

**Fig. S1. Validation of rotoscopy.** Comparison of kinematics of the third floating rib in savannah03 animated using the marker-based method (solid lines) and markerless Scientific Rotoscopy (dashed lines). Pump handle (red), caliper (green), and bucket handle (blue) rotations are centered around their average values and scaled to total breath duration. Five breaths are depicted.

**Table S1:** Rotations in degrees of vertebral ribs 1 and 2 (V1, V2) and sternal ribs 1 and 2 (S1 and S2) at the costovertebral joints and sternocostal joints, respectively for savannah01 (n=8), savannah02 (n=6), and savannah03 (n=5).

		<b>V1</b>			<b>V2</b>			<b>S1</b>			<b>S2</b>	
		sav01	sav02	sav03	sav01	sav02	sav03	sav01	sav02	sav03	sav02	sav03
<b>Z Bucket<sup>1</sup></b>												
max Inhale	mean	-32.4	-20.0	-13.9	-35.6	-1.5	-3.6	-42.4	-45.9	-59.6	-23.1	-22.2
	s.d.	6.1	6.6	1.2	3.7	11.7	0.7	4.1	5.6	2.0	24.8	25.9
max Exhale	mean	-44.1	-28.7	-37.4	-44.4	-9.4	-8.4	-57.1	-78.7	-89.9	-40.5	-30.1
	s.d.	7.8	6.5	1.8	5.5	13.4	2.1	4.6	4.6	2.2	37.9	36.5
magnitude <sup>2</sup>	mean	11.7	8.7	23.5	8.7	7.8	4.9	11.9	22.3	30.3	17.3	7.9
	s.d.	3.1	3.8	1.0	2.7	2.3	2.1	3.7	3.9	0.6	14.6	10.7
<b>Y Caliper<sup>1</sup></b>												
max Inhale	mean	-0.12	-5.7	-6.5	0.7	15.8	47.7	10.3	0.86	3.7	26.2	57.0
	s.d.	4.3	3.6	1.7	2.7	7.9	2.3	6.0	6.8	2.2	26.1	38.2
max Exhale	mean	-2.8	-9.8	-9.7	-1.4	1.7	39.4	8.4	-5.6	-1.4	10.7	42.1
	s.d.	4.2	2.3	1.9	2.5	2.4	2.1	6.2	7.3	1.3	19.1	31.8
magnitude <sup>2</sup>	mean	2.6	4.1	3.2	2.1	14.1	8.4	1.8	6.4	5.1	15.5	14.9
	sd	0.9	1.7	1.7	1.2	7.2	1.5	0.8	2.6	1.1	10.8	7.6
<b>X Pump<sup>1</sup></b>												
max Inhale	mean	10.5	27.3	35.5	0.8	13.7	0.1	7.6	46.1	26.2	24.3	14.8
	s.d.	6.3	3.1	2.7	2.4	14.9	0.2	6.4	8.4	5.0	27.8	32.9
max Exhale	mean	2.5	9.8	31.1	-6.0	2.7	-0.5	-4.4	23.8	7.3	14.6	10.7
	s.d.	7.6	3.1	2.0	3.1	4.6	0.5	9.5	8.6	4.6	16.7	23.9
magnitude <sup>2</sup>	mean	8.0	17.6	4.4	6.8	10.9	0.6	14.8	32.8	18.9	10.0	4.1
	s.d.	1.8	3.3	0.9	2.1	12.2	0.6	2.8	7.7	0.8	11.3	9.0

<sup>1</sup>rotation axes are defined by the JCS in Fig. 2.

<sup>2</sup>magnitude is defined as the difference in degrees between maximum exhale and maximum inhale.

**Table S2:** Rotations in degrees of vertebral rib 3 and floating ribs 2, 4, 6, and 8 (V3, F2, F4, F6, F8) at the costovertebral joints for savannah01 (n=4), savannah02 (n=3), and savannah03 (n=5).

		<b>V3</b>		<b>F2</b>			<b>F4</b>		<b>F6</b>		<b>F8</b>
		sav01	sav02	sav01	sav02	sav03	sav01	sav02	sav01	sav02	sav02
<b>Z Bucket<sup>1</sup></b>											
max Inhale	mean	-47.97	-19.85	-37.88	-11.67	-30.08	-30.46	-22.18	-18.60	-19.45	-35.57
	s.d.	6.74	4.35	8.06	11.36	1.42	7.28	4.87	9.77	21.55	24.97
max Exhale	mean	-61.56	-38.40	-56.07	-32.77	-44.93	-45.99	-43.72	-28.16	-36.36	-46.03
	s.d.	2.98	10.07	9.12	12.45	1.74	9.25	6.09	10.55	20.13	28.53
magnitude <sup>2</sup>	mean	13.60	18.55	18.19	21.09	14.85	15.53	21.54	9.56	16.91	1.46
	s.d.	4.00	6.61	1.79	4.14	0.52	2.00	5.28	3.99	3.64	4.86
<b>Y Caliper<sup>1</sup></b>											
max Inhale	mean	-14.53	-3.36	-8.56	-4.80	-1.70	-8.51	-9.98	-0.06	-17.08	-10.79
	s.d.	4.14	6.37	2.74	5.65	2.25	8.03	4.35	6.65	5.11	4.32
max Exhale	mean	-18.32	-16.04	-13.49	-11.16	-10.04	-12.99	-17.69	-6.88	-23.20	-16.12
	s.d.	2.52	7.57	0.99	5.44	1.81	7.84	5.23	5.25	7.17	4.14
magnitude <sup>2</sup>	mean	3.79	9.68	4.93	6.65	8.34	4.49	7.71	6.83	6.11	5.33
	s.d.	1.63	3.17	2.42	1.86	3.00	0.70	1.36	1.54	2.09	2.02
<b>X Pump<sup>1</sup></b>											
max Inhale	mean	15.30	35.89	13.51	22.77	22.89	8.25	23.11	20.23	25.84	21.87
	s.d.	6.01	2.34	4.74	5.58	4.52	7.68	14.82	10.32	12.37	5.88
max Exhale	mean	2.69	18.87	2.43	10.17	7.60	2.56	11.77	10.40	15.16	13.21
	s.d.	3.76	5.79	2.62	3.76	4.36	7.36	7.57	9.78	10.18	5.00
magnitude <sup>2</sup>	mean	12.61	17.02	11.08	12.61	15.29	5.69	11.34	9.82	10.68	8.66
	s.d.	4.48	8.09	2.32	2.76	2.23	2.59	7.41	3.36	5.04	4.69

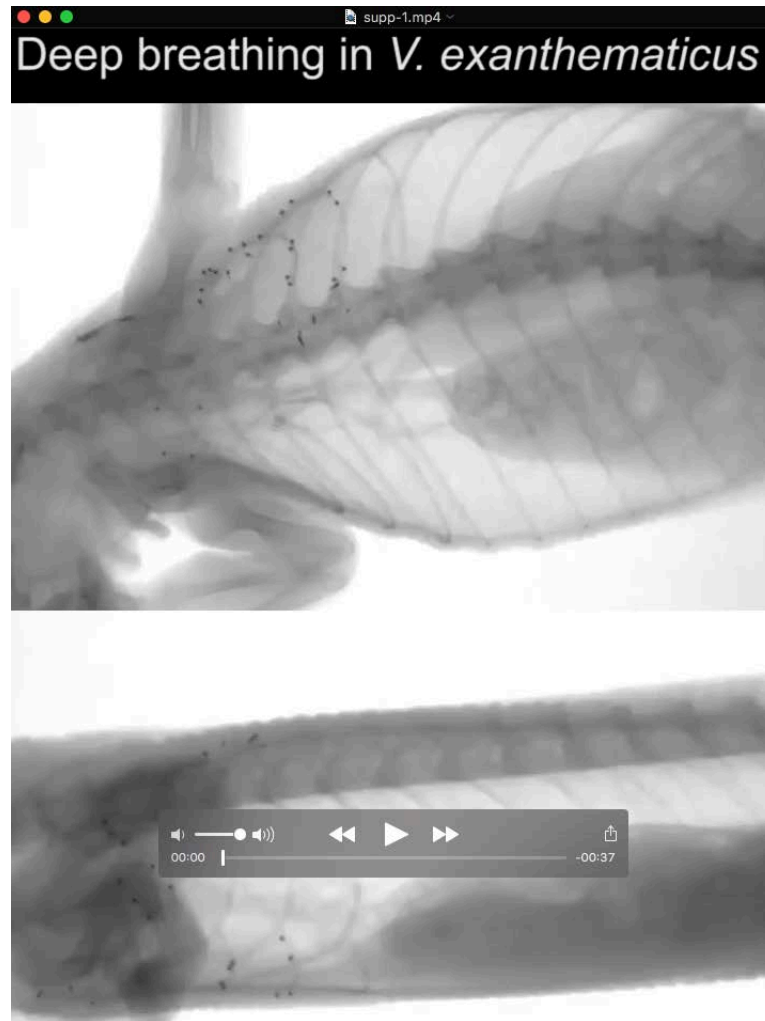
<sup>1</sup>rotation axes are defined by the JCS in Fig. 2.

<sup>2</sup>magnitude is defined as the difference in degrees between maximum exhale and maximum inhale.

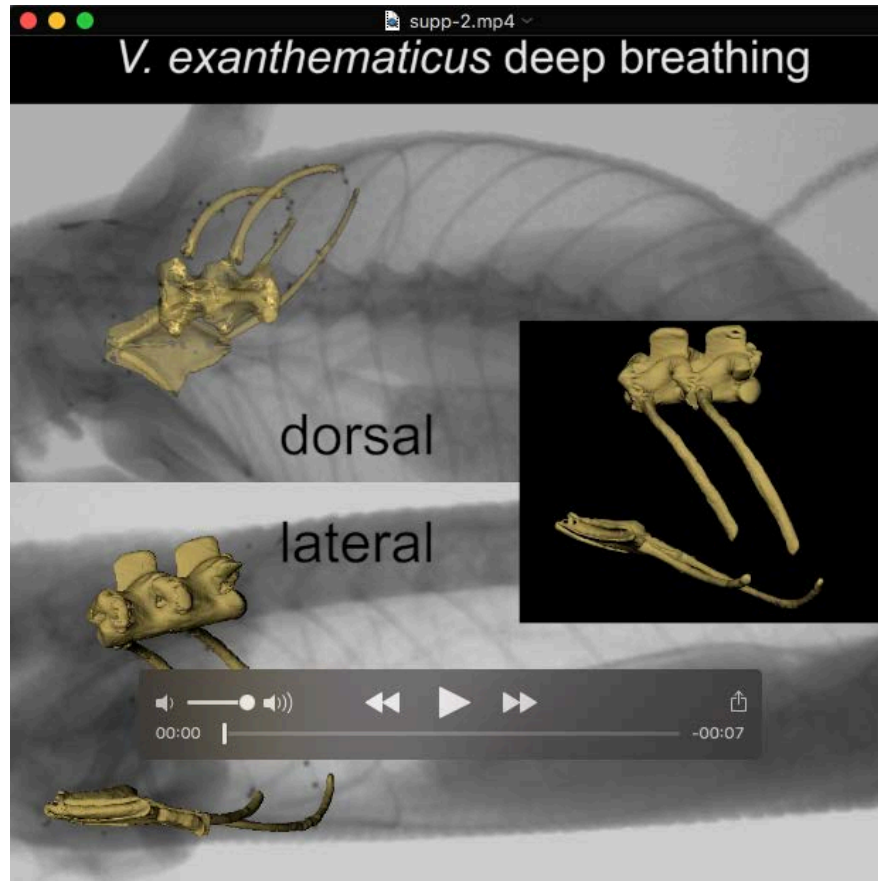
**Table S3:** Range of vertical displacement (mm) between the sternum and vertebral column measured by the vertebral-sternal JCSs during breaths in *Iguana iguana*<sub>1</sub> and *Varanus exanthematicus*<sub>2</sub>.

	<b>Breath 1</b>	<b>Breath 2</b>	<b>Breath 3</b>	<b>Breath 4</b>	<b>Breath 5</b>	<b>Breath 6</b>	<b>Breath 7</b>	<b>Breath 8</b>
Iguana02	0.66	01.36	0.556	0.586	0.97			
Iguana05	1.14	0.90	2.51					
Iguana mean		1.08 ± 0.64						
Savannah01	2.29	4.89	4.98	06.57	4.86	4.69	1.90	6.59
Savannah02	1.91	1.05	2.33	1.70	7.03	1.13		
Savannah03	1.00	1.43	8.30	1.07	1.17			
Varanid mean		3.41 ± 2.43						

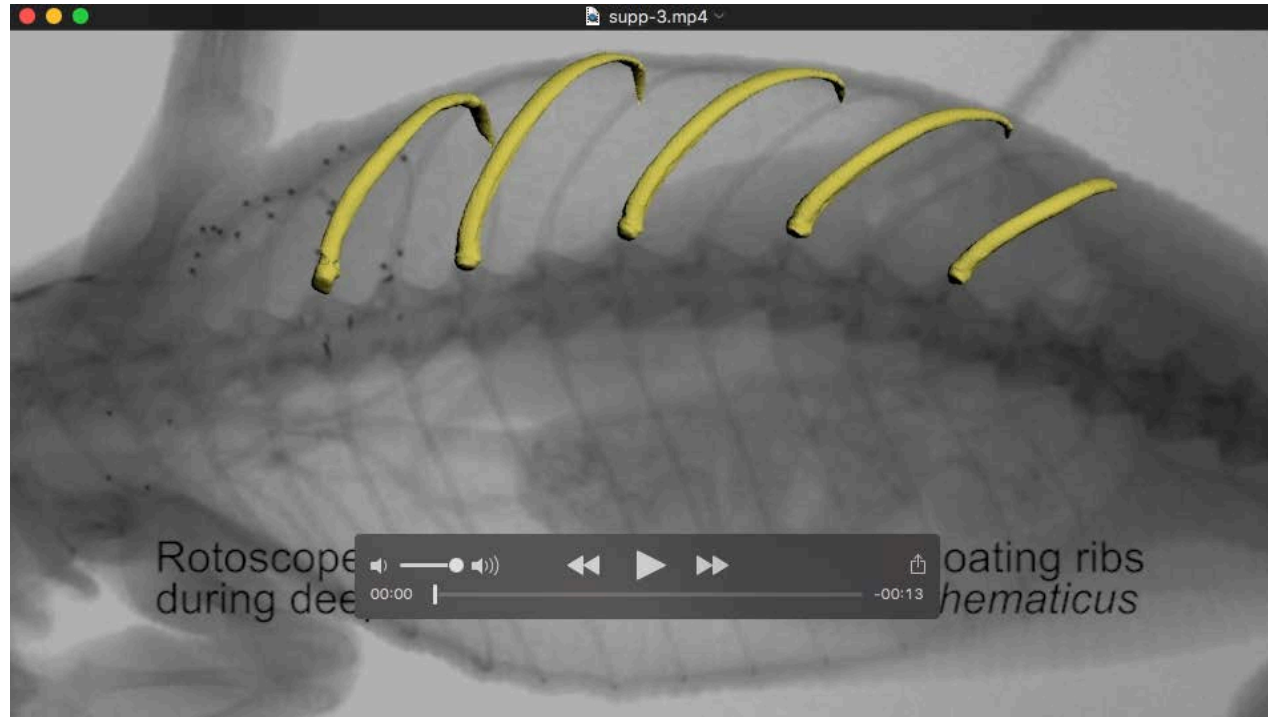
1: Brainerd et al., 2016; 2: This study



**Movie S1** – Biplanar x-ray video of lung ventilation in the savannah monitor (*Varanus exanthematicus*) savannah02. The animal is breathing deeply after treadmill locomotion. Lateral view (left) and dorsal view (right).



**Movie S2** – XROMM animation of the first and second vertebral and sternal ribs during typical deep breathing in the savannah monitor (*Varanus exanthematicus*) savannah02 superimposed upon biplanar x-ray video and the same XROMM animation alone (inset).



**Movie S3** – XROMM animation of the third vertebral and second, fourth, sixth, and eighth floating ribs during deep breathing in the savannah monitor (*Varanus exanthematicus*), savannah02. Bones were animated using Scientific Rotoscoping.