

Memory Retrieval and Monitoring in the Cerebellum

Between June 23rd and August 25th, 2008, I conducted research in Professor David Gallo's memory lab at the University of Chicago as part of the NIH Summer Program in Neuroscience and Neuroengineering. In the two years preceding my addition to the lab, Dr. Gallo and colleagues had amassed a sizeable database of neuroimages from functional magnetic resonance imaging (fMRI) studies that had largely been unanalyzed. Of particular interest to the lab was the activation of dorsolateral prefrontal cortex (PFC) during episodic memory tasks associated with post-retrieval memory monitoring strategies. Specifically, this DLPFC region in Brodmann areas (BA) 9 and 46 was strongly activated during word criterial recollection tests with respect to picture criterial recollection tests, suggesting that the DLPFC is more activated the more "effortful" or difficult the memory task is.¹ In addition to the DLPFC region, five regions in the cerebellum were similarly activated during word memory tests as opposed to picture memory tests. During my time in the lab, I analyzed fMRI neuroimages and conducted region-of-interest studies of the cerebellum with respect to episodic memory to construct a sound theoretical framework for cerebellar involvement in memory and other higher cognitive functions.

Historically, the cerebellum has been solely identified with motor function, although in the past ten years the body of literature citing cerebellar activation during cognitive tasks has become quite substantial.^{2,3} Recently, some have suggested that the cerebellum is involved in executive function, or cognitive control, and that the cerebellum helps to coordinate and plan cognitive processes such as memory, language, and learning.⁴ From these historical precedents, I hypothesized that the cerebellum is involved in coordinating both memory retrieval and monitoring, and that it should therefore be more active when memory retrieval is more effortful and post-retrieval memory monitoring is greater. In addition, for the cerebellum to coordinate memory retrieval and monitoring, I hypothesized that cerebellar activity is associated with activation in PFC regions implicated in memory retrieval and monitoring. Furthermore, such a connection between the PFC and the cerebellum is feasible due to anatomical studies which have identified a contralateral cortical-cerebellar pathway which involves the pons, dentate, red nucleus, thalamus, and basal ganglia.² Since semantic memory retrieval and monitoring is typically identified with the left PFC and the theoretical cortical-cerebellar loop is contralateral, I hypothesized that there would be greater activation in the right cerebellar hemisphere during word memory tests as opposed to non-semantic, visual memory tests.

¹ Gallo et al., "Prefrontal activity and diagnostic monitoring of memory retrieval: fMRI of the criterial recollection task." *J Cogn Neurosci*. 2006;18(1):135-48.

² Andreasen et al., "The cerebellum play a role in conscious episodic memory retrieval." *Hum Brain Mapp*. 1999;8(4):226-34.

³ Desmond, J. and Fiez, J., "Neuroimaging studies of the cerebellum: language, learning, and memory." *Trends in Cog Sci*. 1998;2(9):355-62.

⁴ Marklund et al., "Unity and diversity of tonic and phasic executive control components in episodic and working memory." *Neuroimage*. 2007;36(4):1361-73.

I performed two sets of five fMRI contrasts each which alternatively controlled or varied memory retrieval success, memory monitoring, memory type (word, picture, or new), and test type (word or picture test). After initial data exploration, four regions of the cerebellum were activated at a statistically significant threshold of $p = 0.001$, and these regions of activation fell into two categories: two regions were consistently activated during successful memory retrieval of a particular memory type (word or picture) whereas the other two regions were more activated during the word test as opposed to the picture test regardless of retrieval success, suggesting that these regions are involved in planning particular memory orientations. Interestingly, the right cerebellar hemisphere was more activated during semantic memory tasks while the left cerebellar hemisphere was more often identified with retrieval of visual memories.

After this preliminary narrowing of data to statistically significant regions of cerebellar activation, a more rigorous conjunction contrast was developed to control for memory retrieval success as well as memory type, such that the only variable was the test type. In this final step, I found strong activation during the word test versus the picture test in the pyramis of the right cerebellar hemisphere, posterior lobe, with MNI coordinates of (6, -27, -30) and no activation during the picture test versus the word test. This suggests that the cerebellum, and the pyramis in particular, is involved in coordinating memory monitoring as well as retrieval. The pyramis was found to be more activated when the memory task was more effortful and cognitive processing load was heavier, supporting claims that regions in the cerebellum are involved in handling cognitive planning and coordination. Furthermore, this research corroborates and elaborates upon a 2007 study by Marklund et al. that found activation in the same cerebellar region during episodic and working memory tasks.⁴ This research also supports the 2004 claim by Gallo et al. that words are less easily remembered in comparison with pictures due to familiarity-monitoring strategies versus use of the distinctiveness heuristic.⁵ Finally, and perhaps most conclusively, I found strong activation of a PFC region in BA 10 with MNI coordinates (24, 60, -6) that has been previously implicated with episodic memory retrieval, and that is correlated with activity in the (6, -27, -30) region of the cerebellum. This last correlation supports the proposed cortical-cerebellar loop through which the cerebellum can function to plan higher cognitive processes in the PFC.

⁵ Gallo et al., "Reducing false recognition with criterial recollection tests: Distinctiveness heuristic versus criterion shifts." *Jour of Mem and Lang*. 2004;51:473-93.