Spontaneous brain activity and the self

Nicola De Pisapia
Center for Mind/ Brain Sciences (CIMeC) - University of Trento
Via delle Regole, 101- 38100 Mattarello (TN) – ITALY
nicola.depisapia@unitn.it

1. A paradigm shift

In this manuscript I review recent developments in neuroscience which are profoundly changing the way in which we interpret the whole activity of the brain. In my view these new findings and ideas have not reached the whole cognitive science community yet. Here I assemble various crucial pieces of these developments and point to future directions, with the aim of showing why this topic should be of pivotal interest to the many disciplines composing cognitive science. Since Thomas Kuhn wrote about "paradigm shifts" [1] to indicate radical changes of perspective in science (such as from a geocentric to a heliocentric view of the universe), the expression has been over-used, and adopted even to indicate ordinary changes of opinion. Nonetheless, paradigm shifts in the original sense are still possible in science – though rare and hard to achieve. Neuroscience is witnessing a radical change of perspective of this sort, which has the potential to spread to all the research on the brain and mind.

In the traditional view the brain is interpreted mainly as a reflexive system, where local activations are seen as a reaction induced by external stimuli. In the alternative view - corroborated by the most recent findings in neuroscience - the brain is instead conceived as a closed system mainly involved in intrinsic processing. External stimuli, instead of being the main cause of cerebral activity, are interpreted as modulators of the spontaneous activity. Growing evidence shows that the brain spends most of its energy for intrinsic

processing, and only a small portion of its resources goes to the processing of external stimuli. It is this spontaneous activity to determine how the system responds to stimuli from the environment ([2], [3]).

This change of perspective is full of consequences, and a growing number of neuroscientists are now investigating cognitive constructs or functions that until a few years ago were neglected. The most important case is the increase of studies on the cognitive and emotional constituents of one's identity, or the *self*, which - even though it is a psychological and philosophical concept of great importance – until recently it was a focus of interest only of a few researchers in cognitive science (e.g., [4]).

2. Default brain activity

All along the history of neuroscience, there have been a few individuals who have supported the alternative view of the brain as mainly involved in internally driven activity. Such is the case of T. G. Brown ([5]), who formulated the same principles relatively to the spinal cord, Hans Berger ([6]), who was also the first to record brain activity using the electroencephalogram, and R. Lynas ([7]), who formulated similar ideas in relationship to higher brain functions. But, apart from these few notable cases, this view has not been the dominant one.

The widespread adoption of the traditional view has had inevitable consequences on the scientific methodologies commonly adopted. For example, until a few years almost all neuroimaging experiments consisted of (a) an experimental condition, in which volunteers were engaged in some kind of stimuli-based task (auditory, visual, mnemonic, executive, etc), and (b) a fixation condition, acting as a control phase, in which the participants simply looked at a central cross and –supposedly - thought to nothing, thus giving a baseline toward which compare activity during task execution. This method presupposed that during fixation the brain was not significantly active.

In [8], Shulman et al. - for the first time in neuroimaging - investigated instead the idea that fixation, far from being a passive and empty condition, was occupied by spontaneous and "internal" mental activities (i.e., not initiated by the environment, and not inducing overt behaviour), such as unconstraint verbal thinking (or inner speech), imagination, unfocused monitoring of the emotional and bodily state, and so on. A specific set of cortical regions was found to be linked to this activity, including the medial prefrontal cortex, the medial temporal lobes, the posterior cingulate cortex, the precuneus and the inferior parietal cortex. Different brain networks were instead involved when individuals were executing externally oriented tasks (executive net-

works), and engagement of these networks was found to occur simultaneously with a decrease of activity in the regions more active during fixation.

Subsequently, Raichle et al. in [9] named "default mode network" this set of regions spontaneously active when not engaged in goal directed behaviour, giving officially birth to a new view in neuroscience [10].

3. The self

In the very first studies on default mode networks, the relevance of spontaneous activity to the concept of the self was not explicit. It was in [11] that the reference became open. Gusnard et al. found that self-referential mental activity was associated with increases of activity in medial prefrontal cortex (part of the default mode network), and vice versa execution of attention-demanding tasks induced reductions of activity in this regions. They hypothesized that self-referential processing was linked to the default activity in medial prefrontal cortex, and they suggested that the exploration of the dynamics of this activity was a promising direction to understand the biology of the self. Subsequently, the first author of this study argued even more explicitly in favour of the adoption of function neuroimaging to study self-referential processing in the human brain ([12]). Since then, increasingly many researchers have tackled the issues that revolve around the concept of self and identity (e.g., [13] and [14]).

The whole approach is not without fundamental criticisms (e.g., [15] and [16]). One of the critiques involves the subjective aspect of the internally driven mental activities. Subjective information - by definition - cannot be studied as an objective phenomenon, as required by the scientific method. One technique that has been adopted to overcome the problem of the inaccessibility of internal thoughts is to simply ask to participants what they are thinking of. This straightforward psychological method (called *direct experience sampling*) has been adopted in a very recent neuroimaging study ([17]). The researchers asked volunteers to perform an easy task consisting in looking at digits on a screen, and correspondingly in pressing a button as fast as they could after every occurrence, with the exception of the digit "3", in which case they had to do nothing. Crucially, from time to time during the execution of this task, the experimenters asked to the volunteers if they were thinking to something else. They found that regions in the default mode network, and in particular the medial prefrontal cortex, were more active when the volunteers reported that were indeed thinking of something else and engaged in mind wandering activities.

These discoveries on spontaneous cortical activity and its hypothesized relationship with self-referential processing are opening a number of new in-

vestigative directions. For example, one new direction concerns the degree to which these self related activities can take place unconsciously. It is well known in psychology and in cognitive neuroscience that only part of our cognitive activities are conscious ([18]). Even cognitive constructs traditionally considered to be necessarily conscious, such as executive control, are progressively found to be sensitive to unconscious processing of information ([19]). Interestingly, mind wandering activities are also known to take place without the capacity of people to report about its content ([20]). And indeed, in [17], when volunteers reported that they were mind wandering, often they were not able to report the content of their thinking. Comprehensive analyses of cognition should devise methodologies to investigate spontaneous processing of unconscious information.

Not unrelated to this topic, another line of research regards how the knowledge of the dynamics of the cortical regions involved in self-related information can shed new light on existing psychological theories of the self (such as S. Freud's psychoanalysis, or C. G. Jung's analytic psychology). In particular, for parts of these theories that are falsifiable, the question is how to translate them into precise neurobiological hypotheses that can be put to test and experimented with. As S. Freud himself hoped in his "Project for a Scientific Psychology" ([21]), such a program of research would allow a rigorous reduction of psychoanalytic constructs to neuronal mechanisms. The work by Carhart-Harris and Friston ([22]) constitutes an important and, in some respects, courageous theoretical step in this directions.

Other examples of possible new directions of research are the effects of brain disease on intrinsic network activations, especially for conditions that involve the self and personality, such as for example schizophrenia or depression (e.g., [23]), or the relationship between self related activity in the default mode network and the first-person perspective (e.g., [24]).

4. Conclusions

A Kuhnian paradigm shift is taking place in cognitive neuroscience. The perspective is shifting from a view of the brain as a "stimulus driven" processor of information, to a view of the brain as a closed system mainly involved in spontaneous and self related activity, only occasionally modulated by external stimuli. The cognitive counterpart of these internally driven brain activities includes internal speech, planning or fantasizing, mind-wandering, introspection, and the whole domain of self-referential activities in which individuals are engaged when they are awake and not focussed on the external world. Several new exciting investigative directions in cognitive science are open by this change of perspective.

References

1. Kuhn, T. S: The Structure of Scientific Revolutions. Univ. of Chicago Pr. (1962).
2. Raichle, M. E.: A paradigm shift in functional brain imaging. J Neurosci 29(41): 12729-12734 (2009).
3. Raichle, M. E.: Two views of brain function." Trends Cogn Sci 14(4): 180-190 (2010).
4. Gallagher, S.: Philosophical conceptions of the self: implications for cognitive science. Trends Cogn Sci, 4, 14-21 (2000).
5. Brown, T.G.: On the nature of the activity of the nervous centres. J. Physiol., 48:18-46. (1914).
6. Berger, H.: Uber des Elektrenkephalogramm des Menschen, Archiv fur Psychiatrie 87,527–580 (1929).
7. Llinás, R. R.: I of the Vortex. Cambridge, MA, MIT Press. (2001).
8. Shulman, G. L., Fiez, J. A., Corbetta, M., Buckner, R. L., Miezin, F. M., Raichle, M. E., Petersen, S. E.: Common Blood Flow Changes across Visual Tasks: II. Decreases in Cerebral Cortex. J Cognitive Neurosci, 9(5): 648-663 (1997).
9. Raichle, M.E., MacLeod, A.M., Snyder, A.Z., Powers, W.J., Gusnard, D.A., Shulman, G.L.: Default mode of brain function. Proc Natl Acad Sci, 98 (2): 676–82 (2001).
10. Buckner, R.L., Andrews-Hanna, J.R., Schacter, D.L.: The brain's default network. Ann N Y Acad Sci 1124: 1–38 (2008).
11. Gusnard D.A., Akbudak E., Shulman G.L., and Raichle M.E.: Medial prefrontal cortex and self-referential mental activity: relation to a default mode of brain function. PNAS (98): 4259-4264 (2001).
12. Gusnard, D.A.: Being a self: considerations form functional neuroimaging. Conscious Cogn 14: 679-697 (2005).
13. Northoff, G., Heinzel, A., Greck, M., Bermpohl, F., Dobrowolny, H., Pan-ksepp, J.: Self-referential processing in our brain--A meta-analysis of imaging studies on the self. Neuroimage, 31, 440-457 (2006).
14. Buckner, R.L., Carroll, D.C.: Self-projection and the brain. Trends Cogn Sci. 11:49–57 (2007).
15. Morcom, A.M., Fletcher, P.C.: Does the brain have a baseline? Neuroimage 37: 1073–82 (2007)
16. Legrand, D., Ruby, P.: What is self-specific? Psychol. Rev. 116, 252–282 (2009).
17. Christoff, K., Gordon, A. M., Smallwood, J. and Schooler, J. W.: Experience sampling during fMRI reveals default network and executive system contributions to mind wandering. Proc Natl Acad Sci, 106(21): 8719-8724 (2009).
18. Hassin, R.R., Uleman, J.S:, Bargh, J.A (Eds.) The New Unconscious. Oxford University Press (2005).
19. Suhler CL, Churchland PS (2009) Control: conscious and otherwise. Trends Cogn Sci 13:341-347.
20. Smallwood, J., Schooler, J.W.:The restless mind. Psychol Bull 132:946-958 (2006).
21. Freud, S.: Project for a scientific psychology (1895), The Standard Edition of the Complete Psychological Works of Sigmund Freud, vol. 1, Hogarth Press, London, 283–397 (1953).
22. Carhart-Harris, R.L., Friston, K..J.: The default mode, ego-functions and free-energy: a neurobiological account of Freudian ideas. Brain, 133(4): 1265-83 (2010).
23. Sheline, Y.I., Barch, D.M., Price, J.L., Rundle, M.M., Vaishnavi, S.N., et al. The default mode network and self-referential processes in depression. Proc Natl Acad Sci U S A.,106:1942–1947 (2009).
24. Blanke, O., Metzinger, T.: Full-body illusions and minimal phenomenal selfhood.Trends Cogn Sci. 13(1):7-13 (2009).