PRINCIPAL COMPONENT ANALYSIS TO DETECT CHANGES IN GAIT KINETICS IN PATIENTS WITH ANKLE OSTEOARTHRITIS

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SUMMARY
Principal component analysis was used to characterize the ankle moment and the vertical ground reaction force of healthy subjects and ankle osteoarthritis patients during walking. Significant differences were found in the first two principal component scores of the healthy controls and the affected leg of the patients. For the non-affected leg, only some of the scores were different. With this analysis, it was possible to quantify osteoarthritis effects on the affected leg and the contra-lateral healthy side. Additionally, these principal components were used to classify the subjects’ gait kinetics using a support vector machine which was able to discriminate between the affected side of the patients and the healthy controls with a recognition rate of 93.4 %.

INTRODUCTION
Osteoarthritis (OA) of the ankle joint leads to changes in the gait pattern due to pain and a reduced range of motion of the joint. Kinematic values, like the range of motion of the ankle joint during a gait cycle, have often been analyzed [1, 2]. However, much less is known on the changes that occur in the gait kinetics of ankle OA patients. For the kinetics the focus lay on the description of the ground reaction forces (GRF) pattern [1] or on the peak values of the joint moments and GRF [2].

Principal component analysis (PCA) is a statistical method that allows reducing data without losing temporal information. For example, it has been used to discriminate between the vertical GRF of healthy subjects and of subjects with a unilateral lower leg fracture [3] and to characterize gait patterns of patients with knee OA [4]. Another study used PCA to extract features of the vertical GRF during gait for classification between young and elderly people with a recognition rate of 93.4 %.

The purpose of this study was to study changes in gait kinetics of ankle OA patients using the PCA and use these changes to classify the kinetics of the ankle OA patients compared to the healthy controls.

METHODS
Gait kinetics of 15 healthy controls (48.5 ± 10.5 years) with no history of leg injuries (surgeries), neurological or muscular disorders and 8 posttraumatic ankle OA patients (53.4 ± 11.4 years) were analyzed (Table 1). The subjects walked with a self selected speed on a 15 m walkway. Ankle moments and GRF were obtained with the Vicon Plug-in-gait model (VICON, Oxford, UK) and 2 force plates (Kistler, Winterthur, CH). Both the ankle moment and the vertical GRF were normalized to one gait cycle (101 values) and then further processed.

PCA was performed with a total of 276 trials: 90 from each leg of the healthy controls, and 48 from both the affected (AFL) and non-affected (NAL) leg of the OA patients. The ankle moment and vertical GRF waveforms were submitted separately to a PCA. To show the contribution of one PC vector to the deviation from the mean waveform, this vector was multiplied with the corresponding mean PC score of the group and added to the average waveform. Statistical differences between the groups were tested using a Mann-Whitney U-test with a significance level of α = 0.05.

Table 1: Characteristics of the two subject groups (mean ± standard deviation)

<table>
<thead>
<tr>
<th></th>
<th>Body mass [kg]</th>
<th>Height [m]</th>
<th>Walking speed [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>74.6 ± 9.9</td>
<td>1.73 ± 0.12</td>
<td>1.26 ± 0.11</td>
</tr>
<tr>
<td>Patients</td>
<td>86.1 ± 16.3</td>
<td>1.75 ± 0.08</td>
<td>1.28 ± 0.12</td>
</tr>
</tbody>
</table>

In order to classify the PC scores of the different groups, the first two PC scores with significant differences between the groups were retained. A SVM (radial basis function: C = 1, γ = 0.0625) was used to discriminate between the healthy controls and the AFL and NAL, respectively. The recognition rate was calculated using a leave-one-out cross-validation procedure.

RESULTS AND DISCUSSION
The first PC (PC1) of the ankle moment explained 53.8 % of the total variability. It influences the magnitude of the plantarflexion moment during the stance phase. PC2 vector (20.4 % of total variability) acts on the shape and amplitude of the ankle moment. As Figure 1A shows, PC2 scores were on average lower in the AFL than in the NAL (p < 0.0001) and the controls (p < 0.0001). As the range of PC1 scores was similar for all three groups, the scatter plot of PC1 and PC2 scores revealed no distinct clusters. However, PC1 and PC2 scores of the vertical GRF were grouped more clearly (Figure 1B). In contrast to the healthy controls, the AFL had on average, significantly lower PC1 scores (p = 0.0002) and higher PC2 scores (p < 0.0001), whereas the NAL yielded higher PC1 scores (p < 0.0001) and similar PC2 scores (p = 0.829).

Analysis of the GRF waveform showed that the PC1 vector (36.0 % of total variability) is mainly shifting the decrease after the second peak and thus reflects a lengthening and shortening of the stance phase in time of the NAL and AFL, respectively (Figure 2B & 2C). Reconstruction of the GRF in PC space with the mean PC scores of the three different groups showed that for PC1 the AFL had a shorter stance phase whereas the NAL had a longer stance phase compared
to the healthy controls (Figure 2C). The PC2 vector (28.5% of total variability) changes the amplitude of the GRF. The reconstruction with PC2 scores showed that the mean of the AFL had lower peaks and higher valleys than both the NAL and the controls (Figure 2D). This reflects a damped GRF.

As there were no significant differences ($p = 0.160$) in the gait velocity between the patients and the controls, the differences in the gait kinetics were not speed dependent. Especially for the GRF, it was seen that the healthy controls, and both the AFL and NAL of the patients differ not only in peak values but also in the timing aspects of the gait cycle. These effects could be separated by the PCA and thus analyzed independently.

PC2 of the ankle plantarflexion moment and PC1 and PC2 of the vertical GRF were used for the classification with the SVM. The SVM with a radial basis function separated the controls from the AFL with a recognition rate of 93.4% and from the NAL with 83.8%.

CONCLUSIONS
Patients suffering from ankle OA have an altered gait pattern, which was most notably seen in the GRF. This work showed that two main changes can be separated by using a PCA analysis. The first change consisted in a shortening and lengthening of the stance phase of the AFL and NAL, respectively. This leads to the typical limping movement resulting from OA. The second change consisted in a dampening of the GRF in the AFL. This indicates a more careful ground contact of the AFL. However, the damping did not alter or increase the GRF of the NAL. Together with the PC scores from the ankle moment, this analysis enabled us to classify the gait kinetics of the healthy controls and the AFL with a high recognition rate of 93.4%. This recognition rate is compelling enough that we can propose using the SVM classification as an additional factor for the diagnoses of OA.

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REFERENCES