Supplementary Information

BRAIN–CONTROLLED MODULATION OF SPINAL CIRCUITS IMPROVES RECOVERY FROM SPINAL CORD INJURY

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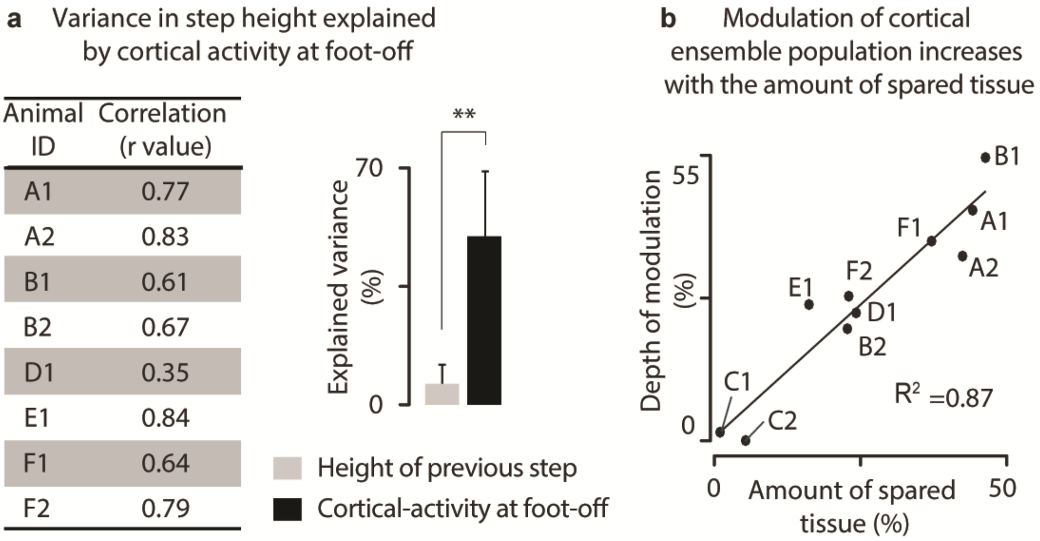
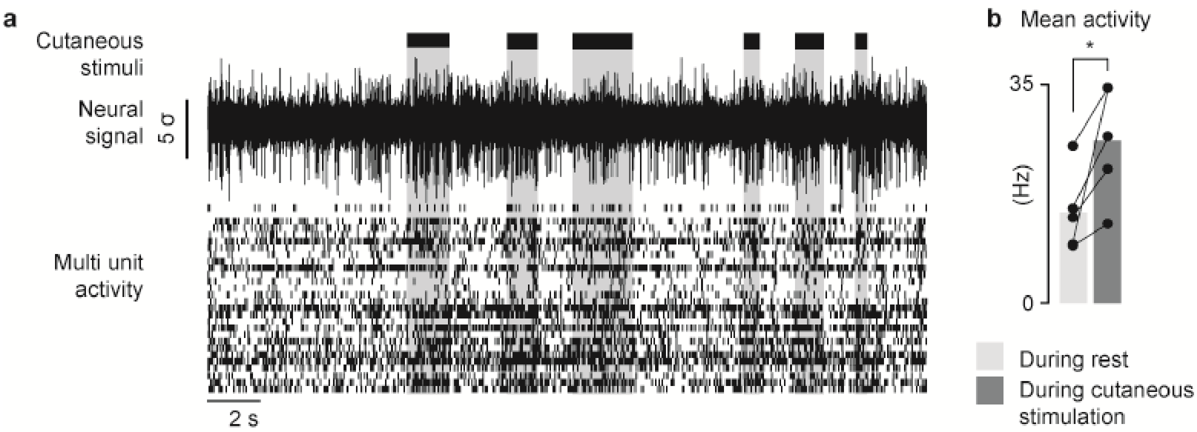
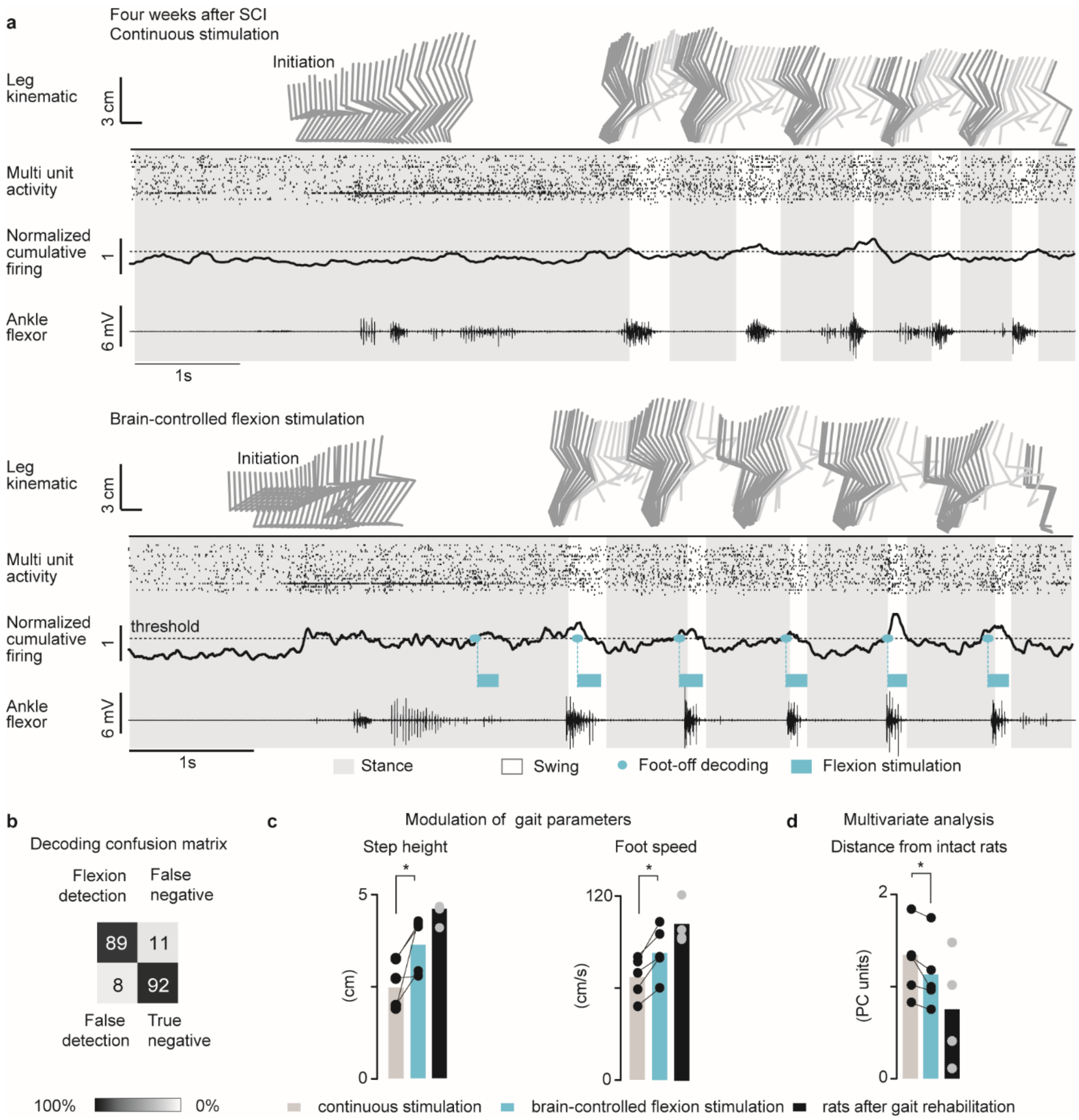


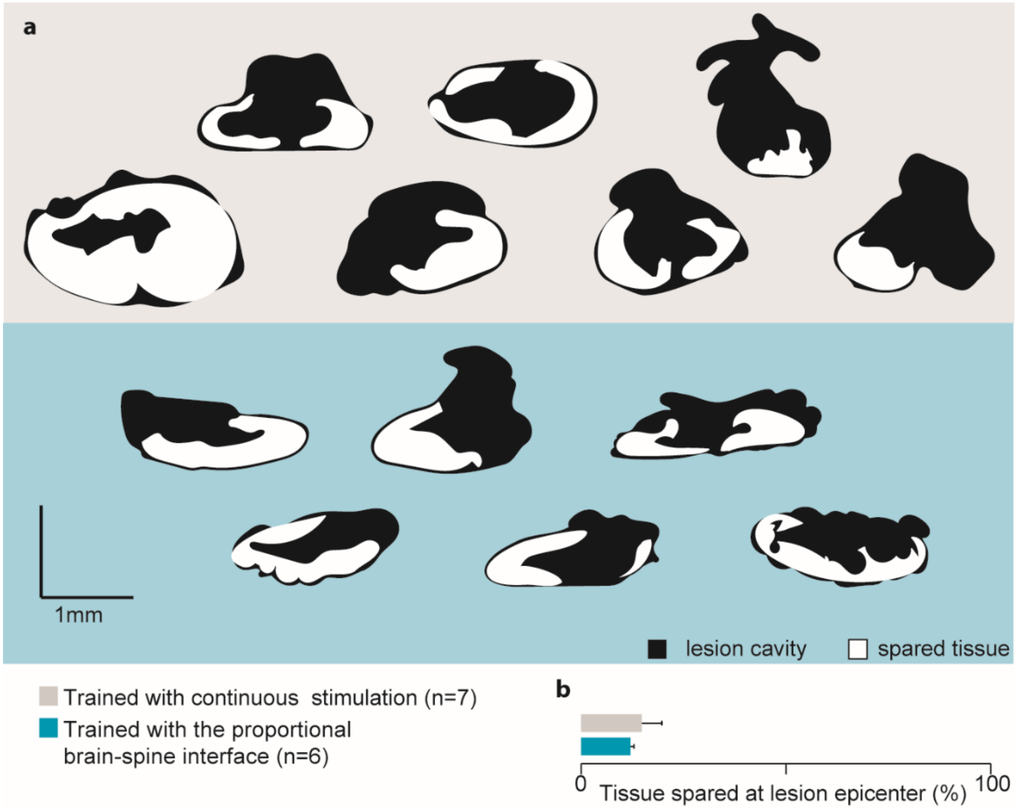
Supplementary Fig. 1. Modulation of cortical ensemble population correlates with step height, but depends on the amount of spared tissue. (a) For each rat, the correlation between the cortical activity at foot–off and the step height was calculated. The value of correlation coefficients is reported for each rat. The bar plot reports the mean variance of step height explained by the cortical activity at foot–off measured during the preceding step and for the ongoing step (n=8, mean ± SD). **, $P < 0.01$. **(b)** Correlation between the amount of spared tissue (%) and the extent of cortical population ensemble modulation during locomotion for all the experimental rats involved in the design of the brain–spine interface. The modulation is expressed in percent of increase of firing rate during locomotion compared to rest. The labels identifying each rat refer to **Supplementary Table 1**. Note that rats C1 and C2 were excluded from the study due to the absence of modulation in cortical ensemble population due to pronounced tissue damage (outside the targeted range of SCI severity).



Supplementary Fig. 2. Cortical activity evoked by sensory stimulation of the paw. (a) Example of cortical activity (single channel and multi-unit activity) in response to successive applications of a pressure on the paw contralateral to the recordings. The horizontal bars and shaded region highlight the time windows over which the stimulation was applied. Recordings were performed at 3 weeks post-injury. **(b)** Bar plot reporting the mean activity measured over all the recorded multi-units during rest and over the period of cutaneous stimulation (n=5). *, $P < 0.05$.



Supplementary Fig. 3. Binary brain–spine interface alleviates locomotor deficits during overground locomotion. (a) Recordings of bipedal locomotion along the runway at 3 weeks post–injury during continuous stimulation and with the binary brain–spine interface. Conventions are the same as in **Fig. 2**. **(b)** Confusion matrix of foot–off event decoding calculated across the 5 rats. **(c)** Bar plots reporting mean values and individual mean values of parameters modulated during continuous stimulation versus brain–controlled flexion stimulation. The values recorded in rats after gait rehabilitation are reported as a reference. **(d)** Bar plot reporting the distance from intact rats in the PC space calculated from 55 gait parameters, which thus quantifies locomotor performance. *, $P < 0.05$.



Supplementary Fig. 4. Quantification of the amount of spared spinal cord tissue. (a) Reconstruction of the lesion cavity (black) and spared tissue (white) at the epicentre of the contusion for both trained groups. **(b)** Bar plot reporting the amount of spared tissue for the two trained groups (mean ± SEM).

Animal ID	Binary BSI on treadmill Fig. 2	Binary BSI overground Supp. Fig. 3	Cortical modulation vs. spared tissue Supp. Fig. 1	Proportional BSI early after SCI Fig. 6	Rehabilitation enabled by proportional BSI Fig. 10	Proportional BSI staircase/overground Fig. 8	Cutaneous paw stimulation Supp. Fig. 2
A1	✓		✓				✓
A2	✓		✓				✓
B1		✓	✓				
B2		✓	✓				
C1			✓				
C2			✓				
D1			✓				
E1	✓	✓	✓				
F1	✓	✓	✓	✓			
F2	✓	✓	✓	✓			
G1				✓			
G2				✓			
G3				✓			
H1					✓		
H2					✓		
H3					✓		
H4					✓		
H5					✓		
H6					✓		
H7					✓		
I1					✓		
I2					✓	✓	
I3					✓	✓	
I4					✓	✓	
I5					✓	✓	
I6					✓	✓	
J1							✓
J2							✓
J3							✓

Supplementary Table 1. List of experimental procedures conducted per group of rats that participated to the experiments.

Temporal features of gait	
1	Duration of gait cycle
2	Speed of animal during stride
3	Stance duration
4	Swing duration
5	Drag duration
Limb endpoint trajectory	
6	Step height
7	Ankle clearance
8	Maximal foot speed during swing
9	Foot acceleration at swing onset
10	Foot speed at swing onset
11	Foot lateral displacement during swing
Stability	
12	Stance width
13	Maximum hip vertical position
14	Minimum hip vertical position
15	Hip oscillation amplitude
16	Pelvic center of mass vertical motion
Joint angles	
17	Hip joint excursion
18	Knee joint excursion
19	Ankle joint excursion
20	Hip joint speed depth
21	Knee joint speed depth
22	Ankle joint speed depth
23	Foot lateral oscillation
Segmental oscillations	
24	Whole-limb excursion amplitude
25	Whole-limb lateral excursion amplitude
26	Whole limb speed depth
27	Crest elevation depth
28	Thigh elevation depth
29	Leg elevation depth
30	Foot elevation depth
Limb coordination	
31	Temporal coupling between crest and thigh
32	Temporal coupling between thigh and leg
33	Temporal coupling between leg and foot
34	Correlation between crest and thigh oscillations
35	Correlation between crest and leg oscillations
36	Correlation between crest and foot oscillations
37	Correlation between thigh and leg oscillations
38	Correlation between thigh and foot oscillations
39	Correlation between leg and foot oscillations
40	Relative duration between crest and thigh angle minima
41	Relative duration between crest and leg angle minima
42	Relative duration between crest and foot angle minima
43	Relative duration between thigh and leg angle minima
44	Relative duration between thigh and foot angle minima
45	Relative duration between leg and foot angle minima
46	Phase of Crest maximal contraction
47	Phase of Hip maximal contraction
48	Phase of Knee maximal contraction
49	Phase of Ankle maximal contraction
50	Phase of Foot maximal contraction
51	Lag between crest and thigh maxima
52	Lag between thigh and leg maxima
53	Lag between leg and foot maxima
Robotic assistance required	
54	Percentage of body weight supported
55	Robot vertical force

Supplementary Table 2. Analysis of kinematic activity: parameters computed for quantification.