Advances in Functional Neuroimaging of Spontaneous Thought

Julia Kam Co Organizer
University of Calgary
Calgary, Alberta
Canada

Jonathan Smallwood Co Organizer
Queen's University
Kingston, Ontario
Canada

Aaron Kucyi Organizer
Northeastern University
Brookline, MA
United States

Symposium

Understanding the neural basis of spontaneous thought is an emerging question in contemporary cognitive neuroscience, which cuts across two of the most important issues facing the human brain mapping community. First, different features of ongoing experience emerge consistently at rest, making it critical to understand how these states contribute to measures in resting state analyses as currently performed. Second, contemporary studies highlight that the default mode network is a core feature of many different patterns of ongoing experience. Accordingly, a better understanding of spontaneous thought will inform both neural and cognitive perspectives on the role of the default mode network in human cognition.

Our symposium will highlight important perspectives on both a dominant methodology (resting state) and a critical question regarding neural function (the default mode network). Attendees will learn how state-of-the-art analyses, such as predictive modeling and unsupervised learning, as well as experimental approaches that account for psychological context, reveal the neural bases of spontaneous thought. Choong-Wan Woo will present evidence from fMRI multivariate pattern-based predictive modeling for representations of spontaneous, self-relevant thoughts with varying affective valence. Adam Turnbull will present fMRI evidence for context-dependent relationships between mind wandering and functional brain networks. Matthias Mittner will present a Hidden Markov Model analysis of fMRI-pupillometry to detect switches between task-focused and mind wandering states. Aaron Kucyi will describe an fMRI connectome-based predictive model of stimulus-independent, task-unrelated thought. Together, these different approaches will provide important next steps relevant to key questions facing the neuroimaging community moving forward.

Objective

- Understand the value of using diverse theory- and data-driven analysis approaches to reveal different features of ongoing thought patterns.
- Describe the nuanced, dynamic relationship between ongoing thought patterns and underlying brain network interactions.
- Elaborate on the importance of predicting subjective attentional states, and its associated real world implications.

Target Audience

We envision two main groups of target audience. 1) Researchers who are interested in a deeper understanding of the context- and content- dependent nature of ongoing thought patterns and its relevance to brain dynamics, in particular the default mode network and resting state experiments. 2) Researchers interested in implementing sophisticated analytic approaches to understand the inner workings of the healthy and diseased mind.

Presentations

When Self Comes to a Wandering Mind: Brain representations and affective dynamics of spontaneous thought

Self-relevant and autobiographical concepts are major building blocks of spontaneous thought, and their dynamics in the natural stream of thought are likely to reveal one's internal state important for mental health. However, the dynamical characteristics of spontaneous thought and their brain representations have yet to be investigated with quantitative tools and tasks. Here we conducted an fMRI experiment (n = 62) using a newly developed free association-based thought sampling task. The dynamical characteristics of the self-generated concepts were predictive of the individual differences in negative affectivity, and thinking about the self-generated concepts strongly activated the autobiographical memory and emotion-related brain regions within the medial prefrontal and temporal brain structures. Multivariate pattern-based predictive modeling of fMRI data revealed that the brain representations of valence became more idiosyncratic with a higher level of self-relevance, providing a hint of how self-relevance modulates the affective and semantic representations in the brain.

Presenter

Choong-Wan Woo, Sungkyunkwan University, Biomedical Engineering, Suwon-si, Gyeonggi-do, Republic of Korea

---

Linking Thoughts to Cognition: The need to understand what, when, and for how long

Measuring self-reported thoughts provides insight into underlying neurocognitive processes, particularly those supporting executive functions and memory (Konu et al., 2020; Wang et al., 2020). However, there is still no consensus on exactly how measures of self-reported thoughts reflect cognition (McVay & Kane, 2010; Smallwood & Schooler, 2006). Theoretical work has suggested that understanding what people are thinking about (content), what they are doing (context), and how their thoughts evolve over time (dynamics) is essential to properly delineating what cognitive processes those thoughts engage in the moment and what cognitive traits they reflect over time (Smallwood, 2013; Smallwood & Schooler, 2015). We designed two experiments to test whether analyzing self-reported thoughts in a content-, context-, and dynamics-dependent framework would allow for a better understanding of the neurocognitive basis of ongoing thought. Participants performed two tasks (0-back and 1-back) that varied in their need for continuous monitoring, and we measured their thoughts across multiple dimensions of content. We measured their brain activity while performing the task (n=60: Turnbull, Wang, Murphy, et al. (2019)) or had them perform the task over 3 days and measured their functional connectivity at rest (n=146: Turnbull, Wang, Schooler, et al. (2019)). We analyzed whether certain brain regions and cognitive measures were functionally related to specific thought contents, and whether including interactions with both the context (task) and dynamics (time since the last task target) allowed us to identify unique associations. Across both experiments, we found that the ventral attention network (VAN) was related to mind wandering in a context-dependent manner (linked positively with on-tasks thoughts in the 1-back and off-task thoughts in the 0-back). Conversely, the dorsal attention network (DAN) was related to on-task thoughts across both tasks, and could be linked to a dynamic drift away from on-task thoughts over time. These results are in line with the dissociable roles of these networks in attention (Dosenbach et al., 2007). Inhibition was related to on-task thought immediately following task performance, while fluid intelligence was linked to allowing your thoughts to drift off-task over time in the 0-back, adding to recent findings (Welhaf et al., 2019) suggesting a role for executive functions in allowing individuals to flexibly mind wander while not hindering task performance. These findings show that understanding the content, context, and dynamics of self-reported thoughts allows a more precise mapping of their neurocognitive basis.

Dosenbach, N. U., Fair, D. A., Miezin, F. M., Cohen, A. L., Wenger, K. K., Dosenbach, R. A., . . . Raichle, M. E.

(2007). Distinct brain networks for adaptive and stable task control in humans. Proceedings of the National Academy of Sciences, 104(26), 11073-11078. Konu, D., Turnbull, A., Karapanagiotidis, T., Wang, H.-t., Brown, L., Jefferies, E., & Smallwood, J. (2020). A role for ventromedial prefrontal cortex in self-generated episodic social cognition. Neuroimage, 116977. McVay, J. C., & Kane, M. J. (2010). Does mind wandering reflect executive function or executive failure? Comment on Smallwood and Schooler (2006) and Watkins (2008). Smallwood, J. (2013). Distinguishing how from why the mind wanders: a process–occurrence framework for self-generated mental activity. Psychological Bulletin, 139(3), 519. Smallwood, J., & Schooler, J. W. (2006). The restless mind. Psychological Bulletin, 132(6), 946. Smallwood, J., & Schooler, J. W. (2015). The science of mind wandering: empirically navigating the stream of consciousness. Annual Review of Psychology, 66, 487-518. Turnbull, A., Wang, H., Murphy, C., Ho, N., Wang, X., Sormaz, M., . . . Margulies, D. (2019). Left dorsolateral prefrontal cortex supports context-dependent prioritisation of off-task thought. Nature communications, 10(1), 1-10. Turnbull, A., Wang, H.-T., Schooler, J. W., Jefferies, E., Margulies, D. S., & Smallwood, J. (2019). The ebb and flow of attention: Between-subject variation in intrinsic connectivity and cognition associated with the dynamics of ongoing experience. Neuroimage, 185, 286-299. Wang, H.-T., Ho, N. S. P., Bzdok, D., Bernhardt, B. C., Margulies, D. S., Jefferies, E., & Smallwood, J. (2020). Neurocognitive patterns dissociating semantic processing from executive control are linked to more detailed off-task mental time travel. Scientific reports, 10(1), 1-14. Welhaf, M. S., Smeekens, B. A., Gazzia, N. C., Perkins, J. B., Silvia, P. J., Meier, M. E., . . . Kane, M. J. (2019). An exploratory analysis of individual differences in mind wandering content and consistency. Psychology of Consciousness: Theory, Research, and Practice.

Presenter

Adam Turnbull, University of Rochester Rochester, NY, United States

---

Modeling the Dynamics of the Wandering Mind

Previous research has shown that large-scale brain networks such as the default mode network (DMN), the executive network and the dorsal-attention network (DAN) are involved in mind-wandering (MW). In particular, both their respective activity but also their (dynamic) functional connectivity seem to be highly predictive of MW (Mittner et al., 2014; Groot et al., 2020). However, current state-of-the-art methods for predicting MW based on neural data are lacking an explicit model for the temporal evolution and dynamic switches between on-task and MW states. Based on a theoretical model of mind-wandering that postulates that attentional shifts are modulated by norepinephrinergic activity (Mittner et al., 2016), we investigate attentional switches in a combined fMRI and pupillometry study (N=27). We are using a recently established task, the finger-tapping random-sequence generation task (FTRSGT) that was recently established as a useful paradigm for measuring the recruitment of executive control with high temporal resolution in a mind-wandering context (Boayue et al., 2020). We report the results of a custom-tailored Hidden-Markov model (HMM) that we modified to allow for including all observed non-fMRI measures (including thought-probes) into the fitting process. This model features a specific representation of the dynamic process underlying attentional switches in a MW context and can be used to extract brain-signatures of the different attentional states. We find that our novel HMM outperforms other models, providing important insights into the dynamics of mind wandering. References: Mittner, M., Boekel, W., Tucker, A. M., Turner, B. M., Heathcote, A., & Forstmann, B. U. (2014). When the brain takes a break: a model-based analysis of mind wandering. Journal of Neuroscience, 34(49), 16286-16295. Mittner, M., Hawkins, G. E., Boekel, W., & Forstmann, B. U. (2016). A neural model of mind wandering. Trends in cognitive sciences, 20(8), 570-578. Groot, J. M., Boayue, N. M., Csifcsák, G., Boekel, W., Huster, R., Forstmann, B. U., & Mittner, M. (2020). Probing the neural signature of mind wandering with simultaneous fMRI-EEG and pupillometry. NeuroImage, 224, 117412. Boayue, N. M., Csifcsák, G., Kreis, I., Schmidt, C., Finn, I. C., Vollsund, A. E., & Mittner, M. (2020). The interplay between cognitive control, behavioral variability and mind wandering: Insights from a HD-tDCS study.

Presenter

Matthias Mittner, University of Tromsø Tromsø, Norway, Norway

Generalizable Prediction of Stimulus-independent, Task-unrelated Thought from Functional Brain Networks

Neural substrates of mind wandering have been widely reported, yet experiments have varied in their contexts and their definitions of this psychological phenomenon, limiting generalizability. I will present a multi-dataset fMRI analysis in which we aimed to develop and test the generalizability, specificity, and clinical relevance of a functional brain network-based marker for a well-defined feature of mind wandering—stimulus-independent, task-unrelated thought (SITUT). Combining fMRI with online experience sampling in healthy adults, we defined a connectome-wide model of inter-regional coupling—dominated by default-frontoparietal control subnetwork interactions—that predicted trial-by-trial SITUT fluctuations within novel individuals. Model predictions generalized in an independent sample of attention-deficit/hyperactivity disorder (ADHD) adults, who reported increased SITUTs and also showed increased expression of the SITUT neural marker. In three additional resting-state fMRI studies (total n=1,115), including healthy and ADHD populations, we demonstrated further prediction of SITUT (at modest effect sizes) defined using multiple trait-level and in-scanner measures. Our findings suggest that SITUT is represented within a common pattern of brain network interactions across time scales, populations, and contexts.

Presenter

Aaron Kucyi, Northeastern University Brookline, MA, United States