose:	0.18603061139583588
RightEye:	0.26004311442375183
LeftEye:	0.03944849967956543
EarRight:	0.23984484374523163
EarLeft:	0.05004309117794037
ShoulderRight:	0.8349515795707703
ShoulderLeft:	0.525480329990387
ElbowRight:	0.9355745911598206
ElbowLeft:	0.5942854881286621
WristRight:	0.8668220639228821
WristLeft:	0.6277182102203369
HipRight:	0.8679563403129578
HipLeft:	0.8504389524459839
KneeRight:	0.9760268330574036
KneeLeft:	0.7911625504493713
AnkleRight:	0.6079144477844238
AnkleLeft:	0.5996537804603577

Image:	CatStretchShort2
Brightness:	225
Nose:	0.4022809863090515
RightEye:	0.37739717960357666
LeftEye:	0.13776765763759613
EarRight:	0.3041023015975952
EarLeft:	0.04298265650868416
ShoulderRight:	0.4639497697353363
ShoulderLeft:	0.568307638168335
ElbowRight:	0.2340710312128067
ElbowLeft:	0.4226676821708679
WristRight:	0.5394131541252136
WristLeft:	0.8207435607910156
HipRight:	0.9145392179489136
HipLeft:	0.8059834241867065
KneeRight:	0.9785130023956299
KneeLeft:	0.9271172881126404
AnkleRight:	0.9198600053787231
AnkleLeft:	0.9262604117393494

Image:	CowStretchShort
Brightness:	233
Nose:	0.4729105234146118
RightEye:	0.4273327589035034
LeftEye:	0.2274560183286667
EarRight:	0.5387988090515137
EarLeft:	0.1473790407180786
ShoulderRight:	0.8415550589561462
ShoulderLeft:	0.6194161176681519
ElbowRight:	0.20604164898395538
ElbowLeft:	0.22899912297725677
WristRight:	0.5266048312187195
WristLeft:	0.3322654664516449
HipRight:	0.8070310354232788
HipLeft:	0.8188803195953369
KneeRight:	0.9515679478645325
KneeLeft:	0.652310848236084
AnkleRight:	0.6175288558006287
AnkleLeft:	0.6756129264831543

Image:	CowStretchShort2
Brightness:	227
Nose:	0.998104989528656
RightEye:	0.9966893792152405
LeftEye:	0.9744179248809814
EarRight:	0.953130841255188
EarLeft:	0.3304330110549927
ShoulderRight:	0.9639487266540527
ShoulderLeft:	0.954472005367279
ElbowRight:	0.93596351146698
ElbowLeft:	0.5207996964454651
WristRight:	0.5065010190010071
WristLeft:	0.15258271992206573
HipRight:	0.9487479329109192
HipLeft:	0.9131450653076172
KneeRight:	0.9429168701171875
KneeLeft:	0.94380122423172
AnkleRight:	0.9505845904350281
AnkleLeft:	0.9184675216674805

Image:	LowerbackStretchShort
Brightness:	227
Nose:	0.03033248335123062
RightEye:	0.019208652898669243
LeftEye:	0.008054254576563835
EarRight:	0.0251653790473938
EarLeft:	0.01190910767763853
ShoulderRight:	0.2795068621635437
ShoulderLeft:	0.22922399640083313
ElbowRight:	0.6247444152832031
ElbowLeft:	0.3186807632446289
WristRight:	0.16107241809368134
WristLeft:	0.210515096783638
HipRight:	0.6376208066940308
HipLeft:	0.6698644757270813
KneeRight:	0.6585243344306946
KneeLeft:	0.4903229773044586
AnkleRight:	0.2088201642036438
AnkleLeft:	0.23303304612636566

Image:	LowerbackStretchShort2
Brightness:	241
Nose:	0.061054620891809464
RightEye:	0.03291234374046326
LeftEye:	0.016513394191861153
EarRight:	0.02798004075884819
EarLeft:	0.04296248406171799
ShoulderRight:	0.17860369384288788
ShoulderLeft:	0.3843253552913666
ElbowRight:	0.28856953978538513
ElbowLeft:	0.2762082517147064
WristRight:	0.7069504857063293
WristLeft:	0.5854261517524719
HipRight:	0.4285886883735657
HipLeft:	0.4658425748348236
KneeRight:	0.516091525554657
KneeLeft:	0.5010338425636292
AnkleRight:	0.2596857249736786
AnkleLeft:	0.12582999467849731

Image:	ObliqueStretchShort
Brightness:	225
Nose:	0.8672321438789368
RightEye:	0.7358959913253784
LeftEye:	0.8431145548820496
EarRight:	0.22810830175876617
EarLeft:	0.8246247172355652
ShoulderRight:	0.8653660416603088
ShoulderLeft:	0.7765616178512573
ElbowRight:	0.8677115440368652
ElbowLeft:	0.9218124747276306
WristRight:	0.8821477890014648
WristLeft:	0.7143487334251404
HipRight:	0.9881568551063538
HipLeft:	0.9860486388206482
KneeRight:	0.9633947014808655
KneeLeft:	0.9782704710960388
AnkleRight:	0.9327895641326904
AnkleLeft:	0.9653209447860718

Image:	ObliqueStretchShort2
Brightness:	219
Nose:	0.5063463449478149
RightEye:	0.46058231592178345
LeftEye:	0.435141384601593
EarRight:	0.4373120069503784
EarLeft:	0.5700017809867859
ShoulderRight:	0.9108529686927795
ShoulderLeft:	0.8408092856407166
ElbowRight:	0.915919303894043
ElbowLeft:	0.7854278683662415
WristRight:	0.9133936166763306
WristLeft:	0.8186390399932861
HipRight:	0.9865317344665527
HipLeft:	0.931878924369812
KneeRight:	0.9057044386863708
KneeLeft:	0.811336100101471
AnkleRight:	0.8394436240196228
AnkleLeft:	0.7941036224365234

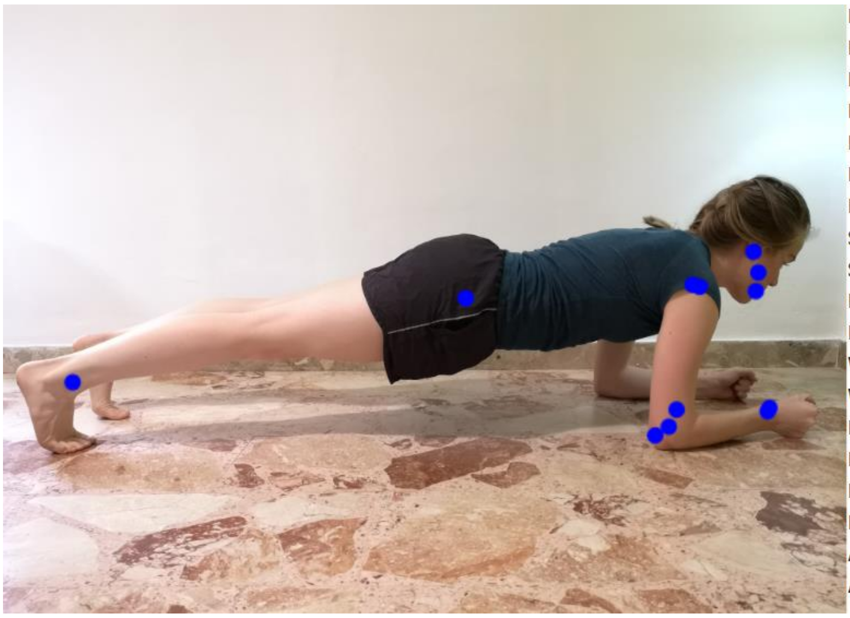


Image:	PlankShort
Brightness:	221
Nose:	0.8415461778640747
RightEye:	0.8630475401878357
LeftEye:	0.32873764634132385
EarRight:	0.9432846903800964
EarLeft:	0.17948602139949799
ShoulderRight:	0.9891197681427002
ShoulderLeft:	0.918635368347168
ElbowRight:	0.9529576897621155
ElbowLeft:	0.7390528321266174
WristRight:	0.9428562521934509
WristLeft:	0.8277018666267395
HipRight:	0.2769497036933899
HipLeft:	0.3172247111797333
KneeRight:	0.611484169960022
KneeLeft:	0.5182892680168152
AnkleRight:	0.5872480273246765
AnkleLeft:	0.4495163559913635

Image:	PlankShort2
Brightness:	225
Nose:	0.9937920570373535
RightEye:	0.9892626404762268
LeftEye:	0.856268048286438
EarRight:	0.9469441771507263
EarLeft:	0.02133174054324627
ShoulderRight:	0.9022766947746277
ShoulderLeft:	0.9202992916107178
ElbowRight:	0.7932050228118896
ElbowLeft:	0.8184996247291565
WristRight:	0.8026425838470459
WristLeft:	0.8789653182029724
HipRight:	0.26497894525527954
HipLeft:	0.26184046268463135
KneeRight:	0.40543055534362793
KneeLeft:	0.47910064458847046
AnkleRight:	0.15863105654716492
AnkleLeft:	0.2688259482383728

Image:	PlankShort2
Brightness:	147
Nose:	0.6960924863815308
RightEye:	0.6238154172897339
LeftEye:	0.6761056184768677
EarRight:	0.5335714221000671
EarLeft:	0.8195814490318298
ShoulderRight:	0.9453676342964172
ShoulderLeft:	0.9505817294120789
ElbowRight:	0.4411173462867737
ElbowLeft:	0.9916314482688904
WristRight:	0.45817360281944275
WristLeft:	0.739635705947876
HipRight:	0.9772036075592041
HipLeft:	0.9749336838722229
KneeRight:	0.7912022471427917
KneeLeft:	0.8194122910499573
AnkleRight:	0.6619996428489685
AnkleLeft:	0.5832564830780029

Image:	SquatShort
Brightness:	230
Nose:	0.8851502537727356
RightEye:	0.8026252388954163
LeftEye:	0.24540959298610687
EarRight:	0.9863194823265076
EarLeft:	0.099367655813694
ShoulderRight:	0.9546751379966736
ShoulderLeft:	0.9188094735145569
ElbowRight:	0.868808925151825
ElbowLeft:	0.8223843574523926
WristRight:	0.7591754794120789
WristLeft:	0.9469470381736755
HipRight:	0.8507446050643921
HipLeft:	0.747765064239502
KneeRight:	0.9652165174484253
KneeLeft:	0.7656543850898743
AnkleRight:	0.722231388092041
AnkleLeft:	0.7174443006515503

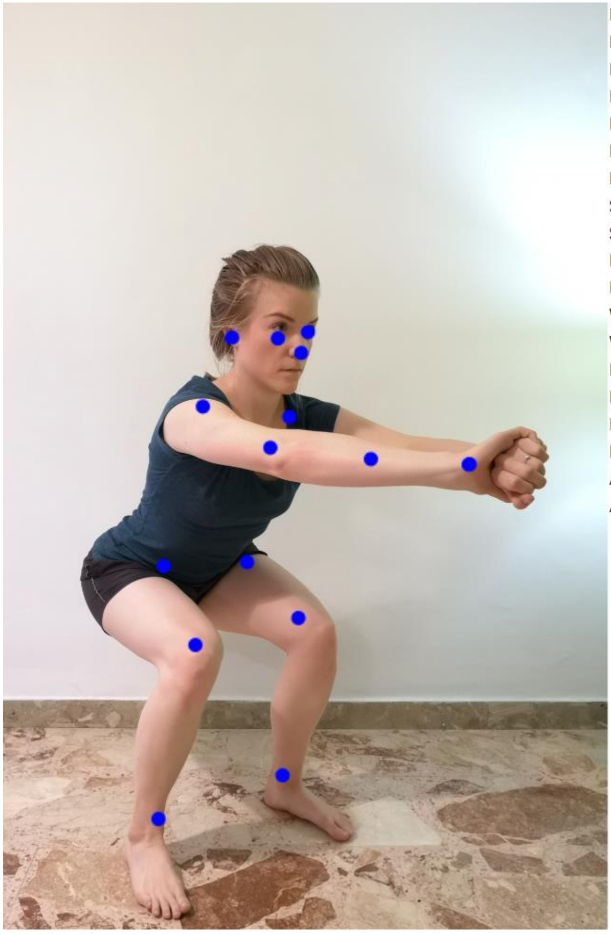


Image:	SquatShort2
Brightness:	234
Nose:	0.9988412261009216
RightEye:	0.9975462555885315
LeftEye:	0.9834483861923218
EarRight:	0.9714452028274536
EarLeft:	0.0998789519071579
ShoulderRight:	0.9868831038475037
ShoulderLeft:	0.977601945400238
ElbowRight:	0.920153021812439
ElbowLeft:	0.9550338983535767
WristRight:	0.7050256729125977
WristLeft:	0.9492472410202026
HipRight:	0.9773005843162537
HipLeft:	0.9440887570381165
KneeRight:	0.9776818156242371
KneeLeft:	0.9657005667686462
AnkleRight:	0.9824954867362976
AnkleLeft:	0.9323678016662598


Image: BlueShirtBlackShorts
Brightness: 178
Nose: 0.9984570741653442
RightEye: 0.9927886128425598
LeftEye: 0.9933306574821472
EarRight: 0.939825713634491
EarLeft: 0.8394007682800293
ShoulderRight: 0.9963843822479248
ShoulderLeft: 0.9983356595039368
ElbowRight: 0.9944443106651306
ElbowLeft: 0.990714430809021
WristRight: 0.9888758659362793
WristLeft: 0.9947047829627991
HipRight: 0.9965759515762329
HipLeft: 0.9955382943153381
KneeRight: 0.9829671382904053
KneeLeft: 0.9834153056144714
AnkleRight: 0.9643842577934265
AnkleLeft: 0.978061854839325


Image: BlueShirtBlackShorts2
Brightness: 173
Nose: 0.9987695217132568
RightEye: 0.9925536513328552
LeftEye: 0.9146897792816162
EarRight: 0.9850831031799316
EarLeft: 0.1181188076734542
ShoulderRight: 0.997664213180542
ShoulderLeft: 0.9933680891990662
ElbowRight: 0.998412549495697
ElbowLeft: 0.7249690890312195
WristRight: 0.9953848719596863
WristLeft: 0.5761279463768005
HipRight: 0.989177405834198
HipLeft: 0.9924013614654541
KneeRight: 0.9792458415031433
KneeLeft: 0.9760589599609375
AnkleRight: 0.9764375686645508
AnkleLeft: 0.9450591802597046

Image:	thoracicextentionshort1
Brightness:	172
Nose:	0.9858004450798035
RightEye:	0.9780979156494141
LeftEye:	0.986246645450592
EarRight:	0.6864498853683472
EarLeft:	0.9172183871269226
ShoulderRight:	0.9733386635780334
ShoulderLeft:	0.9587512016296387
ElbowRight:	0.8532435894012451
ElbowLeft:	0.8864080905914307
WristRight:	0.8188825845718384
WristLeft:	0.8649035692214966
HipRight:	0.9950513243675232
HipLeft:	0.9982118606567383
KneeRight:	0.9741929769515991
KneeLeft:	0.9927850961685181
AnkleRight:	0.9132910966873169
AnkleLeft:	0.9060751795768738

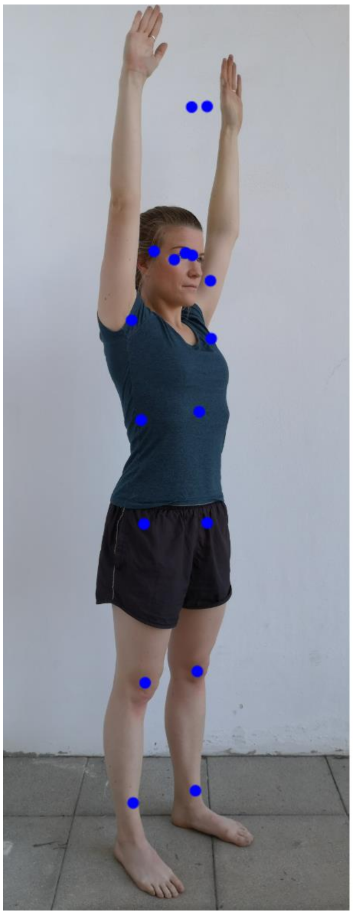


Image:	thoracicextentionshort2
Brightness:	184
Nose:	0.9887121915817261
RightEye:	0.9868597388267517
LeftEye:	0.9323981404304504
EarRight:	0.889523983001709
EarLeft:	0.6099464893341064
ShoulderRight:	0.9937001466751099
ShoulderLeft:	0.9868366122245789
ElbowRight:	0.7852596044540405
ElbowLeft:	0.6703280210494995
WristRight:	0.7977979779243469
WristLeft:	0.7811766862869263
HipRight:	0.9976748824119568
HipLeft:	0.9938079714775085
KneeRight:	0.9927259683609009
KneeLeft:	0.993506669998169
AnkleRight:	0.900800883769989
AnkleLeft:	0.9356074929237366

Image:	armandlegliftbaggy1
Brightness:	228
Nose:	0.9762467741966248
RightEye:	0.9629952907562256
LeftEye:	0.40967753529548645
EarRight:	0.986461341381073
EarLeft:	0.08851201087236404
ShoulderRight:	0.9901887774467468
ShoulderLeft:	0.9459103345870972
ElbowRight:	0.8932148218154907
ElbowLeft:	0.698510468006134
WristRight:	0.8051803708076477
WristLeft:	0.820839524269104
HipRight:	0.5569656491279602
HipLeft:	0.5545300841331482
KneeRight:	0.6948665380477905
KneeLeft:	0.6737953424453735
AnkleRight:	0.612660825252533
AnkleLeft:	0.7868410348892212

Image:	armandlegliftbaggy2
Brightness:	207
Nose:	0.9952139854431152
RightEye:	0.9810278415679932
LeftEye:	0.8221817016601562
EarRight:	0.9955618381500244
EarLeft:	0.05162377655506134
ShoulderRight:	0.9960508942604065
ShoulderLeft:	0.9667874574661255
ElbowRight:	0.8686034679412842
ElbowLeft:	0.9489313364028931
WristRight:	0.8447625637054443
WristLeft:	0.9399917125701904
HipRight:	0.35190656781196594
HipLeft:	0.28937995433807373
KneeRight:	0.5779409408569336
KneeLeft:	0.33766040205955505
AnkleRight:	0.31485772132873535
AnkleLeft:	0.2280578911304474

Image:	restingposebaggy1
Brightness:	217
Nose:	0.2638155221939087
RightEye:	0.07556510716676712
LeftEye:	0.39754408597946167
EarRight:	0.024852445349097252
EarLeft:	0.4703817665576935
ShoulderRight:	0.35355496406555176
ShoulderLeft:	0.4693661332130432
ElbowRight:	0.21812468767166138
ElbowLeft:	0.2329290509223938
WristRight:	0.5449028015136719
WristLeft:	0.5730785727500916
HipRight:	0.3985576331615448
HipLeft:	0.31609588861465454
KneeRight:	0.14656390249729156
KneeLeft:	0.14890901744365692
AnkleRight:	0.30367618799209595
AnkleLeft:	0.3621719181537628

Image:	restingposebaggy2
Brightness:	232
Nose:	0.6506224274635315
RightEye:	0.620330810546875
LeftEye:	0.5304286479949951
EarRight:	0.4697578251361847
EarLeft:	0.421681672334671
ShoulderRight:	0.7457215785980225
ShoulderLeft:	0.8378562927246094
ElbowRight:	0.560944139957428
ElbowLeft:	0.4740772545337677
WristRight:	0.8351753354072571
WristLeft:	0.6270310878753662
HipRight:	0.8581538200378418
HipLeft:	0.8119195103645325
KneeRight:	0.31335780024528503
KneeLeft:	0.3303285241127014
AnkleRight:	0.28841787576675415
AnkleLeft:	0.3719085156917572

Image:	BridgeBaggy
Brightness:	226
Nose:	0.046631865203380585
RightEye:	0.023076042532920837
LeftEye:	0.06600213795900345
EarRight:	0.012253405526280403
EarLeft:	0.025928281247615814
ShoulderRight:	0.05004057660698891
ShoulderLeft:	0.060360800474882126
ElbowRight:	0.09333935379981995
ElbowLeft:	0.15573936700820923
WristRight:	0.5276557207107544
WristLeft:	0.18013782799243927
HipRight:	0.12049724906682968
HipLeft:	0.14060792326927185
KneeRight:	0.3900446593761444
KneeLeft:	0.5371907949447632
AnkleRight:	0.6007469296455383
AnkleLeft:	0.5161537528038025

Image:	BridgeBaggy3
Brightness:	236
Nose:	0.8336452841758728
RightEye:	0.7251392006874084
LeftEye:	0.28839102387428284
EarRight:	0.5732463598251343
EarLeft:	0.175645649433136
ShoulderRight:	0.7207156419754028
ShoulderLeft:	0.39550891518592834
ElbowRight:	0.28928545117378235
ElbowLeft:	0.2615637481212616
WristRight:	0.44129928946495056
WristLeft:	0.5907995700836182
HipRight:	0.24557706713676453
HipLeft:	0.18415582180023193
KneeRight:	0.07597208768129349
KneeLeft:	0.09658912569284439
AnkleRight:	0.12168219685554504
AnkleLeft:	0.08643784373998642

Image:	CatStretchBaggy
Brightness:	221
Nose:	0.2873651683330536
RightEye:	0.26875609159469604
LeftEye:	0.06738190352916718
EarRight:	0.25484851002693176
EarLeft:	0.02978513576090336
ShoulderRight:	0.5084084272384644
ShoulderLeft:	0.3758573830127716
ElbowRight:	0.8833930492401123
ElbowLeft:	0.6236159205436707
WristRight:	0.8622460961341858
WristLeft:	0.3566998839378357
HipRight:	0.8666386604309082
HipLeft:	0.8520685434341431
KneeRight:	0.8868204951286316
KneeLeft:	0.7264963984489441
AnkleRight:	0.4398859739303589
AnkleLeft:	0.5086671113967896

Image:	CatStretchBaggy2
Brightness:	215
Nose:	0.43425366282463074
RightEye:	0.37574514746665955
LeftEye:	0.1216842457652092
EarRight:	0.28373631834983826
EarLeft:	0.07371577620506287
ShoulderRight:	0.5859294533729553
ShoulderLeft:	0.2058621048927307
ElbowRight:	0.8345320820808411
ElbowLeft:	0.3405733108520508
WristRight:	0.871293306350708
WristLeft:	0.7809646129608154
HipRight:	0.7991493344306946
HipLeft:	0.6961461305618286
KneeRight:	0.9460381269454956
KneeLeft:	0.9275459051132202
AnkleRight:	0.9651151299476624
AnkleLeft:	0.9106317758560181

Image:	CowStretchBaggy
Brightness:	220
Nose:	0.9787418842315674
RightEye:	0.9755889177322388
LeftEye:	0.47158437967300415
EarRight:	0.9721981883049011
EarLeft:	0.06700658053159714
ShoulderRight:	0.7841094136238098
ShoulderLeft:	0.7513717412948608
ElbowRight:	0.2998005747795105
ElbowLeft:	0.3021054267883301
WristRight:	0.202629953622818
WristLeft:	0.10364042967557907
HipRight:	0.8792108297348022
HipLeft:	0.8336226344108582
KneeRight:	0.9199641942977905
KneeLeft:	0.8286208510398865
AnkleRight:	0.5002527236938477
AnkleLeft:	0.6840890645980835

Image:	CowStretchBaggy2
Brightness:	227
Nose:	0.9981325268745422
RightEye:	0.9986405968666077
LeftEye:	0.9942250847816467
EarRight:	0.9232281446456909
EarLeft:	0.3239070773124695
ShoulderRight:	0.9673218131065369
ShoulderLeft:	0.9376322031021118
ElbowRight:	0.8498803377151489
ElbowLeft:	0.21297883987426758
WristRight:	0.23993438482284546
WristLeft:	0.11871100962162018
HipRight:	0.9864451885223389
HipLeft:	0.9867927432060242
KneeRight:	0.9315006136894226
KneeLeft:	0.9683968424797058
AnkleRight:	0.9061007499694824
AnkleLeft:	0.8279469013214111

Image:	LowerbackStretchBaggy
Brightness:	230
Nose:	0.019123312085866928
RightEye:	0.014813043177127838
LeftEye:	0.007305576000362635
EarRight:	0.009463517926633358
EarLeft:	0.018262246623635292
ShoulderRight:	0.03021201491355896
ShoulderLeft:	0.0914001613855362
ElbowRight:	0.21910031139850616
ElbowLeft:	0.29658451676368713
WristRight:	0.4536387622356415
WristLeft:	0.7022745013237
HipRight:	0.08063817769289017
HipLeft:	0.06924239546060562
KneeRight:	0.19896696507930756
KneeLeft:	0.3332841098308563
AnkleRight:	0.19848211109638214
AnkleLeft:	0.34813615679740906

Image:	LowerbackStretchBaggy2
Brightness:	232
Nose:	0.09429457783699036
RightEye:	0.060324158519506454
LeftEye:	0.029223281890153885
EarRight:	0.07501596212387085
EarLeft:	0.018110986799001694
ShoulderRight:	0.10733380913734436
ShoulderLeft:	0.14261294901371002
ElbowRight:	0.525134265422821
ElbowLeft:	0.2950095534324646
WristRight:	0.7406886219978333
WristLeft:	0.5392113327980042
HipRight:	0.4338447153568268
HipLeft:	0.36220040917396545
KneeRight:	0.29315900802612305
KneeLeft:	0.27557963132858276
AnkleRight:	0.1525992900133133
AnkleLeft:	0.1857026368379593

Image:	ObliqueStretchBaggy
Brightness:	232
Nose:	0.961139440536499
RightEye:	0.9007402062416077
LeftEye:	0.9441330432891846
EarRight:	0.4053278863430023
EarLeft:	0.8042687177658081
ShoulderRight:	0.9337366819381714
ShoulderLeft:	0.9357985854148865
ElbowRight:	0.8624201416969299
ElbowLeft:	0.8228309750556946
WristRight:	0.8994303345680237
WristLeft:	0.6063107848167419
HipRight:	0.9879570603370667
HipLeft:	0.991060197353363
KneeRight:	0.9811034202575684
KneeLeft:	0.9743671417236328
AnkleRight:	0.9207994341850281
AnkleLeft:	0.8829522132873535

Image:	ObliqueStretchBaggy2
Brightness:	218
Nose:	0.766814649105072
RightEye:	0.6582342982292175
LeftEye:	0.7436076998710632
EarRight:	0.30945736169815063
EarLeft:	0.693569540977478
ShoulderRight:	0.9713395833969116
ShoulderLeft:	0.8559340238571167
ElbowRight:	0.9203280210494995
ElbowLeft:	0.8372340202331543
WristRight:	0.971385657787323
WristLeft:	0.7381792068481445
HipRight:	0.9624913930892944
HipLeft:	0.9537707567214966
KneeRight:	0.7545009255409241
KneeLeft:	0.8557083010673523
AnkleRight:	0.6663164496421814
AnkleLeft:	0.5337399244308472

Image:	PlankBaggy
Brightness:	220
Nose:	0.82471764087677
RightEye:	0.8684245944023132
LeftEye:	0.31480273604393005
EarRight:	0.9299775958061218
EarLeft:	0.12851184606552124
ShoulderRight:	0.9658307433128357
ShoulderLeft:	0.8574433922767639
ElbowRight:	0.9508835077285767
ElbowLeft:	0.6892958283424377
WristRight:	0.8633984327316284
WristLeft:	0.7162884473800659
HipRight:	0.19099503755569458
HipLeft:	0.3417341411113739
KneeRight:	0.4681699872016907
KneeLeft:	0.5569526553153992
AnkleRight:	0.4681077003479004
AnkleLeft:	0.4620668888092041

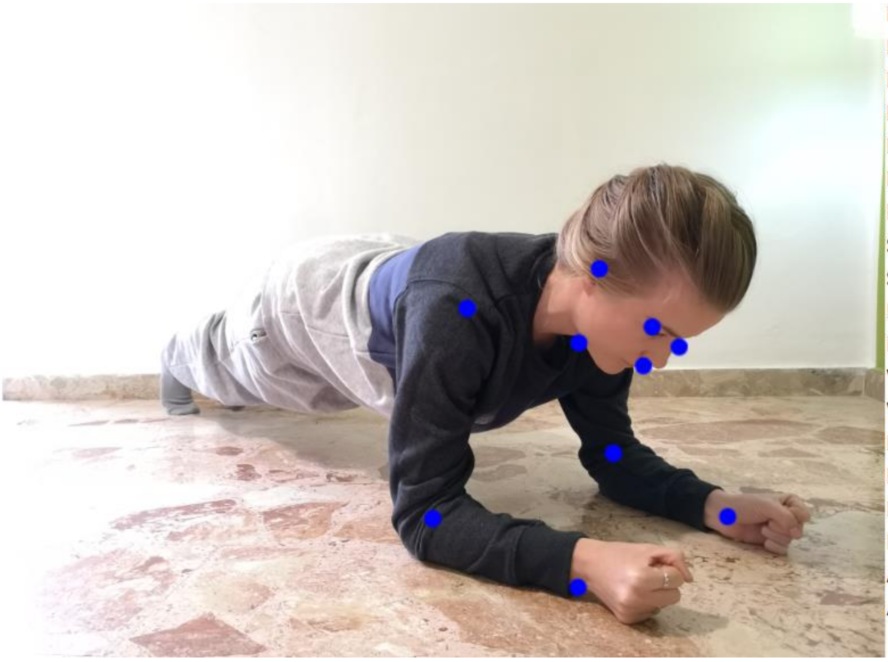


Image:	PlankBaggy2
Brightness:	235
Nose:	0.9416465163230896
RightEye:	0.9413784146308899
LeftEye:	0.877130389213562
EarRight:	0.8640915751457214
EarLeft:	0.015118397772312164
ShoulderRight:	0.9472083449363708
ShoulderLeft:	0.873046875
ElbowRight:	0.9527704119682312
ElbowLeft:	0.9517993927001953
WristRight:	0.8227216601371765
WristLeft:	0.9780173897743225
HipRight:	0.23956385254859924
HipLeft:	0.35802558064460754
KneeRight:	0.27906784415245056
KneeLeft:	0.20912359654903412
AnkleRight:	0.1637706160545349
AnkleLeft:	0.11918601393699646

Image:	PlankBaggy
Brightness:	156
Nose:	0.9329870939254761
RightEye:	0.7356540560722351
LeftEye:	0.9147491455078125
EarRight:	0.2631663680076599
EarLeft:	0.8766382336616516
ShoulderRight:	0.8617682456970215
ShoulderLeft:	0.861008882522583
ElbowRight:	0.664153516292572
ElbowLeft:	0.8524473905563354
WristRight:	0.4646332561969757
WristLeft:	0.6671907901763916
HipRight:	0.7993457317352295
HipLeft:	0.8741011619567871
KneeRight:	0.8490533232688904
KneeLeft:	0.5123543222873612
AnkleRight:	0.6265438737881224
AnkleLeft:	0.5723354350182022

Image:	SquatBaggy
Brightness:	233
Nose:	0.961554229259491
RightEye:	0.9427397847175598
LeftEye:	0.3224015235900879
EarRight:	0.992720365524292
EarLeft:	0.08160538971424103
ShoulderRight:	0.9820141196250916
ShoulderLeft:	0.9206153154373169
ElbowRight:	0.8691364526748657
ElbowLeft:	0.7818995118141174
WristRight:	0.7668424248695374
WristLeft:	0.9520722031593323
HipRight:	0.7337641716003418
HipLeft:	0.8008562326431274
KneeRight:	0.9534425139427185
KneeLeft:	0.5401203036308289
AnkleRight:	0.8700634241104126
AnkleLeft:	0.629734992980957

Image:	SquatBaggy2
Brightness:	240
Nose:	0.9981827735900879
RightEye:	0.9983446598052979
LeftEye:	0.9667848944664001
EarRight:	0.9895870089530945
EarLeft:	0.05206499993801117
ShoulderRight:	0.9843981862068176
ShoulderLeft:	0.9859353303909302
ElbowRight:	0.7256110906600952
ElbowLeft:	0.9678134322166443
WristRight:	0.5571615695953369
WristLeft:	0.9792419672012329
HipRight:	0.971637487411499
HipLeft:	0.9162285327911377
KneeRight:	0.9402430653572083
KneeLeft:	0.9783180952072144
AnkleRight:	0.8276049494743347
AnkleLeft:	0.9569618105888367


Image: BlueShirtGreyLoosePants
Brightness: 192
Nose: 0.9978737831115723
RightEye: 0.9925635457038879
LeftEye: 0.9950309991836548
EarRight: 0.9477708339691162
EarLeft: 0.8386121392250061
ShoulderRight: 0.994234502315521
ShoulderLeft: 0.997785747051239
ElbowRight: 0.99301856756210
ElbowLeft: 0.9891228079795837
WristRight: 0.9892792105674744
WristLeft: 0.9967297315597534
HipRight: 0.996891438961029
HipLeft: 0.9952455163002014
KneeRight: 0.9869269728660583
KneeLeft: 0.9899435043334961
AnkleRight: 0.9718941450119019
AnkleLeft: 0.97031533718109


Image: BlueShirtGreyLoosePants2
Brightness: 206
Nose: 0.9979677200317383
RightEye: 0.9890022277832031
LeftEye: 0.8519382476806641
EarRight: 0.9907617568969727
EarLeft: 0.0994135811949344
ShoulderRight: 0.998263895511627
ShoulderLeft: 0.9922158718109131
ElbowRight: 0.9969366788864136
ElbowLeft: 0.9632065296173096
WristRight: 0.9964292645454407
WristLeft: 0.9834054112434387
HipRight: 0.990061879158
HipLeft: 0.9922959804534912
KneeRight: 0.9618839025497437
KneeLeft: 0.9873042702674866
AnkleRight: 0.9212767481803894
AnkleLeft: 0.968555212020

Image:	thoracicextentionbaggy1
Brightness:	176
Nose:	0.9867250919342041
RightEye:	0.992285966873169
LeftEye:	0.9544913172721863
EarRight:	0.7029089331626892
EarLeft:	0.8271608352661133
ShoulderRight:	0.9424263834953308
ShoulderLeft:	0.9476452469825745
ElbowRight:	0.7036041617393494
ElbowLeft:	0.901037335395813
WristRight:	0.9316520690917969
WristLeft:	0.8308398723602295
HipRight:	0.9975572228431702
HipLeft:	0.9972512125968933
KneeRight:	0.9849744439125061
KneeLeft:	0.9603087306022644
AnkleRight:	0.9754583239555359
AnkleLeft:	0.9643491506576538

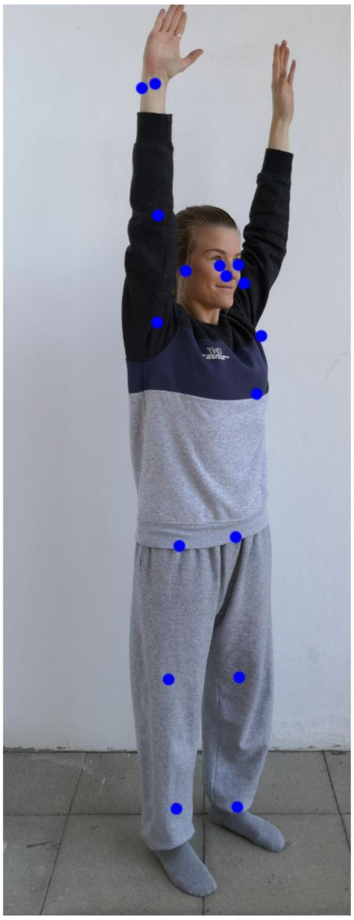


Image:	thoracicextentionbaggy2
Brightness:	185
Nose:	0.9892656803131104
RightEye:	0.9916812777519226
LeftEye:	0.9386917948722839
EarRight:	0.7648490071296692
EarLeft:	0.6772001385688782
ShoulderRight:	0.9757351875305176
ShoulderLeft:	0.9916122555732727
ElbowRight:	0.5507441163063049
ElbowLeft:	0.5037638545036316
WristRight:	0.6714643239974976
WristLeft:	0.5267764329910278
HipRight:	0.9950699806213379
HipLeft:	0.9973157048225403
KneeRight:	0.9883695840835571
KneeLeft:	0.981709361076355
AnkleRight:	0.9792501926422119
AnkleLeft:	0.9726060032844543

D.2 Different brightnesses

The first three images were taken with Acer Swift 12, and the last three images were taken with the Huawei P20.

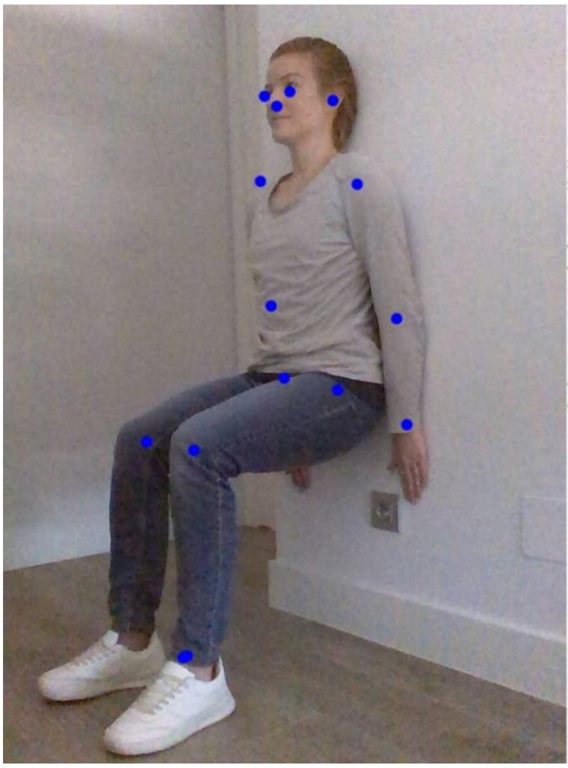


Image:	webcam3
Brightness:	147
Nose:	0.9959902167320251
RightEye:	0.9788448810577393
LeftEye:	0.9968777894973755
EarRight:	0.2801625430583954
EarLeft:	0.9807314276695251
ShoulderRight:	0.9826419949531555
ShoulderLeft:	0.9958609938621521
ElbowRight:	0.670806348323822
ElbowLeft:	0.9923266172409058
WristRight:	0.20995217561721802
WristLeft:	0.9801559448242188
HipRight:	0.9753835797309875
HipLeft:	0.9923717975616455
KneeRight:	0.9498397707939148
KneeLeft:	0.8999365568161011
AnkleRight:	0.9141097664833069
AnkleLeft:	0.8250842094421387

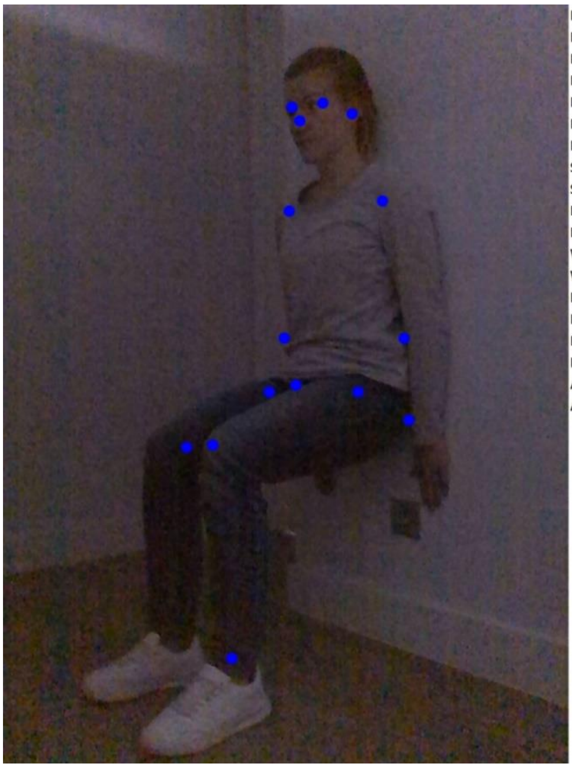


Image:	webcam4
Brightness:	71
Nose:	0.9900397658348083
RightEye:	0.9585300087928772
LeftEye:	0.9928786158561707
EarRight:	0.30939146876335144
EarLeft:	0.9669992327690125
ShoulderRight:	0.9538438320159912
ShoulderLeft:	0.9938812255859375
ElbowRight:	0.7484915256500244
ElbowLeft:	0.9532795548439026
WristRight:	0.6631228923797607
WristLeft:	0.8323640823364258
HipRight:	0.94008868932724
HipLeft:	0.9779514074325562
KneeRight:	0.742431104183197
KneeLeft:	0.8980380296707153
AnkleRight:	0.5397403836250305
AnkleLeft:	0.4925757348537445

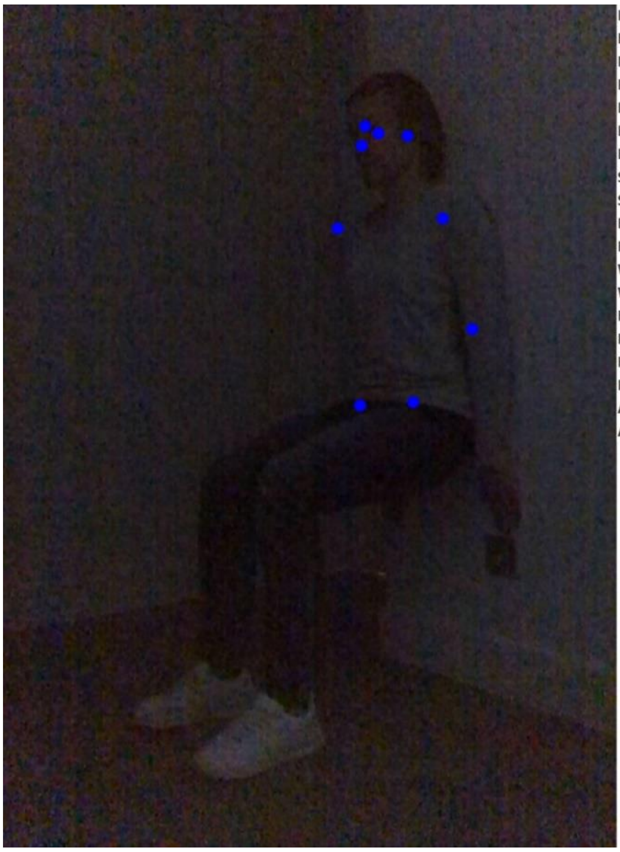


Image:	webcam5
Brightness:	38
Nose:	0.6796322464942932
RightEye:	0.5686498880386353
LeftEye:	0.7520131468772888
EarRight:	0.08089720457792282
EarLeft:	0.6748868227005005
ShoulderRight:	0.6130324006080627
ShoulderLeft:	0.9539454579353333
ElbowRight:	0.38276100158691406
ElbowLeft:	0.8356490731239319
WristRight:	0.09881546348333359
WristLeft:	0.41988271474838257
HipRight:	0.5822170376777649
HipLeft:	0.6878145933151245
KneeRight:	0.04933106154203415
KneeLeft:	0.0992254838347435
AnkleRight:	0.14328445494174957
AnkleLeft:	0.12278854846954346

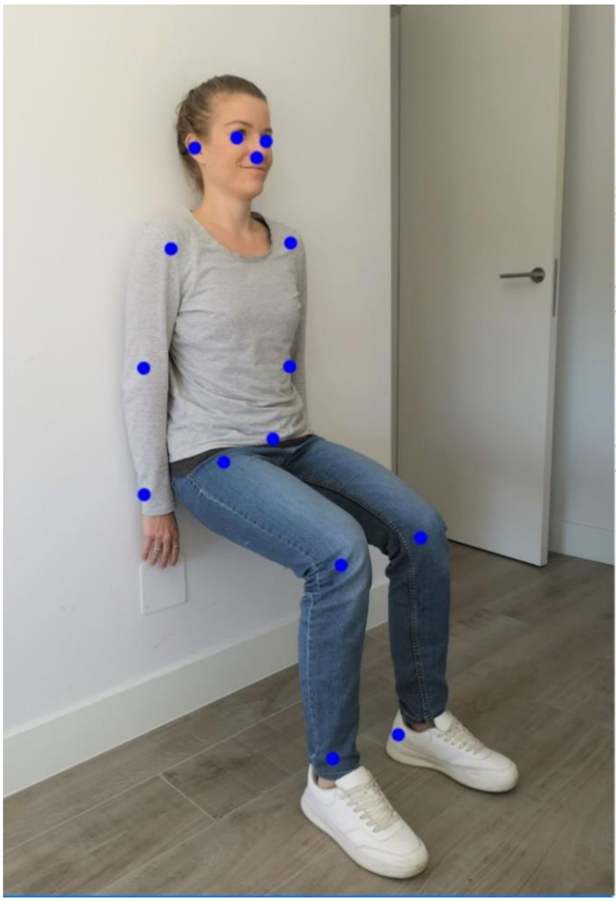


Image:	phone3
Brightness:	149
Nose:	0.9985126852989197
RightEye:	0.9953983426094055
LeftEye:	0.9905089139938354
EarRight:	0.9795571565628052
EarLeft:	0.4042694866657257
ShoulderRight:	0.995868444442749
ShoulderLeft:	0.9956560134887695
ElbowRight:	0.991877555847168
ElbowLeft:	0.6333289742469788
WristRight:	0.9250091314315796
WristLeft:	0.24047718942165375
HipRight:	0.9951197504997253
HipLeft:	0.9932250380516052
KneeRight:	0.8696547746658325
KneeLeft:	0.9267507195472717
AnkleRight:	0.8285384774208069
AnkleLeft:	0.8799490332603455

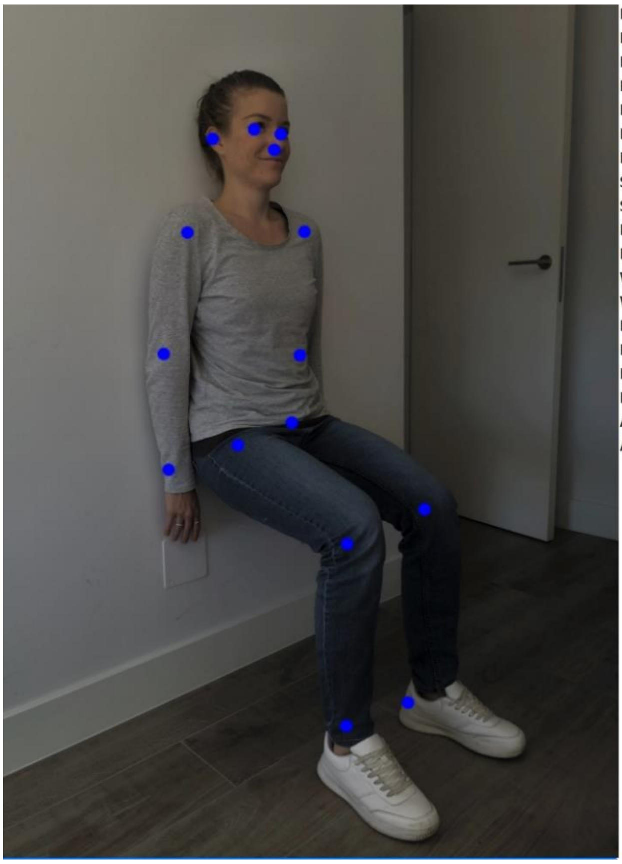


Image:	phone4
Brightness:	71
Nose:	0.9988481998443604
RightEye:	0.9965896606445312
LeftEye:	0.9888157844543457
EarRight:	0.98521888256073
EarLeft:	0.2810097336769104
ShoulderRight:	0.9937484264373779
ShoulderLeft:	0.994041383266449
ElbowRight:	0.9939624667167664
ElbowLeft:	0.6529989838600159
WristRight:	0.8906714916229248
WristLeft:	0.15513917803764343
HipRight:	0.9956552982330322
HipLeft:	0.9938576817512512
KneeRight:	0.8455601930618286
KneeLeft:	0.92479407787323
AnkleRight:	0.8672450184822083
AnkleLeft:	0.8747929334640503

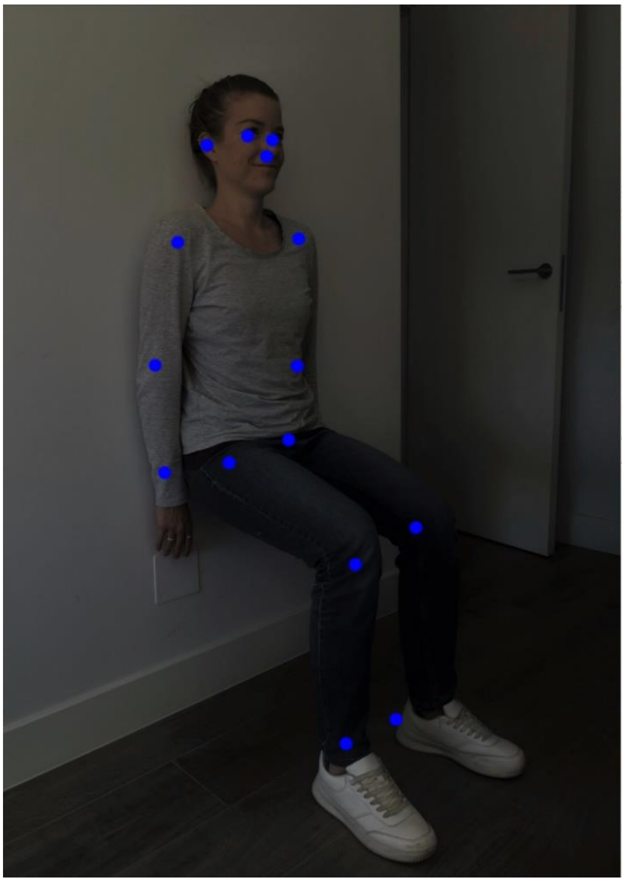


Image:	phone5
Brightness:	42
Nose:	0.9989140033721924
RightEye:	0.9965702295303345
LeftEye:	0.987750232219696
EarRight:	0.9792648553848267
EarLeft:	0.24720418453216553
ShoulderRight:	0.9929070472717285
ShoulderLeft:	0.9923531413078308
ElbowRight:	0.9885880947113037
ElbowLeft:	0.694862961769104
WristRight:	0.6824750304222107
WristLeft:	0.11525166034698486
HipRight:	0.9923343658447266
HipLeft:	0.9957687854766846
KneeRight:	0.5359918475151062
KneeLeft:	0.8673187494277954
AnkleRight:	0.6145038604736328
AnkleLeft:	0.59548419713974

D.3 Different backgrounds

Image:	bedroom
Brightness:	124
Nose:	0.9984232187271118
RightEye:	0.9968256950378418
LeftEye:	0.8550942540168762
EarRight:	0.9940492510795593
EarLeft:	0.044620320200920105
ShoulderRight:	0.9840812683105469
ShoulderLeft:	0.9498295783996582
ElbowRight:	0.30836519598960876
ElbowLeft:	0.8208803534507751
WristRight:	0.34305423498153687
WristLeft:	0.7700291872024536
HipRight:	0.9743322730064392
HipLeft:	0.9117316603660583
KneeRight:	0.8326855897903442
KneeLeft:	0.968795120716095
AnkleRight:	0.8074027895927429
AnkleLeft:	0.8095497488975525

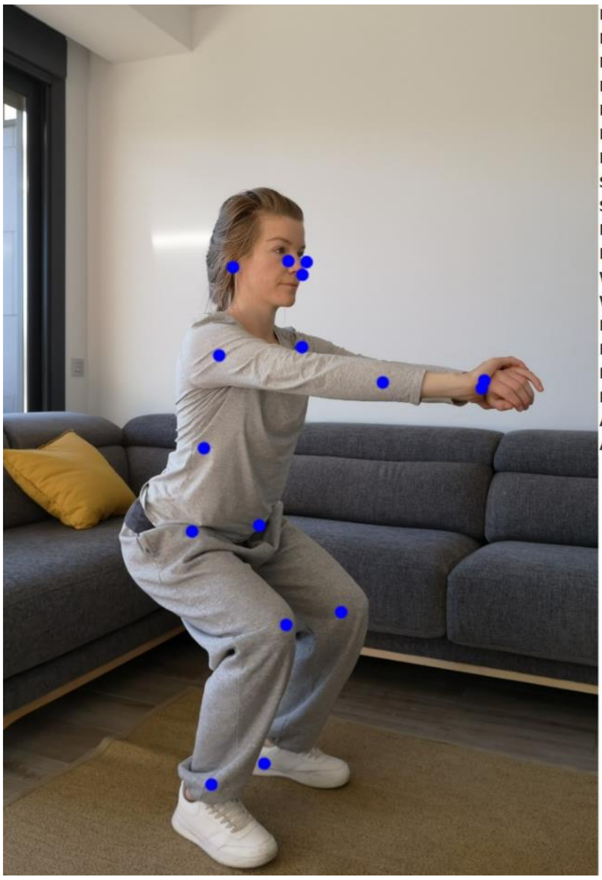


Image:	couch
Brightness:	177
Nose:	0.9949681162834167
RightEye:	0.9973100423812866
LeftEye:	0.9271694421768188
EarRight:	0.9933886528015137
EarLeft:	0.10342764854431152
ShoulderRight:	0.9790463447570801
ShoulderLeft:	0.9822752475738525
ElbowRight:	0.6391429901123047
ElbowLeft:	0.9718019366264343
WristRight:	0.5331013202667236
WristLeft:	0.9406167268753052
HipRight:	0.9893926382064819
HipLeft:	0.9731048941612244
KneeRight:	0.9090672135353088
KneeLeft:	0.9259536862373352
AnkleRight:	0.8695753216743469
AnkleLeft:	0.8288494348526001

Image:	greywall
Brightness:	255
Nose:	0.9994677901268005
RightEye:	0.9994677901268005
LeftEye:	0.9812387228012085
EarRight:	0.9878252148628235
EarLeft:	0.11748920381069183
ShoulderRight:	0.9908101558685303
ShoulderLeft:	0.9833796620368958
ElbowRight:	0.9778153896331787
ElbowLeft:	0.6424998641014099
WristRight:	0.7411760091781616
WristLeft:	0.4714880585670471
HipRight:	0.9859511852264404
HipLeft:	0.9409452676773071
KneeRight:	0.8242825269699097
KneeLeft:	0.93964684009552
AnkleRight:	0.7990590333938599
AnkleLeft:	0.8054730892181396

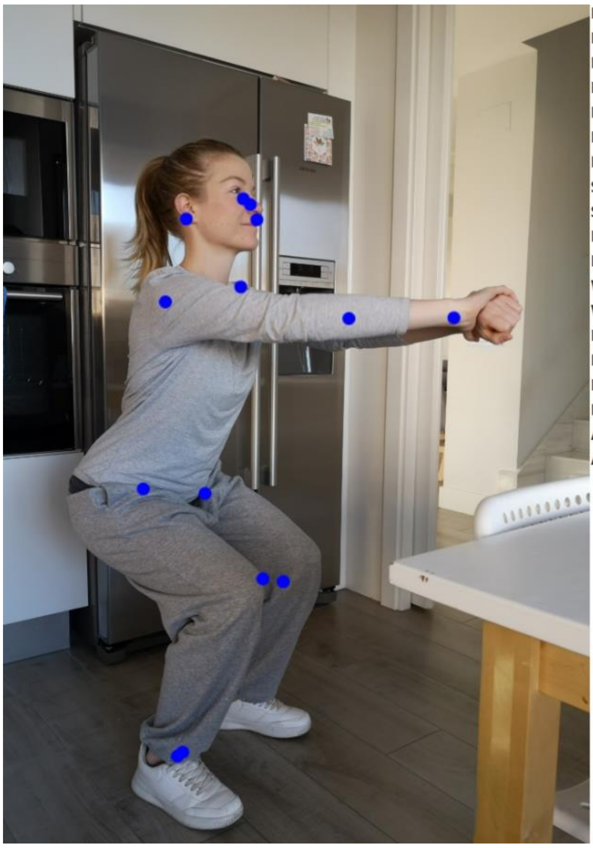


Image:	kitchen
Brightness:	138
Nose:	0.9942424893379211
RightEye:	0.988379716873169
LeftEye:	0.7142977118492126
EarRight:	0.9946276545524597
EarLeft:	0.06958909332752228
ShoulderRight:	0.9749822616577148
ShoulderLeft:	0.945013701915741
ElbowRight:	0.4425419569015503
ElbowLeft:	0.8795492649078369
WristRight:	0.3221651017665863
WristLeft:	0.878298282623291
HipRight:	0.9914277791976929
HipLeft:	0.9798105359077454
KneeRight:	0.9187726974487305
KneeLeft:	0.8835827708244324
AnkleRight:	0.88730388879776
AnkleLeft:	0.8196596503257751

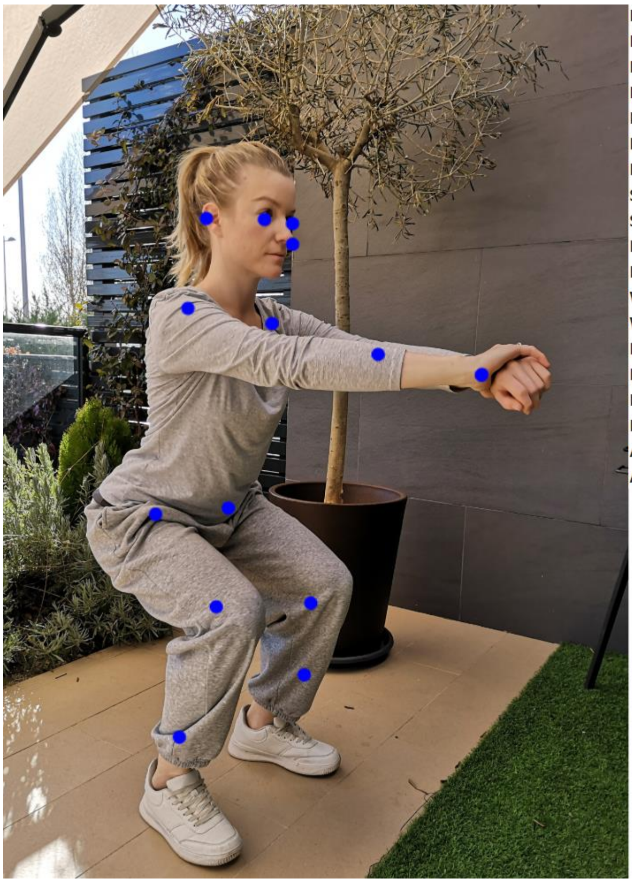
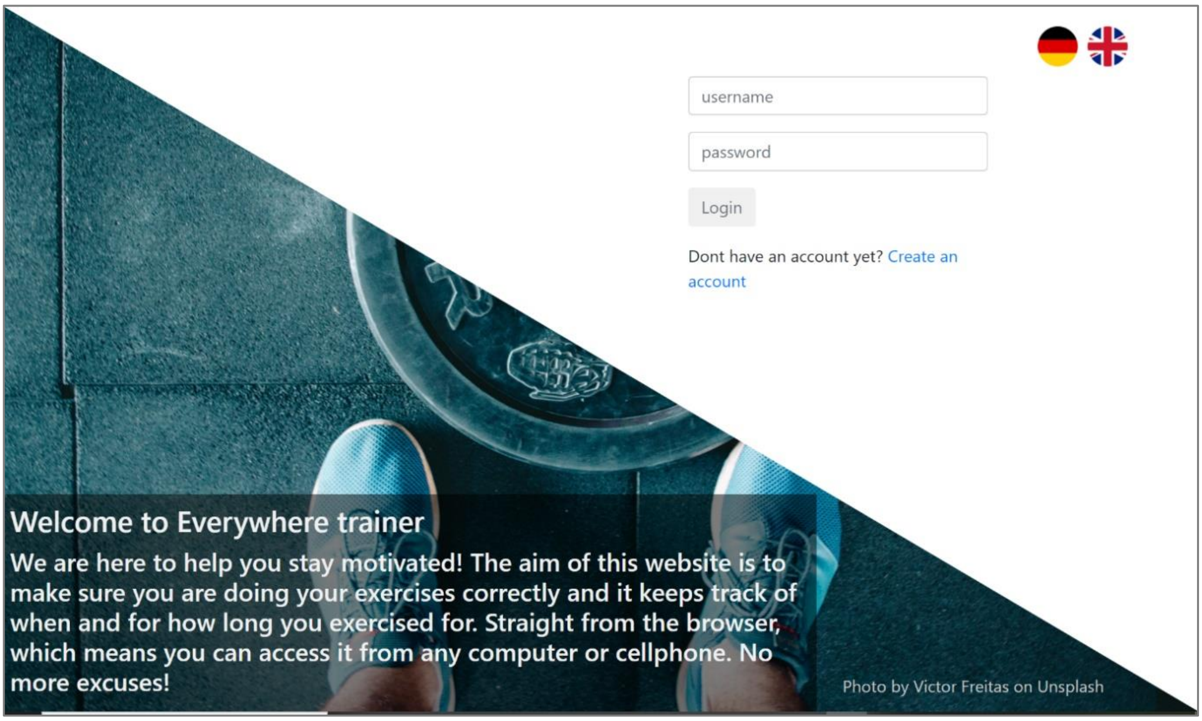


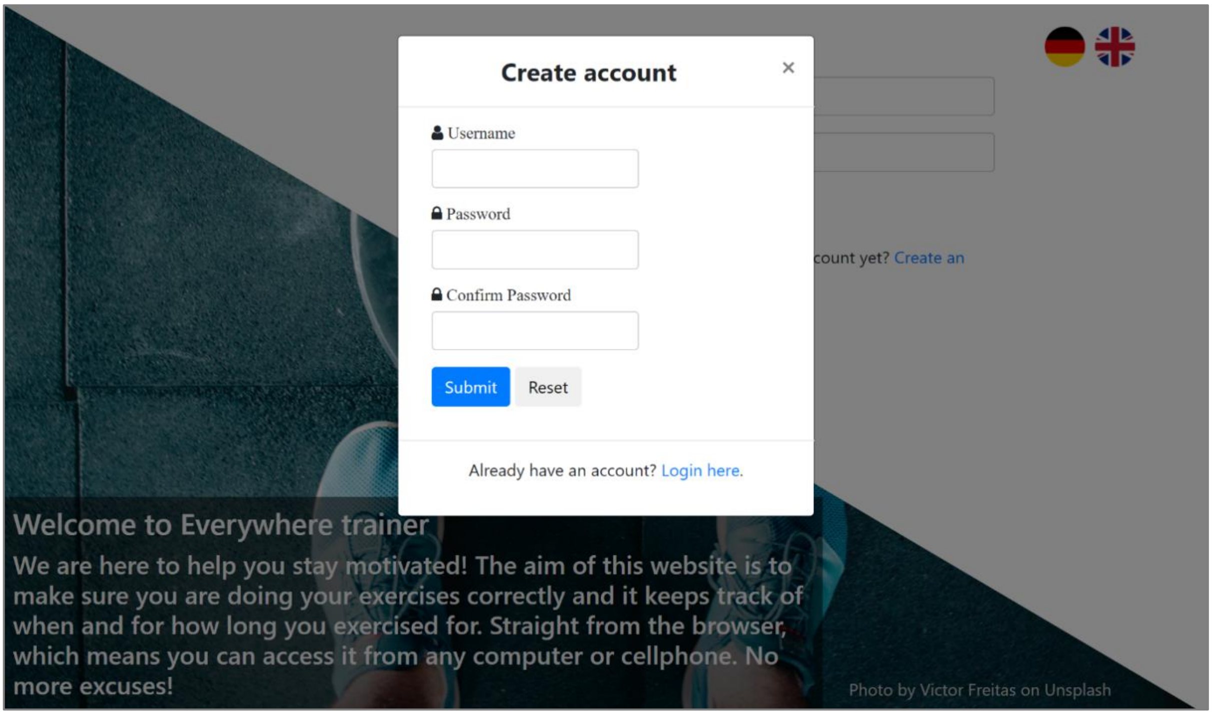
Image:	plants
Brightness:	94
Nose:	0.998234212398529
RightEye:	0.9975887537002563
LeftEye:	0.9447724223136902
EarRight:	0.9969478249549866
EarLeft:	0.0456569641828537
ShoulderRight:	0.9756378531455994
ShoulderLeft:	0.9726588726043701
ElbowRight:	0.2890768051147461
ElbowLeft:	0.9688040614128113
WristRight:	0.6988140940666199
WristLeft:	0.9645317792892456
HipRight:	0.984684944152832
HipLeft:	0.9537510871887207
KneeRight:	0.8312225937843323
KneeLeft:	0.9341433048248291
AnkleRight:	0.9179320335388184
AnkleLeft:	0.8412572145462036

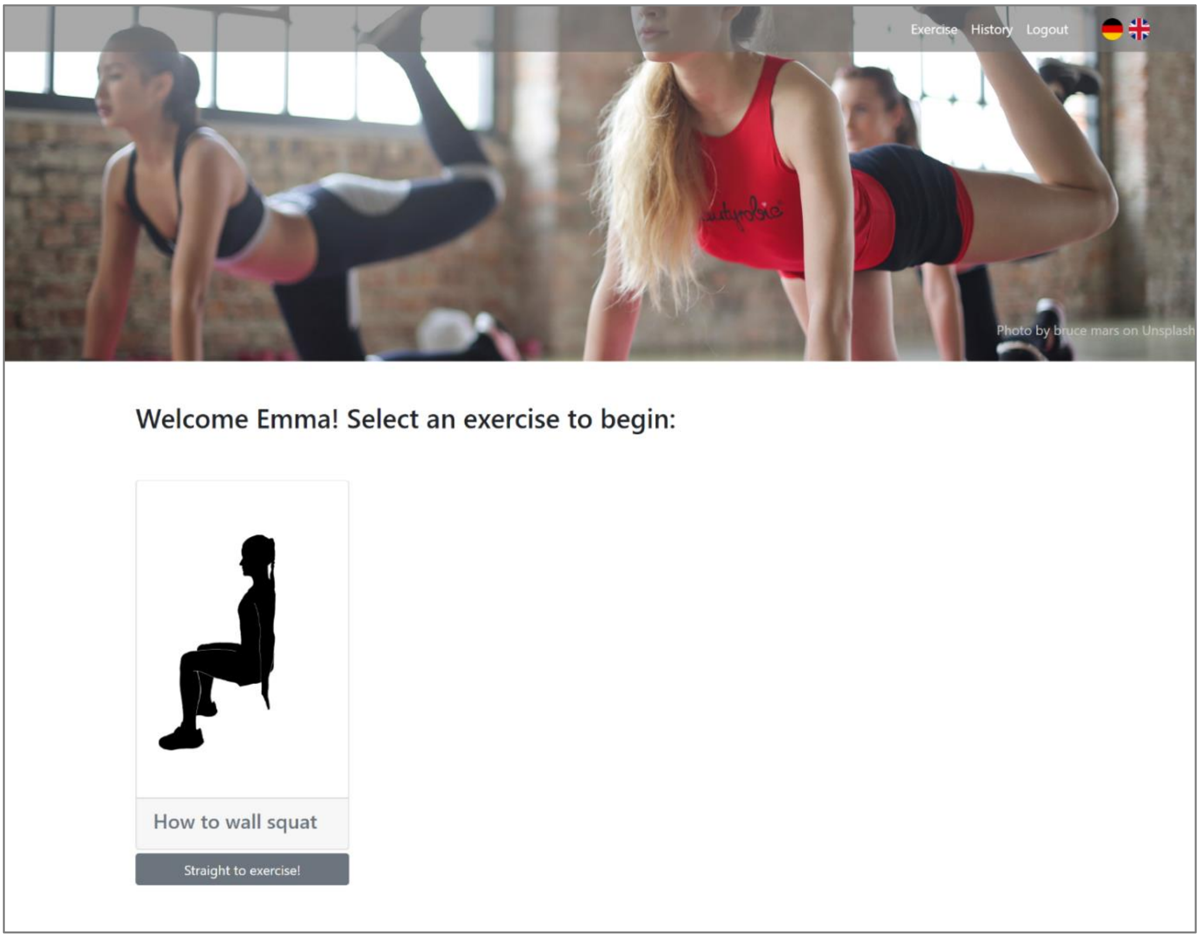
Image:	SquatBaggy2
Brightness:	240
Nose:	0.9981827735900879
RightEye:	0.9983446598052979
LeftEye:	0.9667848944664001
EarRight:	0.9895870089530945
EarLeft:	0.05206499993801117
ShoulderRight:	0.9843981862068176
ShoulderLeft:	0.9859353303909302
ElbowRight:	0.7256110906600952
ElbowLeft:	0.9678134322166443
WristRight:	0.5571615695953369
WristLeft:	0.9792419672012329
HipRight:	0.971637487411499
HipLeft:	0.9162285327911377
KneeRight:	0.9402430653572083
KneeLeft:	0.9783180952072144
AnkleRight:	0.8276049494743347
AnkleLeft:	0.9569618105888367

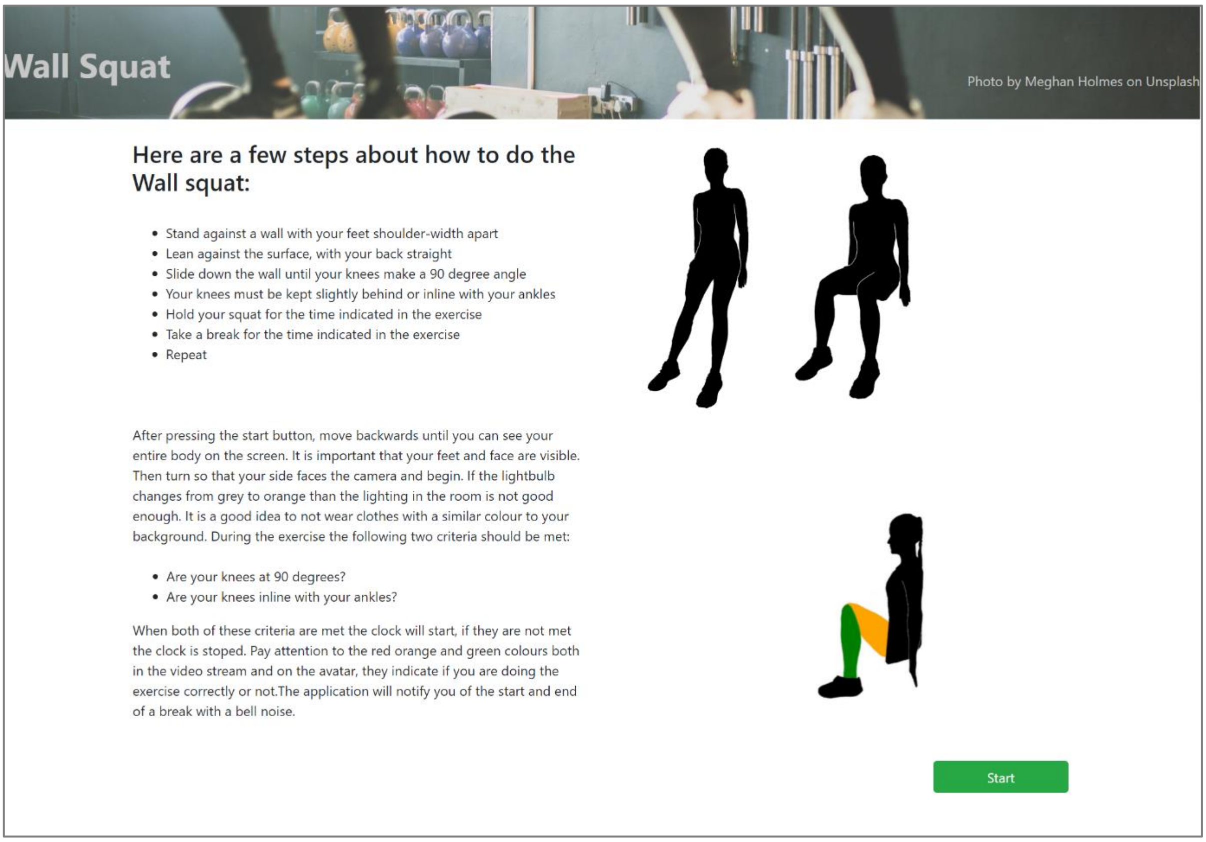
Appendix E: Screenshots from the web application

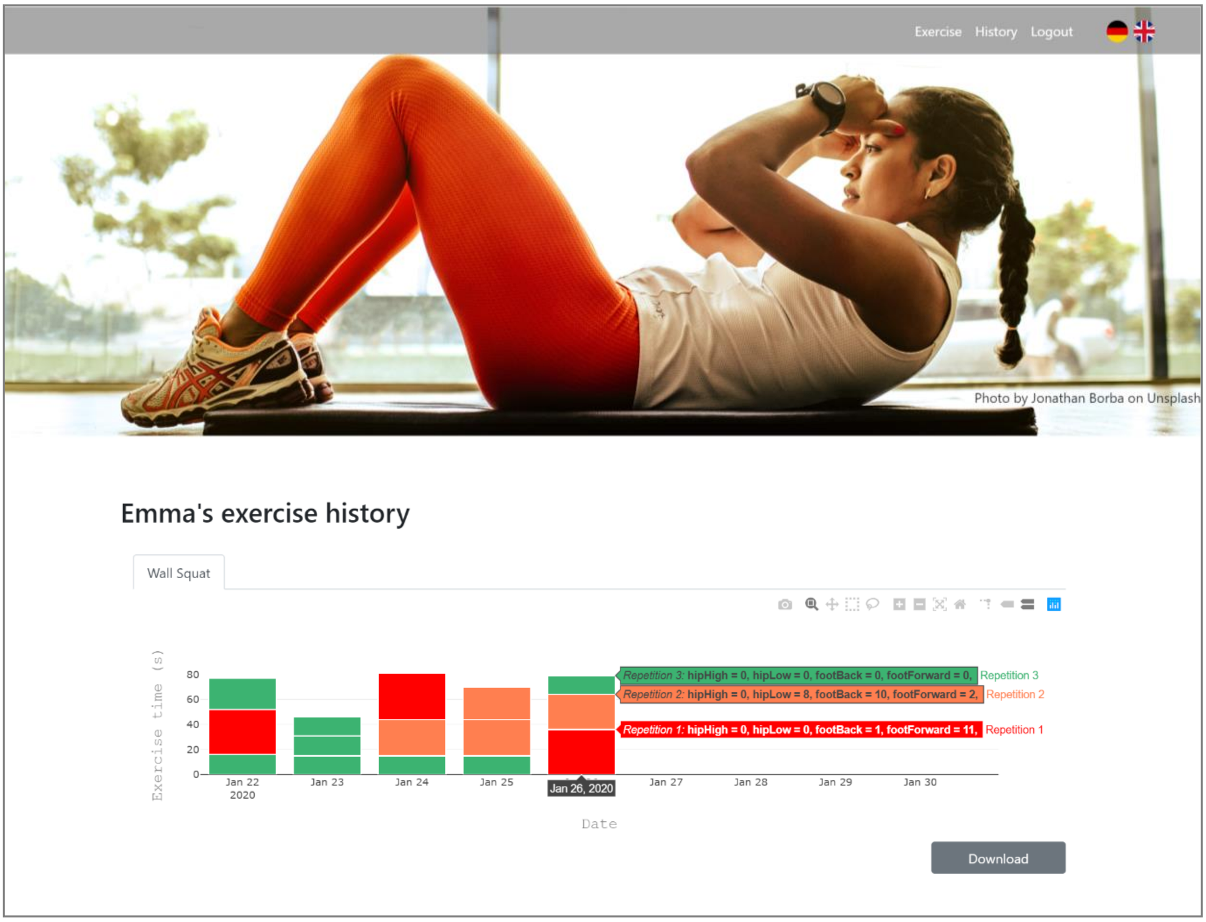
E.1 Each page of the application

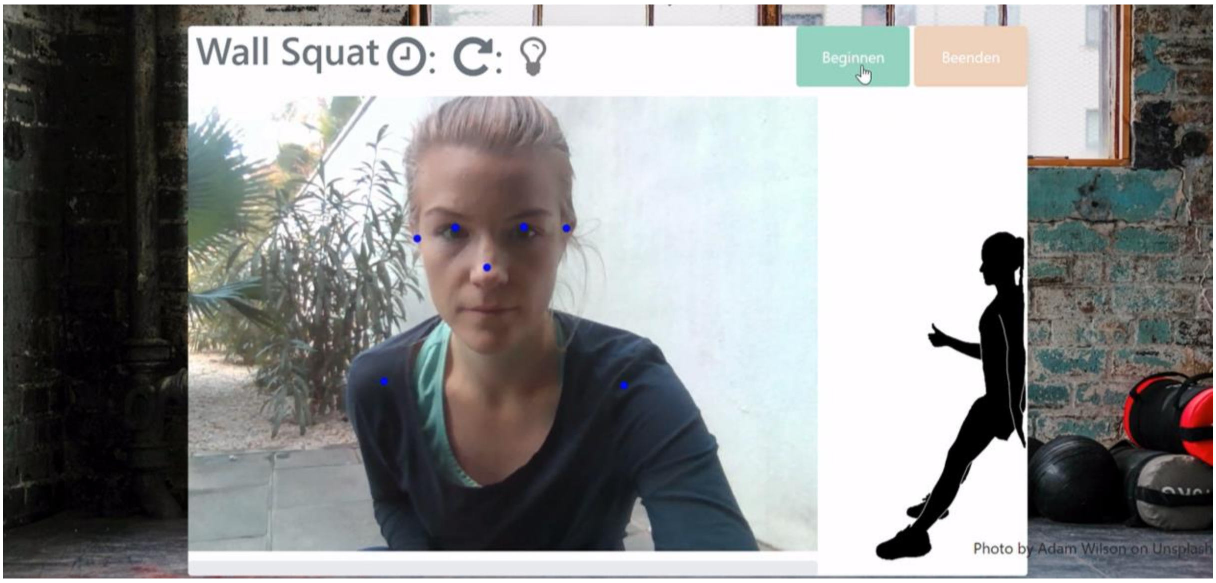


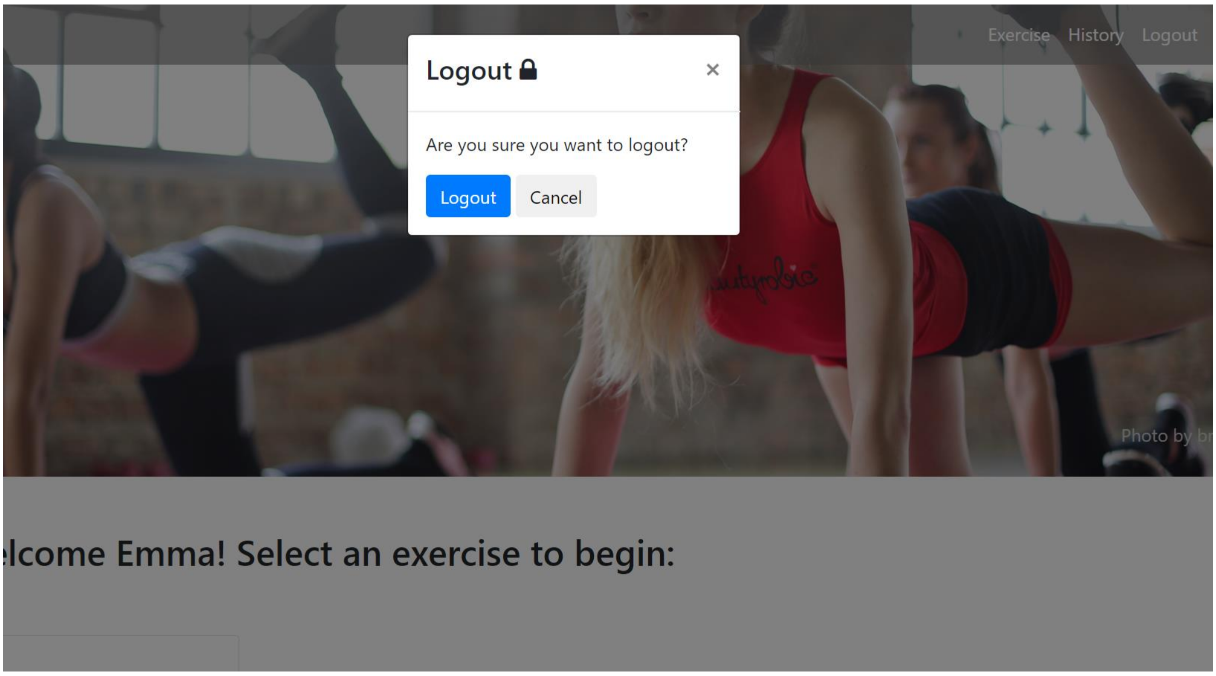



Exercise
History
Logout
Photo by bruce mars on Unsplash
Welcome Emma! Select an exercise to begin:
How to wall squat
Straight to exercise!

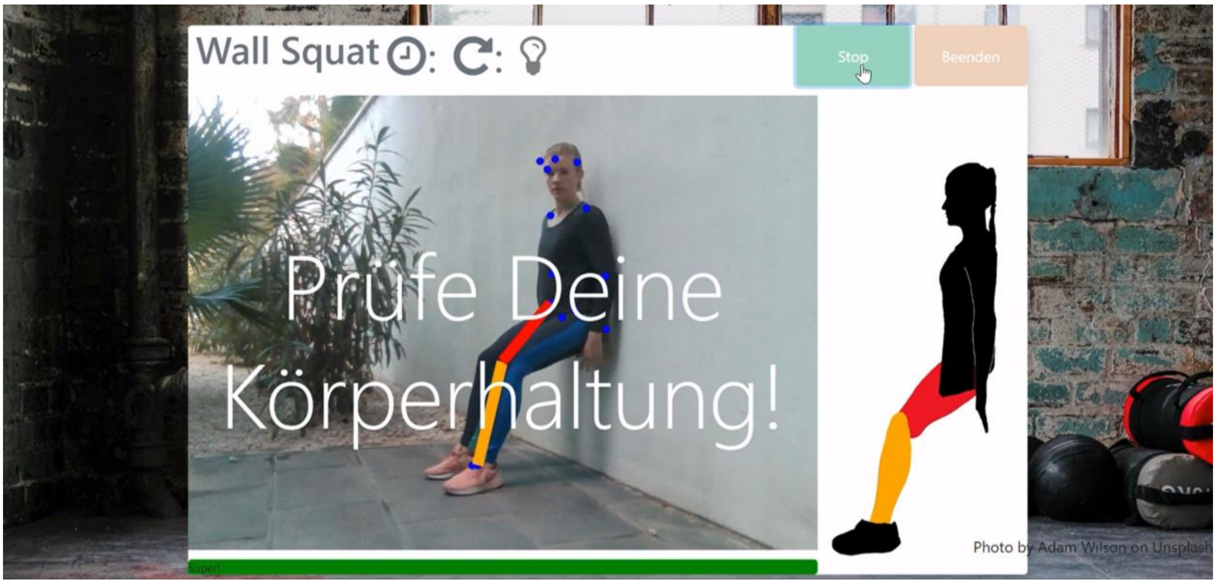

Wall Squat
Photo by Meghan Holmes on Unsplash
Here are a few steps about how to do the Wall squat:
• Stand against a wall with your feet shoulder-width apart
• Lean against the surface, with your back straight
• Slide down the wall until your knees make a 90 degree angle
• Your knees must be kept slightly behind or inline with your ankles
• Hold your squat for the time indicated in the exercise
• Take a break for the time indicated in the exercise
• Repeat
After pressing the start button, move backwards until you can see your entire body on the screen. It is important that your feet and face are visible. Then turn so that your side faces the camera and begin. If the lightbulb changes from grey to orange than the lighting in the room is not good enough. It is a good idea to not wear clothes with a similar colour to your background. During the exercise the following two criteria should be met:
• Are your knees at 90 degrees?
• Are your knees inline with your ankles?
When both of these criteria are met the clock will start, if they are not met the clock is stoped. Pay attention to the red orange and green colours both in the video stream and on the avatar, they indicate if you are doing the exercise correctly or not.The application will notify you of the start and end of a break with a bell noise.
Start

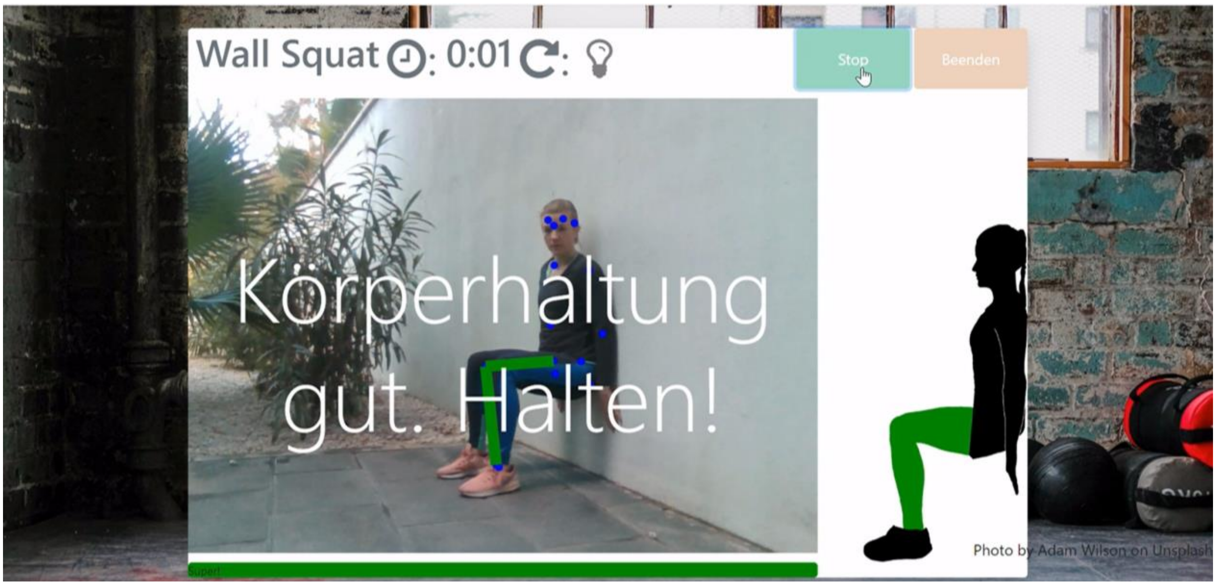

Exercise
History
Logout
Photo by Jonathan Borba on Unsplash
Emma's exercise history
Wall Squat
Exercise time (s)
80
60
40
20
0
Jan 22 2020
Jan 23
Jan 24
Jan 25
Jan 26, 2020
Jan 27
Jan 28
Jan 29
Jan 30
Date
Repetition 3: hipHigh = 0, hipLow = 0, footBack = 0, footForward = 0,
Repetition 3
Repetition 2: hipHigh = 0, hipLow = 8, footBack = 10, footForward = 2,
Repetition 2
Repetition 1: hipHigh = 0, hipLow = 0, footBack = 1, footForward = 11,
Repetition 1
Download

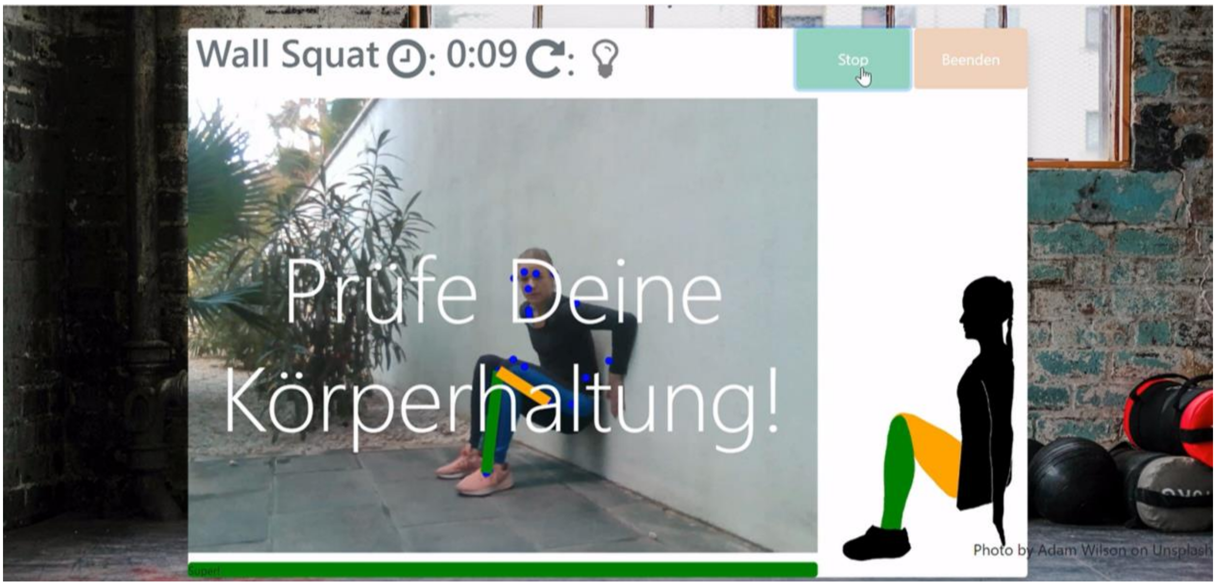

Wall Squat
Beginnen
Beenden
Photo by Adam Wilson on Unsplash

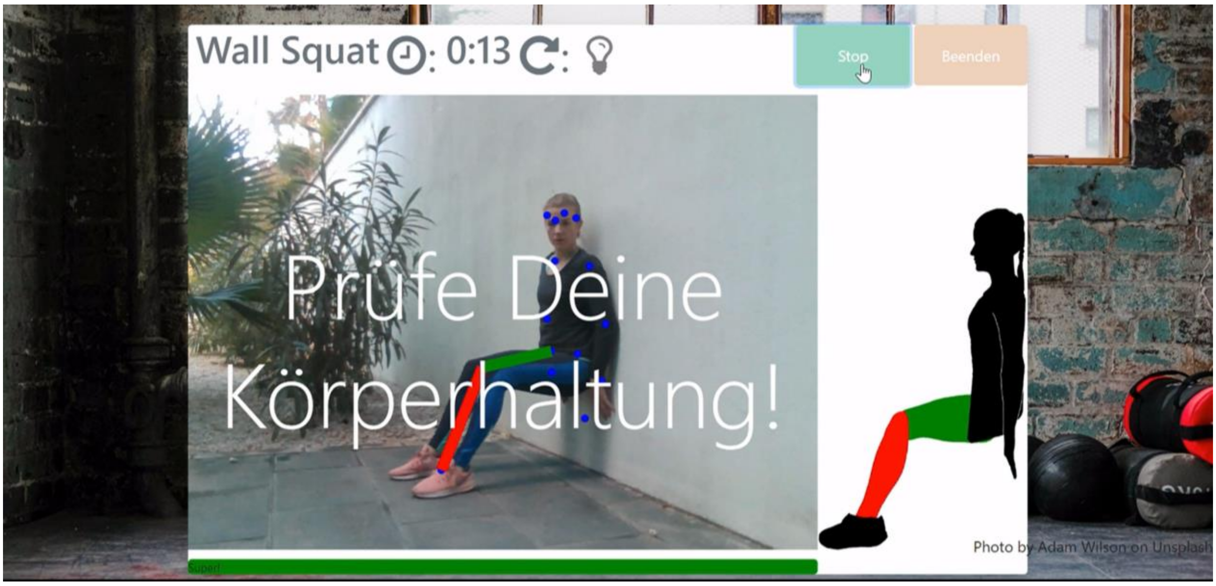

Exercise
History
Logout
Logout
Are you sure you want to logout?
Logout
Cancel
lcome Emma! Select an exercise to begin:

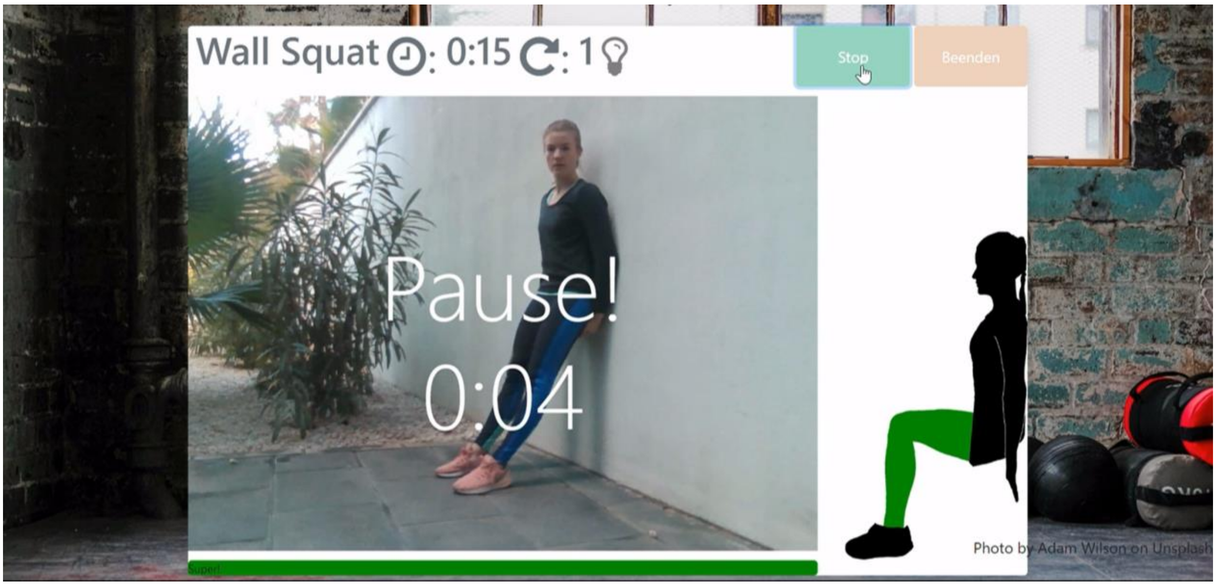
E.2 Sequence of events for the execution of a wall squat in the application






Wall Squat
: 0:09
Stop
Beenden
Prüfe Deine Körperhaltung!
Photo by Adam Wilson on Unsplash


Wall Squat
: 0:13
Stop
Beenden
Prüfe Deine Körperhaltung!
Photo by Adam Wilson on Unsplash


Wall Squat
: 0:15
: 1
Stop
Beenden
Pause!
0:04
Photo by Adam Wilson on Unsplash


Wall Squat
Stop
Beenden
Du hast 3 Wiederholungen geschafft
Möchtest Du mit dieser Übung fortfahren?
Fortfahren
Verlaufseite
Nächste Übung
Körperhaltung gut. Halten!
Photo by Adam Wilson on Unsplash