Supplementary material

Post-stroke kinematic analysis in rats reveals similar reaching abnormalities as humans

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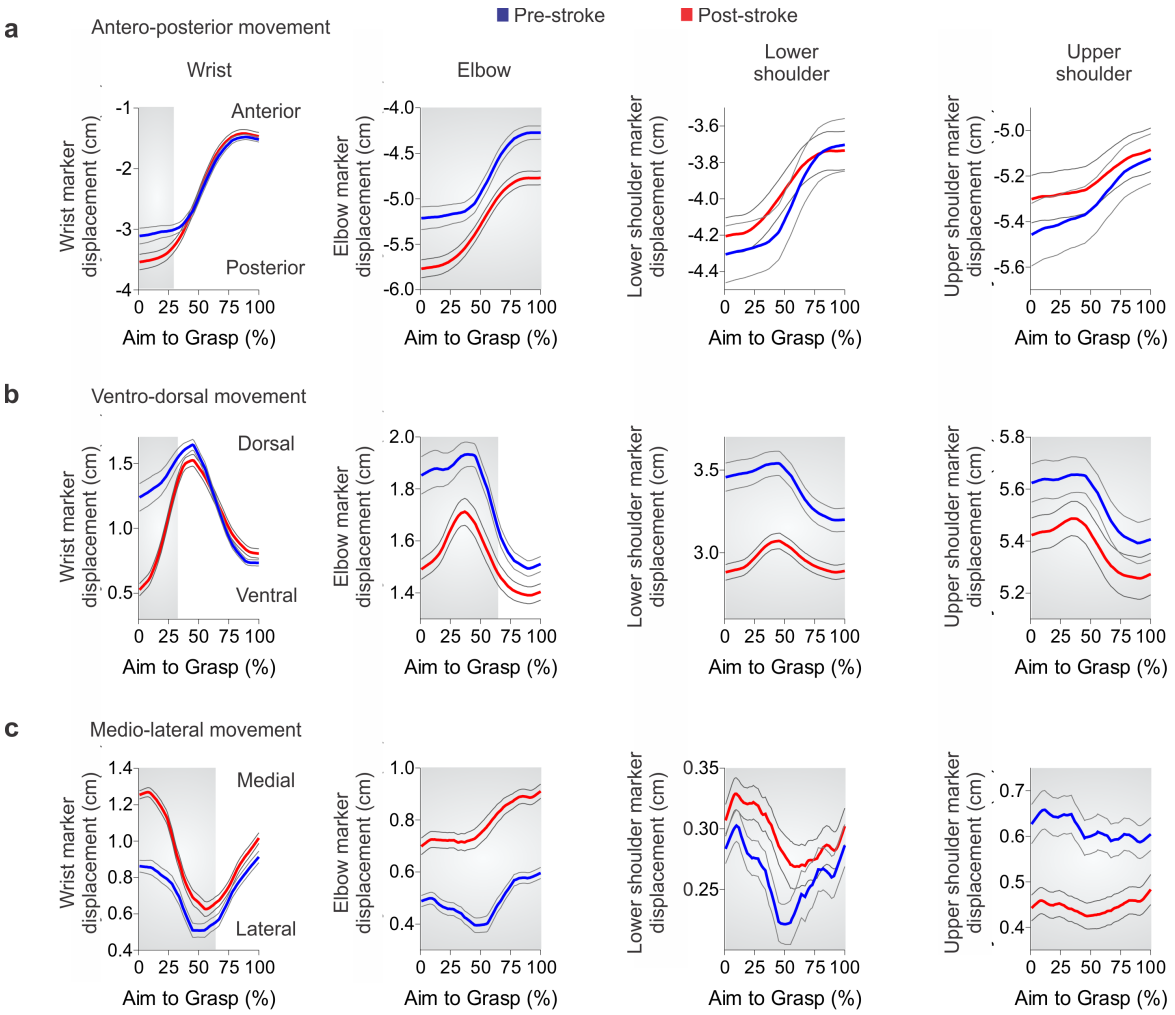
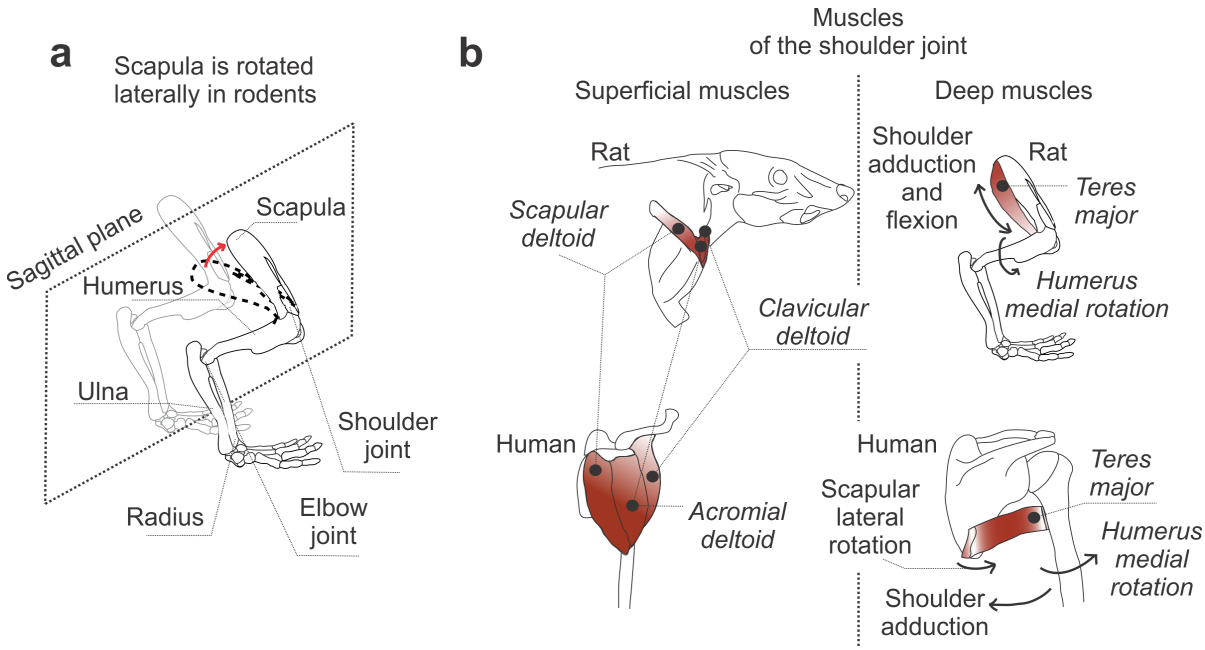
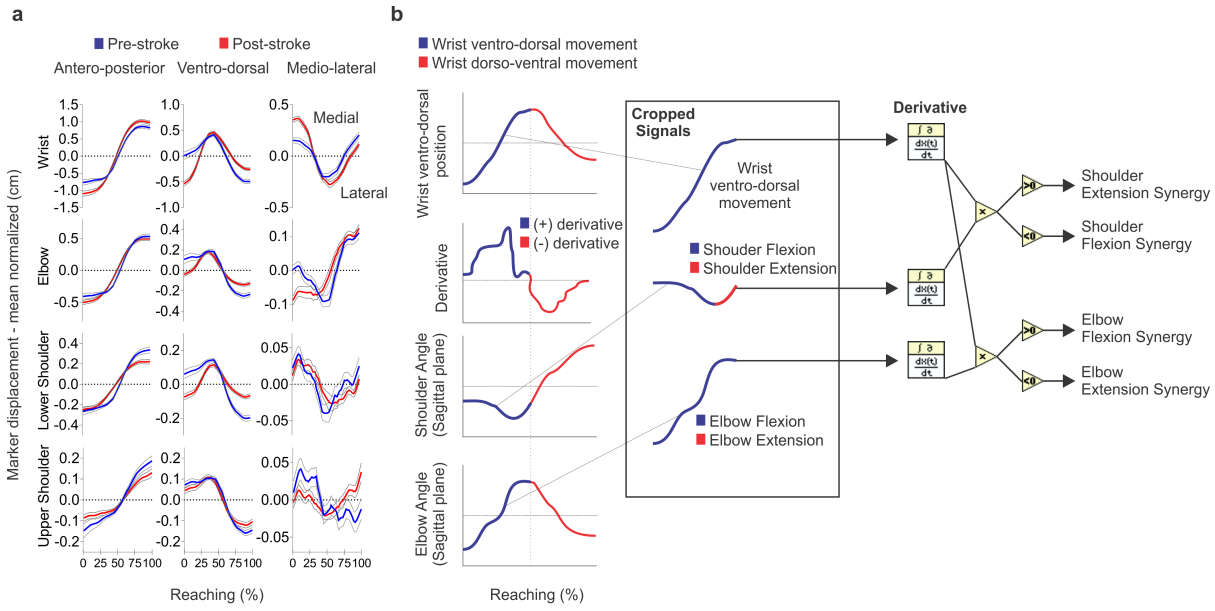
Supplementary material



Supplementary Figure S1. Wrist position throughout reaching by plane of movement. Trajectories normalized to a reflective marker placed on the side of step 5. **(a)** In the anterior-posterior plane post-stroke, the wrist joint was further from the target during 1-31% of the reach ($p < 0.001$) and the elbow was also further from the target, relative to pre-stroke, throughout the entire reach ($p < 0.001$). **(b)** In the ventro-dorsal plane the situation was reversed with all joint segments being positioned closer to the target post-stroke. The wrist from 1-32% ($p < 0.001$), elbow from 1-67% ($p = 0.005$) throughout the reach. Lower and upper markers of the shoulder were significantly closer to the target in the ventro-dorsal plane at all points throughout the reach following stroke ($p < 0.001$). **(c)** Joint position in the medio-lateral plane was mixed, with the wrist (1-67%, $p < 0.001$), elbow (1-100%, $p < 0.001$) and lower shoulder (1-100%, $p < 0.001$) being positioned further from the target following stroke. Conversely, the upper shoulder, was positioned closer to the target following stroke throughout the entire reach ($p < 0.001$). All data are mean ± SEM using linear mixed effects modeling with Bonferroni-corrected post-hoc tests. Shaded areas are statistically different between pre- and post-stroke.



Supplementary Figure S2. Flexion synergy: differences between humans and rodents. (a) In rodents the scapula is rotated into a lateral position (red arrow). (**b**) Muscle mechanics is likely to be affected due to this anatomical change and might explain differences between the biped and quadruped flexion synergy.



Supplementary Figure S3. Position changes during reaching, kinematic synergy and joint individuation modeling. (**a**) Average and mean subtracted wrist, elbow, lower- and upper-shoulder position changes throughout the reaching (0-100%). (**b**) Model of waveform combinations resulting in kinematic synergies. This schematic diagram illustrates how the kinematic data can be analyzed by linearly combining position-position (joint individuation) or position-angle (kinematic synergy) waveforms. Each of the waveforms has distinct variation across reaching, which produces a unique first derivative patterning. By matching positive and negative signal of first derivatives profiles to position or angle signals (herein exemplified by shoulder and elbow angle variations) it produced a synchronized and linear combination of wrist movement and angle variation. Movement waveforms were then compared using another derivation process, the first derivatives were multiplied by each other, where positive products indicate agreement in variation (i.e., the signals are changing in the same direction) and negative products reflect disagreement in variation (i.e., the signals are changing in opposite direction). The movement waveforms were quantified in terms of synergy ranging from 0-100% of the cropped signal to explain different kinematic synergies. Data are mean ± SEM.

Supplementary Video 1. The emergence of an abnormal elbow flexion synergy hampers the ability to extend the limb and reach for pellets. Example of a severely impaired rat that shows pronounced flexor activity following stroke (from 31.3% ± 4.3% to 67.0% ± 11%; left panel). Note how stroke results in an unsuccessful reach attempt, mainly due to failure to transport the paw to the target. Data are mean ± SEM, n = 1 (left panel), n = 13 (right panel).

Supplementary Video 2. Abnormal movement patterns in rats following stroke. Following stroke rats position the body closer to the target; note that the shoulder is closer to step 5. Rats also perform excessive shoulder and elbow ventro-dorsal movements, resembling shoulder elevation, indicative of a less stable proximal joint. Conversely, pre-stroke movement displays a more stable proximal joint, using elbow and shoulder medio-lateral movements that facilitate paw pronation over the target. Also note the increased elbow flexion at the first half of the reach and decreased extension at the second half of the reach in post-stroke movement.

Supplementary Table 1. Abnormal synergies predictors of change in staircase function and grip strength

Dependent Measure	Predictor	Unstandardized B	95% confidence interval for B		Standardized β	t	p-value
			Lower bound	Upper bound			
Staircase performance (#pellets retrieved; %)	Intercept	43.729	33.473	53.984		9.385	<0.001
	Coupling between shoulder adduction and external rotation (%)	-0.59	-0.107	-0.010	-0.627	-2.666	0.022
Grip strength (%)	Intercept	46.314	32.785	59.843		7.535	<0.001
	Elbow flexion during limb advance synergy (%)	0.074	0.016	0.132	0.649	2.828	0.016

Supplementary Table 2. Summary of upper extremity hemiplegia assessment. Joint movement$_{RMS}$, joint individuation deficit, joint angle$_{RMS}$ and kinematic synergy were measured during limb advance, limb lift and limb drop movements (n = 13). Data are mean ± SEM; *p < 0.05, paired t-test; n.s. = not significant; n.a. = not available; #n = data presented in Figure #n.

		Joint movement$_{RMS}$		**Joint individuation deficit**			
Joint	Direction	Pre x Post (cm)	Post - Pre (cm)	Pre x Post (%)			Post - Pre (%)
			Correlation with lesion volume	Limb advance	Limb lift	Limb drop	Correlation with lesion volume
Upper shoulder	Posteriro-anterior	0.139±0.019 (pre) 0.107±0.022 (post) n.s.	r = -0.77 p = 0.002	Posterior-anterior 77.09±4.03 (pre) 73.34±4.33 (post) n.s.	Posterior-anterior 50.87±5.75 (pre) 63.04±4.97 (post) n.s.	Posterior-anterior 81.07±3.64 (pre) 76.23±4.49 (post) n.s.	r = -0.79 (Limb advance) p = 0.001 r = -0.73 (Limb drop) p = 0.004
	Ventro-dorsal	0.102±0.017 (pre) 0.111±0.018 (post) n.s.	n.s.	Ventro-dorsal 27.24±2.78 (pre) 41.27± 3.77(post)*[5a] p = 0.011	Ventro-dorsal 66.52±4.06 (pre) 69.25±3.52 (post) n.s.	Dorso-ventral 78.07±3.02 (pre) 71.37±4.58 (post) n.s.	n.s.
	Medio-lateral	0.037±0.007 (pre) 0.037±0.007 (post) n.s.	n.s.	Medio-lateral 48.25±2.06 (pre) 44.53±1.68 (post) n.s.	Medio-lateral 47.21±2.97 (pre) 51.13±2.74 (post) n.s.	Medio-medial 55.83±3.31 (pre) 58.33±3.05 (post) n.s.	n.s.
Lower shoulder	Posteriro-anterior	0.246±0.035 (pre) 0.215±0.030 (post) n.s.	n.s.	Posterior-anterior 86.46±3.48 (pre) 84.68±2.38 (post) n.s.	Posterior-anterior 49.20± 5.70 (pre) 72.47±4.23 (post)* p = 0.004	Posterior-anterior 82.84±3.12 (pre) 78.12±4.59 (post) n.s.	n.s.
	Ventro-dorsal	0.123±0.013 (pre) 0.103±0.021 (post) n.s.	n.s.	Ventro-dorsal 30.41±2.64 (pre) 47.41±3.46 (post)*[5a] p = 0.001	Ventro-dorsal 79.16±3.51 (pre) 79.76±2.34 (post) n.s.	Dorso-ventral 79.76±2.01 (pre) 76.48±3.99 (post) n.s.	r = 0.57 (Limb lift) p = 0.039

	Medio-lateral	0.044±0.008 (pre) 0.033±0.010 (post) n.s.	n.s.	Medio-lateral 45.01±2.04 (pre) 47.25±1.60 (post) n.s.	Medio-lateral 53.96±3.60 (pre) 51.47±1.70 (post) n.s.	Latero-medial 58.51±2.48 (pre) 56.62±2.60 (post) n.s.	n.s.
Elbow	Posteriro-anterior	0.400±0.034 (pre) 0.408±0.024 (post) n.s.	n.s.	Posterior-anterior 92.53±1.13 (pre) 94.58±0.96 (post) n.s.	Posterior-anterior 48.31±5.17 (pre) 76.05±4.35 (post)* p < 0.001	Posterior-anterior 84.14±2.18 (pre) 83.64±4.27 (post) n.s.	n.s.
	Ventro-dorsal	0.167±0.021 (pre) 0.147±0.022 (post) n.s.	n.s.	Ventro-dorsal 29.15±2.69 (pre) 40.99±1.97 (post)*[5a] p = 0.008	Ventro-dorsal 76.27± 3.55 (pre) 77.88±2.92 (post) n.s.	Dorso-ventral 77.47±2.57 (pre) 78.15±3.63 (post) n.s.	n.s.
	Medio-lateral	0.082±0.013 (pre) 0.106±0.013 (post) n.s.	n.s.	Medio-lateral 37.43±2.36 (pre) 29.98±1.80 (post)* p = 0.029	Medio-lateral 60.31± 3.38 (pre) 45.54±3.96 (post)* p = 0.001	Lateral-medial 65.09±3.19 (pre) 70.86±2.66 (post) n.s.	n.s.
Wrist	Posteriro-anterior	0.684±0.046 (pre) 0.871±0.065 (post)*[6c] p = 0.013	n.s.	n.a.	n.a.	n.a.	n.a.
	Ventro-dorsal	0.334±0.025 (pre) 0.373±0.047 (post) n.s	n.s.	n.a.	n.a.	n.a.	n.a.
	Medio-lateral	0.166±0.022 (pre) 0.223±0.026 (post)*[6c] p = 0.021	n.s.	n.a.	n.a.	n.a.	n.a.

		Joint angle$_{RMS}$		**Kinematic synergy**			
Joint	Plane	Pre x Post (deg.)	Post - Pre (deg.)	Pre x Post (%)			Post - Pre (%)
			Correlation with	Limb advance	Limb lift	Limb drop	Correlation with lesion volume

			Lesion volume				
Elbow	Coronal	19.54±3.01 (pre) 26.53±3.33 (post)*[4i] p = 0.048*	r = 0.64 p = 0.016	External rotation 48.46±2.85 (pre) 43.49±3.01 (post) n.s.	External rotation 40.13±6.30 (pre) 40.84±4.51 (post) n.s.	Internal rotation 51.56±5.56 (pre) 55.75±4.62 (post)* p = 0.028	r = 0.67 (Limb advance/internal rotation) p = 0.011
	Transverse	9.42±1.79 (pre) 6.20±0.66 (post) n.s.	n.s.	External rotation 36.36±3.16 (pre) 39.13±3.39 (post) n.s.	External rotation 67.46±4.02 (pre) 69.52±3.81 (post) n.s.	Internal rotation 69.98±3.26 (pre) 81.15±2.24 (post)* p = 0.001	n.s.
	Sagittal	6.63±0.71 (pre) 8.00±0.72 (post) n.s.	n.s.	Flexion 27.00±2.73 (pre) 42.69±3.96 (post)*[4c] p < 0.001	Flexion 90.15±1.73 (pre) 90.33±1.85 (post) n.s.	Extension 92.77±1.66 (pre) 94.64±1.27 (post) n.s.	n.s.
Shoulder	Coronal	5.08±1.17 (pre) 4.58±0.85 (post) n.s.	n.s.	Adduction 51.30±4.22 (pre) 67.03±2.90 (post)* p < 0.001	Adduction 45.39±3.53 (pre) 51.10±4.96 (post)* p = 0.034**	Adduction 54.54±4.21 (pre) 66.03±3.69 (post)* p = 0.010	n.s.
	Transverse	11.20±2.33 (pre) 8.86±1.75 (post) n.s.	n.s.	Adduction 66.61±2.51 (pre) 74.85±2.54 (post)* p = 0.004	Adduction 37.54±2.93 (pre) 60.45±4.58 (post)*[4f] p < 0.001	Adduction 67.03±4.23 (pre) 74.72±3.83 (post) n.s.	r = 0.64 (Limb advance/adduction) p = 0.018
	Sagittal	3.79±0.70 (pre) 3.85±0.52 (post) n.s.	n.s.	Flexion 36.54±5.28 (pre) 34.30±3.87 (post) n.s.	Extension 42.52±7.30 (pre) 43.60±6.27 (post) n.s.	Extension 63.56±5.27 (pre) 74.30±2.44 (post)*[5f] p = 0.047	n.s.