On the ubiquity of movement

Summary

Nearly every choice you make eventually leads to a movement. You have to move to act on your decision, otherwise your decision will have little effect. Unfortunately, for some people movement is or becomes a challenge. Severe paralysis or progressive motor disease may increasingly limit a person's ability to interact and communicate with their surroundings. One of the most natural ways to increase an individual's independence and ability to move and communicate may be brain-computer interfaces (BCIs). A BCI records neural activity and translates it into a control signal for an assistive device. Many options exist to restore movement, such as motorized wheelchairs, mouse pointers for click-and-select and robotic arms or neural prostheses to restore reach and grasp function.

BCIs consists of two main components. First, neural data need to be recorded at one or more brain areas that contain motor related neural activity. Secondly, a neural decoder needs to translate the high-dimensional neural activity into a control signal. To achieve the first part, many BCIs use data recorded from the motor cortex: an area demonstrated to contain sufficient information to control robotic arms. However, recent discoveries in brain-wide recordings reveal that motor-related neural activity is correlated with movement throughout the brain, expanding from the local area of the motor cortex. These brain-wide signals provide new opportunities for motor decoders to reveal the neural content and improve decoding performance.

The works in this thesis investigate the neural content of these brain-wide activations by decoding movement from them. In chapter 2, we provide an initial demonstration that three classes (rest, left hand movement and right hand movement) can be decoded continuously from most electrode configurations. This led to two insights: first, the brain-wide coverage of stereotactic-electroencephalography (sEEG) electrodes captures sufficient information to predict movement in a continuous paradigm, meaning a prediction could be made 10 times per second.

This property is essential for future clinical applications because it allows for real-time control. Secondly, the performance was significantly above chance for almost all electrode configurations, meaning that movement related neural activity may be present in many different areas.

To further investigate these brain-wide motor related activities, in chapter 3 and 4 we explored the neural dynamics of a low-dimensional representation of global motor-related neural activity. By extracting the neural dynamics from a low dimensional representation of the motor-related neural activity, we were able to decode movement regardless of electrode placement. We named these pervasive dynamics 'global motor dynamics' and demonstrate that these were similar across tasks and across participants, even with non-overlapping electrodes configurations. Specifically, by training our decoder on executed movement, we were able to decode imagined movement. Similarly, by training our decoder on one participant, we were on average able to decode movement, based on the neural activity of another participant. Altogether, the results indicate that global motor dynamics are a brain-wide phenomenon and exhibits stable behavior.

We built on these results by expanding our discrete task to a more complex movement task. In chapter 5, we developed a decoder that aimed to decode continuous 3D hand kinematics from sEEG recordings. To do so, we designed a gamified experiment where the participant had to control a cursor and move it to a target within a 3D space. By using the preferential subspace identification algorithm, we were able to reconstruct non-directional hand movement speed and acceleration using delta activity, alpha-beta power and high-gamma power. As with the global motor dynamics in chapter 4, the decoder was able to decode hand speed trajectories significantly above chance for all participants.

Throughout this work and my PhD, we have recorded many datasets with many participants. To perform these experiments, we had to perform many manual actions and checks to start recordings. This resulted in long setup times and many errors, ultimately reducing the time spent on recording and the total amount of recorded data. To reduce this problem, we developed a recording platform called T-Rex (Chapter 6) that

automates setup and recording. T-Rex is designed to be flexible and is currently in use in three different hospitals with different recording environments. Overall, the implementation of T-Rex greatly reduced the number of errors and setup time, and increased the amount of data recorded.

To conclude, we demonstrate that global motor dynamics can be recorded throughout the brain, that these dynamics are similar between tasks and participants with non-overlapping electrodes, and contain enough information to decode non-directional hand kinematics. We highlight that sEEG provides a unique opportunity to explore the largely untapped potential of high spatial and temporal resolution recordings of brain-wide motor-related neural activity.

Finally, during this PhD, the COVID-19 pandemic spread around the world and impacted our lives as well. During this time, our hospital was on the verge of having insufficient beds to admit all COVID-19 patients. The intensive care unit from the hospital voiced the need for a clinical decision support system that could provide more information in a 'code black' situation: the moment where the clinician needs to choose between patients because there are insufficient beds. Therefore, I diverted my attention and resources to develop a model (chapter 7) that could predict the 21-day all-cause mortality of admitted patients based on admission data. The model outperformed controversial age-based rules. Fortunately, the clinical decision support system never needed to be applied in practice.