The four seasons of cognitive function

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Does cognitive function change with the seasons? This question had never been properly investigated. In an Article published by the American journal *PNAS*, researchers at the University of Liege have been able to show that some brain function, at least, changes in keeping with the seasons. For tasks requiring attention, brain activity is maximal in June, around the time of the summer solstice, and is minimal in December near the time of the winter solstice; for executive tasks (short-term memory), brain activity is maximal around the time of the autumn equinox (September) and is minimal around the time of the spring equinox (March).

We know that humour has a seasonal dimension in humans. It goes without saying that most of us are happier and more cheerful in summer. Conversely, around 3% of individuals suffer from a recurrent depression syndrome, seasonal depression, which begins around October and ends around March. Likewise, in our latitudes, 15% to 20% of the population experience a loss of moral, upset sleep, an increase in fatigue and irritability… ;in short, a slight non-clinical depression syndrome: the "winter blues". "Moreover, some studies seem to show that serotonin, whose importance in regulating humour is known, and dopamine, also involved at this level, but also in the reward circuit and addiction as well as in the regulation of cognitive function, change with the seasons", explains Gilles Vandewalle, a research associate in the FNRS (the Belgian National Funds for Scientific Research) in the GIGA-CRC-In Vivo Imaging (1) unit of the University of Liege (ULg).

In addition to the regulation of humour, the seasonal aspect of the expression of some functions in the organism, such as immunity, blood pressure or the level of cholesterol, is also present in humans while there is a peak in the number of deaths in winter, violent suicides in spring and procreation in winter and spring. On the other hand, the impact of the seasons has been well established for various functions in animals. For example,
reproduction, the search for food, or, for some species, general metabolism culminating in the phenomenon of hibernation.

**Loss of bearings**

But what happens at a cognitive level? Not only do we have no data on animals in this regard, but, in addition, the studies on humans are very rare and focussed almost exclusively on the P300 event related to attention and cognition. These electroencephalographic studies yielded contradictory results with regard to the influence of the seasons on certain cognitive functions. Furthermore, research on animals suggest that the suprachiasmatic nucleus, a structure situated in the anterior hypothalamus and containing around 10,000 cells, is not only the biological clock which regulates the circadian rhythms (a time period of around 24 hours), but it is also one of the structures which controls seasonal rhythms. This points to the fact that, in humans, the suprachiasmatic nucleus, which is known to play a key role in variations in circadian rhythms of cognitive functions, could be involved in possible yearly variations in these functions.

In summary, apart from all the speculations and strongly-held views, the study of possible seasonal aspect in cognitive functions in humans appears to be a blank canvas. This situation stems principally from the fact that measuring pure seasonal rhythms in the human brain is an extremely arduous process due to the necessity to control a high number of factors likely to affect brain function: exposure to light, sleep-waking rhythm, external temperature, food intake, physical activity, social interactions…

Researchers at the GIGA-CRC-In Vivo Imaging Laboratory of the University of Liege, in collaboration with scientists at the Surrey Sleep Research Centre, in England, conducted a study on the seasonal aspect of human cognitive functions in strictly controlled conditions. This work, whose first author is Doctor Christelle Meyer, was published on February 8th 2016 by the American journal Proceedings of the National Academy of Sciences of the United States of America (PNAS) (2).

The researchers measured the brain activity of 28 healthy male and female volunteers around the age of twenty at different times of the year. During their visit to the laboratory, the participants were deprived of any seasonal bearings. Therefore they had no access to daylight, Internet, telephone and, more broadly, any information from the outside. The experiment lasted a total of four and a half days during which they lived their lives in normal conditions. The conditions were practically constant during the last two and a half days. "The light in the laboratory was dimmed while the temperature and other parameters that usually vary with the seasons were kept constant. The subjects slept for 8 hours and then had to stay in bed in a semi recumbent position for 42 hours during which they were deprived of sleep and they took a protein snack every two hours. Then they slept again for 12 hours before being taken by stretcher to a functional magnetic resonance imaging (fMRI) apparatus one hour after waking", explains Gilles Vandewalle.
Solstices and equinoxes

After being allowed to recuperate from their 42 hour period without sleep, they were asked to complete two tasks during which their brain activity was recorded. The first task was a simple one called the *Psychomotor Vigilance Task* and was attention-based. The subjects had to press a button as quickly as possible after a chronometer was randomly triggered. In the second task, called *3-back*, the participants were enunciated letters one after the other. When they heard a letter, they were required to indicate whether the letter was the same as the letter suggested three steps before. For example, when the fifth letter was enunciated, they had to say if it was the same as the second. This was therefore a memory task requiring the intervention of executive functions, high-level cognitive processes which enable us to adapt to our environment when routine actions are not sufficient. On a cognitive level, the second task was evidently more complex to perform than the first. The subjects had to remember previous information, to inhibit non-relevant data and to make comparisons… The question was: would cerebral activity fluctuate according to a seasonal rhythm while the tasks were being performed? The response was positive. Although the performance level of the subjects remained constant during the year, their brain was significantly affected by the seasons. In the attention-based task, the variations were to be seen in the thalamus and the *amygdala*, regions that are involved in vigilance, as well as the frontal
areas and the hippocampus, structures that intervene in executive control. Seasonal variations were also detected in the globus pallidus, the parahippocampal gyrus, the fusiform gyrus, the supermarginal gyrus and the temporal pole. "All the areas called on to contribute were affected in the same way with regard to their functioning", explains Gilles Vanderwalle. "In other words, they presented the same variations in activity under the influence of the seasons".

A similar phenomenon was observed during the memory task, where the researchers detected the impact of the seasons on the functioning of the thalamus, the prefrontal and fronto-polar cortex as well as the insula, a region concerned with executive processes, attention and regulation of the emotions. However, there was an unexpected element: the seasonal rhythms demonstrated with regard to the cerebral resources used to carry out the two tasks were not the same. For the attention-based task, brain activity reached its maximum level in June, around the time of the summer solstice, and its minimum level in December around the time of the winter solstice; for the executive task (short-term memory), it reached its maximum level around the time of the autumn equinox (September) and its minimum level around the time of the spring equinox (March). It is important to note that complementary analyses made it possible to rule out any connection between these results and neurophysiological variations in the waking state, the quality of sleep or endocrine fluctuations in the level of melatonin, the "circadian sleep hormone".

More questions

The rhythm associated with the accomplishment of the attention-based task seems to correlate to the photoperiod, that is to say, the division, during the day, between the diurnal phase and the nocturnal phase. "It's one of two things", says Gilles Vanderwalle. "Either we have a memory of the photoperiod which extends beyond several days, or human beings possess a veritable seasonal rhythm that is independent from the photoperiod and is endogenous similarly to the circadian rhythmicity which modulates different physiological or cognitive functions. In this second theory, external factors only serve to re-establish or re-entrain the rhythm. An example of the occurrence of this would be when we travel to the southern hemisphere where the seasons are inverted by comparison to our hemisphere".

The performance to the executive task was not correlated to the photoperiod. On the other hand, it was strangely correlated to the daylight duration differential. The more quickly daylight duration diminishes or increases, the more cerebral activity reaches its optimal or minimum level. Could there be a causal element here? It remains a mystery, according to Gilles Vanderwalle. "As for the photoperiod, however, factors such as the temperature of the air and humidity vary in parallel with the length of the day, to the extent that they can also contribute to the seasonal aspect of cognitive functions", point out the authors of the article published by PNAS on February 8th.
One of their theories was that the variations in seasonal rhythms are more marked in the case of a basic task such as the Psychomotor Vigilance Task than in a more complex cognitive task. In the latter case, the cognitive processes are based on an increased number of variables such as, for example, social interactions. The fact that a somewhat reduced number of areas of the brain are involved in seasonal response to the work memory task in relation to the attention-based task could add weight to this theory.

It remains to confirm these results on other populations, to test other cognitive functions and to more thoroughly address the relationship between performance and the "cost of cognition", notably by means of more mentally demanding tasks, to study the influence of the subjects' age on the nature and extent of seasonal rhythms, but also to gain an insight into the secrets and fine workings of this seasonal aspect to cognitive functions which seem to have been brought out of the shadows and into the full light of day by the researchers at the University of Liege.

(1) Formerly, the Cyclotron Research Centre (CRC).