Real-life computer programming learning effects on brain diffusion in naive and expert learners

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Background

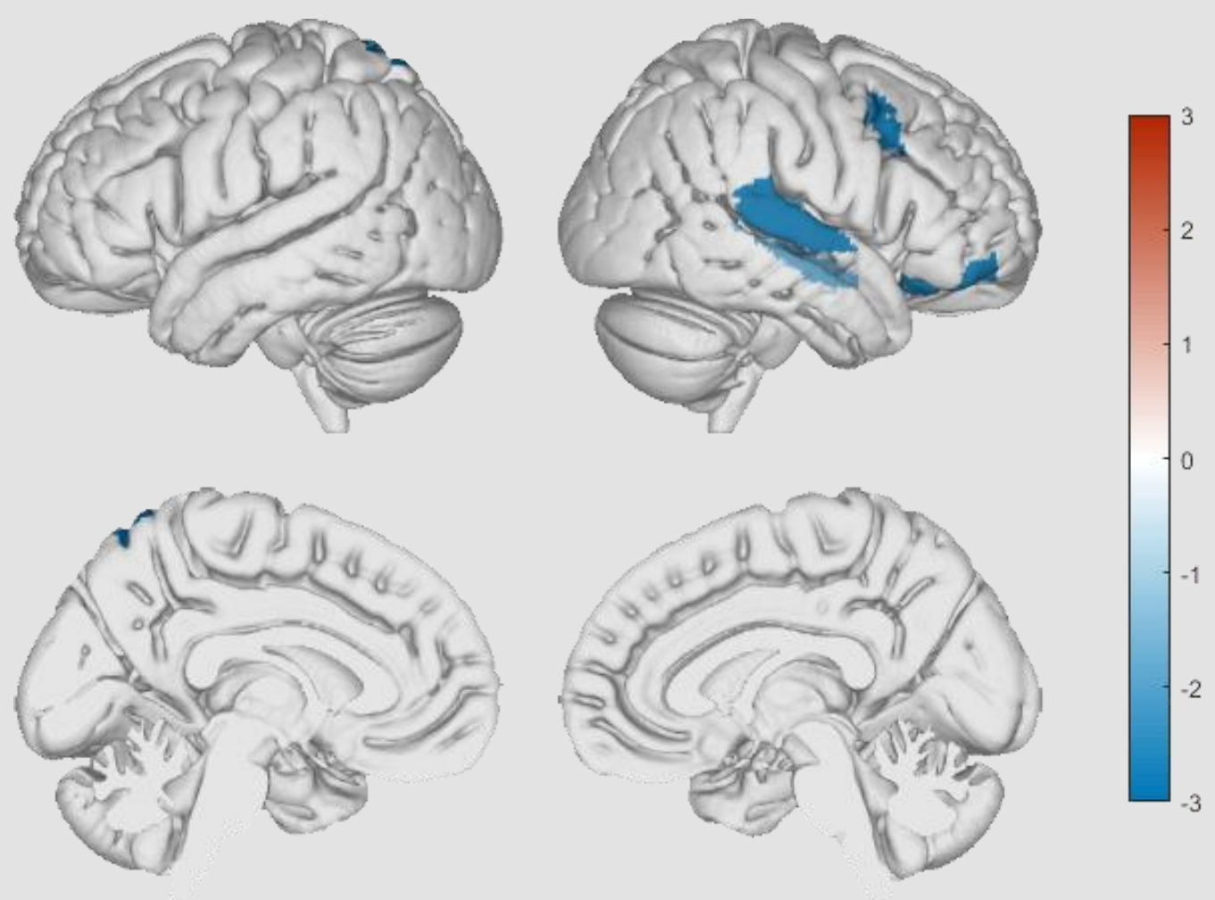
- When learning to code an individual must engage many different cognitive skills, including logics, arithmetics, language and attention. For example, the act of debugging code entails more activation in networks related to attention, working memory and planning, mostly in the right hemisphere, while the act of reading code or fixing syntax errors activates language related areas[1,2].
- The changes that learning processes induce in the brain takes a major part in the research of learning. These changes, while happening at the cellular level, can be measured or modeled by imaging methods. for example, previous studies have shown that neural plasticity in learning can be observed in a decrease in the MD measured in the gray matter[3].
- In this study we observe neuroplasticity induced by real-life learning experiences, as measured in diffusion imaging and observed in changes in the mean diffusivity (MD). This measure has been observed as a biomarker for microstructural changes induced by different types of learning, and is used in this study to examine the neuroplasticity during the learning sessions.

Difference between groups

Difference between the two groups was observed mostly in the right hemisphere, where all areas with a significant difference had higher MD values for the programmers' group.

In the left hemisphere, these included the superior parietal lobule, in an area associated with a language use among other high level processing tasks.

In the right hemisphere differences were seen in temporal and frontal areas homologues to areas associated with language and semantic perception, areas associated with attention and theory of mind, and the insula.



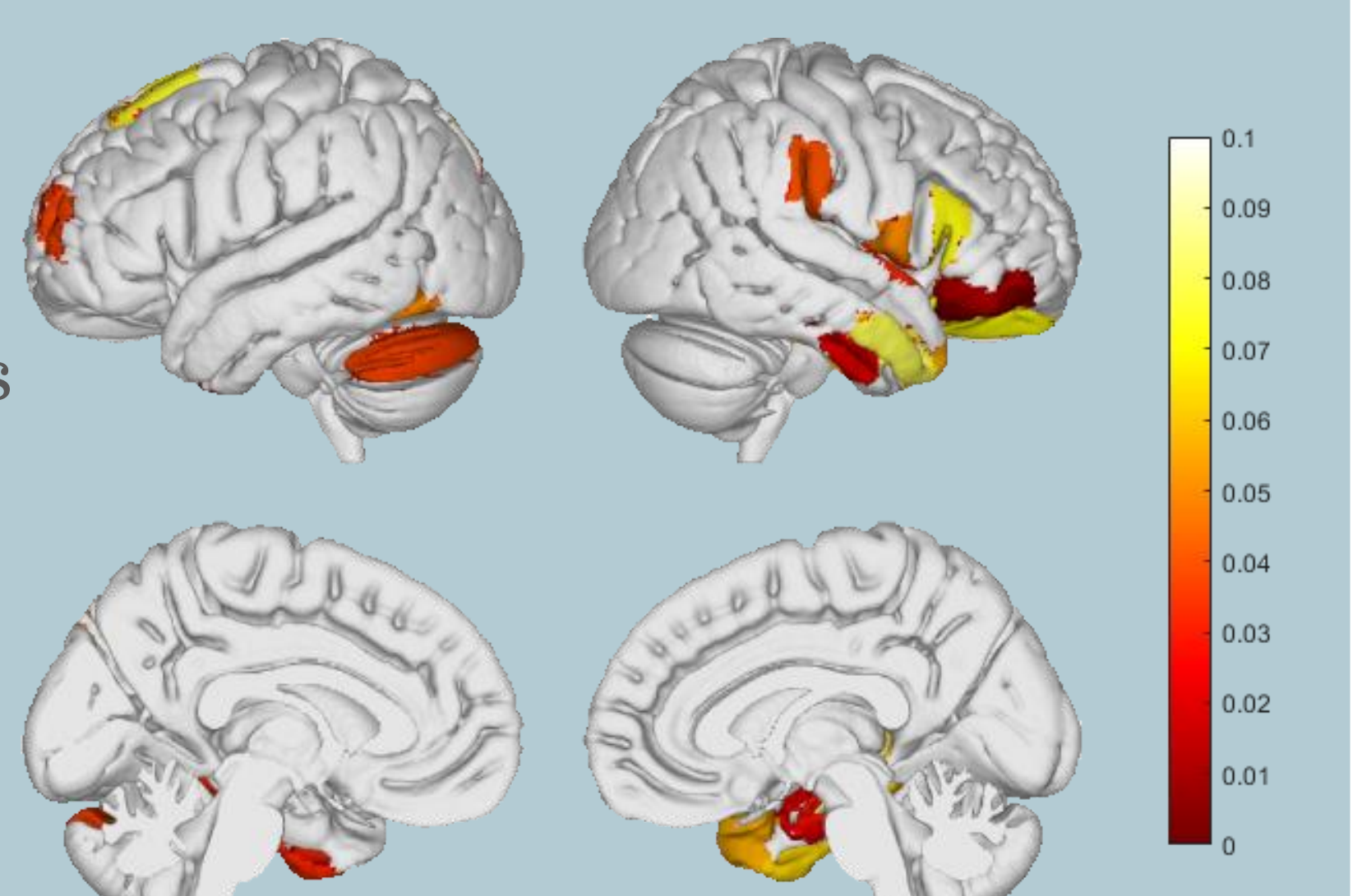
difference in MD between groups. T values of the post-hoc t-test for the difference between programmers and non-programmers for areas with $p<0.05$. The areas measured were only those that had a significant result in the mixed model anova. Negative values represent areas where the non-programmers' MD was significantly lower than the programmers'.

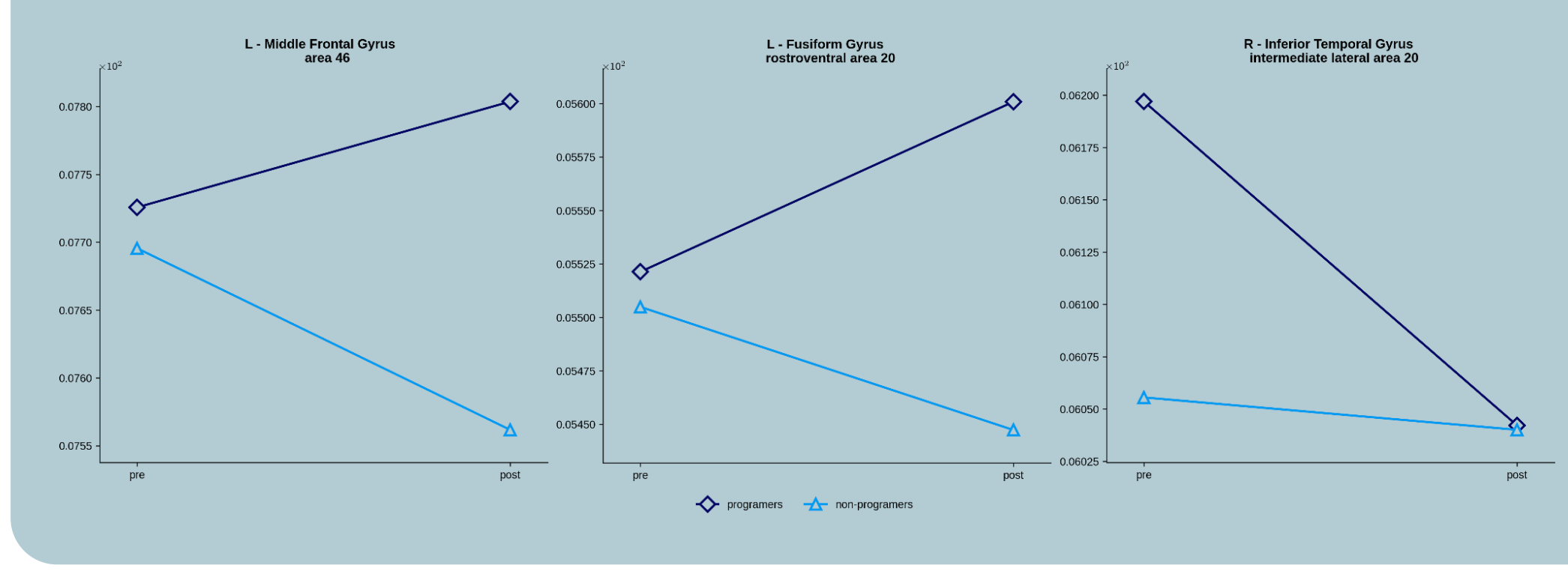
Changes induced by learning

For the time effect, a significant decrease in MD was observed in the right amygdala and left ventral caudate nucleus, along with temporal and frontal areas associated with attention, high level processing and working memory, including the bilateral inferior temporal gyrus, the right superior frontal gyrus and the left parahippocampal gyrus and middle frontal gyrus. An increase in MD was observed in the right inferior temporal gyrus and parietooccipital sulcus and in the cerebellum.

For the interaction effect, areas with a decrease in MD in the naïve group included the right inferior temporal gyrus and the left FFA, along with the left middle frontal gyrus in areas associated with working memory and attention.

A decrease in MD in the programmers' group was observed in a larger variety of areas associated with high level processing, semantics, language and attention. Those areas include the right inferior and superior temporal gyri, the right orbital gyrus, inferior parietal lobule, parahippocampal gyrus, the hippocampus and the amygdala.





Interaction effect of the change in MD over time between the groups. Above - p values of the interaction effect for areas with $p<0.1$. To the left - interaction plots for the areas located. Programmers are marked with dark blue and non-programmers in light blue

References

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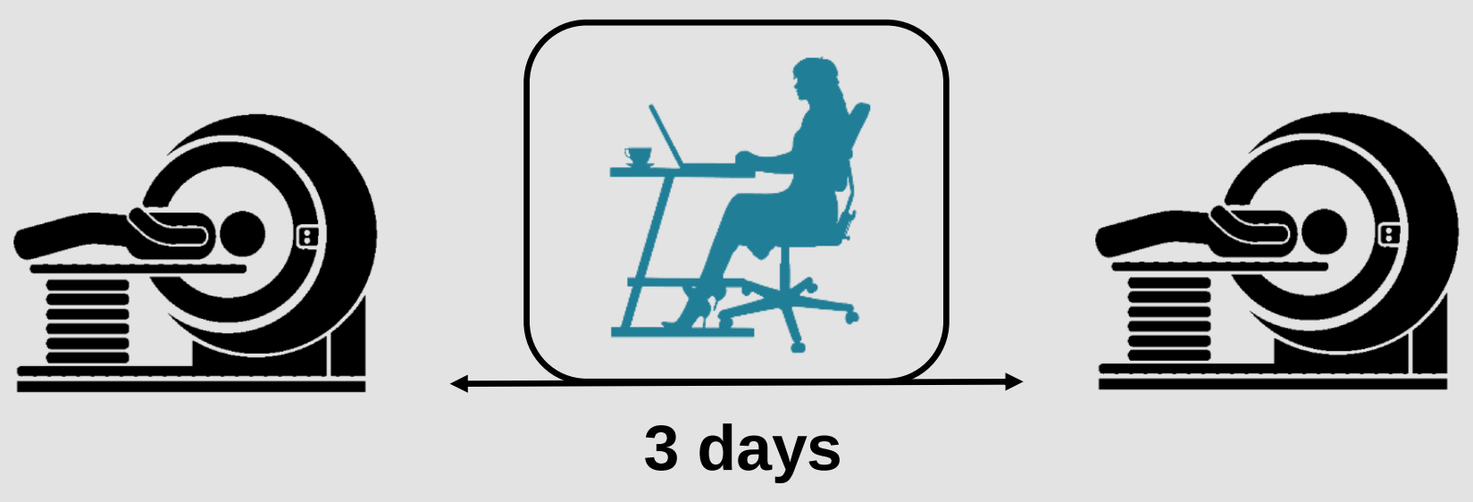
Data acquisition

Participants in this experiment underwent a 3-day, intro to python course:

- 89 students in 6 groups of 12-20 participants
- 44 (age 32.6 (8.6), 26 female) had no past experience with coding of any kind (naïve), and 45 (age 33.8 (10.8), 19 female) have learned or worked with code in other programming languages and were considered a control group (experts).
- All subjects were scanned for structural and multi-shell DWI images within a 3-day period before and after the course.
- Participants also underwent a programming-anxiety questionnaire before the course, adapted and translated to Hebrew from the Computer Anxiety Rating Scale[4].



MRI data analysis

The Brainnetome atlas[5] was registered to each subject's native space using FSL flirt and fnirt algorithms . MD was computed for each voxel using DiPy dti_fit. The mean diffusivity values were averaged over each atlas ROI.

Linear mixed models were fitted for each ROI. The models were formed as:

$$MD \sim time \ \times group + (1|subject) + covariates$$

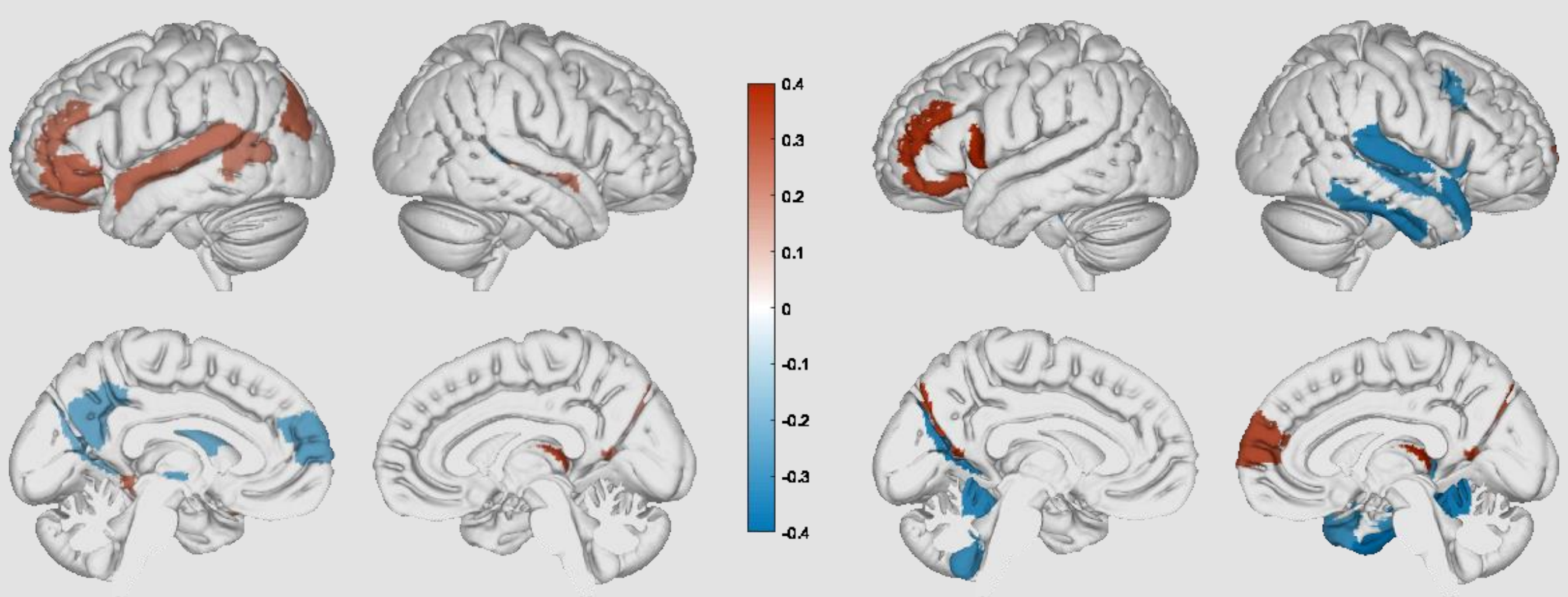
Where time signifies pre-/post- course scan, group is naïve/experts and the covariates included were age and gender.

Paired t-test was used for post hoc analysis for the time effect (i.e. changes in MD between scans before and after the learning experience for the naive subjects) and unrelated t-test was used as post hoc analysis for the group effect (difference in MD between naive and expert participants at the course onset).

Computer anxiety and MD

Of the participants in all courses, 71 participants (36 non-programmers) have filled the form. T-test between the anxiety values for the non-programmers versus the programmer group showed that programmers had a significantly lower anxiety value than the naive subjects ($p=0.011$).

Pearson's correlation between each area's ΔMD and the participants computer anxiety score showed a negative correlation in areas seen in our other results – that is, subjects' anxiety was connected to changes in areas that were either different between the groups at the onset of the course or changed more significantly during the course



Correlation between changes in MD and CARs results. Correlations for the non-programmers group. Only significant correlations ($P < 0.05$, $|r| > 0.25$) are presented. On the left – all participants. On the right – naïve learners.

Conclusions

- The results point to an apparent change in the diffusion values following a real-life learning experience. These changes appear even after a short learning period, and are detectable right after the experience.
- The changes are focused in right frontal and temporal areas associated mostly with attention for all subjects, while for programming experts we also observed more changes focused on language areas.
- There is a large variance in programming background among the programmers' group. This might explain the small difference between the groups in the interaction effect.
- These results show a potential prominent change in the brain initiated by learning, and will lead to more works pinpointing areas related to learning success.
- These results may point to the neural networks and cognitive modules at the base of programming learning and might help predict, based on the baseline scans, which students have a stronger potential to succeed.