Typical large-scale organization of the hand action observation network in individuals born without hands

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SUPPLEMENTARY MATERIAL

SUPPLEMENTAL RESULTS

Decoding of hand and foot actions in the AON

Having found the typical above chance decoding accuracies for hand actions in the IDs' bilateral IPL and right LOTC ROIs, we undertook to search for possible differences between the hand action decoding in the IDs and in the TDs, and between the hand and foot action decoding in the IDs using traditional and Bayesian mixed ANOVAs and two-sample t tests. The Bayesian analyses were performed to provide additional orientation for the interpretation of effects of the traditional statistics. They allowed to compute Bayes factors (BFs), obtained by dividing the likelihood of the alternative model by that of the null hypothesis (Rouder et al. 2009; Rouder et al. 2012). Therefore, BF values below 1 provide evidence in favor of the null hypothesis (no difference or interaction) and values above 1 evidence for the alternative hypothesis.

In a first step, we tested whether there was a deviant hand action decoding in the IDs. This should be signified by an interaction of GROUP (TDs, IDs) x EFFECTOR (hand, foot), as foot actions are similarly motorically possible for both groups, and thus a sensorimotor experience effect should be limited to hand action observation. To this end, decoding accuracies were entered into mixed ANOVAs with GROUP as between-subject factor, EFFECTOR as within-subject factor, and participants as random factor. Bayes factors of the ANOVA models were computed for the main effects and the interaction, using the BayesFactor R package (Morey et al. 2015) and a default Cauchy prior width of $r = 0.707$ for effect size). Then, we used traditional directional two-samples t-tests to test the hypothesis that the IDs show weaker decoding for hand actions than the controls; Bayesian directional two-samples t-tests (Cauchy prior width of $r = 0.707$) to quantify the evidence in the data for the hypothesis that the IDs show weaker decoding for hand actions than the controls; traditional directional paired-samples t-tests to test the hypothesis that the IDs show weaker decoding for hand than feet action; and Bayesian directional paired-samples t-tests (Cauchy prior width of $r = 0.707$) to quantify the evidence in the data for the hypothesis that the IDs show weaker decoding for hand than feet actions.

The results of these analyses conducted in the ROIs that showed significant decoding in at least one of the two groups (bilateral LOTC and IPL) indicated: (1) that the absence of an interaction between GROUP (IDs, TDs) and EFFECTOR (hand, foot) in our data was slightly more likely than its presence (all ANOVAs, $Fs \leq 1.04$, $ps \geq 0.33$; all Bayesian ANOVAS, BF10s ≤ 0.77; Table S1); (2) slightly stronger support for the hypothesis that the IDs decode hand actions as accurately as the controls (or more) rather than less than them (all directional two-sample t-tests, $-1.18 < ts < 1$, $ps > 0.17$; all directional Bayesian two-sample t-tests; BF10s < 1; Table 2) and moderately stronger support for the hypothesis that the IDs decode hand actions as accurately (or more) as feet actions rather than less than them (all directional paired-sample t-tests: $ts \leq -0.43$, all $ps \geq 0.66$; all Bayesian directional paired-sample t-tests , BF10s ≤ 0.31; Tables S2). Thus, we consistently failed to find evidence of group differences, even anecdotal (Jeffreys, 1961). Of course, and especially given the small sample size, a failure to find significant group differences should be interpreted with caution. It is nonetheless important to note that the Bayesian analyses of the data systematically provided slightly more support for the hypothesis that the groups were similar than different (with a default Cauchy prior width of r = 0.707 for effect size). In addition, even though moderate evidence for the null hypothesis (BF < 0.3) is difficult to reach with the small sample size of the dysplasics, the results of the Bayesian analyses of the foot and hand decoding data in the IDs provided moderate evidence that the two action categories are processed similarly in the IDs' AON (Jeffreys, 1961).

Whole-brain decoding of hand and foot actions

The interaction between GROUP (IDs, TDs) and EFFECTOR (hand, foot) performed to search for possible differences between the hand and foot action decoding in the IDs and in the TDs revealed no significant clusters that survived the cluster-size correction for multiple comparisons using a stringent cluster size correction approach using Monte Carlo simulations. To explore further the data and seek for areas of possible more subtle interaction effect, we thresholded the maps at a lenient threshold of p = 0.01 and corrected the maps using a bootstrapping approach in which TD and ID labels were randomly assigned to the subjects (cut-off at p = 0.05). Surviving voxels thus had t values that were higher than in 95% of the permuted group assignments. This procedure revealed small clusters in occipitotemporal and frontal areas (Figure 3B) whereas most of the AON did not show such interaction. The frontal and most ventral cluster in the occipitotemporal area were found in regions where decoding was not significant in any of the two groups and are therefore difficult to interpret. Interestingly, however, the dorsal cluster in the left LOTC fell into an area of significant hand decoding by one of the two groups (see yellow line at the 95% decoding interval in Figure 3B) and showed an interaction pattern suggesting a circumscribed sensorimotor developmental effect (selectively weaker hand action decoding in IDs). Thus, besides a small portion of dorsal left LOTC that may be affected by individual sensorimotor experience, we failed to find any other evidence suggesting that the large-scale brain specialization for observed human actions in the AON (or in any other brain regions) is dependent on sensorimotor experience.

Univariate analyses

We performed traditional and Bayesian mixed ANOVAs and two-sample t tests to explore possible differences between the representation of hand and foot actions in the two groups. We found no evidence for a selective decrease of activation for hand actions in IDs vs. TDs (one-tailed *t* tests, all *t*s > 0.98, all *p*s < 0.18; all BFs < 0.63) or for hand vs. foot actions in the IDs (one-tailed *t* tests, all *t*s > 1.8, all *p*s < 0.07; all BFs < 1.08) and no interactions between GROUP and EFFECTOR (all BFs < 0.88; all *Fs* > 2.08, all *p*s > 0.26) in any part of the AON (Figure S4, Tables 4 and 5).

For whole brain analysis, both random effects and fixed analyses were performed using the same design matrix as in the ROI analysis. To compute baseline contrasts for hand and foot actions in each group separately, we performed (non-generalizable) fixed effects analysis to account for the small sample sizes. For both subject groups (TDs, IDs,), the contrasts hand actions vs. baseline and foot actions vs. baseline were computed. The resulting t maps were FDR corrected at $p = 0.05$ (as we used a fixed effects analysis a Monte Carlo cluster size correction, which required individual beta maps as input, was not possible). We found no evidence for hand action selective increase of activation in any other area of the brain (even at a liberal threshold) that could suggest the use of an alternative action processing mechanism. These results suggest a typical distribution of brain activation during the observation of hand actions in the IDs.

Supplementary References

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SUPPLEMENTARY TABLES

Table S1. Mixed ANOVA for the across object action decoding

	EFFECTOR (hand, foot)			GROUP (TDs, IDs)			Interaction		
	F(1,10)	p	BF10	F(1,10)	p	BF10	F(1,10)	p	BF10
left IPL	3.37	0.09	1.60	0.01	0.93	0.48	0.08	0.77	0.47
right IPL	2.62	0.14	1.22	2.94	0.12	0.96	0.12	0.74	0.5
left LOTC	4.28	0.06	3.13	0.57	0.47	0.52	0.09	0.76	0.49
right LOTC	3.32	0.09	2.76	0.00	0.99	0.45	1.04	0.33	0.77

Table S2. One tailed t tests and Bayesian comparisons for the across object action decoding

	TD vs. ID (Hand)			Foot vs. Hand (IDs)		
	t(10)	p	BF10	t(4)	p	BF10
left IPL	-0.11	0.54	0.44	-1.30	0.87	0.22
right IPL	-1.18	0.87	0.27	-0.91	0.79	0.25
left LOTC	0.99	0.17	0.98	-1.18	0.85	0.23
right LOTC	0.90	0.19	0.92	-0.43	0.65	0.31

Table S3. One tailed t tests and Bayesian comparisons for the across effector and across object/effector action decoding

	TD vs. ID, across effector			TD vs. ID, across object/effector		
	t(10)	p	BF10	t(10)	p	BF10
left IPL	-0.80	0.78	0.31	0.32	0.37	0.58
right IPL	-0.79	0.77	0.31	-1.12	0.85	0.28
left LOTC	1.44	0.09	1.49	0.72	0.24	0.79
right LOTC	-0.44	0.66	0.37	0.51	0.31	0.67

Table S4. Mixed ANOVA for univariate effects of hand and foot action observation

	EFFECTOR (hand, foot)			GROUP (TDs, IDs)			Interaction		
	F(1,10)	p	BF10	F(1,10)	p	BF10	F(1,10)	p	BF10
left PMv	3.91	0.07	1.48	0.03	0.87	0.64	0.42	0.53	0.5
right PMv	2.11	0.18	0.83	0.18	0.68	0.64	0.10	0.75	0.46
left IPL	1.39	0.27	0.71	0.21	0.66	0.59	2.08	0.18	0.92
right IPL	0.05	0.82	0.39	0.37	0.56	0.69	0.01	0.93	0.43
left LOTC	0.01	0.93	0.37	0.10	0.76	0.82	0.02	0.89	0.44
right LOTC	14.14	0.00	11.98	0.04	0.84	0.97	0.05	0.82	0.42

Table S5. One tailed t tests and Bayesian comparisons for univariate effects of hand and foot action observation

	TD vs. ID (Hand)			Foot vs. Hand (IDs)		
	t(10)	p	BF10	t(4)	p	BF10
left PMv	-0.029	0.511	0.46	0.81	0.232	0.76
right PMv	0.285	0.391	0.57	0.614	0.286	0.64
left IPL	-0.172	0.567	0.43	-0.378	0.638	0.315
right IPL	-0.568	0.709	0.35	0.175	0.435	0.45
left LOTC	0.324	0.376	0.58	0.11	0.459	0.43
right LOTC	-0.178	0.569	0.42	1.843	0.07	1.97

SUPPLEMENTARY FIGURES

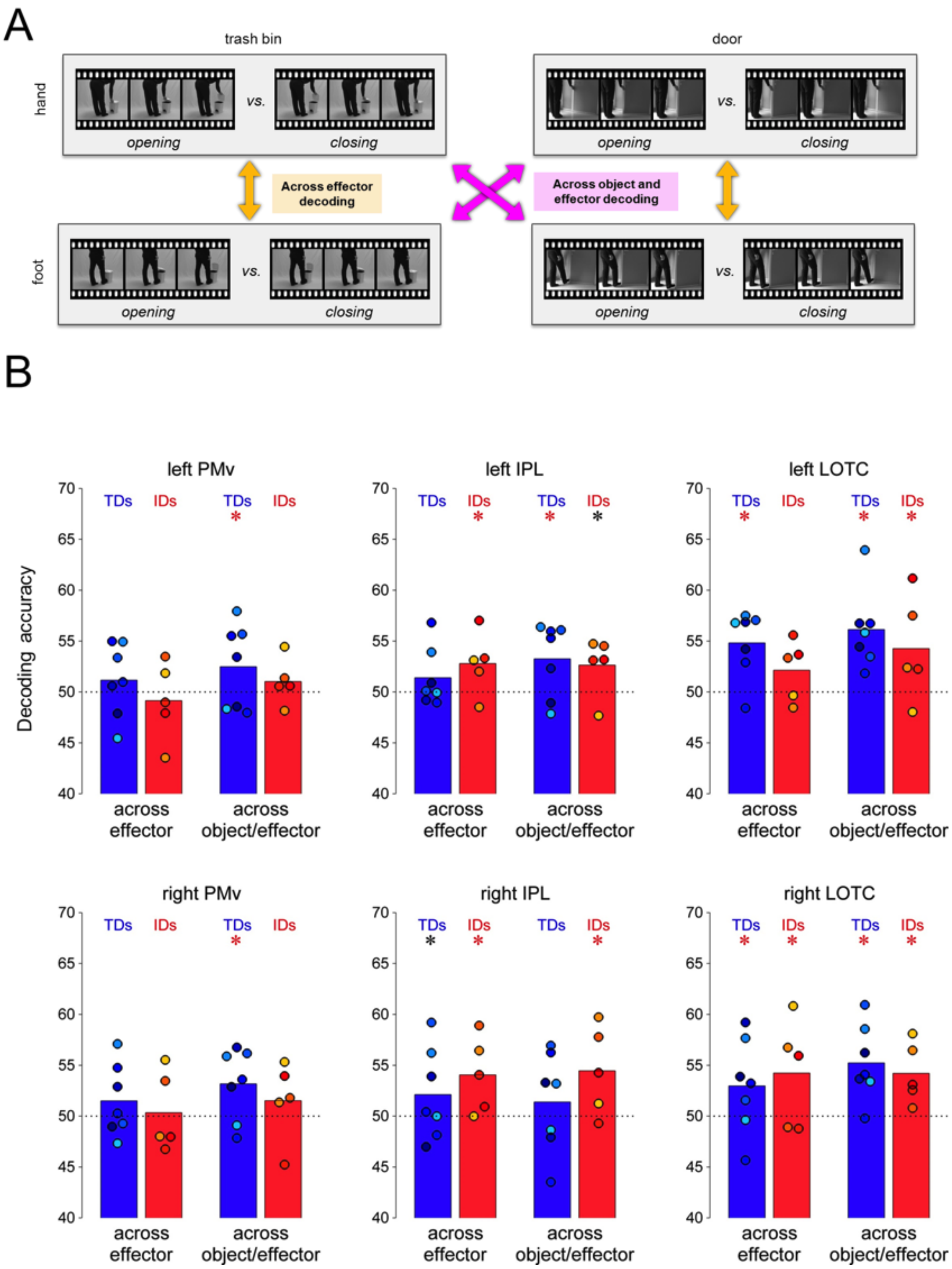

Figure S1. (A) "Across effector" and "across object and effector" decoding schemes. In the across effector decoding, a classifier was trained to discriminate between opening vs. closing with the hand and tested on opening vs. closing with the foot, and vice versa. This was done for each object separately; decoding accuracies were averaged across objects. The across effector decoding thus targeted action representations that generalize across the effector used to carry out the actions but do not necessarily across the object involved in the action (outcome-specific action representations). In the across object and effector decoding, a classifier was trained to discriminate between opening vs. closing door with the hand and tested on opening vs. closing trash bin with the foot. The same was done for the other possible combination (train on opening vs. closing trash bins with the foot and tested on opening vs. closing doors with the hand, opening vs. closing trash bins with the hand); resulting accuracies were averaged. The across object and effector decoding thus targeted action representations that generalize across the effector used to carry out the actions as well as across the object involved in the action. (B) Across effector and across objects and effectors decoding accuracies (50% = chance) in the action observation network for TDs (blue) and the IDs (red). Superimposed colored dots indicate individual decoding accuracies. Asterisks above bars indicate significance (red = FDR corrected for the number of tests = 24). For those ROIs and tests that show significant effects for both decoding tests in at least one of the groups (all except left and right PMv), further second level analyses were conducted (see Table 3).

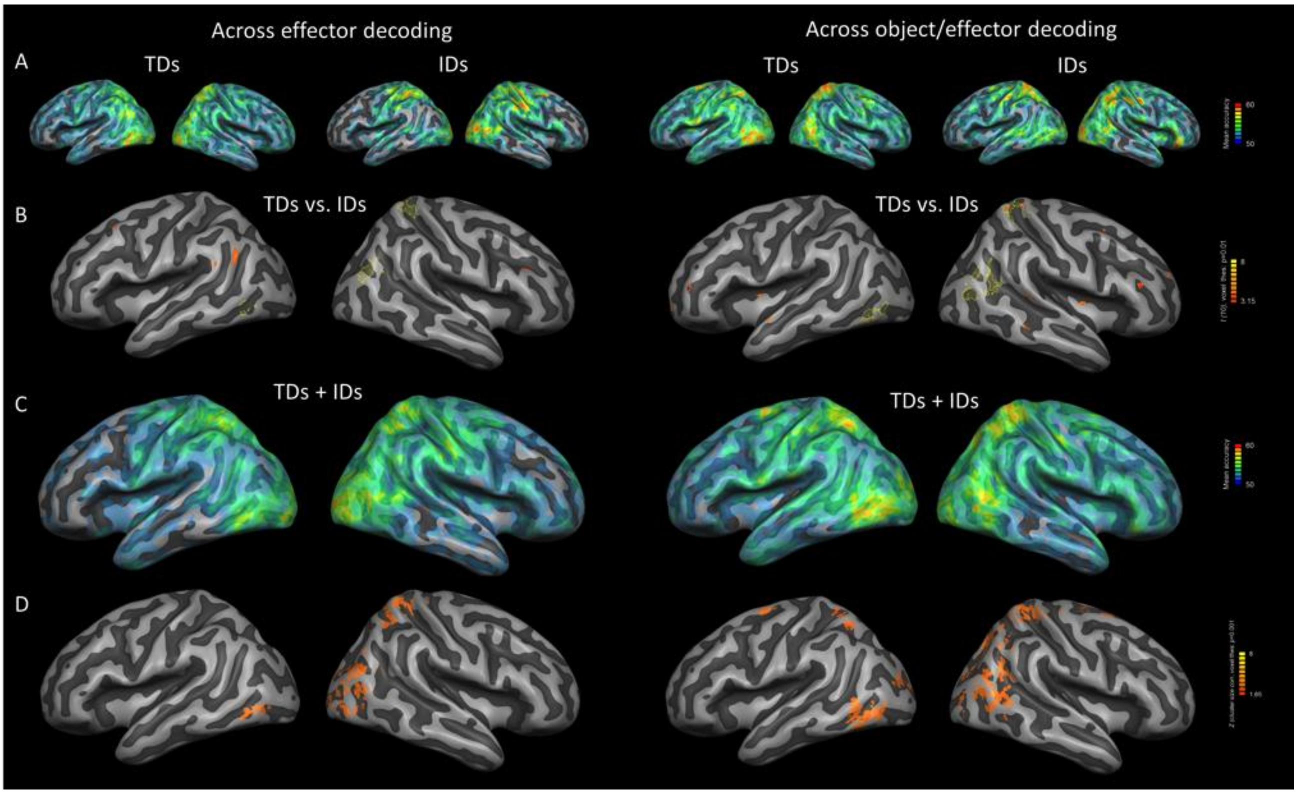

Figure S2. Across effector and across object/effector searchlight decoding. (A) Mean accuracy maps of across effector (left) and across object/effector (right) action decoding for the TDs and IDs. (B) Independent t test (TDs vs. IDs). Maps were corrected using a group label bootstrapping procedure identical to the procedure for the across object decoding. Yellow outlined areas indicate clusters of decoding of the TDs (corresponding to the TD mean accuracy maps in panel A), corrected for multiple comparisons (voxel threshold p = 0.001, cluster threshold p = 0.05). (C) Mean accuracy maps and (C) cluster-sized corrected statistical maps (voxel threshold p = 0.001, cluster threshold p = 0.05) of the across effector (left) and across object/effector (right) action decoding for the collapsed group (N=12).

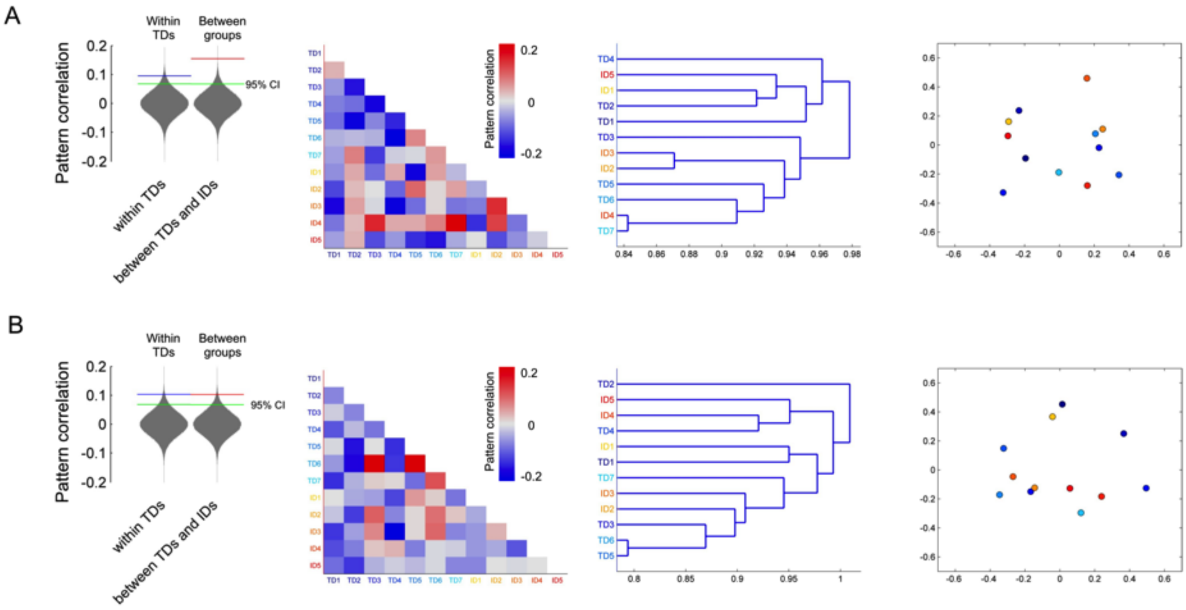

Figure S3. Pattern similarity of the across effector (A) and across object and effector (B) searchlight decoding maps. Procedures were identical to the similarity analysis of the across object decoding (Figure 2): For both decoding tests, decoding maps were vectorized, averaged in groups of 3 and 4 subjects, respectively, and correlated within TDs (r = blue line) and between TD and ID groups (r = red line; left panels). The same was done for random permutation decoding maps (100000 iterations; 95% confidence interval = green line). To further investigate similarities of individual subjects, each subject's decoding map was correlated with each of the other subjects' decoding maps (second panels from left). Dissimilarities between the subjects' maps (1 – r) were entered into hierarchical cluster analysis using average distance, visualized as dendrogram (panels third from left), and multidimensional scaling (right panels). Blue and red dots indicate TDs and IDs, respectively. For both decoding analyses, within TD correlations were significant (across effector: $p = 0.01$, across object and effector: $p = 0.008$). Also between TD and ID correlations were significant (across effector: $p < 0.001$, across object and effector: $p = 0.003$) suggesting that decoding patterns were similar between IDs and TDs.

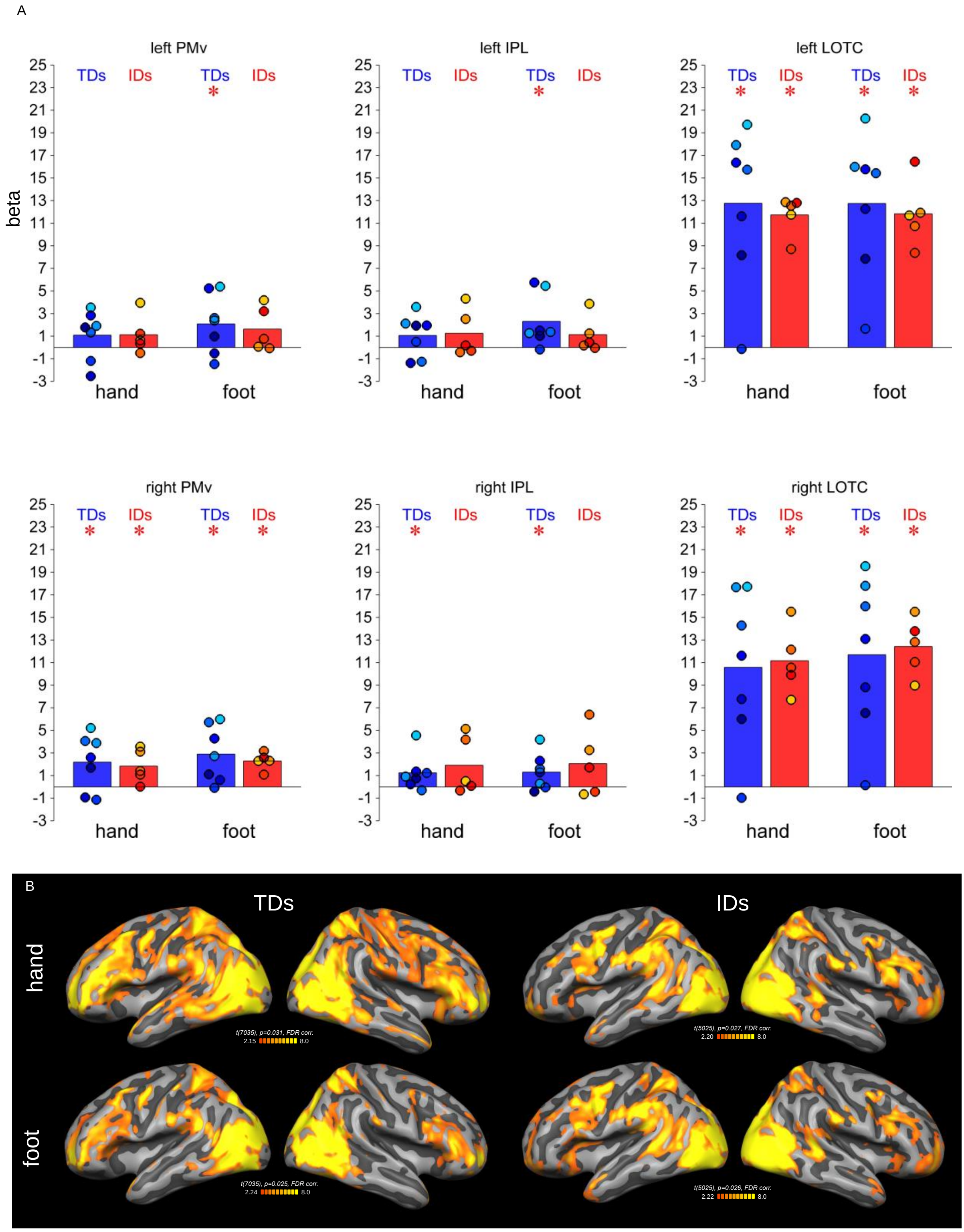

Figure S4. (A) Univariate activation in the action observation network. Mean beta values were extracted from the contrasts hand actions vs. baseline and foot actions vs. baseline. Blue and red bars represent mean beta values of TDs and IDs, respectively. Superimposed colored dots indicate individual decoding accuracies. Asterisks above bars indicate significance (red: FDR corrected for the number of tests = 24; black: < 0.05 uncorrected). See Tab. S4-5 for the corresponding results of t-tests, mixed ANOVA, and Bayesian model comparisons. (B)

Whole-brain maps of the contrasts hand actions vs. baseline and foot actions vs. baseline in TDs and IDs, respectively. Maps are FDR-corrected at $p = 0.05$.

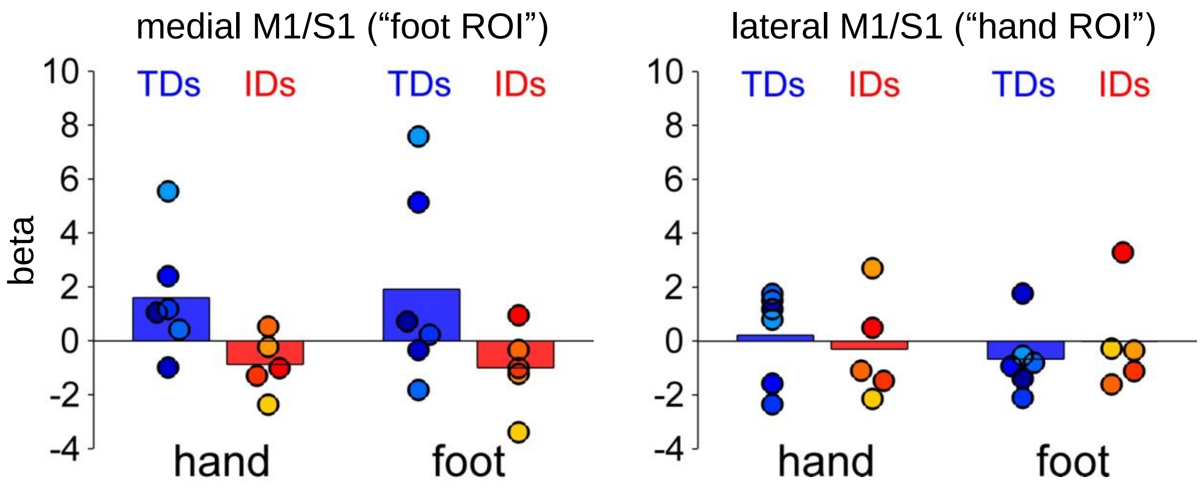

Figure S5. Univariate activation in somato-motor ROIs. Spherical ROIs (5 mm radius) were based on individual localizers for hand and foot movements (TDs) and foot movements (IDs) (Striem-Amit et al. in press). One TD subject did not participate in the localizer experiment and was therefore excluded from this ROI analysis. IDs revealed a cluster in lateral M1/S1 corresponding to the TDs’ hand area, which was used to substitute the TDs’ hand area. Mean beta values were extracted from the contrasts hand actions vs. baseline and foot actions vs. baseline. Blue and red bars represent mean beta values of TDs and IDs, respectively. Superimposed colored dots indicate individual decoding accuracies. No ROI revealed significant activation (all $p>0.05$, one-tailed one sample *t*-tests). The TDs revealed marginally significant activation for hand actions in medial M1/S1 ($p = 0.051$).