A Hierarchy of Temporal Receptive Windows in Human Cortex

U. Hasson[1], E. Yang[1], I. Vallines[3] , D. J. Heeger[1], N. Rubin[1]

[1]New York University,   [2]University of Regensburg

Real-world events unfold at different time scales, and therefore cognitive and neuronal processes must likewise occur at different time scales. We present a novel procedure that identifies brain regions responsive to sensory information accumulated over different time scales. We measured fMRI activity while observers viewed silent films presented forward (the original intact films), backward, or piecewise-scrambled in time. We then compared the reliability of the responses in each brain area to the intact films with that obtained when the temporal structure was disrupted. Early visual areas (e.g., V1 and MT+) exhibited high response reliability regardless of temporal structure. In contrast, the reliability of responses in several higher brain areas, including the superior temporal sulcus (STS), precuneus, posterior lateral sulcus (LS), temporal parietal junction (TPJ) and frontal eye field (FEF), were affected by information accumulated over longer time scales. These regions showed highly reproducible responses for repeated forward, but not for backward or piecewise-scrambled presentations. Responses in LS, TPJ and FEF depended on information accumulated over long durations (~ 36 s), STS and precuneus over intermediate durations (~12 s), and early visual areas over short durations (< 4 s).

The dependence of the fMRI responses on temporal order could not be attributed to differences in eye movements. The measured eye positions were independent of temporal order, and were equally reliable for forward and backward presentations. That is, observers fixated on similar image locations for similar durations, but in the opposite order, when the films were presented backwards. Moreover, the reproducibility of the eye movements suggests a comparable level of engagement while observers viewed the forward and backward films, removing potential concerns that the unreliable responses to the backward films were because observers paid less attention to them.

Finally, we found a clear dissociation between the reliability of the responses and response amplitudes. For example, in the LS and TPJ we observed large response amplitudes for all films, but the responses to the scrambled and time-reversed films were much less reliable than the responses to the intact forward films. In a separate behavioral study we confirmed that playing the films backward had a great impact on their intelligibility. We interpret the strong response amplitudes as reflecting incessant processing, aimed to extract meaningful information from the stimuli. At the same time, the low reliability of the responses to temporally disrupted movies indicates a failure to attain a consistent/stereotypical sequence of neural (and cognitive) states.

We conclude that, similar to the known cortical hierarchy of spatial receptive fields, there is a hierarchy of progressively longer *temporal receptive windows* in the human brain. Response reliability provides information about neural processing that is complementary to that derived from more traditional measurements of response amplitude, and can uncover phenomena that response amplitudes alone do not reveal, such as the long temporal receptive windows found in this study.

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