FINGER-FORCE MEASUREMENT-DEVICE FOR HAND REHABILITATION

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Abstract - The purpose was to develop an extension finger-force measurement device, and investigate the intra-individual repeatability. The design of the measuring device allows single finger force and whole hand measurements, and the repeatability error on extension finger forces was measured, both on the whole hand, as well as on individual fingers. The tests showed that a repeatability error of less then 15 % can be achieved for single finger measurements and less then 21 % for whole hand measurements.

I. INTRODUCTION

The hand is used in many ways, and in many different situations in our daily lives, and injuries, diseases, or deformations of the hand can affect our quality of life. In diseases like rheumatoid arthritis (RA), the hands are frequently affected by pain, a feeling of weakness and mobility difficulties. It is necessary to find methods to objectively measure these parameters in order to be able to evaluate functional impairment, as well as the results of therapeutic interventions i.e. surgery or physical therapy after hand trauma or disease. Today there are devices available for measuring finger flexion force, e.g. the Gripp-it device [1]. However, no commercial product exists for both single finger and whole hand extension force, although extension ability is important for developing grip power function and grip stability for managing daily activities. In the literature assessment methods for finger measurements have suggested complicated devices directly attached to the finger or as a glove [2,3,4].

The objective of the present work was to develop and validate a user-friendly force measurement device for extension finger-force assessment.

With the instrument the isometric force $F$ can be measured at every single phalange around the meta-carpophalangeal (MCP) joint (see figure 1).

The measurements can be made at different angles, $\alpha$, of the joint. The force is generated by the extension muscles located in the forearm.

As a test group we have chosen healthy subjects and patients with RA. The latter group frequently experiences muscle symptoms such as weakness, pain, instability as well as deformities of the hand. The device is designed to fit most patients with hand disabilities.

II. DESIGN

The evaluation of different intervention methods in an objective way makes the repeatability for this measuring device very important. The challenge here is to make sure that the repeatability on the same test subject is reliably. Our primary interest is to take a relative measurement on one individual. At this stage, we are not interested in comparing two or more individuals. The repeatability or precision is very important, but at this stage, the accuracy is not. The repeatability is described by a stochastic variable, often by a Gaussian distribution. We assume a Gaussian distribution and quantify the repeatability with a so-called repeatability error (also called imprecision, non-repeatability or variability, see [5]), which in our case is the standard deviation expressed as percentage of the measured value.

The accuracy of a measurement device is composed of the repeatability and of a deterministic error called bias. The bias can in principle be determined and corrected by careful calibration [5]. The accuracy aspect of the device will not be addressed in this paper. There are three main causes which contribute to the repeatability performance.

1) The repeatability of the measurement device itself, which can be tested separately by applying known loads on the device. Factors that cause the variations can be, for example, friction in the device, and repeatability of the used
transducer in the device. The choice of the transducer and the design of the device do influence this.

2) The repeatability of the measurement due to the interaction between the device and the user. The major factor here is the repeatability of the placement of the hand and the fingers in the device. The design of the device does influence this greatly.

3) The repeatability of the user’s ability to apply the maximum available force generated by the muscles. Factors that can cause variations are the motivation and concentration of the user, tiredness of the muscles, and pain in cases with disease. The design of the device does not influence this in principle.

Unfortunately we are not able to measure the repeatability of the cause 2 and 3 separately. From experience we know that a repeatability error of the user of ± 10 % can be regarded as good. Therefore we do not have to require a very high repeatability error of the device itself (cause 1) and our aim is below 0.5 % of the applied load. The real challenge is to design a device which is able to fit all types of individuals, including subjects with hand diseases, while still performing with good repeatability. The following specifications can now be formulated for our device.

**A. Specifications**

The specific design criteria are:

1) Repeatability error of less then 0.5 % of the measured force (see above).

2) To be able to measure forces from zero to about 350 N (The force of one single finger from RA-group, for example, proved to be 5 N, whereas the force of a whole hand of a well-trained person proved to be 268 N. Data from pilot study).

3) Measure isometric extension force around the MCP-joints.

4) Allow each finger, (excluding the thumb), to be measured separately as well as the whole hand.

5) To fit both left and right hands.

6) To fit different hand sizes, and hands with deformities (see fig. 2). We have used the anthropometric standard for hand size: 95-69mm wide and 205-159mm length.

7) Easy to use and transport.

8) Mobile.

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**B. Primary design**

A major problem with measurements of the human hand is the fixation of the joints. Two different solutions were evaluated.

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**Figure 2. Evaluation of the measuring device on a patient with RA, showing the deformation of the hand.**

**Figure 3. Prototype measurement device 1.**

**Figure 4. Forces for prototype 1.**

**Figure 5. Prototype measurement device 2.**
Measurement device 1
A force sensor is placed between the finger and a fixed point with a certain distance to the MCP-joint. The forearm is placed into a supporting structure and the hand is fixed in the device by a glove (see fig. 3 and 4). An elbow support is introduced to eliminate the force component along the forearm. Tests using this device showed that the forces through the forearm and a little play between the support and the elbow made it difficult for the user to concentrate on the finger extension muscles as other muscle groups were activated as well. Preliminary tests showed a rather poor repeatability error of about 35% and the users found it uncomfortable to use. Therefore, we decided to develop another prototype.

Measurement device 2
The idea of a supporting structure for the forearm was abandoned, and a device which only involved the hand and the fingers was designed (see fig 2 and 5). The advantage was that all forces were eliminated within the hand (see fig 6). This gave a comfortable and easy-to-use design which allowed the user to involve the muscles of interest only.

The new construction made it possible to measure in two intervals by a simple gear-mechanism. Interval I range from 0-90N, which in practice covers single finger measurements and whole hand measurement for the RA patient group. Interval II ranges from 0-370N and covers in practice whole hand measurements on a healthy control group. The measurement device is rather small and light, which makes it mobile. The size of the equipment was minimized by placing the sensor on the dorsal side. The device can adapt to different sizes of the hand by three different adjustments.

C. Sensor and development of software
A single point load cell was used as a sensor. It is physically small, has high accuracy, and low weight due to its aluminium construction. The capacity of the sensor was from 3 to 35 kg and total error ±0.03 % of applied load. A DSP-based computer board equipped with an AD-converter takes care of measured data. Through a serial link the data can be sent to a data processing program, Matlab. In Matlab a user interface has been developed for the measurement device, for example, showing plots of the results (fig. 7).

III. RESULTS
A. Repeatability
As described in section II the repeatability error of the measurement device itself was evaluated by applying known loads on the device. Three different weights were used, and for each weight, ten different measurements were made. The standard deviation, sd, was calculated for each weight and expressed in % of the load. The results are shown in table 1 and 2 for the low range and high range of the device. The conversion from sensor output values to Newton was done by a least square fit of a straight line through the measured values.

<table>
<thead>
<tr>
<th>range</th>
<th>load [N]</th>
<th>sd [N]</th>
<th>% of load</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-90</td>
<td>9.81</td>
<td>0.085</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>40.71</td>
<td>0.2595</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>17.45</td>
<td>0.5977</td>
<td>0.78</td>
</tr>
<tr>
<td>0-370</td>
<td>9.81</td>
<td>0.1225</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>150.94</td>
<td>1.4447</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>289.03</td>
<td>2.2711</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Table 1. Results for repeatability-test for the low and high range of the device.
The results show that the repeatability error, i.e. standard deviation, shows a high correlation with the load and can be expressed as percentage of the load. The low range shows a repeatability error of less then 1 % of the load. The same is valid for the high range as the relatively low load of 9.81 N showing a repeatability error of 1.25 % is not of practical use. The low range variant will then be used instead.

B. Repeatability test subjects
As stated in the beginning of section II, it is very important for this measuring device to have good repeatability for the same individual. Unfortunately, we also have to include the repeatability of the user to be able to generate the maximum force, as explained in section II.

C. Whole hand measurements
The repeatability error of the whole hands extension force was tested nine times on three different subjects under the
same circumstances. The results are shown in table 2. The measurements were recorded during three seconds and the average value is calculated during one second of the values after the first second, see figure 7.

<table>
<thead>
<tr>
<th>Test Person</th>
<th>Mean [N]</th>
<th>SD [N]</th>
<th>%</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>173.3</td>
<td>11.54</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>119.9</td>
<td>9.24</td>
<td>21</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>216.7</td>
<td>9.39</td>
<td>12</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 2. Statistic values of nine repeated whole hand measurements from three test persons.

The results in table 2 show that a repeatability error is achieved ranging from 12 % for person 3 and 21 % for person 2.

D. Finger measurements
The repeatability error for extension finger force on every single finger was tested five times on two subjects under the same circumstances. The results are showed in table 3 and fig 8.

<table>
<thead>
<tr>
<th>Test Person/Finger</th>
<th>Mean [N]</th>
<th>SD [N]</th>
<th>%</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 finger II</td>
<td>21.8</td>
<td>3.11</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>1 finger III</td>
<td>21.2</td>
<td>3.42</td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td>1 finger IV</td>
<td>18.6</td>
<td>2.30</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>1 finger V</td>
<td>10.8</td>
<td>0.84</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>2 finger II</td>
<td>38.6</td>
<td>3.50</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>2 finger III</td>
<td>46.6</td>
<td>3.84</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>2 finger IV</td>
<td>38.0</td>
<td>3.80</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>2 finger V</td>
<td>28.2</td>
<td>3.63</td>
<td>13</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 3. Statistic values of five repeated finger force measurements for two test persons.

This study shows that our device is a valuable tool for finger extension force measurements, and that reproducible data can be obtained. Tests on a few persons showed that a repeatability error of less then 15 % can be achieved for single finger measurements and less then 21 % for whole hand measurements. Although more measurements must be performed on more subjects, these first results are promising. We must also keep in mind that the repeatability includes the repeatability of the test subject being able to generate the maximum available force, a parameter also influenced by biological variation that could be substantial.

REFERENCES