Changes in white matter and connectivity induced by real-life programming learning experiences

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Background

- Programming learning is a complex experience that involves many different modules. As such, exploring it through a simple, contained task may not reflect on the whole experience.
- Neuroplasticity is one of the key mechanisms in learning, such that learning success, capacity to learn and engagement in learning is expected be reflected in various brain measures.
- Connectome and white matter structure were shown to be affected by various cognitive tasks, as well as be related to intelligence [1].
- Functional imaging of programmers while preforming a programming task show activity in the left hemisphere, ,mostly in language processing areas [2].
- Many works show programming tasks invoke activity in frontal areas and the attention or salience network [3].

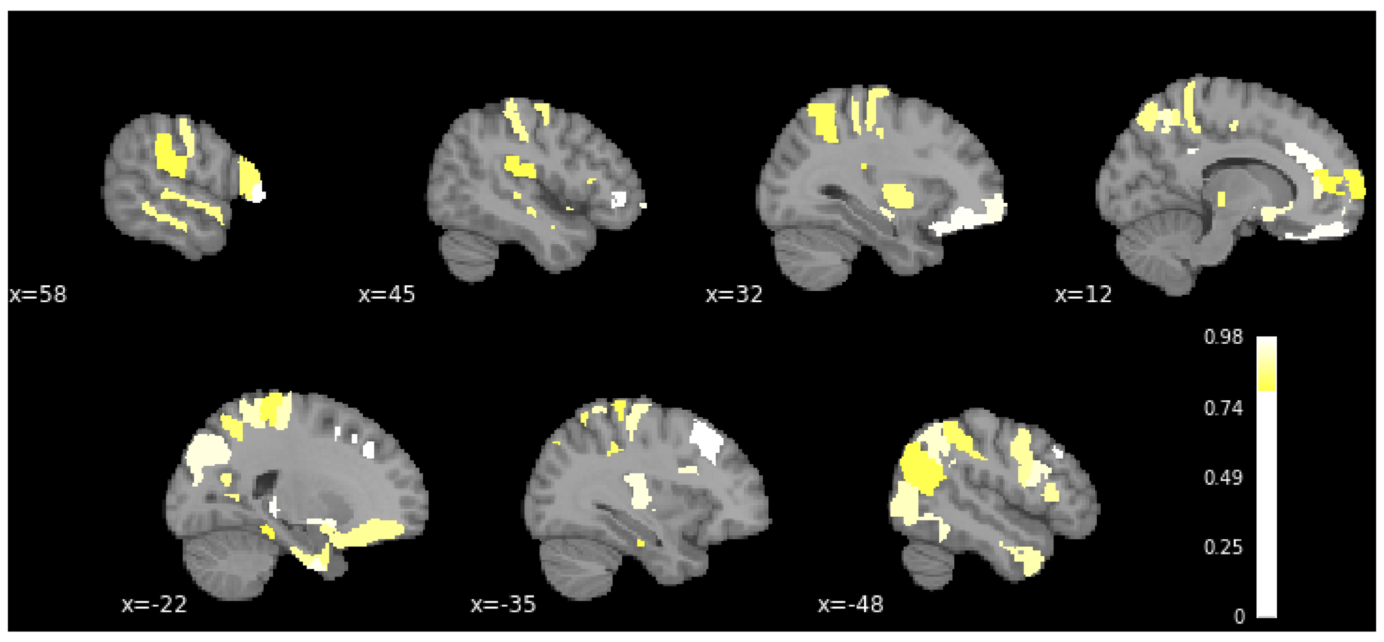
Data

- 72 subjects (34 programmers and 38 naïve) participated in 3-day, intro to python courses, consisting of both theoretical classes and practice.
- All subjects were scanned for structural and multi-shell DWI images within a 3-day period before and after the course.
- Each scan was parcellated into 274 ROIs based on the brainnetome atlas [4] and two maps were computed:
  - Mean diffusivity (MD) was computed for each voxel and averaged for each ROI.
  - CSD-based deterministic tractography was computed, and connectivity matrices were computed for each scan, weighted by the number of tracts connecting each two ROIs.

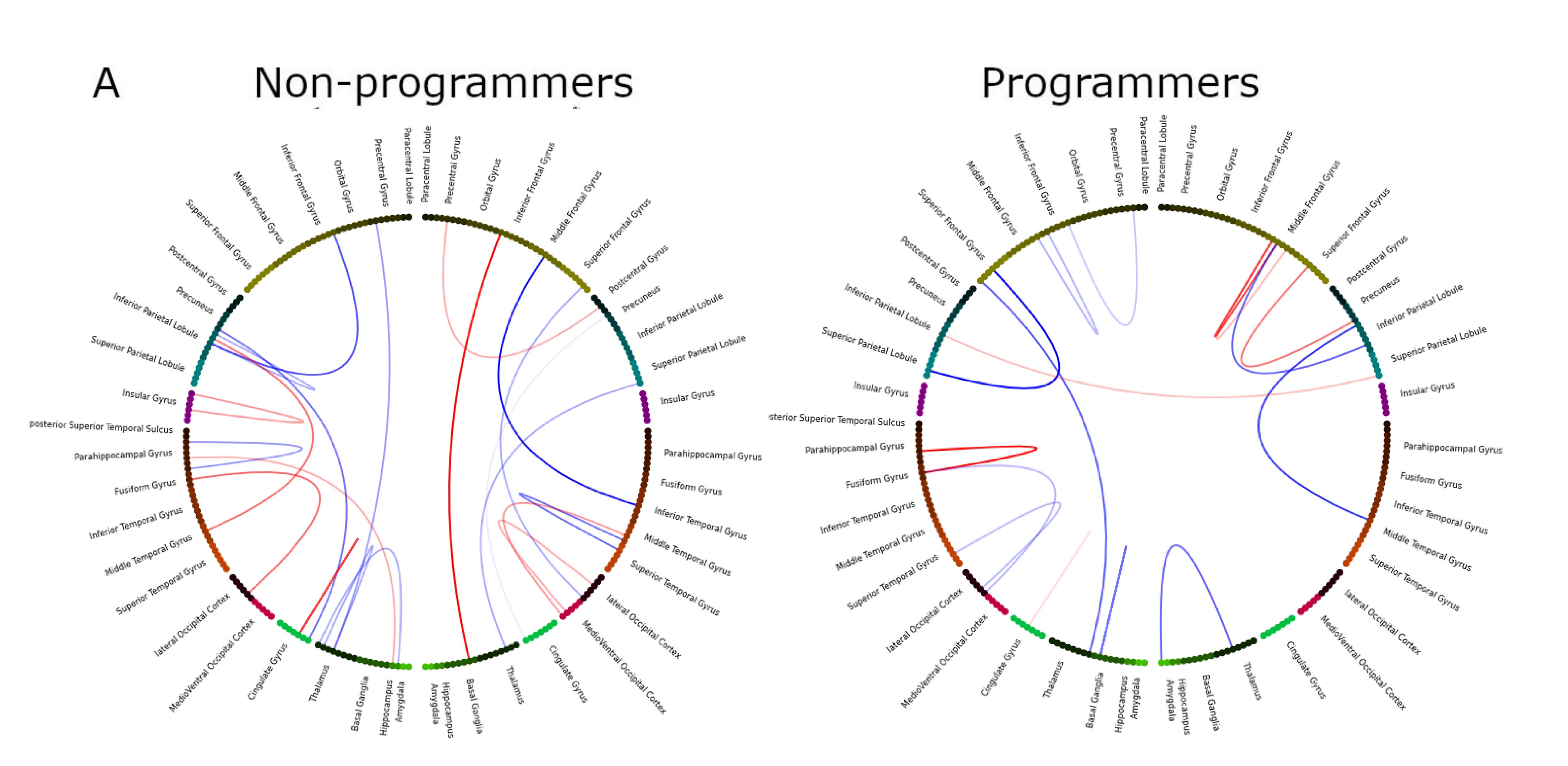
Changes in Mean Diffusivity

We used a mixed-model ANOVA to examine the effect of either the time of scanning, the subject group or their interaction, and a pairwise t-test as post-hoc examination.

- A significant decrease in MD was observed over all subjects, mostly in the left middle frontal gyri and the right parahippocampal gyrus.
- The time * group interaction showed significantly different changes between the groups in several areas, including the bilateral inferior temporal gyrus, the right parahippocampal gyrus, and left insula and frontal gyri.
- the parahippocampal and inferior temporal gyri showed an increase in MD in the subject group, while the insular and frontal gyri showed an increase only in the control group



Change in MD over time in both subject groups. *Partial ETA squared values for areas that show a change in MD that presented a time * subject group interaction. Areas with a large effect size show either a decrease or increase in MD in one group, but not the other, throughout learning. These include the bilateral inferior temporal gyrus, the right parahippocampal gyrus, left insula and left frontal gyri.*



Changes in structural connections throughout the course. *changes measured in the non-programmers versus the programmers (control) group. We observed more changes in the non-programmer groups, especially in the right hemisphere, with a strong increase in right fronto-subcortical connections, while the control group displayed a strong increase in the left fronto-temporal connections.*

Connectome Plasticity

Changes in the connectome were examined by a pairwise t-test between corresponding edge weights. Only changes that appeared in over 50% of subjects were included.

Comparison between overall pre- and post-connectomes revealed:

- Changes mostly in inter-hemisphere connections, especially in fronto-subcortical and fronto-occipital areas.
- Specifically, a significant change in the attention network was observed.

Examination of the difference in plasticity between the groups showed:

- more changes in the non-programmer groups were observed, especially in the right hemisphere.
- Changes in the non programmer group focused on a strong increase in right fronto-subcortical connections associated with the attention network
- The control group displayed a strong increase in left fronto-temporal connections, mostly associated with language learning and processing.

Conclusions

This is the first of many groups of subjects to undergo this course. Despite the small number of scans, the results point to an apparent change in the brain's white matter and diffusion values following an intensive, real-life learning experience. The changes observed :

- Appear even after a short learning period, and are detectable right after the learning experience
- Are focused in frontal and temporal areas associated with logic, cognitive processes, and language learning
- Are different for programming experts versus naive learners.

These results are a pilot for many further explorations, that may lead to the neural networks and cognitive modules at the base of programming learning.

1. Nusbaum et al. (2017), Front. Neourosci.
2. Siegmund et al. (2014), ICSE
3. Castelhano et al. (2019), Brain Imaging Behav.
4. Fan et al. (2016) , Cereb. Cortex