

# The Accumulation of Salient Changes in Visual Cortex Predicts Subjective Time

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## Abstract:

The mechanisms underlying human estimations of duration are frequently said to rely on conceptually unrealistic ‘internal clocks’ that track elapsed time. Roseboom et al. recently presented a novel model of duration estimation, in which human reports of subjective time were replicated by accumulated salient changes in activity across hierarchically organized perceptual classifiers responding to sensory input [1]. Here we tested this model on human neuroimaging data, acquiring fMRI scans while subjects watched silent videos and estimated their duration. Using a pre-registered, model-based fMRI analysis, we will test whether the accumulation of salient moment-to-moment signal changes in visual cortex voxels predicts human subjective time. We hypothesize that this will not occur when accumulating changes detected by auditory or somatosensory cortices, indicating that our ‘internal clock’ is not instantiated by a specialized system for time, but rather is grounded in the sensory systems with which we perceive our environment.

**Keywords:** time perception; fMRI; computational modelling; perceptual classification; human behavior

## Methods

We acquired multi-band functional EPI volumes (fMRI) from 40 human participants while they performed a duration estimation task. On each trial (40-60 total), participants watched a video of 8-24 seconds and reported their duration estimate on a rating scale. Videos either depicted office or city scenes (with few/many salient changes respectively). Our key dependent variable was normalized bias  $B$ , which for trial  $k$  and duration  $t$  was computed as:

$$B_{t,k} = \frac{x_{t,k} - \bar{x}_t}{\bar{x}_t}$$

Table 1: Hierarchies

Layer	Visual	Auditory	Somatosensory
1	V1, V2v, V3v	BA 41	BA 3
2	hV4, LO1-2	BA42	BA 1
3	VO1-2, PHC1-2	BA22p	BA 2

We are following a pre-registered pipeline for pre-processing and data analysis, using SPM12, Python and custom code ([osf.io/ce9tp](https://osf.io/ce9tp)). This abstract presents preliminary fMRI analyses on 17/40 subjects.

## Results

### Overestimation of duration for busy scenes

Each participant exhibited a monotonic relationship between veridical and reported duration, indicating they could perform the task well. As predicted, and replicating results from [1], durations for city scenes with more salient changes were over-estimated relative to office scenes with few salient changes,  $BF_{H(0,10.5)} = 160$  (Figure 1A).

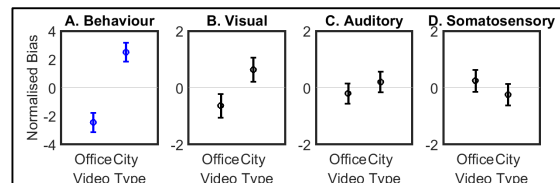


Figure 1. Normalised bias by video type for (A) behavioral data and (B-D) model predictions based on neuroimaging data

### Preliminary fMRI results

GLM on the BOLD data revealed that the behavioral effect of video type on normalized bias was associated with BOLD activity in middle and superior temporal gyrus, and in middle occipital gyrus.

To test whether subjective time arises from the accumulation of salient changes in visual cortex, we constructed a three-layer visual hierarchy of ROIs (see Table 1). From each layer we extracted voxel-wise BOLD activation, and defined *change* in each TR  $t$  as  $\sum_v |x_t - x_{t-1}|$ . Each change was then classified as salient or not by a criterion with exponential decay, corrupted by Gaussian noise. Accumulated salient



changes in each of the three hierarchical levels were converted into units of time by combining data from all participants, training a multi-class support vector machine (SVM) to classify veridical video duration.

For each trial, the SVM's predicted duration was converted to normalized bias. As shown in Figure 1, our behavioral effect of video type was only mirrored by the model trained on salient changes detected by visual cortex, and not when the model was trained on auditory or somatosensory hierarchies.

Taken together, results thus far are supportive of the notion that perceptual classification by sensory cortices generate the relevant signals for human estimation of time, and that 'Internal Clock' models need not depend upon mechanisms specialized for time.

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### **References**

Roseboom, W., Fountas, Z., Nikiforou, K., Bhowmik, D., Shanahan, M., & Seth, A. K. (2019). Activity in perceptual classification networks as a basis for human subjective time perception. *Nature communications*, 10(1), 267.