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Classification of attempted and executed hand movements from ipsilateral motor cortex in amputees

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Introduction: Decoding complex hand movements from the motor cortex is an important strategy for brain-computer interface (BCI) control, with the sensorimotor cortex (M1/S1) contralateral to the moving hand being a natural and successful target for movement decoding using fMRI and electrocorticography (ECoG) [1]. We have shown recently that also *attempted* complex movements can be decoded accurately from this area in subjects with arm amputation [2], suggesting that, despite years of denervation, detailed information remains present. This finding is interesting, since arm amputation is accompanied by reorganization of the motor network [3]. Hand movements have previously also been decoded from ipsilateral M1/S1 in stroke patients [4], suggesting a preserved ipsilateral hand representation in spite of lost hand function. Here, we investigate whether the ipsilateral representation is also preserved in amputees. For this purpose we analysed 7T fMRI BOLD data, which shows good correspondence with ECoG [5], obtained during (attempted) gestures, and tested whether classification is possible from the hemisphere ipsilateral to the amputation side.

Methods: Eight subjects with above-elbow arm amputation participated (age 52 ± 12 y, 1 female, 7 right arm amputation, acquired 16.4 ± 11.5 years ago), as well as 8 control subjects (age 36 ± 18 y, 4 females). All subjects performed a task in which they had to *execute* (controls and intact hand of amputees) or *attempt* (missing hand of amputees) making six different complex gestures. After preprocessing, data from each gesture was contrasted against baseline in a general linear model. We then selected 450 voxels with highest *t*-values over all six contrasts within the left and the right sensorimotor cortex. The BOLD data in the ROIs was detrended and normalised, and the average signal in volume 4, 5 and 6 of each scan was used as feature set for classification. The classification score was obtained by a support vector machine using a cross-validation scheme (20 folds). The overall classification score was calculated as the mean score over all folds. The *differential classification score* (DCS) was defined as the difference between the score from the contralateral minus that of the ipsilateral hemisphere for the left (intact) or right (missing) hand.

Results and discussion: Contralateral cortex decoding yielded significant scores for amputees and controls (M = 73%, $p < 0.001$). Decoding scores for ipsilateral cortex were lower but still significant (M = 46% in controls and M = 62% in amputees, $p < 0.001$). For the left (intact) hand, the DCS was positive for controls (21 ± 11%, $p < 0.01$) and amputees (22 ± 12%, $p < 0.01$), which means that all subjects decoded better with the contralateral than with the ipsilateral side. For controls, also the DCS for the right hand was positive (31 ± 15%, $p < 0.001$). However, for the missing hand in amputees, the DCS was *not* different from zero (-1 ± 10%, n.s.), and direct comparison between the DCS of the missing hand of amputees with the right hand of controls revealed a significant difference ($p < 0.001$, $1 - \beta = 0.99$). Together, these data show that in controls, and for the intact hand of amputees, the classification score is higher when decoded from the contralateral side than from the ipsilateral side, whereas for attempted movements with the amputated hand, the classification scores from the contra- and ipsilateral sides are comparable, and are as high as the contralateral score from the intact hand.

Significance: These results strengthen the notion that information about complex movements is still present in M1/S1 after amputation: not only contralateral, but also ipsilateral to the amputation side. It may be speculated that, if this also applies to people with brain lesions, this might open possibilities for BCI targets in these patients.

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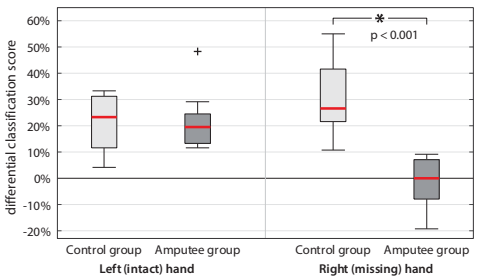

Figure 1. Differential classification scores: scores from the contralateral hemisphere minus the scores from the ipsilateral hemisphere. Left panel: left (or intact) hand differential scores. Right panel: right (or missing) hand differential scores. Red lines indicate the median DCS.