A DTI INVESTIGATION ON NEURAL CIRCUIT UNDERLYING METAMEMORY-DRIVEN COGNITIVE OFFLOADING

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Introduction

Prospective memory refers to the ability to remember an intention to be fulfilled under an appropriate context in the future. Although successful fulfillments of delayed intentions constitute a substantial part of meaningful life, 50%-70% of memory failures actually stem from failures in prospective memory. Therefore, people may choose to use external aids to support internal memorization of delayed intentions. In cognitive science, such a strategy of using physical actions to reduce information processing requirements and cognitive demands in prospective memory is known as cognitive offloading.

Recent evidence has also demonstrated that cognitive offloading is causally driven by metacognition or metamemory, the ability to monitor and control one's own memory process. Recent evidence has also demonstrated that cognitive offloading is causally driven by metacognition or metamemory, the ability to monitor and control one's own memory process. However, little is known about how the decision to use external aids and offload memory demand is implemented in the brain at the neural level.

In the present study, we sought to extend these previous findings by employing diffusion tensor imaging (DTI) to investigate the connections between different brain regions that support the metamemory-driven cognitive offloading. Based on the previous findings, we focused on the following white matter fiber tracts: fornix, uncinate fasciculus (UF), superior longitudinal fasciculus (SLF), cingulum bundle, and para-hippocampal cingulum bundle (HCB).

Materials and Methods

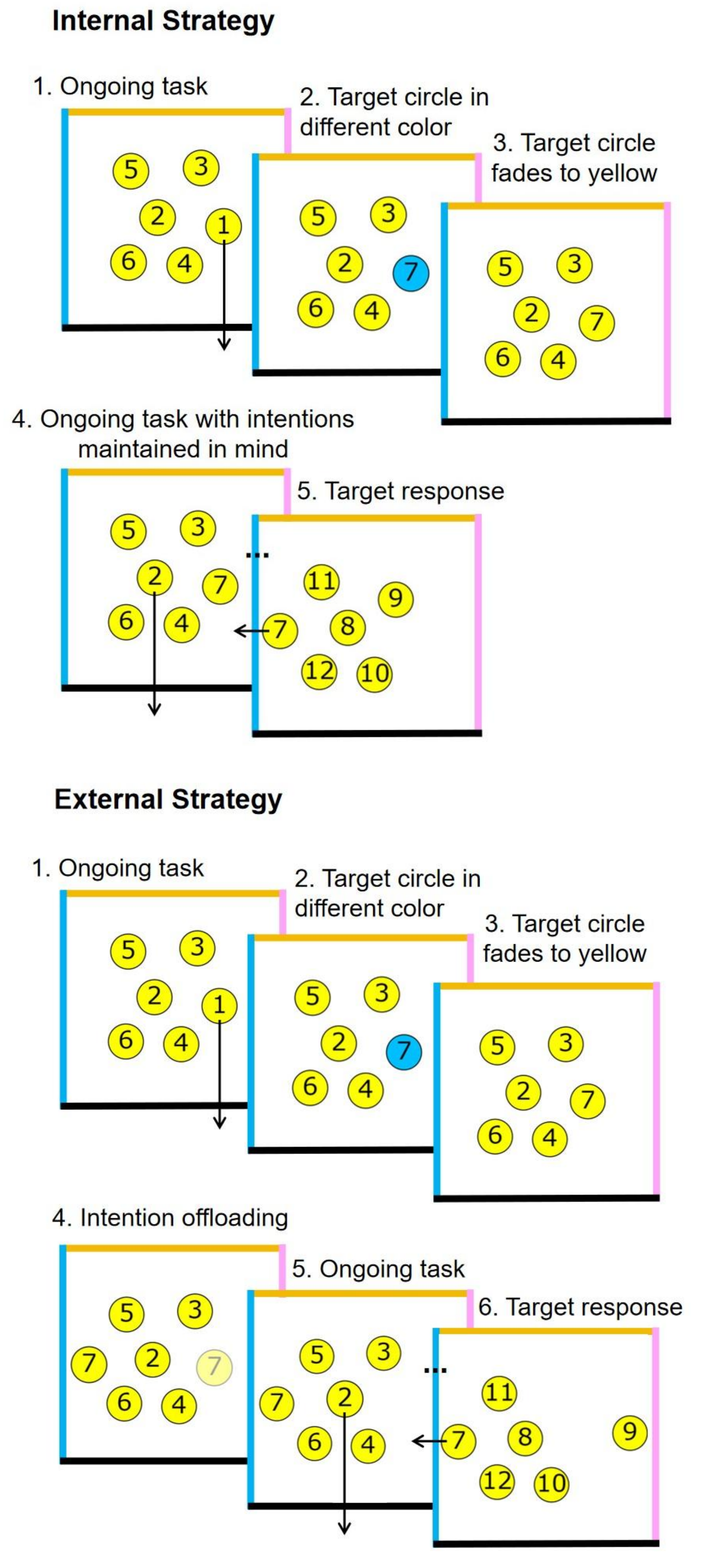

Fig. 1 Experimental paradigm. Intention offloading task by Gilbert (2015)

38 healthy adults participated in the intention offloading task (See *Fig. 1*) and were asked to report separate confidence ratings (i.e., the prospective confidence) for successfully dragging all non-yellow circles to their corresponding locations in each trial using internal memory or external reminders.

The structural integrity of individual white matter fiber tracts was assessed using the Diffusion Tensor Imaging (DTI) technique.

Results

Behavioral results

The accuracy in forced internal conditions (*M* = 60.3642, *SD* = 15.54) was lower than in the forced external conditions (*M* = 95.6583, *SD* = 8.4020; *t*(50.775) = -11.649, *p* <.001).

The estimated actual indifference point (*M* = 5.5967, *SD* = 1.8494) was smaller than the optimal indifference point (*M* = 6.1827, *SD* = 1.3179; *t*(59.644) = -1.5047, *p* = .0344).

Participants show positive reminder bias (*M* = .5860, *SD* = 2.0357; one-sided t-test, *t*(33) = 1.6785, *p* = .0257).

Reminder bias was correlated with metacognitive bias in internal trials (*r*(32) = -.384, *p* = .0125).

DTI Tractography and relationship with behavioral indices

Table 1 Correlation Results between Behavioral Indices and Interested WM Fibre Tracts

	ACC_{FI}	ACC_{FE}	internal confidence	external confidence	internal metabias	external metabias	reminder bias
Fornix	.225	.064	.168	.304	.018	.231	.392 *
UF	.199	.060	.105	.210	-.026	.152	-.040
CB	-.236	-.069	-.288	-.202	-.124	-.140	.048
HCB	-.201	.119	-.050	-.325	.080	-.349 *	-.117
SLF	-1.02	-.065	-.397 *	-.157	-.313	-.103	.009

Note: UF stands for uncinate fasciculus, CB stands for cingulum bundle, HCB stands for para-hippocampal cingulum bundle, SLF stands for superior longitudinal fasciculus. *** indicates p value < .001, ** indicates p value < .01, * indicates p value < .05

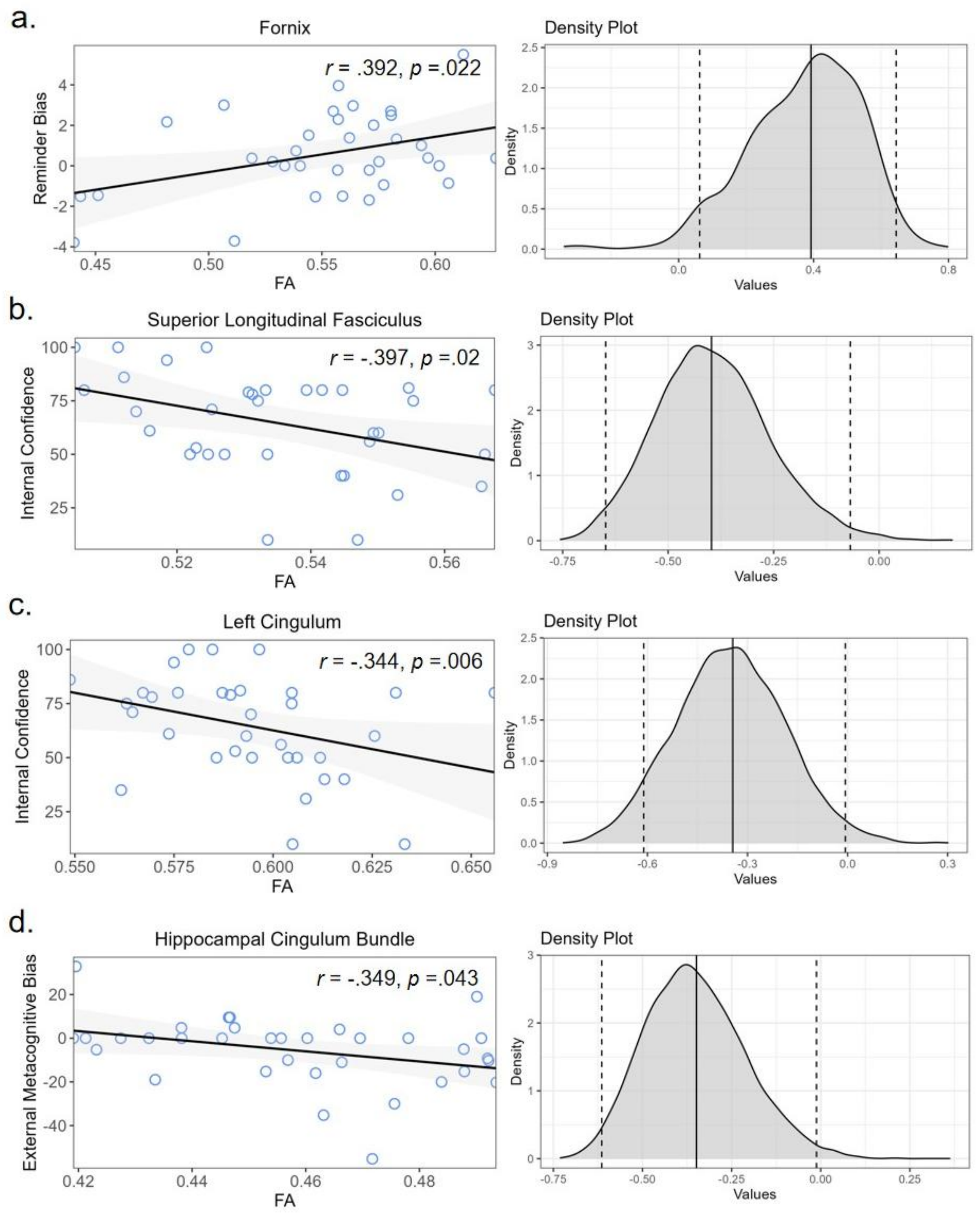

Fig. 2 Correlations with bootstrapping analysis.

a. Positive orrelation between fornix FA and reminder bias (*r*(32) = .3922, *p* = .0218, 95% CI [0.0623, 0.6448]);

b. Negative correlation between superior SLF FA and confidence using internal memory (*r*(32) = -.3973, *p* = .0200, 95% CI [-0.6483, -0.0683]);

c. Negative correlation between left cingulum FA and confidence using internal memory (*r*(32) = -.3442, *p* = .0462, 95% CI [-0.6112, -0.0068]);

d. Negative correlation between para-hippocampal cingulum FA and external metacognitive bias (*r*(32) = -.3486, *p* = .0433, 95% CI [-0.6143, -0.0118]).

We also found the right SLF FA as a moderator for the correlation between reminder bias and internal metacognitive bias (b = 2.0972, p = .0086).

Discussion

(1) Fornix

Fornix connects the hippocampus (episodic memory; retrieval of spatial memory across short delays) to modulatory subcortical structures, including the anterior thalamus that has reciprocal connections with the prefrontal cortex (relaying integrated information from the hippocampal-diencephalic network to prefrontal areas).

Higher fornix integrity contributes to a more efficient transmission of mnemonic information, prompting the prefrontal cortex to interpret the mnemonic challenges or deficits into a desire for external reminders as a compensatory mechanism to support the task performance.

(2) Superior longitudinal fasciculus (SLF)

SLF connects the inferior parietal lobule (IPL) (mnemonic metacognition; 'output gating' of prospective memory for information selection) to dorsolateral prefrontal cortex (DLPFC) (domain-general metacognition; 'input gating' of mnemonic information related to the primary decision-making and computing metacognitive judgements).

A higher the integrity of SLF allows the DLPFC to more precisely use the first-order decision-making related information from IPL to compute metacognitive evaluations.

(3) Left cingulum bundle

CB connects precuneus (metamemory-related region) to dorsal anterior cingulate cortex (dACC) (task-generic metacognitive monitoring and control).

Higher left cingulum integrity contributes to better at integrating self-referential information with metacognitive monitoring signals; less inclined to overestimate their mnemonic capabilities.

(4) Para-hippocampal cingulum bundle (HCB)

Para-hippocampal cingulum connects hippocampus to precuneus.

Higher HCB integrity contributes to a more efficient transmission of mnemonic information for meta-memory eveluations, leading to less metacognitive bias towards setting reminders.

Conclusion

Despite extensive research into the factors that trigger cognitive offloading, neural processes underlying the metacognition-driven decision to employ external aids and offload memory remain unclear. In this study, we applied the DTI method to investigate the neural mechanisms behind metacognition-driven offloading. Our findings reveal that fornix, superior longitudinal fasciculus, left cingulum bundle, and para-hippocampal bundle are associated with one's metacognitive ability.

Fornix plays an important role in memory tasks (e.g., visuo-spatial memory, associative memory, and episodic memory) and has been extensively studied for memory processing and functions. Our findings lend support to studies that extend the role of fornix from memory to metamemory-guided decision making.

It is important to acknowledge that the results might slightly vary if the tracts are separated into different nodes. Future studies are expected to identify and analyze more detailed regions of tracts with regional specificity by dividing the tracts into nodes.

Acknowledgement

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