Table S1. MRI sequence specifications				
MRI	MRI_s1: Spoiled FLASH sequence		MRI_s2: 2D Turbo spin echo	
	Chimpanzee	Human	Chimpanzee	Human
Slices	Sagittal, 2mm, 2D gradient echo, 14 per finger	Sagittal, 51 in total, 2mm	Sagittal, 2mm, 2D gradient echo, 14 per finger	Sagittal, 52 in total, 2mm
Repetition, Echo times	TR=500ms, TE=5ms	604ms, 5.2ms	4000ms, 94ms	3800ms, 94ms
Flip angle	90°		154°, turbo factor 13	
Averages	4		4	
Field of View	105x140 mm		98 x 150 mm	
Image matrix (voxel size)	288x384 (0.365 x 0.365 mm)		336 x 512 (0.293 x 0.293 mm)	

Table S2. Measured joint angles (degrees) in positions 1-9 of Figure 9
(angles positive for flexion, negative for hyperextension)

Position	Wrist	MCP	PIP	DIP
1	123	120	138	87
2	90	145	124	95
3	50	120	126	90
4	0	127	127	90
5	0	0	135	97
6	0	-61	140	77
7	0	0	0	0
8	-28	0	0	0
9	-45	-16	0	0

Table S3. Elongations of the deep (FP) and superficial finger flexors (FS) from positions 1 to 9 in Figure 9

Position number		1	2	3	4	5	6	7	8	9	ΔL from 4 to 8	ΔL (4 to 6)/ ΔL (4 to 8)
FP elongations from pos 1 (mm)	FP_2	0	8	21	35	65	74	99	107	114	72	0.54
	FP_3	0	8	21	36	70	83	116	123	129	87	0.54
	FP_4	0	6	18	33	63	74	105	111	116	78	0.53
FS elongations from pos 1 (mm)	FS_2	0	10	25	41	76	80	98	107	114	66	0.59
	FS_3	0	10	25	43	80	90	108	115	122	72	0.65
	FS_4	0	8	22	40	71	76	99	105	110	65	0.55

Supplementary Materials & Methods.

Estimating finger positions limiting passive and active insufficiency of the finger flexors in Figure 9

The problem

Muscle fiber lengths adapt in growth to the range of motion of the joints. For multi-articular muscles, the maximum contractile ranges will be smaller than required to fully accommodate the accumulated ranges of the individual joints. This is so in human and likely so in other mammals. In chimpanzee, the maximum flexion and extension limits of [Wrist, MCPJ, PIPJ] are about [123°,145°,150°] and [-45°, -61°, 0°], respectively, resulting in maximal joint ranges of about: [ΔWrist, ΔMCPJ, ΔPIPJ] = [168°,206°,150°].

We define from this the accumulated maximum length changes $\Delta L_{\mathrm{F\_Acc\_max}}$ of F, the superficial or deep flexor (S or P) :

$$\Delta L_{\mathrm{F\_acc\_max}} = \sum_{\mathrm{joints}\ i} r_{\mathrm{F}i} \,.\, \Delta\theta_{\mathrm{max}i} \qquad \textbf{Eq. S1}$$

with $\Delta\theta_{\mathrm{max}i}$ the maximal range of joint *i*, and $r_{\mathrm{F}i}$ the mean flexor moment arm at joint *i*. The finger flexor physiologically maximal contractile ranges $\Delta L_{F\_\mathrm{max}}$ are the differences between the passive and active insufficiency lengths ($L_{\mathrm{F\_PI}}$ and $L_{\mathrm{F\_AI}}$) :

$$\Delta L_{\mathrm{F\_max}} = L_{\mathrm{F\_PI}} - L_{\mathrm{F\_AI}} \qquad \textbf{Eq. S2}$$

From Eq. S1 and Eq. S2 a Sufficiency Deficit Fraction (SDF) can be defined:

$$SDF = \frac{\Delta L_{\mathrm{F\_acc\_max}} - \Delta L_{\mathrm{F\_max}}}{\Delta L_{\mathrm{F\_acc\_max}}} \qquad \textbf{Eq. S3}$$

When SDF > 0, as is the case in multi-articular muscles, where does $\Delta L_{\mathrm{F\_max}}$ fit within the range $\Delta L_{\mathrm{F\_acc\_max}}$? In other words, what are the joint positions where the finger flexors reach passive and active insufficiency, and, given the fact that this is difficult to measure in the live animal, can these joint positions be reasonably estimated. To this end, some morphological constraints on muscle fiber length may be considered, together with the experimental data in this study.

Morphological limitations on contractile finger flexor ranges in chimp

Some definitions. The maximum elongation length L_{fmax} of a muscle fiber can be written as:

$$L_{\mathrm{fmax}} = L_{\mathrm{fmin}} + \Delta L_{\mathrm{fmax}}$$

with L_{fmin} the fully contracted fiber length and ΔL_{fmax} the maximal contractile range of the fiber. For simplicity, the contractile range of the muscle fiber will be assumed equal to the contractile range of the muscle as a whole, meaning that pennate angles - which are small in the finger flexors - are not considered. The maximal contractile range can be written as:

$$\Delta L_{\text{fmax}} = X_{\text{E}}.L_{\text{fmin}}$$

Eq. S5

with X_{E} close to 1, so for simplicity it is further assumed that $X_{\text{E}} = 1$. Then:

$$L_{\text{fmax}} = L_{\text{fmin}} + \Delta L_{\text{fmax}} = 2.\Delta L_{\text{fmax}}$$

Eq. S6

We demonstrate now that there is a morphological relationship between the forearm length L_{FARM}, the contractile range ΔL_{fmax}, and the length L_{ORIG} proximal at the forearm that can be used for origin of the finger flexors. Since the flexor muscle bellies should not enter the carpal tunnel even when fully elongated, the most distal finger flexor muscle fiber must arise from its origin at the forearm no more distal than:

$$L_{\text{ORIG}} = L_{\text{FARM}} - L_{\text{fmax}} = L_{\text{FARM}} - 2.\Delta L_{\text{fmax}}$$

Eq. S7

According to (Behringer et al., 2016), the mean forearm length of female chimpanzees $L_{\text{FARM}} = 275\text{ mm}$. In the experiments, the finger flexor length changes were measured between positions 1 and 9 (**Figure 9**). Pos 1 approximates the maximum flexion of all joints. Pos 8, with $[\text{wrist}, \text{MCPJ}, \text{PIPJ}] = [-28°, 0°, 0°]$, was assumed the position at which the finger flexors reach passive insufficiency (see further). If the contractile range of FP_3 would be $\Delta L_{\text{fmax}}(\text{FP}_3) = 123\text{ mm}$, as measured between pos 1 and pos 8, then, by Eq. S7, the FP_3 muscle fibers could only arise from a mere 29 mm long area near the elbow (**Figure S1**, A):

$$L_{\text{ORIG}}(\text{FP}_3) = L_{\text{FARM}} - 2.\Delta L_{\text{fmax}}(\text{FP}_3) = 275\text{ mm} - 246\text{ mm} = 29\text{ mm}$$

Eq. S8

Clearly, this is not conform the anatomy of the FP in chimp, where the FP arises from a longer origin area at the forearm. Therefore, the contractile range $\Delta L_{\text{fmax}}(\text{FP}_3)$ must be significantly shorter than 123 mm. How short? Assume that the FP_3 origin area would reach to 2/3 of the forearm. Then, for the FP_3 muscle belly not entering the carpal tunnel at maximum elongation, $L_{\text{fmax}}(\text{FP}_3)$ = 275/3 = 92 mm, which would result in a contractile range $\Delta L_{\text{fmax}}(\text{FP}_3) = L_{\text{fmax}}(\text{FP}_3)/2$ = 46 mm. Clearly, this contractile range is unrealistically small, as it would only allow a sufficiency range between pos. 5 and pos. 7. Summarized:

$$46\text{ mm} \ll \Delta L_{\text{fmax}}(\text{FP}_3) \ll 123\text{ mm}$$

To determine a morphologically realistic origin length versus contractile range, a number of possibilities is given in **Table 4**. E.g., $L_{\mathrm{ORIG}}(\mathrm{FP}_3) = 0.5L_{\mathrm{FARM}}$ (half the forearm length) corresponds to a contractile range of $\Delta L_{\mathrm{fmax}}(\mathrm{FP}_3)$ = 69 mm, which is from about halfway between pos 4 and pos 5, to pos 8.

What can be concluded from the above?

1. According to this model, the assumption in text that the contractile range of FP_3 would be between pos 4 and pos 8 (ΔL_{fmax} = 87 mm) would allow an origin length $L_{\mathrm{ORIG}}(\mathrm{FP}_3) = 0.37{*}L_{\mathrm{FARM}}$ (**Figure S1**, B). Certainly, the real origin length of FP_3 likely is $L_{\mathrm{ORIG}}(\mathrm{FP}_3) \geq 0.37 * L_{\mathrm{FARM}}$, so that the real contractile range would be $\Delta L_{\mathrm{fmax}}(\mathrm{FP}_3) \leq 87\ \mathrm{mm}$. The index and fourth finger, which have smaller flexor moment arms, would need less contractile range for the same wrist/finger joint ranges as FP_3. Therefore, their available origin length would be somewhat greater and it would be greatest for the little finger. Also for the FS, the available origin length at the forearm would be greater than for the FP for the same wrist, MCPJ and PIPJ joint ranges, since the FS does not need contractile length for the DIPJ. In conclusion, the assumption that the finger flexor sufficiency range corresponds to the range between pos 4 and pos 8 in text is closely conform to geometrical-functional constraints on the feasible origin length for the FP.

2. The maximum human joint ranges are about [Δwrist, ΔMCPJ; ΔPIPJ]= [90°, 90°, 125°]- [-80°,-30°,0°]= $[170°, 120°, 125°]$, which is significantly smaller than in chimpanzee: [ΔWrist, ΔMCPJ, ΔPIPJ] = [168°,206°,150°]. However, the chimpanzee finger flexor moment arms are not significantly smaller than in human (at least not in the PIPJ), while the flexor's contractile lengths $\Delta L_{\mathrm{fmax}} \leq 87\ \mathrm{mm}$ would be comparable between chimp and human. Therefore, the sufficiency deficit fraction SDF (Eq. S3) would be significantly greater in chimpanzee than in human. In other words, chimpanzee would have a smaller range of active finger flexor control over the accumulated joint ranges than human, which correlates with humans having greater manipulation capacity.

The proposed finger flexor passive insufficiency position

Chimpanzees have maximal joint extensions of about:

$$\text{Maximal joint extension: } [\text{wrist}, \text{MCPJ}, \text{PIPJ}] = [-45°, -61°, 0°]$$

Eq. S10

However, they do not significantly hyperextend the wrist and MCPJ when opening the hand, so that the position in Eq. S10 is habitually never reached. Therefore, given the principle that muscle lengths adapt to the actually used ranges of motions and the principle of general shortness of multi-articular muscle fibers to accommodate the accumulated maximal individual ranges of the joints, it is more likely that the physiological limits of finger flexor elongation (passive insufficiency) are already reached at $[\text{wrist}, \text{MCPJ}, \text{PIPJ}] = [-25°, 0°, 0°]$, i.e., pos 8 in **Figure 9**. Possibly, passive insufficiency might even be reached at a smaller wrist extension angle, so perhaps a range should be proposed:

$$[\text{wrist}, \text{MCPJ}, \text{PIPJ}] = [0°, 0°, 0°] < \text{position of passive insufficiency} < [-25°, 0°, 0°]$$

However, even with a passive finger flexor insufficiency limit of $[\mathrm{wrist}, \mathrm{MCPJ}, \mathrm{PIPJ}] = [0°, 0°, 0°]$, the finger flexors in knuckle stance would not be in the range of important passive stretching forces, as evidenced by the length-equivalent reference position MCP_{90} $[\mathrm{wrist}, \mathrm{MCPJ}, \mathrm{PIPJ}] = [0°, 90°, 0°]$: in a finger with a 90° flexed MCPJ the finger flexors clearly will not be passively stretched.

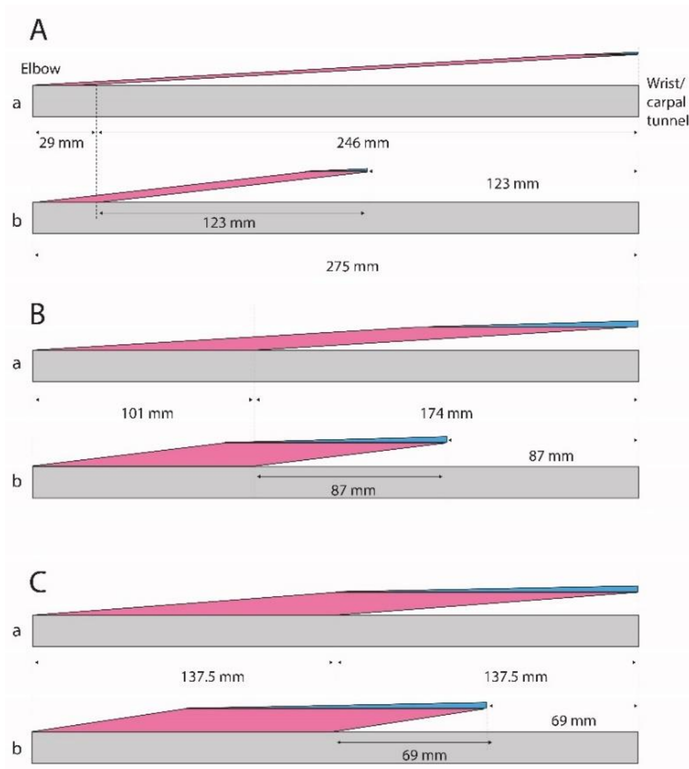

Fig. S1. Length of FP3 origin at forearm as function of maximum contractile range. Length of forearm=275mm. A. When the maximum FP3 contractile range is 123 mm, then the maximally contracted muscle fiber length is also 123 mm (if X_E=1 in **Eq. 5**),so the length of the maximum elongated FP3 muscle fiber is 246 mm. To avoid the FP3 muscle belly to enter the carpal tunnel at maximum elongation, the muscle fibers cannot arise from the origin at less than 246 mm from the wrist. This leaves only 29 mm of feasible origin length at a forearm of 275 mm long. a. Muscle length at maximum elongation. b: Muscle length at maximum contraction. B. When the maximum FP3 contractile range is 87 mm (as measured for FP3 between pos 4 and pos 8 in experiments), then the feasible muscle origin length proximal at the forearm is 101 mm. C. With a maximum FP3 contractile range of about 69 mm, the feasible muscle origin length proximal at the forearm is half of the 275 mm forearm length.

Table S4. Relationship between finger flexor contractile range and maximum finger flexor origin length at female chimpanzee forearm

Muscle	Contractile range ΔL_{fmax} (mm)	Corresponding position changes measured in text	$L_{\max}$ = $2\Delta L_{\mathrm{fmax}}$ mm	Proportion of origin length feasible in forearm of 275mm (275- $L_{\max}$)/275
FP3	123	pos 1 to pos 8	246	0.11
	87	pos 4 to pos 8	174	0.37
	68.75	pos 4.53 to pos 8	137.5	0.50
	53	pos 5 to pos 8	106	0.61
	46	pos 5 to pos 7	92	0.66
FS3	115	pos 1 to pos 8	230	0.16
	72	pos 4 to pos 8	144	0.48
	68.75	pos 4.1 to pos 8	137.5	0.50
	35	pos 5 to pos 8	70	0.75

References

Behringer, V., Stevens, J. M. G., Kivell, T. L., Neufuss, J., Boesch, C. and Hohmann, G. (2016). Within arm's reach: measuring forearm length to assess growth patterns in captive bonobos and chimpanzees. Am. J. Phys. Anthropol. 161, 37-43. doi:10.1002/ajpa.23004