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Experimental evaluation of the forefinger maximum bending moments

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1. Introduction

The development of advanced orthosis requires the knowledge of the forces that can be generated by the human body. This study focuses on the forefinger joint. The aim is to estimate the maximal moment capacity of a finger at different bending angles. Recently, devices have been designed to measure the forefinger force [1,2] but they can only measure the grasping forefinger force in a specific position. The present study describes a custom experimental device that enables to evaluate the forefinger bending moments at different angles. Next, the results obtained for thirty subjects are presented. The results s were analysed by the PCA statistical method to identify three main behaviour modes.

2. Methods

2.1 Experimental set-up

The device was designed in order to measure the maximum bending moments of the forefinger Proximal Inter-Phalangeal (PIP) joint. It consists of a rigid arc and a load sensor that can be fixed according to the arc centre at different angles as presented in figure 1. The hand is fixed to the arc so that PIP joint can freely move. During a first test a camera is used to track movement of the finger in order to determinate the centre of joint. Then, the distal and the middle phalanxes of the forefinger are inserted into a rigid cylindrical tube rested on the sensor. The system limits any movement of the Distal Inter-Phalangeal (DIP) joint, and constrains subsequently the distance between the joint centre and the force application point.

This device was used to test thirty healthy subjects (male and female with different ages). For each subject nine angles (between 0 and 90 degrees) of the joint were tested. Each test was repeated three times in order to study the reproducibility of the results. Between each two tests a break of 2 minutes is given to the subjects.

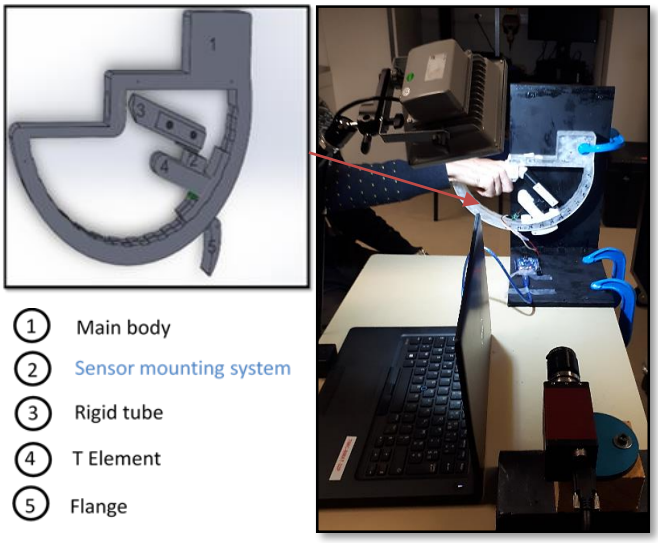


Figure 1-Laboratory set-up developed for the experimental investigations

3.Results and discussion

3.1 Bending moments results

The initial analyses show that our investigations are generally subject-specific. According to the experimental results, the bending moment depends on the angle of the PIP articulation and specific characteristics of the subject, e.g. gender, age, physical conditions, etc.

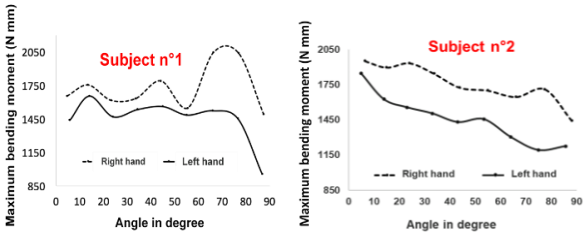


Figure 2: Changing of the maximum bending moment versus the angle of articulation for different subjects

It is illustrated by Figure 2 which shows two different diagrams presenting the changing of the maximum bending moment versus the angle of the joint for two different subjects.

3.2 Statistical Analyses

In order to make some investigations on our results and gain better understandings of the different behaviours of the subjects, a Principal Component Analysis (PCA) was performed.
PCA permits to approximate the variables as a linear combination of the eigenvectors such as :

$$C_N \approx C_{moy} + \sum_{i=1}^{N} Q_i * M_i \qquad (1)$$

where C_N, Mi, Q_i and C_{moy} are the maximum bending moment, the data eigenvector, the multiplicative coefficients of the eigenvectors and the average value, respectively. N is the number of eigenvector used to reconstruct the data. In this study, N=9 provides a perfect reconstruction.

Considering the dominant and non-dominant hands, this method was applied to a population of 30 subjects, among which there were 18 men and 12 women.
Then the eigenvectors and eigen values for the PCA of the whole population were determined. The results are shown in Table 1, in which the first three modes contains almost all the information (relative sum of three first eigen value is 98.1%).

Eigen Modes M_i	1	2	3	4	5	6	7	8	9
Weight of eigen value compared to others	88,37	5,65	4,08	1,2	0,23	0,2	0,11	0,07	0,04

Table 1

Figure 3 represents the maximum bending moment as a function of one the subject's bending angle. The red circle curve is the experimental data. The blue curve shows the average curve C_{moy}. The signal approximation C_N (equation 1) has then been computed by increasing N by step of 1. It confirms for this subject that N=3 provides a satisfying approximation of the measurement.

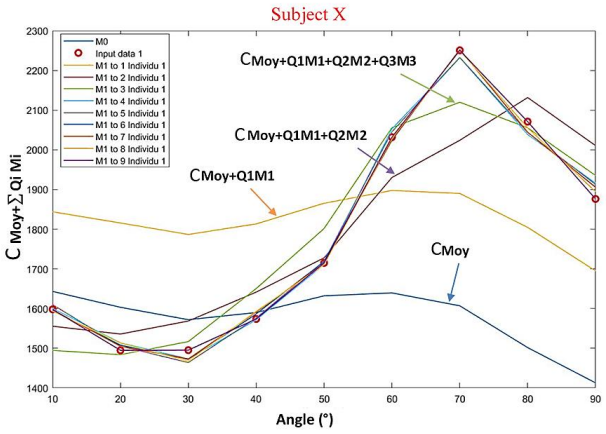


Figure 3-Recontruction of a subject with the modes of the PCA analysis.

4. Conclusions

The maximum bending moment depends both on the specifications of the subject and the angle of the PIP. Using the statistical PCA method allows to approximate the behaviour of each subject based on the linear combination of three dominant simple modes. The maximal bending moment of each subject can thus be described using only three parameters.
Finally, the orthosis stiffness should be a function of its angular configuration. These results will be used later to design patient-specific orthosis.

References

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