Studying continuous structural neuroplasticity during learning using diffusion MRI

Minducate
Research & Innovation Center for Science of Learning

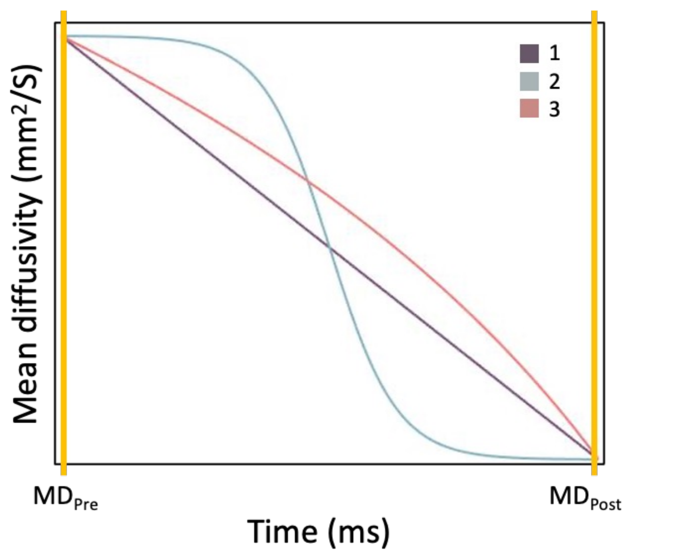
Naama Friedman[1], Inbar Paretz[2], Ido Tavor[1,2]

[1]Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel [2]Sagol School of Neuroscience, Tel Aviv University, Tel Aviv, Israel

Sackler Faculty of Medicine
Tel Aviv University

Introduction

- Structural neural modifications have been detected after short learning periods using Magnetic Resonance Imaging (MRI) (Sagi et al., 2012; Tavor et al., 2020, 2013; Brodt et al., 2018; Jacobacci et al., 2020).
- Previous studies compared 3D images collected at two time-points: before and after learning.
- Here we characterize **continuous microstructural changes during learning** by adding the time dimension to structural MRI scans.
- We focus on learning-induced mean diffusivity (MD) decrease.
- We suggest a novel 4D spatio-temporal dataset that will provide insights into the dynamic nature of neuroplasticity.



$MD_{Pre} - MD_{Post} = \Delta MD_1 = \Delta MD_2 = \Delta MD_3$

Figure 1. Illustrated differences in continuous learning-related MD decrease. Simulated examples of three possible curves of MD decrease that may be discovered by adding the time dimension and investigating the continuous change.

Data

- Thirty participants were scanned in a Siemens PRISMA MRI scanner while performing a finger tapping task (Karni et al., 1995).
- Total task duration was 33.5 minutes, divided into 24 blocks of 60 seconds with a 25-second rest period between blocks.

1-2-3-4-1

Mean diffusivity measurement

To create a continuous measurement of structural changes, we used a novel gradient scheme from which we calculated the tensor using a sliding window method.

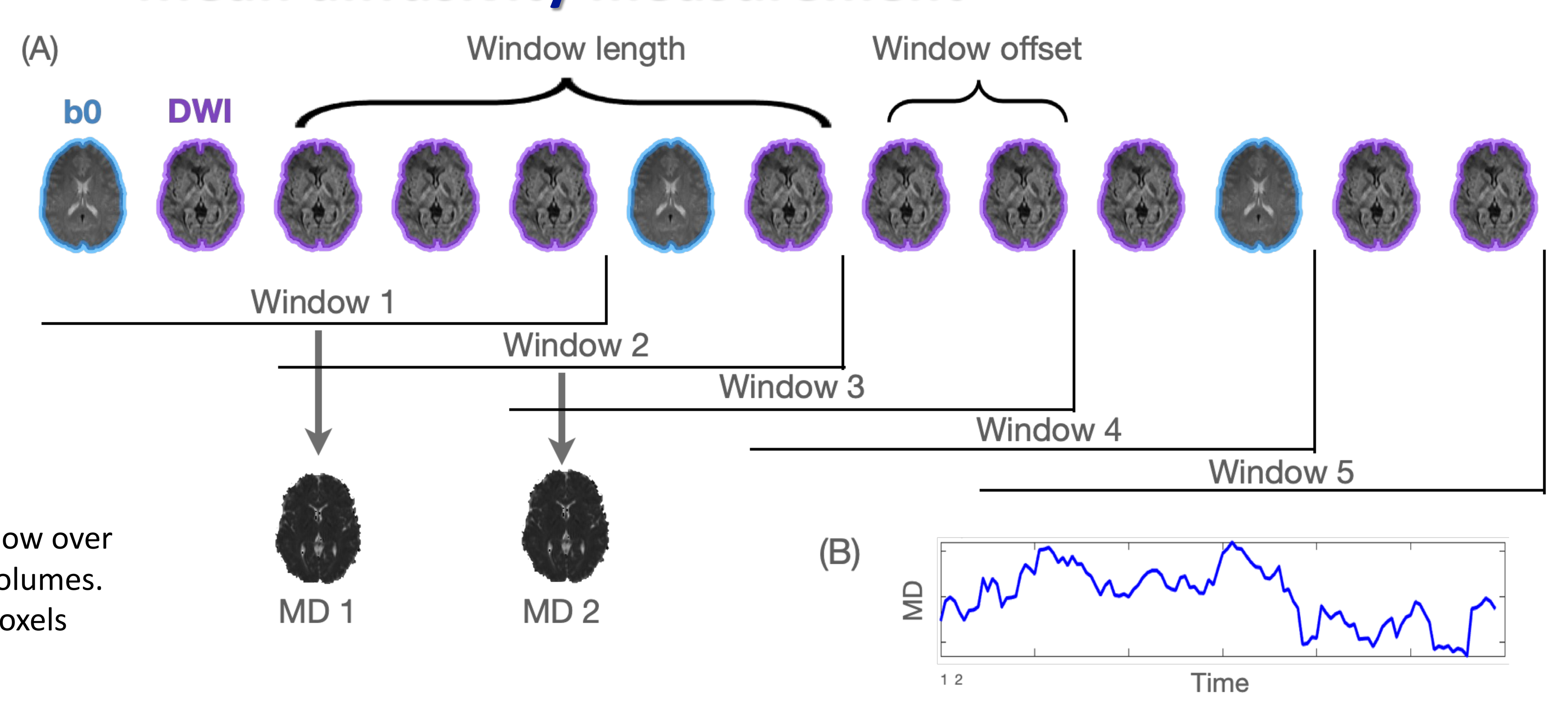


Figure 2. (A) An illustration of a sliding window over multiple diffusion weighted images (DWI) volumes. (B) For each window, an MD value in each voxels was calculated to build a 4D dataset.

Behavioral results

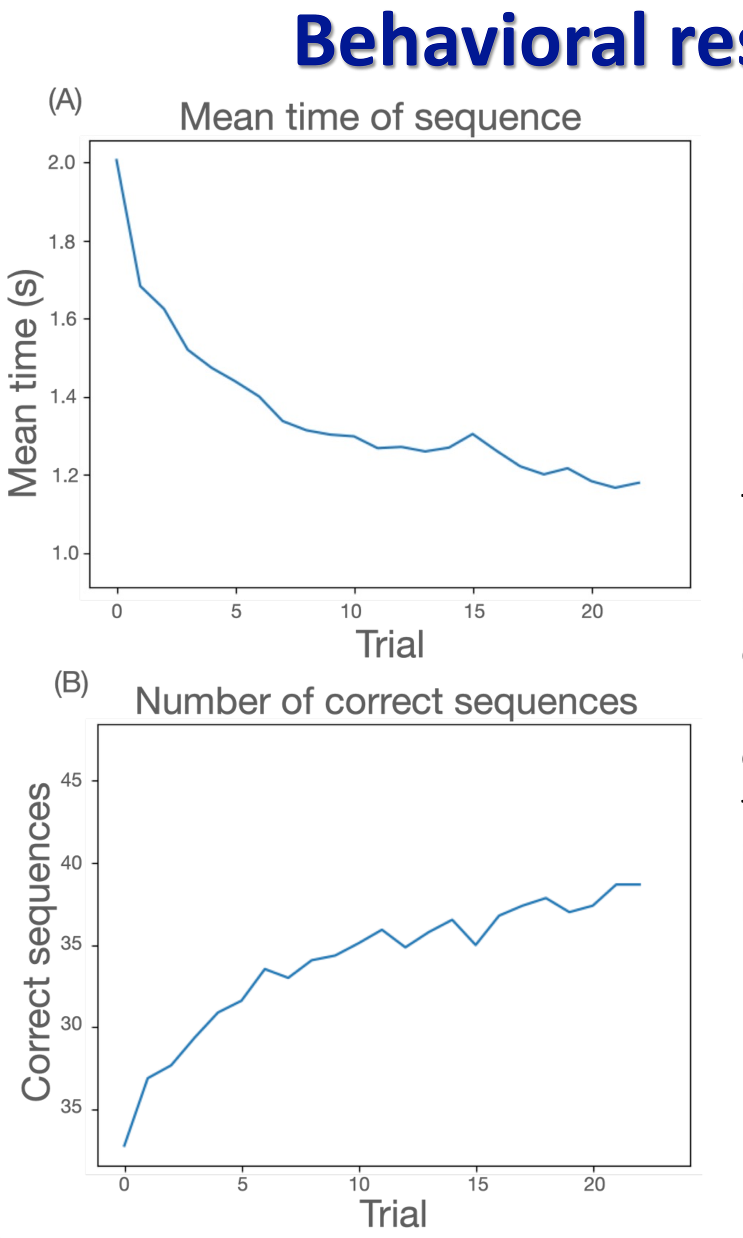
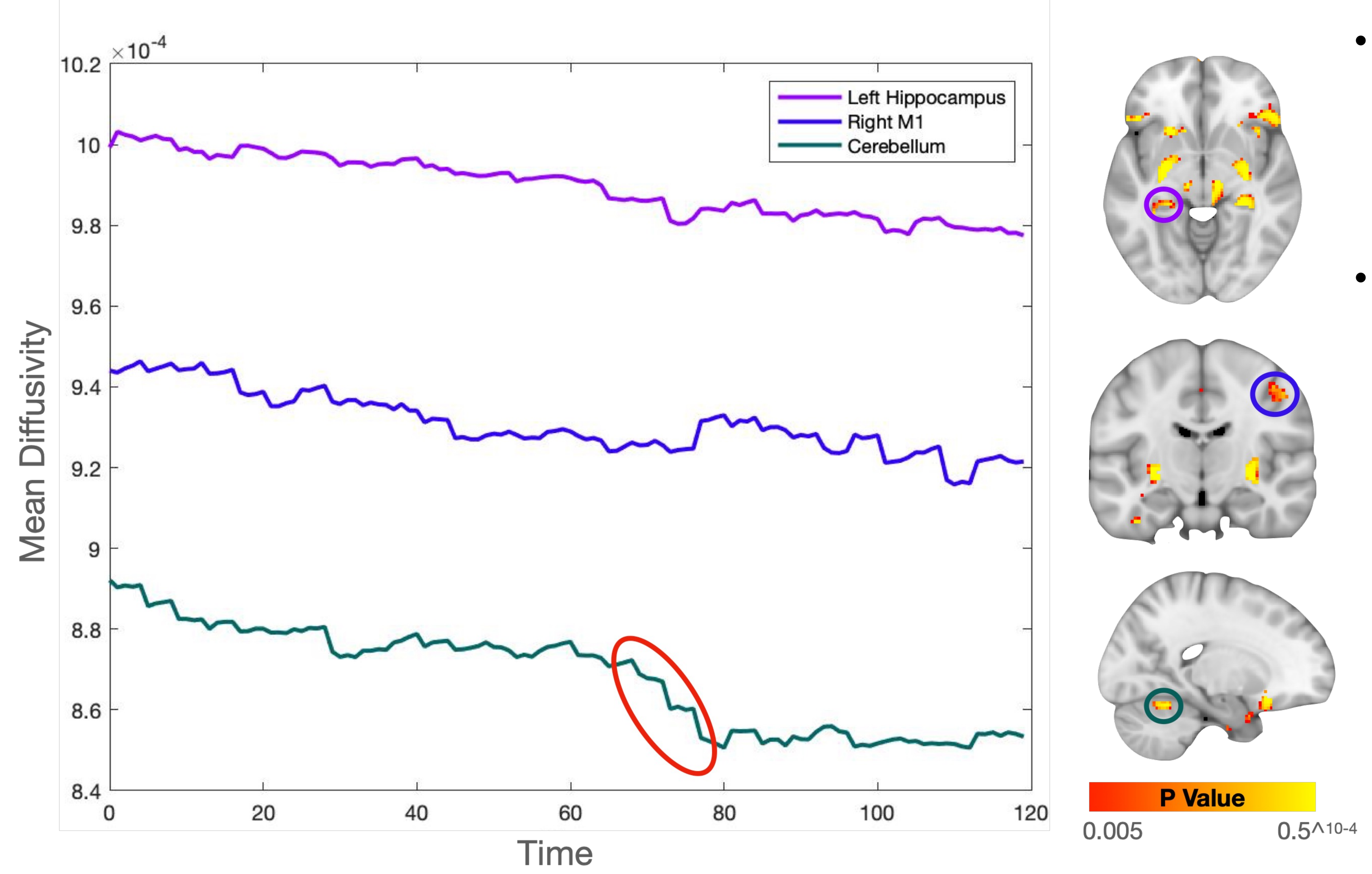


Figure 3. Averaged behavioral scores for 30 participants who performed a finger tapping task for 33.5 minutes (24 trials). (A) Mean sequence duration per trial. (B) Mean number of correct sequences per trial. Both measures indicate successful learning.

Continuous changes in brain microstructure while learning



- Significant changes ($p < 0.005$, cluster size > 30) in microstructural properties following learning were found in several brain areas.
- These areas differed in the temporal development of learning-induced changes.

Figure 4. Continuous changes in MD in three ROIs averaged across 30 participants. (Purple) Left hippocampus; (Blue) Right primary motor cortex (M1); (Green) Bilateral Cerebellum; A significant decrease in MD was found in all areas, but while M1 and the hippocampus presented a linear decrease, the cerebellum showed a steplike decrease (marked in red).

"Similarity networks"

We examined networks of brain regions with similar patterns of MD changes, focusing on the Brainnetome (BNA) atlas (Fan et al., 2016) segments in which MD decreased during the task.

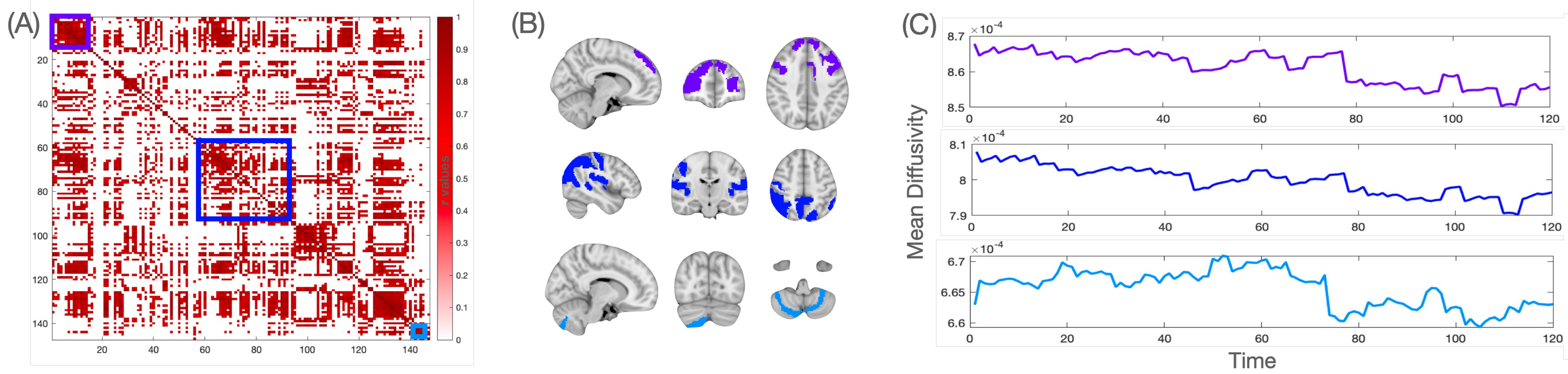


Figure 5. (A) Correlation matrix for the patterns of MD changes in BNA areas that showed an MD decrease during learning. Results are thresholded at Pearson's $r > 0.7$. (B) Three networks were found showing similar patterns of MD changes. (C) Averaged timecourses of MD changes during learning in these three networks.

Conclusions

Our novel MRI protocol allows the exploration of dynamic aspects of neuroplasticity, such as which brain areas are the first to change in the process of learning and which follows, or which areas are gradually changing as opposed to others that demonstrate stepwise modifications. We suggest that different task-related brain areas demonstrate different patterns of structural modifications.

@LabTavor

References

1. Brodt, S., Gais, S., Beck, J., Erb, M., Scheffler, K., & Schönauer, M. (2018). Fast track to the neocortex: A memory engram in the posterior parietal cortex. Science, 362(6418), 1045-1048.
2. Fan, L., Li, H., Zhuo, J., Zhang, Y., Wang, J., Chen, L., & Jiang, T. (2016). The human brainnetome atlas: a new brain atlas based on connectional architecture. Cerebral cortex, 26(8), 3508-3526.
3. Jacobacci, F., Armony, J. L., Yeffal, A., Lerner, G., Amaro Jr, E., Jovicich, J., ... & Della Maggiore, V. (2020). Rapid hippocampal plasticity supports motor sequence learning. *Proceedings of the National Academy of Sciences*, *117*(38), 23898-23903.
4. Kami, A., Meyer, G., Jezzard, P., Adams, M. M., Turner, R., & Ungerleider, L. G. (1995). Functional MRI evidence for adult motor cortex plasticity during motor skill learning. *Nature*, *377*(6545), 155-158.
5. Sagi, Y., Tavor, I., Hofstetter, S., Tzur-Moryosef, S., Blumenfeld-Katzir, T., & Assaf, Y. (2012). Learning in the fast lane: new insights into neuroplasticity. *Neuron*, *73*(6), 1195-1203.
6. Tavor, I., Hofstetter, S., & Assaf, Y. (2013). Micro-structural assessment of short term plasticity dynamics. *Neuroimage*, *81*, 1-7.
7. Tavor, I., Botvinik-Nezer, R., Bernstein-Eliav, M., Tsarfaty, G., & Assaf, Y. (2020). Short-term plasticity following motor sequence learning revealed by diffusion magnetic resonance imaging. Human brain mapping, 41(2), 442-452.