

# Localized Cluster Enhancement: TFCE revisited with valid error control

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June 21, 2024

1. TFCE recap
2. What error rate (if any) does TFCE control?
3. Discuss why TFCE very strongly depends a threshold  $h_0$
4. Introduce a Localized TFCE: to provide precise inference and valid error control

Suppose that we have a test-statistic  $T : \mathcal{V} \rightarrow \mathbb{R}$  at each voxel in the brain. The the TFCE transformation is defined as:

$$S_v(T) = \int_{h_0}^{T_v} h^H e_v(h, T)^E dh.$$

- $S_v$  thresholded at a level based on permutation thresholding.
- Permuted TFCE test-statistics:  $S_{v,1}^*, \dots, S_{v,P}^*$  are calculated.
- level  $t^*$  chosen based on the  $\alpha$  quantile of the permutation distribution of  $\max_{1 \leq p \leq P} S_{v,p}^*$ .

# TFCE increases the number of free parameters

Suppose that we have a test-statistic  $T_v$  at each voxel  $v$  in the brain. The the TFCE transformation is defined as:

$$S_v = \int_{h_0}^{T_v} h^H e_v(h)^E dh. \quad (1)$$

- In practice -  $H = 2$ ,  $E = 0$  and  $h_0 = 0$  are the default parameters chosen.
- Unlike Clustsize inference TFCE thus has 3 free parameters.

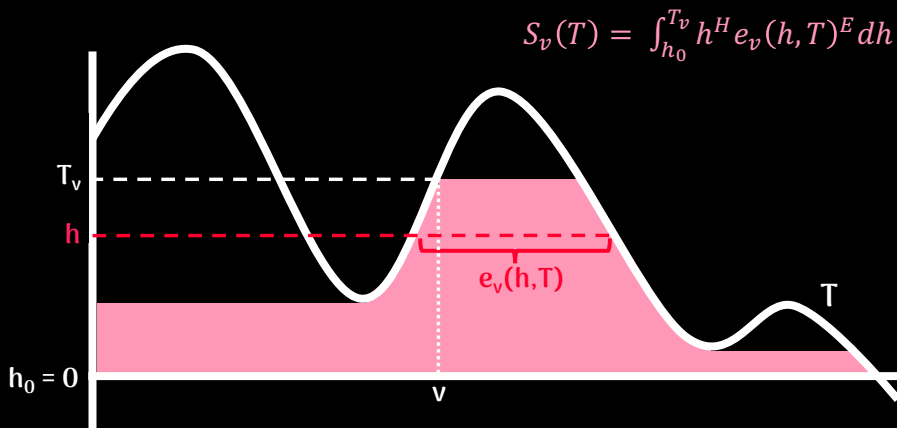
# TFCE has a threshold

Suppose that we have a test-statistic  $T_v$  at each voxel  $v$  in the brain. The the TFCE transformation is defined as:

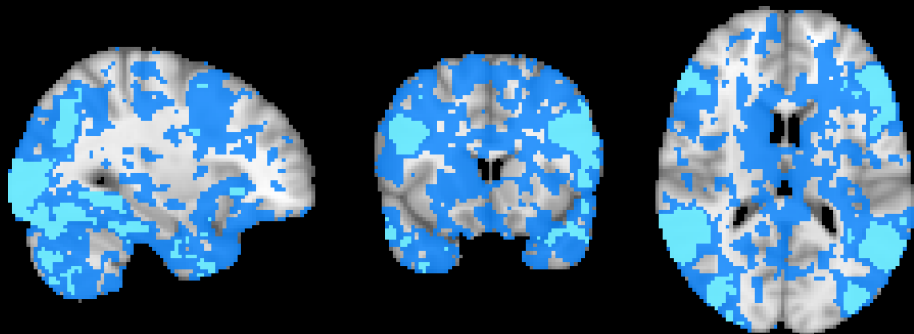
$$S_v(T) = \int_{h_0}^{T_v} h^H e_v(h, T)^E dh. \quad (2)$$

- In particular  $h_0$  acts as a threshold.

# Understanding the TFCE integral



# TFCE illustration



# Global vs voxel vs cluster level inference

There are 3 types of inference statements typically used.

1. Voxel: Every highlighted voxel is active
2. Cluster: Every cluster contains at least one active voxel
3. Global: There is some voxel active somewhere in the brain.



# Classifying fMRI inference methods

There are 3 types of inference statements typically used.

1. Voxel: Every highlighted voxel is active

**Voxelwise inference**

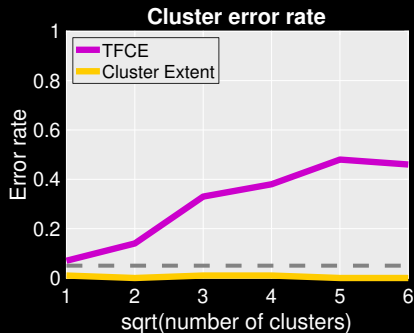
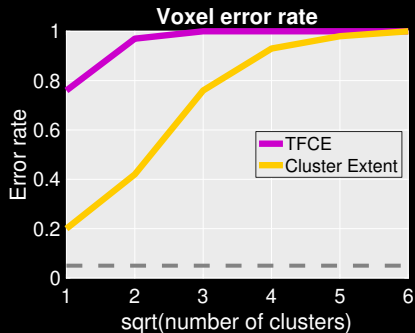
2. Cluster: Every cluster contains at least one active voxel

**Clustersize inference, Localized Cluster Enhancement**

3. Global: There is some voxel active somewhere in the brain.

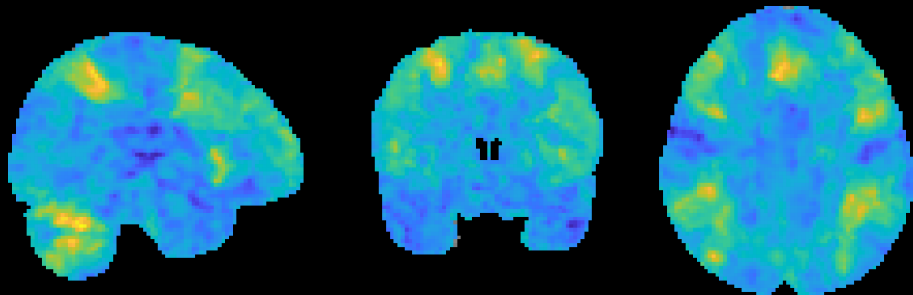
**TFCE**

# TFCE false positives



# Localized Cluster Enhancement illustration

The  $t$ -statistic based on 40 subjects (for the HCP Gambling task)



# Localized Cluster Enhancement

Recall the TFCE statistic is:

$$S_v(T) = \int_{h_0}^{T_v} h^H e_v(h, T)^E \mathrm{d}h.$$

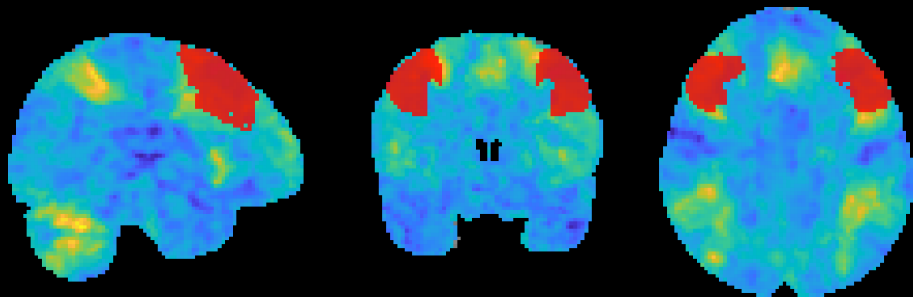
To localize this statistic, for a region  $R \subset \mathcal{V}$  let

$$S_{v,R}(T) = S_v(T \times 1[R]) = \int_{h_0}^{T_v} h^H e_v(h, T \times 1[R])^E \mathrm{d}h.$$

Let  $t^*$  be the  $(1 - \alpha)$  quantile of the permutation distribution of  $\max_{v \in \mathcal{V}} S_v(T)$ . Then we can say  $R$  contains at least one active voxel if  $S_{v,R}(T) > t^*$ .

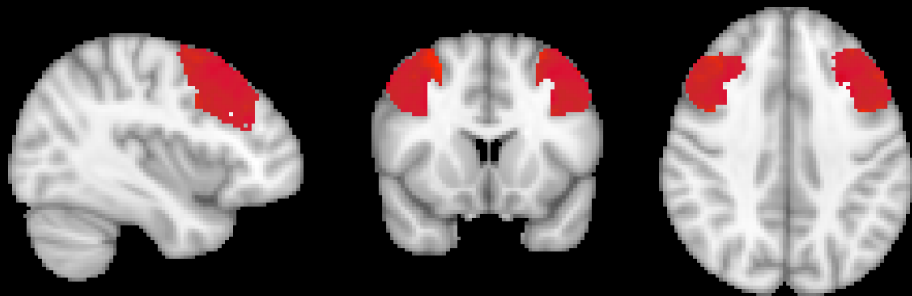
# Localized Cluster Enhancement illustration

Apply a mask of the Middle Frontal Gyrus



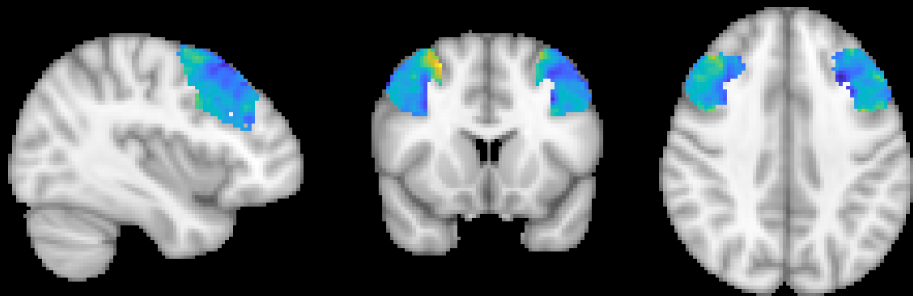
# Localized Cluster Enhancement illustration

Apply a mask of the Middle Frontal Gyrus



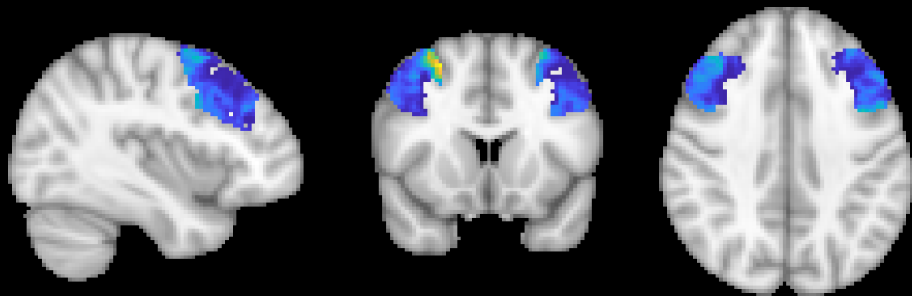
# Localized Cluster Enhancement illustration

Apply a mask of the Middle Frontal Gyrus



# Localized Cluster Enhancement illustration

Apply TFCE on that mask





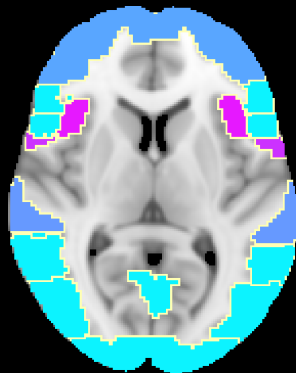
Suppose that the data satisfies an exchangeability assumption. Then

**Theorem:**  $\mathbb{P}(S_{v,R}(T) < t^* \text{ for all inactive } R) \geq 1 - \alpha.$

# Regional activation (HCP - Social)

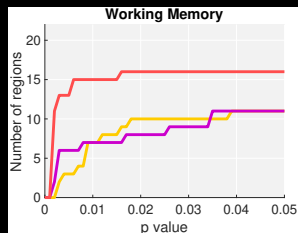
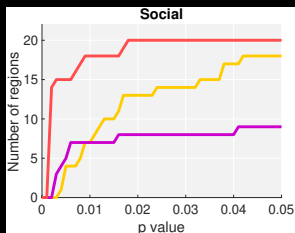
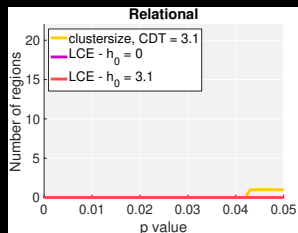
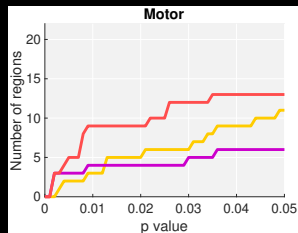
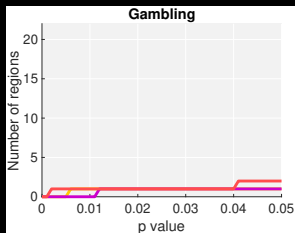
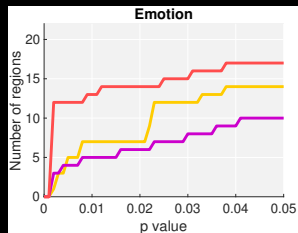


(a) Localized TFCE,  
 $h_0 = 0$



(b) Localized TFCE,  
 $h_0 = 3.1$

# Power comparison for a regional analysis



# Conclusions

- TFCE as classically used can have inflated voxel and clusterwise error rates.
- **Localized Cluster Enhancement** provably controls clusterwise and regional error rates and allows for increases in power and localization.
- TFCE is not threshold free as it (strongly) depends on a threshold  $h_0$ . The default choice of  $h_0 = 0$  means that TFCE typically can only make the weak global statement in practice.
- For localized cluster enhancement we recommend a threshold of  $h_0 = 3.1$  in line with the default for clusterwise inference.

# Thanks

- Slides for this talk are available on my website:  
`sjdavenport.github.io/talks`
- Code to implement LCE and a tutorial on TFCE are available in the StatBrainz MATLAB package available at:  
`sjdavenport.github.io/software`
- Further details available at my poster: 1871