ACCURACY AND REPEATABILITY OF A NEW METHOD OF FINGER MOTION CAPTURE USING FUNCTIONAL JOINT CENTRES

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SUMMARY
Two methods of calculating joint centres using functional techniques have been compared. One used transformation methods, referred to as the phalanx transformation technique (PTT), the second used fitting methods, referred to as the phalanx fitting technique (PFT). An assessment of joint accuracy as both position and angle of the axes of rotation was made. This was subsequently converted to errors in the outputs of a biomechanical model. Six subjects were tested in a single capture session and four returned for a second session to get a measure of repeatability. The PTT was found to be more accurate with a mean joint error or 0.67mm, compared to 1.22mm when using the PFT. This was reflected in errors in the biomechanical model’s outputs of 2.8% compared to 10.2%. Calculated phalanx length was used as a measure of repeatability between sessions. The discrepancy in these lengths between sessions was found to lie within the experimental error bands. The accuracy of these techniques compares favourably with others previously proposed. This is likely a result of the lack of skin movement artefact in the fingers.

INTRODUCTION
An improved understanding of finger biomechanics can aid in prevention, management and rehabilitation of injuries and pathologies of the fingers, and optimise surgical interventions. The internal forces transmitted through the finger can be calculated using biomechanical models and an accurate measurement of finger position is a necessary input to these. The aim of this study was to describe and assess the accuracy and repeatability of a new method of finger motion capture using two techniques to define functional joint centres.

The use of functional joint centres means that the axes of rotation (AoR) and centres of rotation (CoR) are calculated by examining the relative motion of segments, rather than on position relative to externally located landmarks or bone geometry. The use of functional methods reduces the susceptibility to marker placement errors and skin artefact.

Functional methods for determining AoRs and CoRs can be classed into either fitting or transformation techniques [1]. To provide a comparison between these, this study examines two techniques using an identical marker set.

METHODS
Six subjects were recruited for the first session (age: 26 ± 6 years; height: 1.77 ± 0.1 m; Mean ± SD) and four subjects (age: 24 ± 2 years; height: 1.83 ± 0.04 m; Mean ± SD) returned for a second session. A six camera Vicon T20 motion capture system (Vicon, U.K.) was used. 12 hemispherical markers, 4mm in diameter, were attached to each phalanx of the index finger and dorsal surface of the right hand. Each set of three markers defined a marker cluster technical frame (CTF) attached to each segment.

Both techniques modeled the DIP and PIP joints with an AoR about the flexion/extension axis. The metacarpo-phalangeal (MCP) joint was simplified and defined as a spherical joint with a CoR.

The first technique, referred to as the PTT, applied the axis transformation technique (ATT) [1] to determine the distal and proximal interphalangeal (DIP and PIP) joint centres. These were determined in each CTF proximal and distal to the joint of interest. To give the most accurate result the mean of these was taken. The distance from this mean to the two original joint centres was taken as indicative of the joint error for that capture frame. This was of equal magnitude to half the residual of the ATT. The MCP joint was found using the Centre Transformation Technique (CTT) [2]. The mean joint centre and errors were calculated in the same way as for the inter-phalangeal joints.

The second technique, referred to as the PFT, applied the geometric axis fit technique [1, 3] to determine the DIP and PIP joint centres. Unlike the geometric fit, the AoR were calculated in the CTFs both distal and proximal to the joint of interest. Therefore the joint centres and errors could be calculated in the same way as the PTT. The MCP joint centre and error was found using the CTT. Additional constraints were applied to the PFT requiring the phalanx lengths to be constant.

The accuracy of the AoR and CoR was measured in terms of angle and displacement. To quantify the clinical relevance, joint errors were transformed to error in tendon tension output from a biomechanical model.
RESULTS AND DISCUSSION

The joint errors were assumed to be equal to half the residual calculated from the ATT. This agrees with a previous observation that the correlation coefficient between this residual and joint error was $\approx 0.5$ [4].

The mean errors for each technique and the discrepancy between them are shown in Table 1. The mean joint error using the PFT was almost double that of the PTT at 1.22mm compared to 0.67mm. This was predominantly due to the difference at the inter-phalangeal joints. There was very little difference at the MCP joint, as both techniques use the CTT to define it. The errors using the PFT were slightly increased as the CoR was displaced to satisfy the fixed phalanx length constraint. Both techniques used identical data sets, therefore the discrepancy between each could be measured. This was found to be within the total experimental error.

Comparison between capture sessions was important in determining how susceptible the accuracy was to marker attachment position. As the markers were re-attached it was not possible to directly compare joint centres, therefore a comparison in phalanx length was made. The inter-session variability for the PTT is shown in Figure 1. The error bars represent the experimental error associated with each calculated phalanx length, calculated as the sum of the errors at the bounding joints. For all subjects and either technique the inter-session variability was within experimental error.

CONCLUSIONS

It has been shown that both the PTT and PFT provide useful methods for accurate calculation of finger position in comparison with previously proposed techniques. Of these two it was found that the PTT was more accurate in measurement of joint positions, angles and biomechanical model outputs. These techniques have been shown to be repeatable within experimental error through comparison between capture sessions.

Some subjects, like those with injuries or pathologies such as arthritis, may have a significantly reduced range of motion of the joints [5]. The influence of this reduction on accuracy has not been covered in this study, however it is of great relevance to the clinical application of these techniques and has been investigated in a further study [6].

Table 1: Mean joint errors for all subjects using both techniques and the discrepancy between them. Calculated at the distal and proximal interphalangeal (DIP and PIP) joints and the metacarpo-phalangeal (MCP) joint. Errors have also been expressed in terms of tendon tension calculated using a biomechanical model.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Magnitude of joint error (±mm)</th>
<th>Joint angle error (±°)</th>
<th>Error in tendon tension (±%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phalanx Transformation (PTT)</td>
<td>0.21 1.07 0.72</td>
<td>1.37 1.53 2.80</td>
<td>0.72 0.89 0.75 15.40 10.15</td>
</tr>
<tr>
<td>Phalanx Fitting (PFT)</td>
<td>0.75 2.19 0.73</td>
<td>9.40 15.40 7.31</td>
<td>0.84 0.75 0.89 9.77 3.58</td>
</tr>
<tr>
<td>Discrepancy</td>
<td>0.84 0.75 0.89</td>
<td>7.31 9.77 3.58</td>
<td>0.72</td>
</tr>
</tbody>
</table>

Figure 1: Difference in calculated phalanx length between capture sessions for the medial and proximal phalanxes using the phalanx transformation technique (PTT).

REFERENCES