

## **Electronic Supplementary Materials 1 (ESM1) – Results and methodological details of the grip calibration protocol**

This document is an electronic supplementary material (ESM1) for the article entitled “Electromyography-informed musculoskeletal modelling provides new insight into hand tendon forces during tennis forehand”

### **Article information**

Electromyography-informed musculoskeletal modelling provides new insight into hand tendon forces during tennis forehand

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## Grip calibration results

### FDS activation-grip force relationship

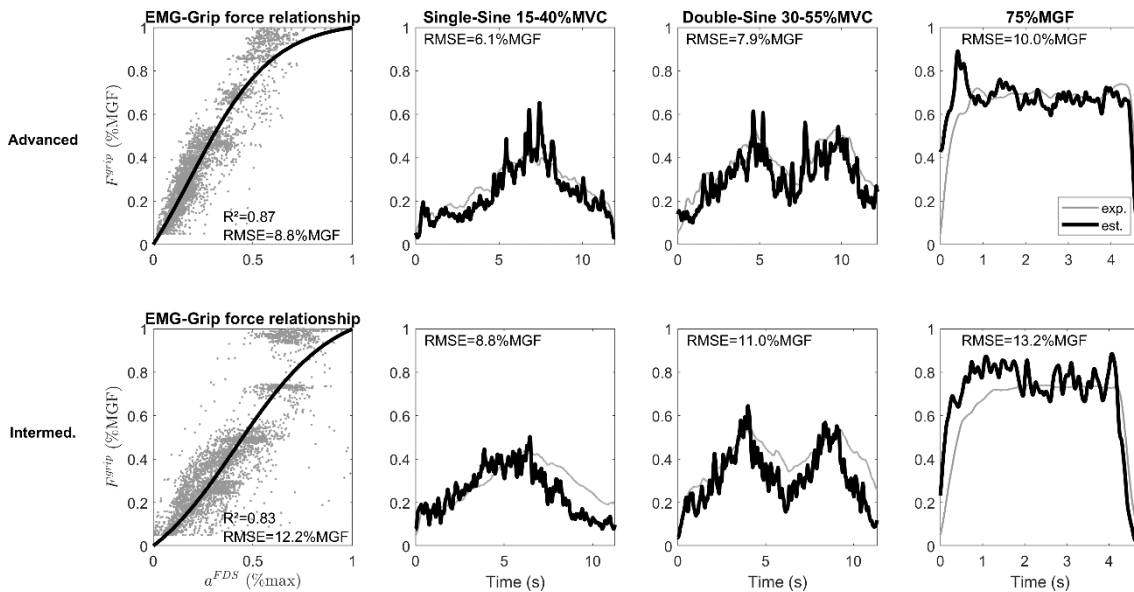


Figure s1-1. Experimental data fitting of the EMG-grip force relationship (first column) and comparison between experimental and estimated grip force for three representative examples (second-fourth columns) of the Advanced (first row) and Intermediate (Second row) player.  $F^{grip}$ : Grip force;  $\alpha^{FDS}$ : flexor digitorum superficialis (FDS) muscle activation; MGF: maximal grip force. See article for detailed explanation of the methodology.

### Grip force distribution

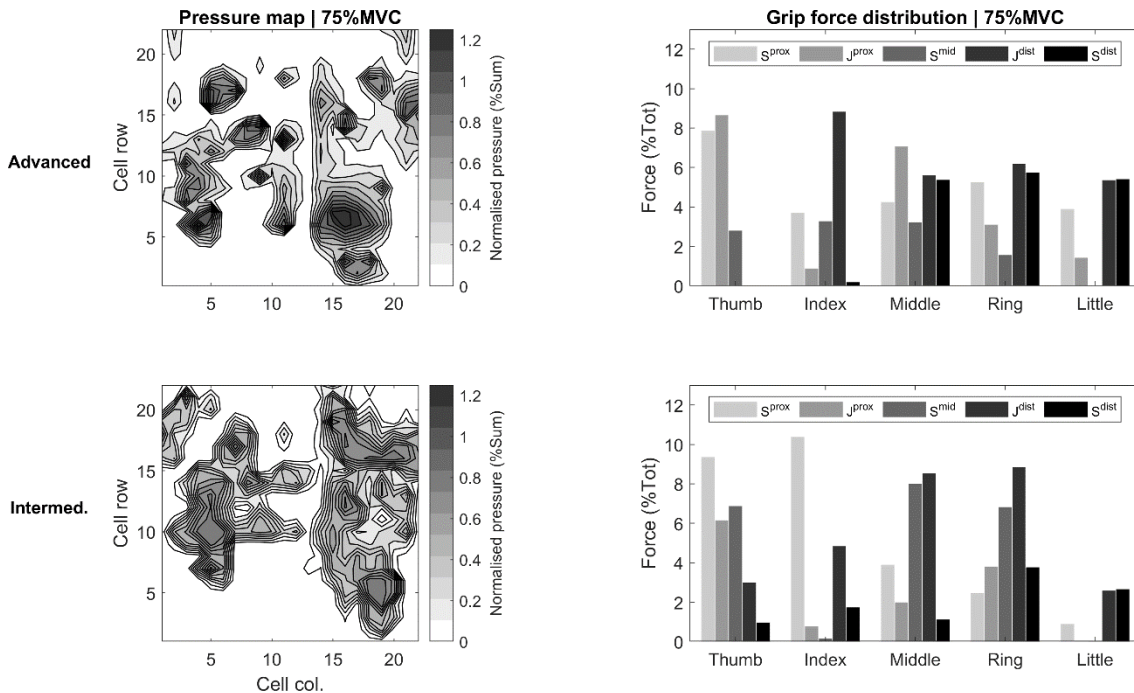


Figure s1-2. Normalised data from pressure map sensor (left panels) and grip force distribution across 25 anatomical areas (right panels) for the Advanced (upper panels) and Intermediate (lower panels) player. See article for detailed explanation of the methodology.

## *Finger posture on the handle*

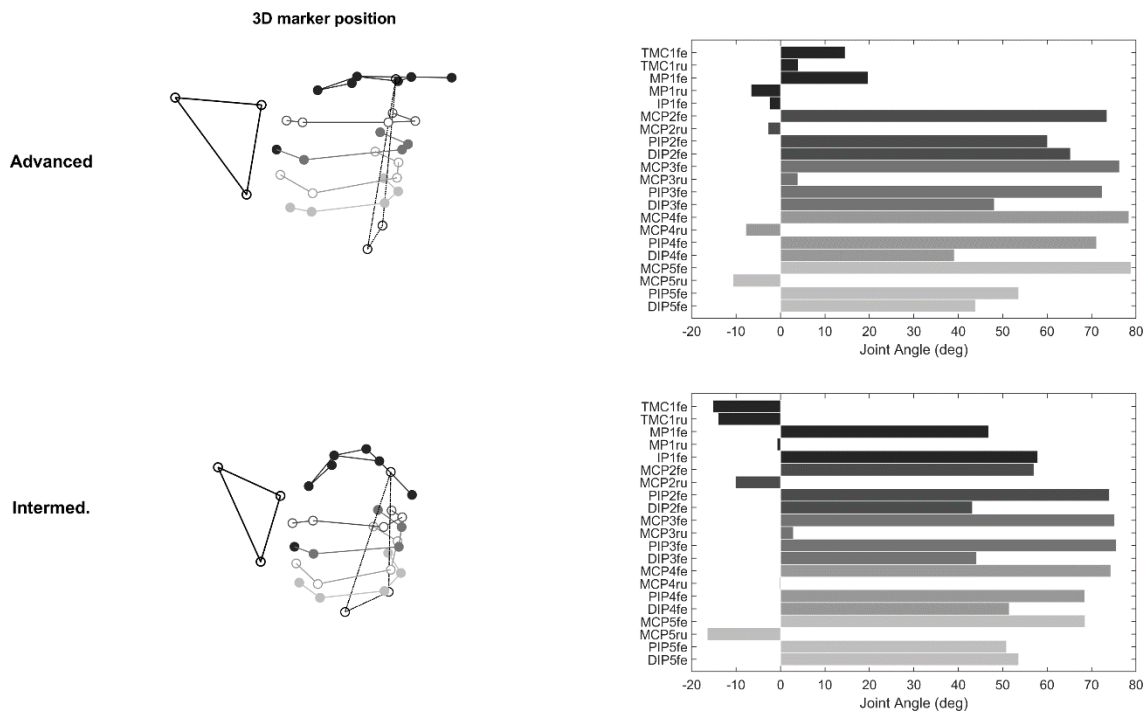


Figure s1-3. Marker 3D coordinates (left panels) and finger joint angles (right panels) for the Advanced (upper panels) and Intermediate (lower panels) player. See article and section below for detailed explanation of the methodology.

## **Grip calibration methodological details**

### ***Marker placement***

Finger segment kinematics were tracked using a motion capture system consisting of seven cameras (MX T40, Vicon, Oxford, UK, 100Hz) tracking 29 reflective hemispheric markers with 6-mm radius placed on the dorsal aspects of the forearm and the hand (Figure s1-4 and Table s1-1). The radius was tracked by three markers placed on the dorsal aspect of the distal forearm. The first metacarpal and the thumb proximal phalanx were tracked by three markers on the thumb dorsal aspect including one placed on a plastic frame. Each long finger metacarpal was tracked by two markers placed on the dorsal aspects of hand. For each long finger, three markers were placed to track the phalanges motion.

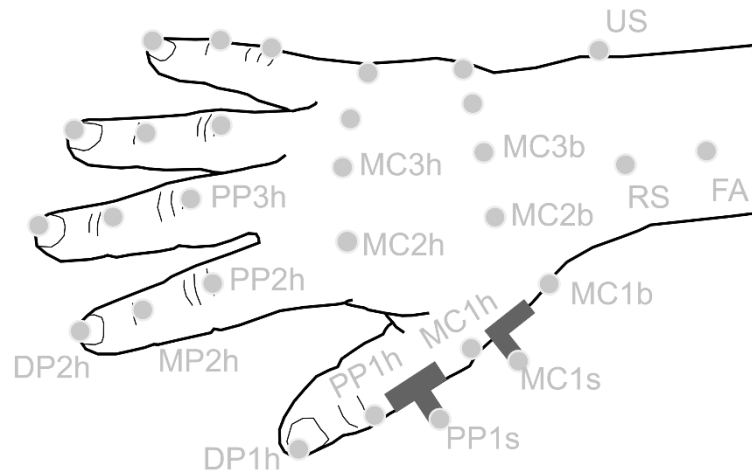


Figure s1-4. Illustration of the marker placement. See Table s1.1 for exact placement.

Table s1-1. Name and locations of the markers.

Name	Location
<b>Forearm</b>	
US	Most distal-dorsal point on ulnar styloid
RS	Most distal-dorsal point on radial styloid
FA	Three fingerbreaths in the proximal direction from RS along the radius
<b>Thumb</b>	
MC1b	Most proximal point of the 1 <sup>st</sup> metacarpal dorsal midline while flexing trapeziometacarpal joint
MC1h	Most distal point on the the 1 <sup>st</sup> metacarpal dorsal midline while flexing metacarpophalangeal joint
MC1s	1.5cm in the ulnar direction from the axis defined by MC1h and MC1b
PP1h	Most distal point of the proximal phalanx head while flexing interphalangeal joint
PP1s	1.5cm in the ulnar direction from the axis defined by PP1h and MC1h
DP1h	Most distal point on the dorsal aspect of the nail.
<b>Fingers</b>	
MCib	Three fingerbreaths in the proximal direction from MCih along the i <sup>th</sup> metacarpal
MCih	Most distal point on the i <sup>th</sup> metacarpal head dorsal aspect while flexing metacarpophalangeal joint
PPih	Most distal point on the i <sup>th</sup> finger proximal phalanx head dorsal midline while flexing proximal interphalangeal joint
MPih	Most distal point on the i <sup>th</sup> finger middle phalanx head dorsal midline while flexing distal interphalangeal joint
DPih	Most distal point on the dorsal aspect of the i <sup>th</sup> finger distal phalanx

### Joint angle computation

The posture of the fingers on the handle during forehand drives was considered fixed during the motion and finger joint angles were calculated from the position of reflective markers during grip calibration protocol using a previously developed method (Goislard de Monsabert et al., 2012). The marker coordinates were averaged on 100 frames during a grip calibration trial to determine joint angles. The 100-frame window was chosen during a grip force exertion period such that all markers were visible. The trapeziometacarpal (TMC) and metacarpophalangeal (MCP) joints were described by two DoF in flexion/extension and radial/ulnar deviation and the proximal (PIP) and distal (DIP) joints by one DoF in flexion/extension. For each joint, a distal and a

proximal segment coordinate system were calculated from the marker coordinates (Table s1.2).

*Table s1-2 – Equations used to compute axes of segment coordinate systems*

	1 <sup>st</sup> axis	2 <sup>nd</sup> axis	3 <sup>rd</sup> axis
Radius	$\vec{x} = \vec{u}_{(RS, FaR)}$	$\vec{y} = \vec{u}_{(US, RS)} \times \vec{x}$	$\vec{z} = \vec{x} \times \vec{y}$
1 <sup>st</sup> metacarpal	$\vec{x} = \vec{u}_{(MC1h, MC1b)}$	$\vec{y} = \vec{u}_{(MC1s, MC1h)} \times \vec{x}$	$\vec{z} = \vec{x} \times \vec{y}$
2 <sup>nd</sup> Metacarpal	$\vec{x} = \vec{u}_{(MC2h, MC2b)}$	$\vec{y} = \vec{u}_{(MC3h, MC2h)} \times \vec{x}$	$\vec{z} = \vec{x} \times \vec{y}$
3 <sup>rd</sup> Metacarpal	$\vec{x} = \vec{u}_{(MC3h, MC3b)}$	$\vec{y} = \vec{u}_{(MC3h, MC2h)} \times \vec{x}$	$\vec{z} = \vec{x} \times \vec{y}$
4 <sup>th</sup> Metacarpal	$\vec{x} = \vec{u}_{(MC4h, MC4b)}$	$\vec{y} = \vec{u}_{(MC4h, MC3h)} \times \vec{x}$	$\vec{z} = \vec{x} \times \vec{y}$
5 <sup>th</sup> Metacarpal	$\vec{x} = \vec{u}_{(MC3h, MC3b)}$	$\vec{y} = \vec{u}_{(MC5h, MC4h)} \times \vec{x}$	$\vec{z} = \vec{x} \times \vec{y}$
Trapezium	$\vec{x} = {}^{TRA}R_{MC3}\vec{x}_{MC3}$	$\vec{y} = {}^{TRA}R_{MC3}\vec{y}_{MC3}$	$\vec{z} = \vec{x} \times \vec{y}$
Thumb proximal phalanx	$\vec{x} = \vec{u}_{(PP1h, MC1h)}$	$\vec{y} = \vec{u}_{(PP1s, PP1h)} \times \vec{x}$	$\vec{z} = \vec{x} \times \vec{y}$
Phalanges	$\vec{x} = \vec{u}_{(Pp, Pd)}$	$\vec{y} = \vec{v}_{prox} \times \vec{x}$	$\vec{z} = \vec{x} \times \vec{y}$

$\vec{u}_{(P1, P2)}$  represents the unit vector associated to the vector going from point P1 to P2. For the phalanges, Pp and Pd refer to the points representing the proximal and distal ends of the segment, respectively, and  $\vec{v}_{prox}$  refers to sagittal axis of the proximal segment.  ${}^{TRA}R_{MC3}$  refers to the rotation matrix from the third metacarpal to the trapezium defined from the work of Cooney *et al.* (1981).

For all segments, three axes were computed with first the longitudinal ( $\vec{x}$ ) axis as the unit vector from the distal to the proximal marker, thus pointing in the proximal direction. The second axis was the coronal ( $\vec{y}$ ), pointing in the dorsal direction, and was orthogonal to the plane defined by  $\vec{x}$  and a vector pointing radially, either built with a third marker or from the sagittal axis of the proximal vector. The third axis was the sagittal ( $\vec{z}$ ) and was the cross product of the two others. For the trapezium, the segment coordinate system was computed from the 3<sup>rd</sup> metacarpal segment coordinate system using a fixed rotation matrix defined from the work of Cooney *et al.* (1981) :

$${}^{TRA}R_{MC3} = R(\vec{z}, 46^\circ)R(\vec{y}, 35^\circ)R(\vec{x}, 82^\circ)$$

Then, joint angles were extracted from the relative orientation (distal to proximal) matrix segment rotation matrix using a Z-Y-X (flexion/abduction/pronation) sequence of Cardan angles. Flexion, and radial deviation angle were considered positive.

## References

Cooney, W., Lucca, M., Chao, E., & Linscheid, R. (1981). The kinesiology of the thumb trapeziometacarpal joint. *Journal of Bone and Joint Surgery, American Volume*, 63(9), 1371-1381. <https://doi.org/PMID:7320028>

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