Flow Dynamics During Naturalistic Gameplay: Results from Behavioral and Functional Magnetic Resonance Imaging Studies

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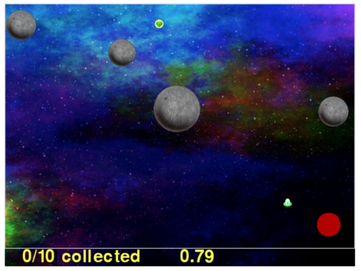
Background

- Flow[1-2] is characterized by a high level of intrinsic reward and is theorized to result from balanced:
  - Task difficulty
  - Individual ability at the task
- Balanced task difficulty and individual ability results in:
  - An inverted-U shaped pattern where self-reported flow and behavioral measures of attention are highest.[3-7]
  - Activation in cognitive control and reward networks.[3-8]
  - Functional connectivity between structures in these networks.[3-4]
  - Down-regulation of structures in the default mode network that is causally implicated in flow.[9-10]
- However, we know very little about how these network dynamics unfold over time.
- Here, we use naturalistic gameplay to:
  - Validate an experimental flow induction.
  - Observe network dynamics during flow, particularly: multilayer community detection and node flexibility
  - Explore the synchrony and metastability[13] in the brain dynamics during flow.

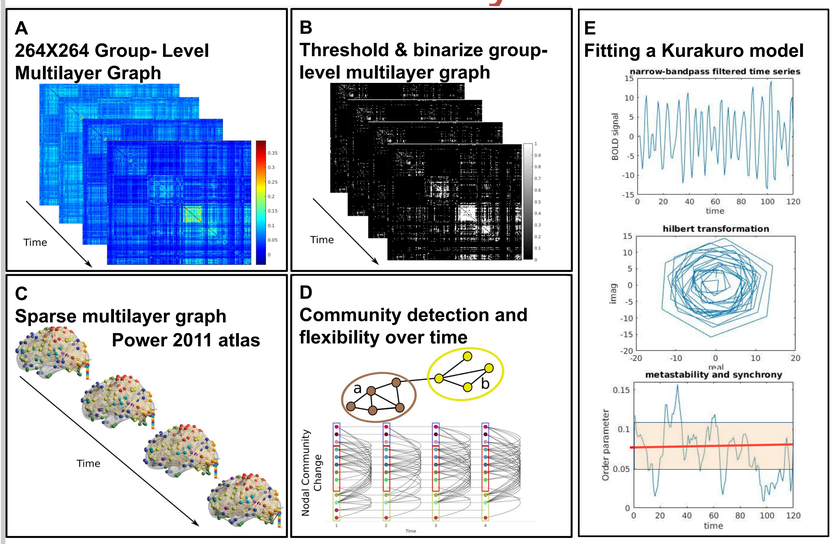
Stimulus & Procedure

- Subjects played *Asteroid Impact:*
  - Ability > Difficulty
  - Ability < Difficulty
  - Ability ≈ Difficulty
- Two experiments
  - Behavioral n = 74
  - fMRI n = 35
- Randomized orders
- Dependent Measures:
  - Self-reported flow
  - Self-reported enjoyment
  - STRT
- GitHub:
  - https://github.com/cogcommscience-lab/flow-dynamic
  - https://github.com/cogcommscience-lab/asteroid_impact

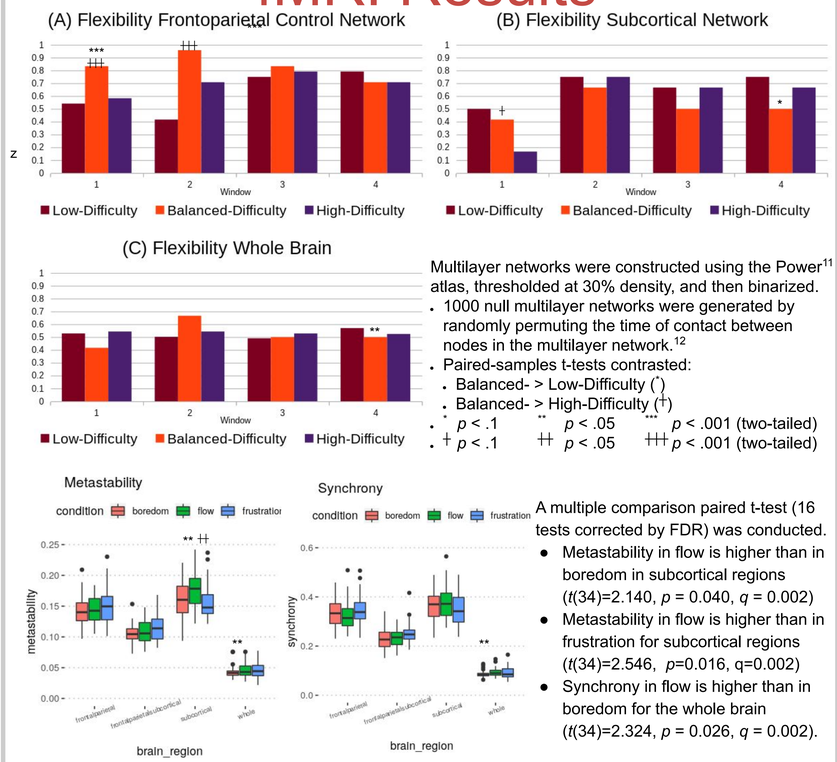


Subjects collected targets while avoiding asteroids that moved around the screen. Difficulty was manipulated by modifying asteroid speed. All other game settings remained the same between conditions. Subjects also responded to a STRT (red circle + auditory tone) during gameplay.

fMRI Analysis



fMRI Results



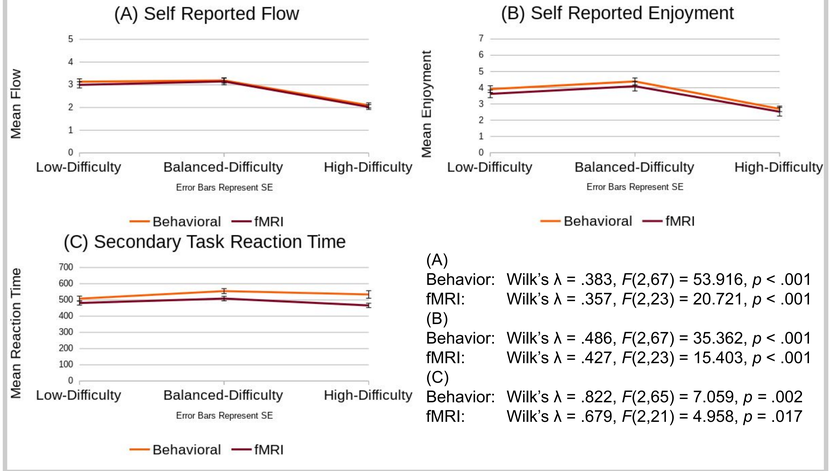
Multilayer networks were constructed using the Power[11] atlas, thresholded at 30% density, and then binarized.

- 1000 null multilayer networks were generated by randomly permuting the time of contact between nodes in the multilayer network.[12]
- Paired-samples t-tests contrasted:
  - Balanced- > Low-Difficulty (*)
  - Balanced- > High-Difficulty (+)
- * $p < .1$ ** $p < .05$ *** $p < .001$ (two-tailed)
- + $p < .1$ ++ $p < .05$ +++ $p < .001$ (two-tailed)

A multiple comparison paired t-test (16 tests corrected by FDR) was conducted.

- Metastability in flow is higher than in boredom in subcortical regions ($t(34)=2.140$, $p = 0.040$, $q = 0.002$)
- Metastability in flow is higher than in frustration for subcortical regions ($t(34)=2.546$, $p=0.016$, $q=0.002$)
- Synchrony in flow is higher than in boredom for the whole brain ($t(34)=2.324$, $p = 0.026$, $q = 0.002$).

Behavioral Results



(A)
Behavior: Wilk's λ = .383, $F(2,67) = 53.916$, $p < .001$
fMRI: Wilk's λ = .357, $F(2,23) = 20.721$, $p < .001$
(B)
Behavior: Wilk's λ = .486, $F(2,67) = 35.362$, $p < .001$
fMRI: Wilk's λ = .427, $F(2,23) = 15.403$, $p < .001$
(C)
Behavior: Wilk's λ = .822, $F(2,65) = 7.059$, $p = .002$
fMRI: Wilk's λ = .679, $F(2,21) = 4.958$, $p = .017$

Discussion

- We replicate previous studies showing the highest levels of self-reported flow and behavioral measures of attention when difficulty and ability are balanced.[3-7]
- Nodes in the fronto-parietal control network are flexible early during flow but decrease and stabilize overtime.
- Nodes in subcortical structures have comparatively low flexibility during flow across across all windows and appear to stabilize in later windows.
- Synchrony is higher in flow than in boredom for the whole brain, and metastability is higher in flow than in boredom and in frustration for subcortical network.
- Conclusion: Flow may require a stabilization of brain network organization that emerges overtime.

References & Funding

1. Csikszentmihalyi, M. Flow: The psychology of optimal experience. (HarperCollins Publishers, 1990).
2. Weber, R., Tamborini, R., Westcott-Baker, A. & Kantor, B. Theorizing flow and media enjoyment as cognitive synchronization of attentional and reward networks. *Commun. Theory* **19**, 397–422 (2009).
3. Huskey, R., Craighead, B., Miller, M. B. & Weber, R. Does intrinsic reward motivate cognitive control? A naturalistic-fMRI study based on the Synchronization Theory of Flow. *Cogn. Affect. Behav. Neurosci.* **18**, 902–924 (2018).
4. Huskey, R., Wilcox, S. & Weber, R. Network neuroscience reveals distinct neuromarkers of flow during media use. *J. Commun.* **65**, 872–895 (2018).
5. Núñez Castellar, E. P., Antons, J., Marinazzo, D. & Van Looy, J. Mapping attention during gameplay: Assessment of behavioral and ERP markers in an auditory oddball task. *Psychophysiology* (2019).
6. Ulrich, M., Keller, J., Hoenig, K., Waller, C. & Grön, G. Neural correlates of experimentally induced flow experiences. *Neuroimage* **86**, 194–202 (2014).
7. Ulrich, M., Keller, J. & Grön, G. Neural signatures of experimentally induced flow experiences identified in a typical fMRI block design with BOLD imaging. *Soc. Cogn. Affect. Neurosci.* **11**, 496–507 (2016).
8. Klasen, M., Weber, R., Kircher, T. T. J., Mathiak, K. A. & Mathiak, K. Neural contributions to flow experience during video game playing. *Soc. Cogn. Affect. Neurosci.* **7**, 485–495 (2012).
9. Ulrich, M., Keller, J. & Grön, G. Dorsal raphe nucleus down-regulates medial prefrontal cortex during experience of flow. *Front. Behav. Neurosci.* **10**, 169 (2016).
10. Ulrich, M. et al. The neural correlates of flow experience explored with transcranial direct current stimulation. *Exp. Brain Res.* **236**, 3223–3237 (2018).
11. Power, J. D. et al. Functional Network Organization of the Human Brain. *Neuron* **72**, 665–678 (2011).
12. Sizemore, A. E. & Bassett, D. S. Dynamic graph metrics: Tutorial, toolbox, and tale. *Neuroimage* **180**, 417–427 (2017).
13. Alderson, TH, Bokde, ALW, Kelso, JAS, Maguire, L, Coyle, D. Metastable neural dynamics underlies cognitive performance across multiple behavioural paradigms. *Hum Brain Mapp*, 1– 23. (2020)

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