Inferring human intentions from the brain data

The human brain is a massively complex organ composed of approximately a hundred billion densely interconnected, interacting neural cells. The neurons are not wired randomly - instead, they are organized in local functional assemblies. It is believed that the complex patterns of dynamic electric discharges across the neural tissue are responsible for emergence of high cognitive function, conscious perception and voluntary action. The brain's capacity to exercise free will, or internally generated free choice, has long been investigated by philosophers, psychologists and neuroscientists. Rather than assuming a causal power of conscious will, the neuroscience of volition is based on the premise that "mental states rest on brain processes", and hence by measuring spatial and temporal correlates of volition in carefully controlled experiments we can infer about their underlying mind processes, including concepts as intriguing as "free will", "agency" and "consciousness". Recent developments in electrophysiology and neuroimaging methods allow for increasingly more accurate estimation of spatial and temporal characteristics of decision processes.

The work presented in this thesis is intended to contribute to our understanding of the dynamics of voluntary decision processes about prospective action. In the two presented studies we probe different types of decisions and compare them in terms of behavioral and EEG characteristics. We show that decision processes are manifested by complex, broadband modulation of brain oscillatory patterns, primarily in Alpha(8-12Hz) and Beta (16-30Hz) ranges. Our results suggest that decisions about whether to act or not, what type of action to perform, and about the timing of the action have distinct dynamic representations, and thus are to some extent mediated by different neural components. Furthermore, free action can be partially explained by low level behavioral preferences, especially in contexts where no explicit incentive favors one action over another.

Apart from the investigation of volition, considerable part of the work presented in this thesis is dedicated to experiment design methodology and efficient EEG processing methods. We have developed a dedicated, flexible Virtual Reality Environment (VRE) platform, suitable for investigation of volition and action preparation processes with range of modalities, including electromyography (EMG), functional magnetic resonance (fMRI), eye-tracking (ET) and behavioral measures. By providing ecologically valid, semi-realistic experience we aimed at reinforcing the natural decision processes and minimize the problem of random-sequence generation and fatigue in participants undergoing highly repeatable cognitive experiments. Other methodological contributions presented in the thesis are related to efficient, automatized and highly data-preserving methods for processing of EEG data, based on minimal number of arbitrarily selected parameters.
Pointing to oneself: active versus passive proprioception revisited and implications for internal models of motor system function

We re-examined the issue of active versus passive proprioception to more fully characterize the accuracy afforded by proprioceptive information in natural, unconstrained, movements in 3-dimensions. Subjects made pointing movements with their non-dominant arm to various locations with eyes closed. They then proprioceptively localized the tip of its index finger with a prompt pointing movement of their dominant arm, thereby bringing the two indices in apposition. Subjects performed this task with remarkable accuracy. More remarkably, the same subjects were equally accurate at localizing the index finger when the arm was passively moved and maintained in its final position by an experimenter. Two subjects were also tested with eyes open, and they were no more accurate than with eyes closed. We also found that the magnitude of the error did not depend on movement duration, which is contrary to a key observation in support of the existence of an internal forward model-based state-reconstruction scheme. Three principal conclusions derive from this study. First, in unconstrained movements, proprioceptive information provides highly accurate estimates of limb position. Second, so-called active proprioception does not provide better estimates of limb position than passive proprioception. Lastly, in the active movement condition, an internal model-based estimation of limb position should, according to that hypothesis, have occurred throughout the movement. If so, it did not lead to a better estimate of final limb position, or lower variance of the estimate, casting doubt on the necessity to invoke this hypothetical construct.
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