Task-Based Brain Networks Detectable with fMRI

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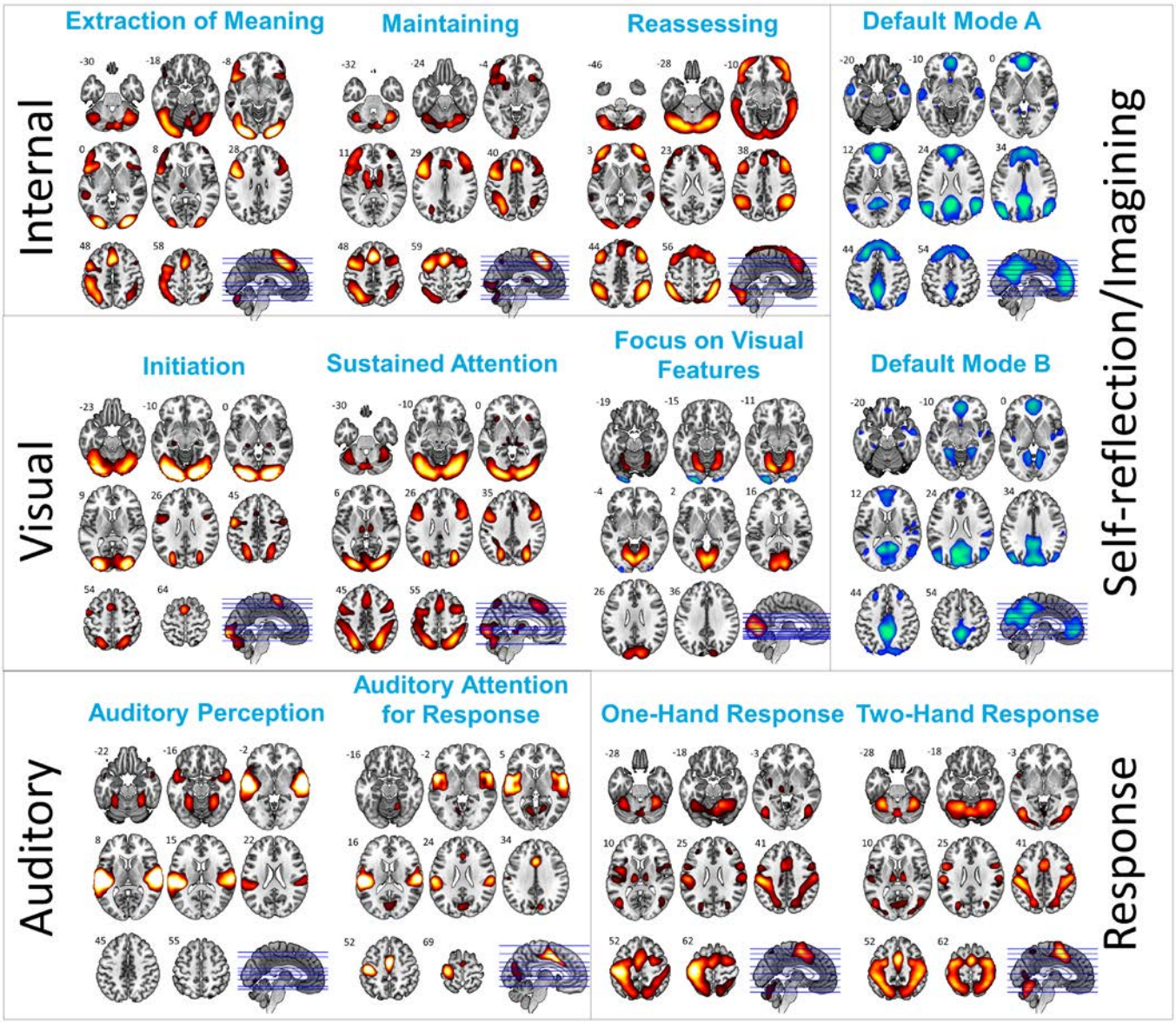
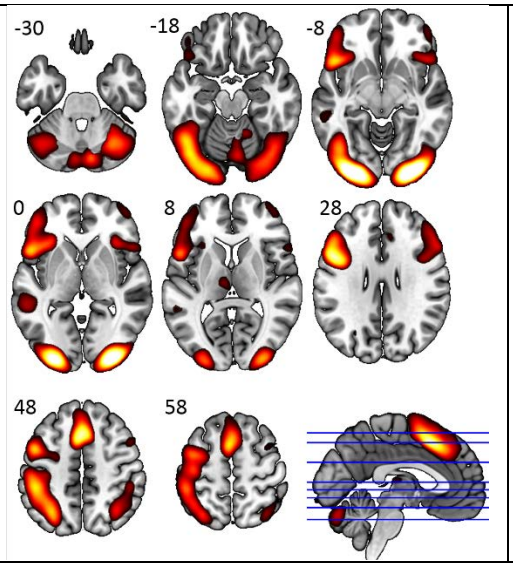
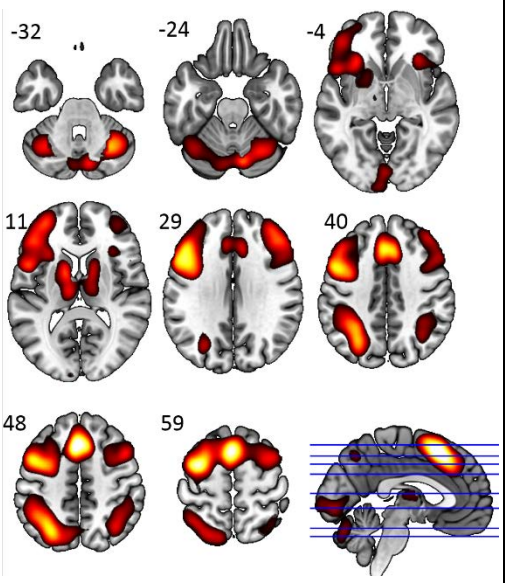
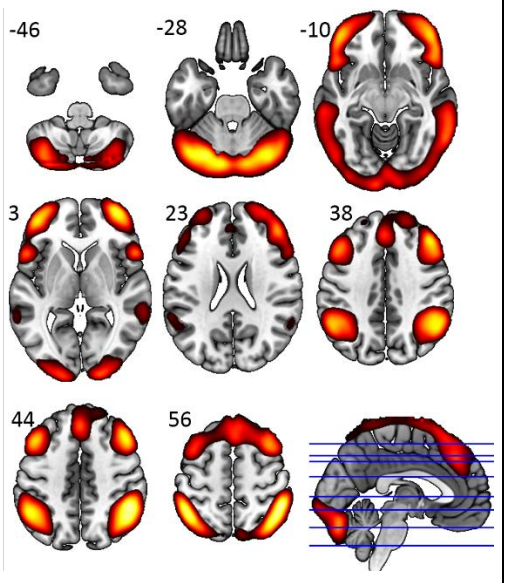


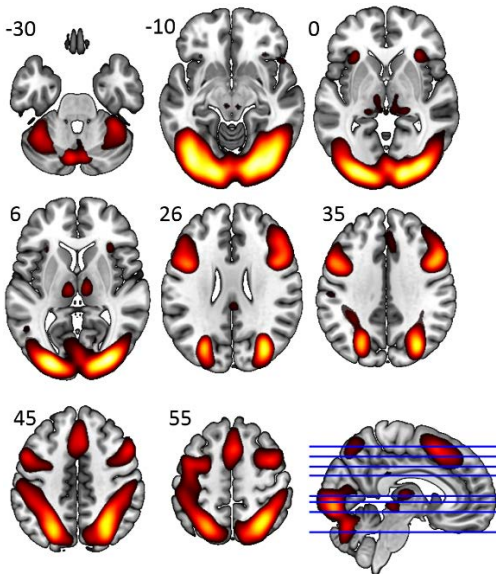
Table 1. *fMRI Measures of Cognitive Functions.*

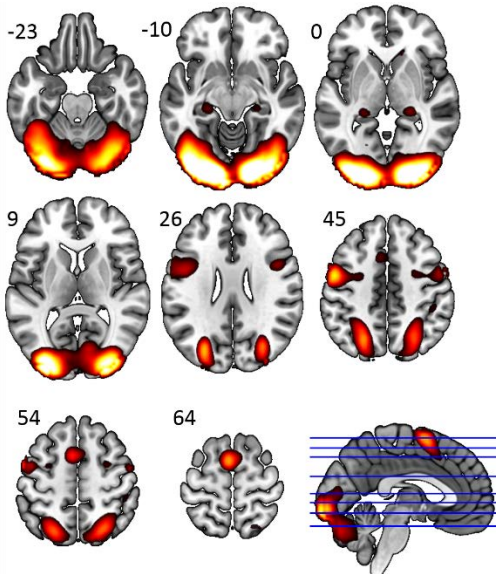
Any network can be automatically classified into those depicted in Figure 1 by a MATLAB-based algorithm that we recently. This involved digitizing 20-30 brain slices prototypical of each of the networks, and correlating newly derived networks with those prototype slices, and classifying based on the magnitude of the correlations. Activation in these networks is thought to be *capturing the neural correlates of the multiple simpler cognitive processes that combine together in the typical cognitive test performance.* Extracting these networks from resting-state data will test the integrity of each of these cognitive functions.

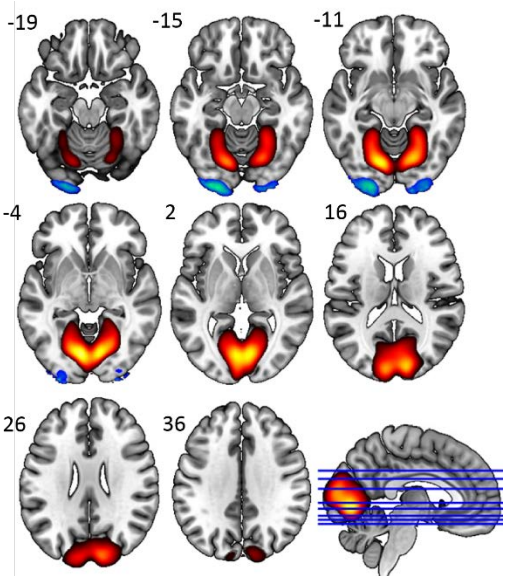
Networks	**Images**	**Examples**
Cognitive processes involved in attending to internal representations There are three networks which measure cognitive processes involved in *attending to internal representations*. The first is *Extraction of Meaning*, which can be for processing linguistic information when left-lateralized, when it is more active for distant semantic associations [1]. It can also be more bilateral and active for non-verbal information (e.g., faces) [2]. Both have been shown to be impaired in schizophrenia [1, 2]. The second is *Maintaining*, which shows load-dependence for items in verbal and spatial working memory [3-5], and increased activity when imagine the past or future relative to episodic recall [6]. The third is *Reassessing*, which involves internal checking, considering that there may have been alternative ways to respond, and internally revising the response. It is more active when disconfirming evidence is presented relative to confirming [7, 8], and this is decreased in delusions (fixed false beliefs) in schizophrenia [8] and delusional ideation in healthy people [7]. It is also more active during incongruent relative to neutral Stroop task performance [4, 5].		
Extraction of Meaning		Component 3 Goghari, V.M., Sanford, N., Spilka, M.J. & Woodward, T.S. (2017). Task-related functional connectivity analysis of emotion discrimination in a family study of schizophrenia. *Schizophrenia Bulletin*, 43(6):1348–1362. PDF Component 3 Wong, S.T.S., Goghari, V.M., Sanford, N., Lim, R., Clark, C., Metzak, P.D., Rossell, S.L., Menon, M., & Woodward, T.S. (2020). Functional brain networks involved in lexical decision. *Brain and Cognition*, 138, doi: 10.1016/j.bandc.2019.103631. PDF

Maintaining		Component 2 Larivière, S., Lavigne, K.M., Woodward, T.S., Gerretsen, P., Graff-Guerrero, A., & Menon, M. (2017). Altered functional connectivity in brain networks underlying self-referential processing in delusions of reference in schizophrenia. *Psychiatry Research: Neuroimaging*, 263 (2017): 32–43. PDF Component 3 Metzak, P.D., Riley, J., Wang, L., Whitman, J.C., Ngan, E.T.C. & Woodward, T.S. (2012). Decreased efficiency of task-positive and task-negative networks during working memory in schizophrenia. *Schizophrenia Bulletin*, 38(4), 803-813. PDF Component 2- Chapter 5 Sanford, N. A. (2019). *Functional brain networks underlying working memory performance in schizophrenia : a multi-experiment approach* (T). University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0387449 Component 3- Multi-Experiment Sanford, N., Whitman, J.C. & Woodward, T.S. (2020). Task-Merging for finer separation of functional brain networks in working memory. *Cortex*, 125, 246-271.doi: 10.1016/j.cortex.2019.12.014. PDF
Reassessing		Component 3- Study 2 Component 3- Study 3 Lavigne, K. M. (2018). *Cognitive biases and functional brain networks underlying delusions in schizophrenia* (T). University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0364055 Component 1 Lavigne, K.M., Metzak, P.D., & Woodward, T.S. (2015). Functional brain networks underlying detection and integration of disconfirmatory evidence. *NeuroImage* 112(2015): 138-151. PDF Component 3- Chapter 4 Analysis 3 TSI Sanford, N. A. (2019). *Functional brain networks underlying working memory performance in schizophrenia : a multi-experiment approach* (T). University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0387449

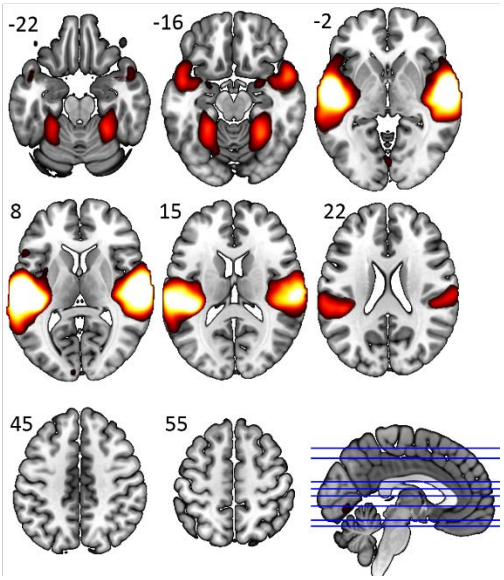
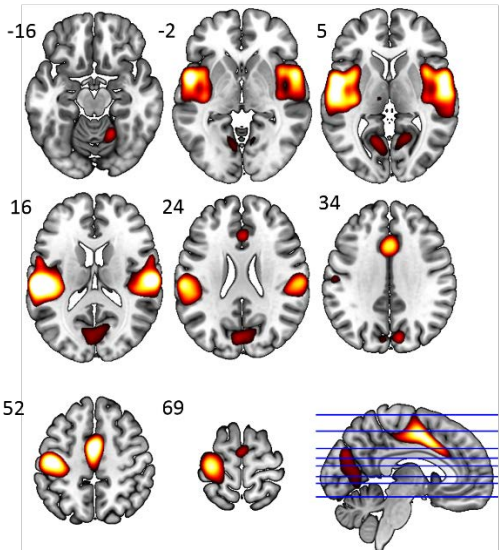
Cognitive processes involved in attending to visually presented stimuli.
There are three networks which measure cognitive processes involved in attending to visual stimuli in different ways. The first is *Initiation*, which involves restarting cognitive processing after a break of a few seconds after a set of operations, and peaks very early in the trial [3]. The second is *Sustained Attention*, which is activated when maintaining attention to rapidly presented stimuli [7, 9], and shows increased activity under conditions of more difficult decision making [10]. The third is *Focus on Visual Features (FVF)*, which is activated when details of a scene are important as in spatial working memory [5], but suppressed when it is better to ignore them, for example, when they could impede performance in the Stroop task [4]. This FVF network has been shown to have reduced suppression under the influence of alcohol [11].

Sustained Attention		Component 1- Study 2 Component 1- Study 3 Lavigne, K. M. (2018). *Cognitive biases and functional brain networks underlying delusions in schizophrenia* (T). University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0364055 Component 2 Lavigne, K.M., Menon, M., Moritz, S. & Woodward, T.S. (2020). Functional brain networks underlying evidence integration and delusional ideation. *Schizophrenia Research*, doi:10.1016/j.schres.2019.11.038. PDF Component 5 Lavigne, K.M., Metzak, P.D., & Woodward, T.S. (2015). Functional brain networks underlying detection and integration of disconfirmatory evidence. *NeuroImage* 112(2015): 138-151. PDF Component 1 Woodward, T.S., Tipper, C.M., Leung, A., Lavigne, K.M., Sanford, N., Metzak, P.D. (2015). Reduced functional connectivity during controlled semantic integration in schizophrenia: A multivariate approach. *Human Brain Mapping*, 36: 2948-2964. PDF

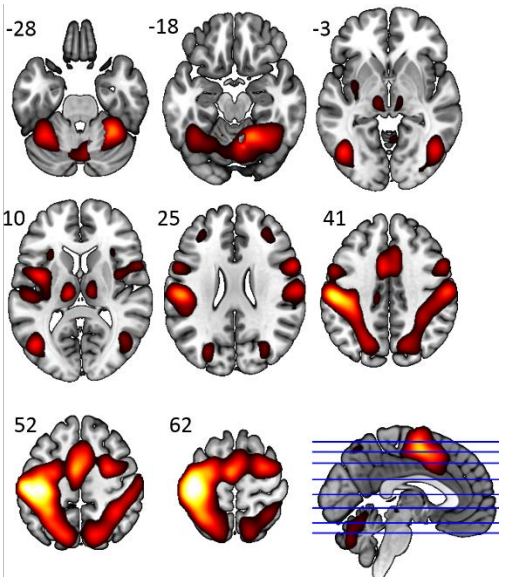
Initiation		Component 2 Lavigne, K.M., Metzak, P.D., & Woodward, T.S. (2015). Functional brain networks underlying detection and integration of disconfirmatory evidence. *NeuroImage* 112(2015): 138-151. PDF Component 1 Lavigne, K.M., Rapin, L.A., Metzak, P.D., Whitman, J.C., Jung, K., Dohen, M., Loevenbruck, H., &Woodward, T.S. (2015). Left-dominant temporal-frontal hypercoupling in schizophrenia patients with hallucinations during speech perception. *Schizophrenia Bulletin*, 41(1): 259-267. PDF Component 2 Metzak, P.D., Riley, J., Wang, L., Whitman, J.C., Ngan, E.T.C. & Woodward, T.S. (2012). Decreased efficiency of task-positive and task-negative networks during working memory in schizophrenia. *Schizophrenia Bulletin*, 38(4), 803-813. PDF Component 2- Chapter 4 Analysis 1 WM Component 1- Chapter 4 Analysis 4 TGT Component 5- Chapter 5 Sanford, N. A. (2019). *Functional brain networks underlying working memory performance in schizophrenia : a multi-experiment approach* (T). University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0387449 Component 2- Single-Experiment Component 2- Multi-Experiment Sanford, N., Whitman, J.C. & Woodward, T.S. (2020). Task-Merging for finer separation of functional brain networks in working memory. *Cortex*, 125, 246-271.doi: 10.1016/j.cortex.2019.12.014. PDF Component 1 Woodward, T.S., Feredoes, E., Metzak, P.D., Takane, Y., & Manoach, D.S. (2013). Epoch-specific functional networks involved in working memory. *NeuroImage*, 65: 529-539. PDF

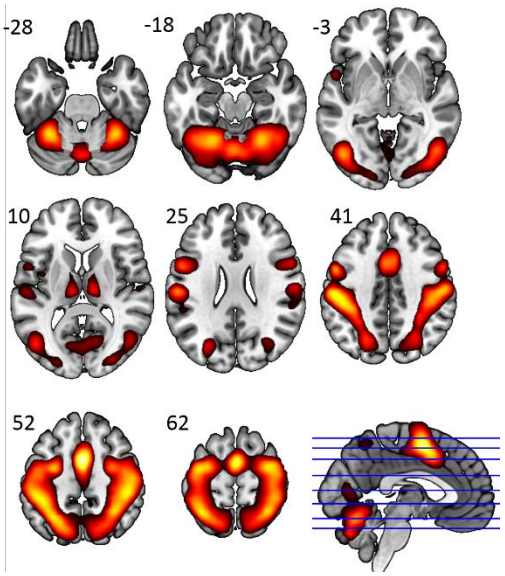
Focus on Visual Features		Component 3 Lavigne, K.M., Metzak, P.D., & Woodward, T.S. (2015). Functional brain networks underlying detection and integration of disconfirmatory evidence. *NeuroImage* 112(2015): 138-151. PDF Component 1- Chapter 4 Analysis 3 TSI Component 7- Chapter 5 Sanford, N. A. (2019). *Functional brain networks underlying working memory performance in schizophrenia : a multi-experiment approach* (T). University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0387449 Component 6- Multi-Experiment Sanford, N., Whitman, J.C. & Woodward, T.S. (2020). Task-Merging for finer separation of functional brain networks in working memory. *Cortex,* 125, 246-271.doi: 10.1016/j.cortex.2019.12.014. PDF Component 4 Woodward, T.S., Feredoes, E., Metzak, P.D., Takane, Y., & Manoach, D.S. (2013). Epoch-specific functional networks involved in working memory. *NeuroImage,* 65: 529-539. PDF

Cognitive processes involved in attending to auditorily presented stimuli.
There are two networks which measure cognitive processes involved in attending to auditory stimuli in different ways. The first is *Auditory Perception* [3], active when listening to speech, and is hyperactive in hallucinations in schizophrenia [1]. The *Auditory Attention for Response* network is activated when auditory stimuli is being monitored when a response is required, but deactivated during intensive monitoring of visual details [1, 12], which is analogous to the familiar situation where someone is visually monitoring their phone, they are less likely to hear what you're saying to them.

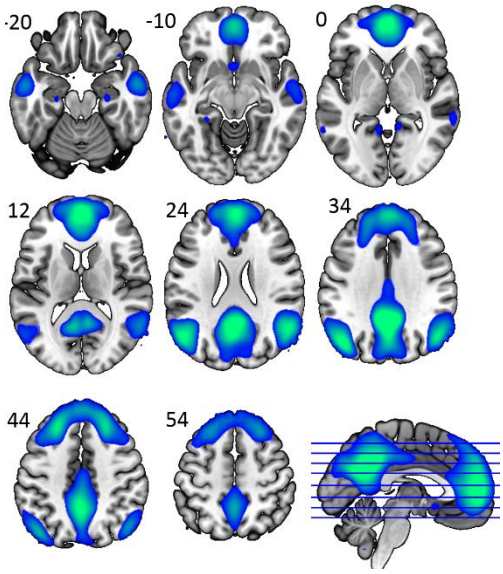
Auditory Perception		Component 4- Chapter 4 Analysis 4 TGT Sanford, N. A. (2019). *Functional brain networks underlying working memory performance in schizophrenia : a multi-experiment approach* (T). University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0387449 Component 7- Multi-Experiment Sanford, N., Whitman, J.C. & Woodward, T.S. (2020). Task-Merging for finer separation of functional brain networks in working memory. *Cortex,* 125, 246-271.doi: 10.1016/j.cortex.2019.12.014. PDF
Auditory Attention for Response		Component 2 Lavigne, K.M., Menon, M., & Woodward, T.S. (2016). Impairment in subcortical suppression in schizophrenia: Evidence from the fBIRN oddball task. *Human Brain Mapping*, 37:4640-4653. PDF Component 1 Lavigne, K.M. & Woodward, T.S. (2018). Hallucination and speech-specific hypercoupling in frontotemporal auditory and language networks in schizophrenia using combined task-based fMRI data: An fBIRN study. *Human Brain Mapping*, 2018(39):1582–1595. PDF Component 3- Chapter 5 Sanford, N. A. (2019). *Functional brain networks underlying working memory performance in schizophrenia : a multi-experiment approach* (T). University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0387449

***Sensorimotor Processes*.**
Motor Response network is involved in responding, with a HDR that peaks late in the trial, but it is lateralized for one-handed response [3], and bilateral for a two-handed response [2, 4].

One-Handed Response		Component 1 Larivière, S., Lavigne, K.M., Woodward, T.S., Gerretsen, P., Graff-Guerrero, A., & Menon, M. (2017). Altered functional connectivity in brain networks underlying self-referential processing in delusions of reference in schizophrenia. *Psychiatry Research: Neuroimaging*, 263 (2017): 32–43. PDF Component 3 Lavigne, K.M., Menon, M., Moritz, S. & Woodward, T.S. (2020). Functional brain networks underlying evidence integration and delusional ideation. *Schizophrenia Research*, doi:10.1016/j.schres.2019.11.038. PDF Component 4 Lavigne, K.M., Metzak, P.D., & Woodward, T.S. (2015). Functional brain networks underlying detection and integration of disconfirmatory evidence. *NeuroImage* 112(2015): 138-151. PDF Component 1- Chapter 4 Analysis 1 WM Component 4- Chapter 5 Sanford, N. A. (2019). *Functional brain networks underlying working memory performance in schizophrenia : a multi-experiment approach* (T). University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0387449 Component 1- Single-Experiment Component 1- Multi-Experiment Sanford, N., Whitman, J.C. & Woodward, T.S. (2020). Task-Merging for finer separation of functional brain networks in working memory. *Cortex*, 125, 246-271.doi: 10.1016/j.cortex.2019.12.014. PDF

Two-Handed Response		Component 1 Goghari, V.M., Sanford, N., Spilka, M.J. & Woodward, T.S. (2017). Task-related functional connectivity analysis of emotion discrimination in a family study of schizophrenia. *Schizophrenia Bulletin*, 43(6):1348–1362. PDF Component 1 Metzak, P.D., Lavigne, K.M., & Woodward, T.S. (2015). Functional brain networks involved in reality monitoring. *Neuropsychologia* 75(2015) : 50-60. PDF Component 1- Chapter 4 Analysis 2 SCAP Component 2- Chapter 4 Analysis 3 TSI Sanford, N. A. (2019). *Functional brain networks underlying working memory performance in schizophrenia : a multi-experiment approach* (T). University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0387449 Component 1 Whitman, J.C., Metzak, P.D., Lavigne, K.M., & Woodward, T.S. (2013). Functional connectivity in a frontoparietal network involving the dorsal anterior cingulate cortex underlies decisions to accept a hypothesis. *Neuropsychologia*, 51(2013):1132–1141. PDF Component 2 Wong, S.T.S., Goghari, V.M., Sanford, N., Lim, R., Clark, C., Metzak, P.D., Rossell, S.L., Menon, M. & Woodward, T.S. (2020). Functional brain networks involved in lexical decision. *Brain and Cognition*, 138, doi: 10.1016/j.bandc.2019.103631. PDF Component 2 Woodward, T.S., Feredoes, E., Metzak, P.D., Takane, Y., & Manoach, D.S. (2013). Epoch-specific functional networks involved in working memory. *NeuroImage*, 65: 529-539. PDF Component 1 Woodward, T.S., Leong, K., Sanford, N., Tipper, C.M., & Lavigne, K.M. (2016). Altered balance of functional brain networks in schizophrenia. *Psychiatry Research: Neuroimaging*, 248:94-104. PDF

Self-reflection/Imagining.
There are two networks thought to be involved in *Self Reflection/Imagining* [2, 4]. They both decrease activity when carrying out a task, unless that task is imagining a past of future event [6]. We call them default-mode network (DMN) A and B. DMN A is commonly found in resting state research, but DMN B appears to be detectable only in task-based fMRI.

Default Mode A		Component 2 Goghari, V.M., Sanford, N., Spilka, M.J. & Woodward, T.S. (2017). Task-related functional connectivity analysis of emotion discrimination in a family study of schizophrenia. *Schizophrenia Bulletin*, 43(6):1348–1362. PDF Component 2- Study 2 Component 2- Study 3 Lavigne, K. M. (2018). *Cognitive biases and functional brain networks underlying delusions in schizophrenia* (T). University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0364055 Component 1 Lavigne, K.M., Menon, M., Moritz, S. & Woodward, T.S. (2020). Functional brain networks underlying evidence integration and delusional ideation. *Schizophrenia Research*, doi:10.1016/j.schres.2019.11.038. PDF Component 4 Lavigne, K.M., Metzak, P.D., & Woodward, T.S. (2015). Functional brain networks underlying detection and integration of disconfirmatory evidence. *NeuroImage* 112(2015): 138-151. PDF Component 3- Chapter 4 Analysis 1 WM Component 2- Chapter 4 Analysis 2 SCAP Component 1- Chapter 5 Sanford, N. A. (2019). *Functional brain networks underlying working memory performance in schizophrenia : a multi-experiment approach* (T). University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0387449 Component 3- Single-Experiment Component 4- Multi-Experiment Sanford, N., Whitman, J.C. & Woodward, T.S. (2020). Task-Merging for finer separation of functional brain networks in working memory. *Cortex,* 125, 246-271.doi: 10.1016/j.cortex.2019.12.014. PDF

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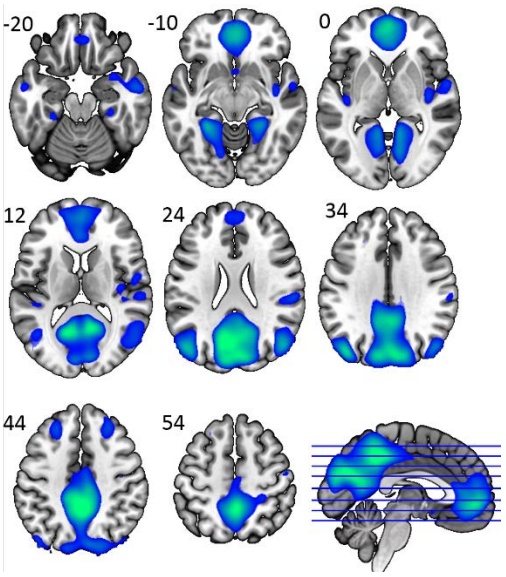
Default Mode B		Component 3 Metzak, P.D., Riley, J., Wang, L., Whitman, J.C., Ngan, E.T.C. & Woodward, T.S. (2012). Decreased efficiency of task-positive and task-negative networks during working memory in schizophrenia. *Schizophrenia Bulletin*, 38(4), 803-813. PDF Component 3 Wong, S.T.S., Goghari, V.M., Sanford, N., Lim, R., Clark, C., Metzak, P.D., Rossell, S.L., Menon, M. & Woodward, T.S. (2020). Functional brain networks involved in lexical decision. *Brain and Cognition*, 138, doi: 10.1016/j.bandc.2019.103631. PDF

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