Neural dynamics underlying relational reasoning – accessible summary

Processing *relations* is a key human cognitive ability, transforming the dynamic influx of information into coherent mental structures which help us to comprehend physical and social world. Relations give thought compositionality and productivity, so important in work, academia, technology, and art. Mental processes responsible for discovering and applying relational representations are called *relational reasoning*, and studied with complex tasks that for instance require matrix induction and analogy. The individual effectiveness of coping with such tasks is strongly associated with fluid intelligence, or *reasoning ability* (called also the *gf* factor). However, even simpler tasks, such as observing constantly changing 3×3 matrices of stimuli and deciding if three items in one row or column end with the same digit, are equal predictors of *gf*. Recently, my own research revealed that constructing even a single trivial binding, such as finding that the transitive relation A<B means the same as relation B>A, strongly loads on *gf*. Such simple relations can still tap reasoning because of individual differences in mechanisms responsible for the dynamic construction, updating, and elimination of task-relevant *temporary bindings*.

Despite a century of research, precise neurocognitive mechanisms underlying relational reasoning have not been understood yet. Although early studies reported the negative relationship of *gf* and various kinds of brain activity (as measured with electroencephalography, EEG, and functional magnetic resonance imaging, fMRI) suggesting that intelligent brains need to engage less resources to do a task, and optimally manage them, more recent studies found complex interactions of neural markers of reasoning performance with several factors, including reasoning task difficulty, time course of a task item, and brain regions involved. This research proposal aims at the comprehensive examination of the dynamics of one such marker that can be observed in EEG signal – an index of the cross-frequency interplay of neuronal oscillations called phase-amplitude coupling (PAC), which reflects how strongly a low-frequency brain rhythm modulates the power of neuronal oscillations at a higher frequency. We will search for the PAC patterns occurring during performance on simple relational reasoning tasks that focus on temporary binding of task-relevant information.

Three large-sample studies are planned in this project. Study 1 will encompass a large spatial resolution of EEG measurement as well as two independent sessions. Study 2 will involve also eye tracking, and will test the effects of varying the complexity of applied tasks. Finally, as initial results suggest that transcranial alternating current stimulation (tACS), which induces low intensity current at the skull that synchronizes underlying neural oscillations, may improve reasoning, Study 3 will target such a stimulation at the PAC mechanisms identified in Studies 1 and 2. Specific project goals are: to test if PAC at the frontal vs. parietal loci is or is not differently related to *gf*, to examine the test-retest reliability of PAC (can it serve as a kind of neuro-trait?), to look for a potential relationship between PAC and the patterns of eye movements, to test whether PAC predicting *gf* is a neural mechanism directly linked to reasoning processes or a more general brain marker, and to verify whether stimulation of PAC strength at the relevant frequencies can improve *gf*.

Intelligence, and especially reasoning ability, is a pervasive psychological variable, predicting individual behavior in various domains, such as academic and professional success, income and social status, health, and longevity. By revealing neurophysiological basis of abilities and processes pertaining to human relational reasoning, the project will help to understand the dynamic neuronal processes underlying them. Advanced methodology and simplified reasoning tests open novel perspectives on how neurocognitive mechanisms of reasoning can be studied. The project will thus bring new knowledge into the cognitive psychology and neuroscience of reasoning. Its contribution to differential psychology will consist of clarifying the concept of intelligence. The project results can also be applied to other disciplines of social science, with new ways of cognitive ability diagnosis and improvement in clinical, developmental and educational contexts.

If the project is successful, its scientific outcomes will include: precise characterization (spectral, spatial, temporal distribution) of oscillatory coupling related to processing relations, explanation of how one's intelligence level depends on individual neural oscillatory dynamics as indexed by PAC, using novel relational tasks and eye tracking to support that this coupling reflects the binding of relational elements, and potential improving relational reasoning by targeted brain stimulation. Speaking shortly, we might be able to know what our brains are doing when we perform on tasks that require structured thinking and reasoning, and why some people excel in such tasks, while others attempt them with great difficulty.