

Supplementary material

Spike detection and sorting

From the continuous wide-band data, spike detection and sorting was carried out by a novel and relatively fast algorithm³⁰. Briefly, once spikes are detected via amplitude thresholding, the algorithm uses the wavelet transform to extract features of the spike shapes that are used as inputs to the clustering algorithm. Clustering is done by means of super-paramagnetic clustering, a method from statistical mechanics that does not assume any particular distribution of the clusters. Super-paramagnetic clustering groups the data into clusters as a function of a single parameter, the temperature. In analogy with spin glasses in statistical mechanics, for low temperatures all the data is grouped into a single cluster and for high temperatures, the data is split into many clusters with few members each. Figure S1 shows an example of the clustering outcome for a single channel. A Matlab implementation of the algorithm as well as exemplary data is available from www.vis.caltech.edu/~rodri. After a first unsupervised processing of the data, the temperature is the main parameter that can be changed by the user if the automatic clustering is not satisfactory. At times, we combine results from two different temperatures and/or we assign membership of unclustered spikes to nearby clusters via template matching.

Subsequently, we classify the clusters into single- or multi-units. Multi-unit clusters are those reflecting the activity from several neurons whose spikes can not be further differentiated due to their low signal to noise ratio. The classification between single- and multi-unit was done visually based on: 1) the spike shape and its variance; 2) the ratio between the spike peak value and the noise level; 3) the ISI distribution of each cluster; 4) the presence of a refractory period for the single-units; *i.e.* less than 1% spikes within less than 3ms inter-spike-interval. In Figure S1, the first (blue) cluster corresponds to a multi-unit and the other 3 to single-units.

Difference to our previous work

We reported before the presence of units in the human medial temporal lobe that responded to faces in comparison to objects¹³ and to different categories of stimuli¹⁴. Over the last three years we introduced several modifications to optimize the recording conditions:

(i) we devised a novel spike sorting algorithm that allowed the detection of more units than before³⁰; (ii) in previous studies spikes were detected on-line via amplitude thresholding and the very selective units were usually not detected because they remained silent at the beginning of the experiment when the thresholds were set; (iii) we increased the number of electrodes that we could record from 16 to 64; (iv) the access to the continuous data allowed us to estimate the noise level, thus being able to differentiate the multiunit activity from noise (something hard to do with the previous setup where only the spike shapes were stored); finally (v) the screening/testing session design allowed us to present multiple views of specific individuals and objects.

More examples of invariant responses

In order to increase the probability of finding invariant cells, we first explored cellular responses by using screening sessions. In these screening sessions, pictures of different individuals, objects, animals and landmarks were shown. After a fast analysis of the data, we identified the pictures eliciting responses in at least one unit. Then, invariance was tested in later testing sessions by showing between 3 and 8 pictures of these individuals or objects. As discussed above, the neuronal selectivity was statistically the same in both sessions. All the images that elicited a response in the screening session were included in testing sessions.

Figures S2 to S11 correspond to cells recorded during testing sessions following earlier screening sessions. These figures complement the examples shown in the main text.

Figure Legends (Supplementary Material)

Figure S1: The spike sorting algorithm at work. Upper subplot: 60 sec of continuous, bandpass-filtered data and the threshold used for detection (red line). Middle subplots: spike shapes of clustered units and their distribution in a 2-D space of wavelet coefficients (leftmost subplot). Lower subplots: Inter-spike interval distribution of clusters and number of spikes in each cluster as a function of the temperature (leftmost subplot; see text). The optimal temperature chosen by the algorithm is marked by the vertical dotted line. Spike amplitudes and amplitude of the continuous data (y-axes) are in μV .

Figure S2: A multi-unit in the right posterior hippocampus recorded in the same session as the unit shown in Figure 1. Conventions for this and the following figures are the same as in Fig. 1. The order of trial number in the raster plots is from top to bottom. Due to insurmountable copyright problems, in this and subsequent figures, all original images were replaced by very similar ones (same subject, animal or building, similar pose, similar colour, line drawing etc). This unit responded selectively to pictures of Jennifer Aniston together with Brad Pitt. This unit did not respond significantly to pictures of Aniston alone.

Figure S3: A single-unit in the right posterior hippocampus that responded to pictures of the actress Pamela Anderson, including a caricature of her and the letter string “Pamela Anderson”, but not to other letter strings. Note that it is difficult to identify common visual features that would explain this invariant response.

Figure S4: A single-unit in the left posterior hippocampus that responded to pictures of the basketball player Kobe Bryant but also to other images. The area under the ROC curve was 0.78, which is close to the lowest value of the distribution of invariant cells (Fig. 4). Noteworthy, this unit was recorded from the same micro-wire as the one in Fig. 1. This stresses the importance of spike sorting: without good spike sorting, we would have observed just one multi-unit responding both to Bryant and to Aniston. Furthermore, this suggests that nearby units can show different selective responses.

Figure S5: A single-unit in the right anterior hippocampus that responded to pictures of the Bahai Temple and the Sydney Opera. Since the patient did not distinguish these two buildings, we considered them as a single landmark. For this cell, there was also an invariant representation of pictures of Aniston together with Brad Pitt (different from the one shown in Figure S2). Responses are extremely sparse, but consistent across trials. (C) ROC curve corresponding to the Sydney Opera/Bahai Temple (green) and Aniston with Pitt (red). Light traces are the surrogates for each case.

Figure S6: A unit in the right posterior hippocampus that responded preferentially to pictures of the Tower of Pisa. There was also a significant response to the Eiffel tower (picture #18).

Figure S7: A single-unit in the left posterior hippocampus that responded to pictures of Jennifer Aniston (different from Figure 1 in the main text). This unit also responded to a similar looking actress (picture #9) that appeared in a famous TV series (“Friends”) with Jennifer Aniston.

Figure S8: A single-unit in the right anterior hippocampus responding preferentially to pictures of Mother Teresa. This cell was recorded from the same microwire as the cell shown in Figure 2. This again stresses the importance of spike sorting, since there are no responses to Halle Berry for this cell and no responses to Mother Teresa for the cell shown in Figure 2.

Figure S9: A single-unit in the right anterior hippocampus responding selectively to pictures of Julia Roberts and to the letter string with her name.

Figure S10: A single unit recorded from the same microwire as the one shown in the previous figure. This unit was selectively activated by pictures of Kobe Bryant.

Figure S11: A single-unit in the right anterior hippocampus responding preferentially to pictures of Catwoman. Interestingly, this cell also responded to other animal pictures.

Fig. S1

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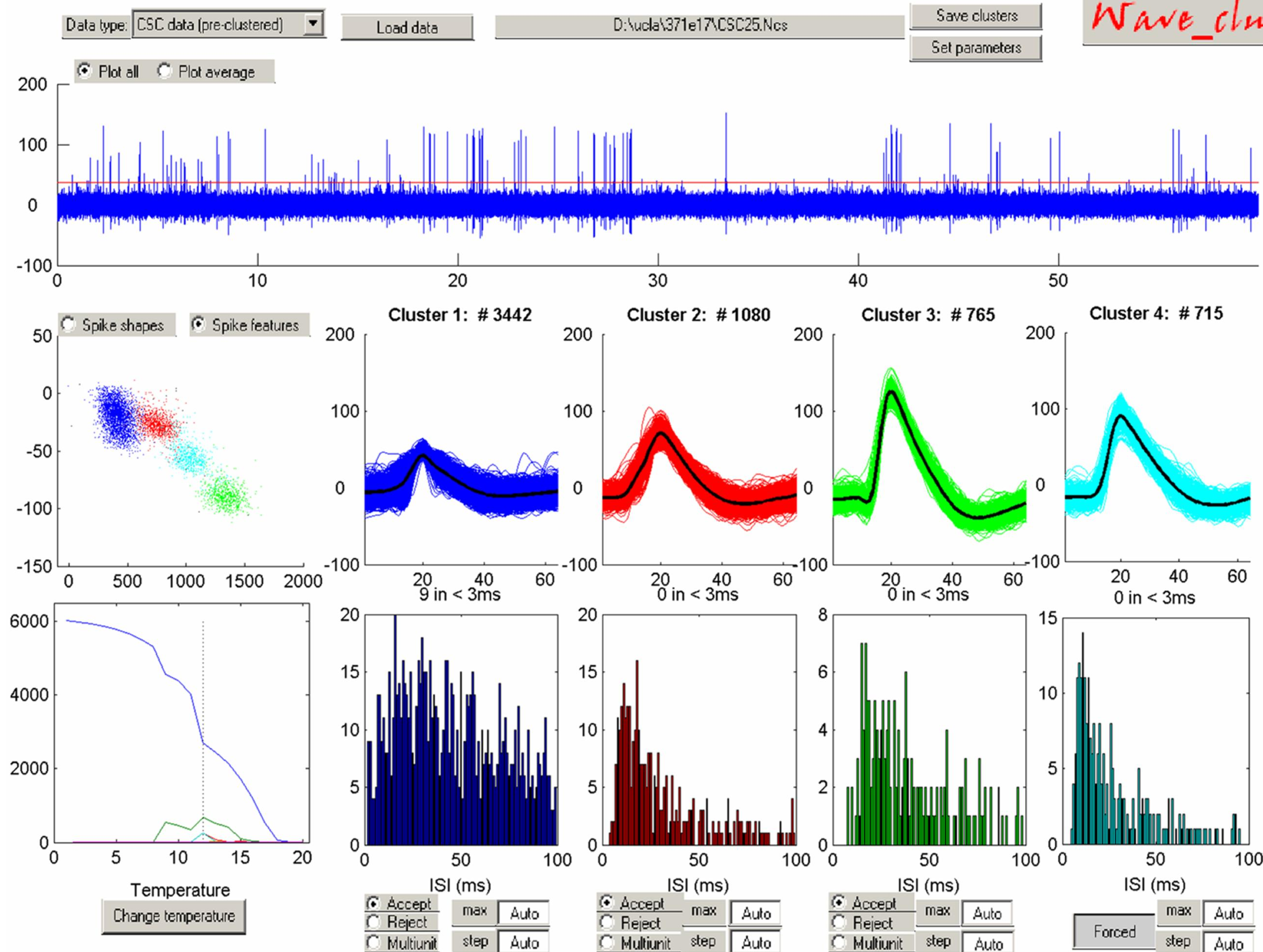
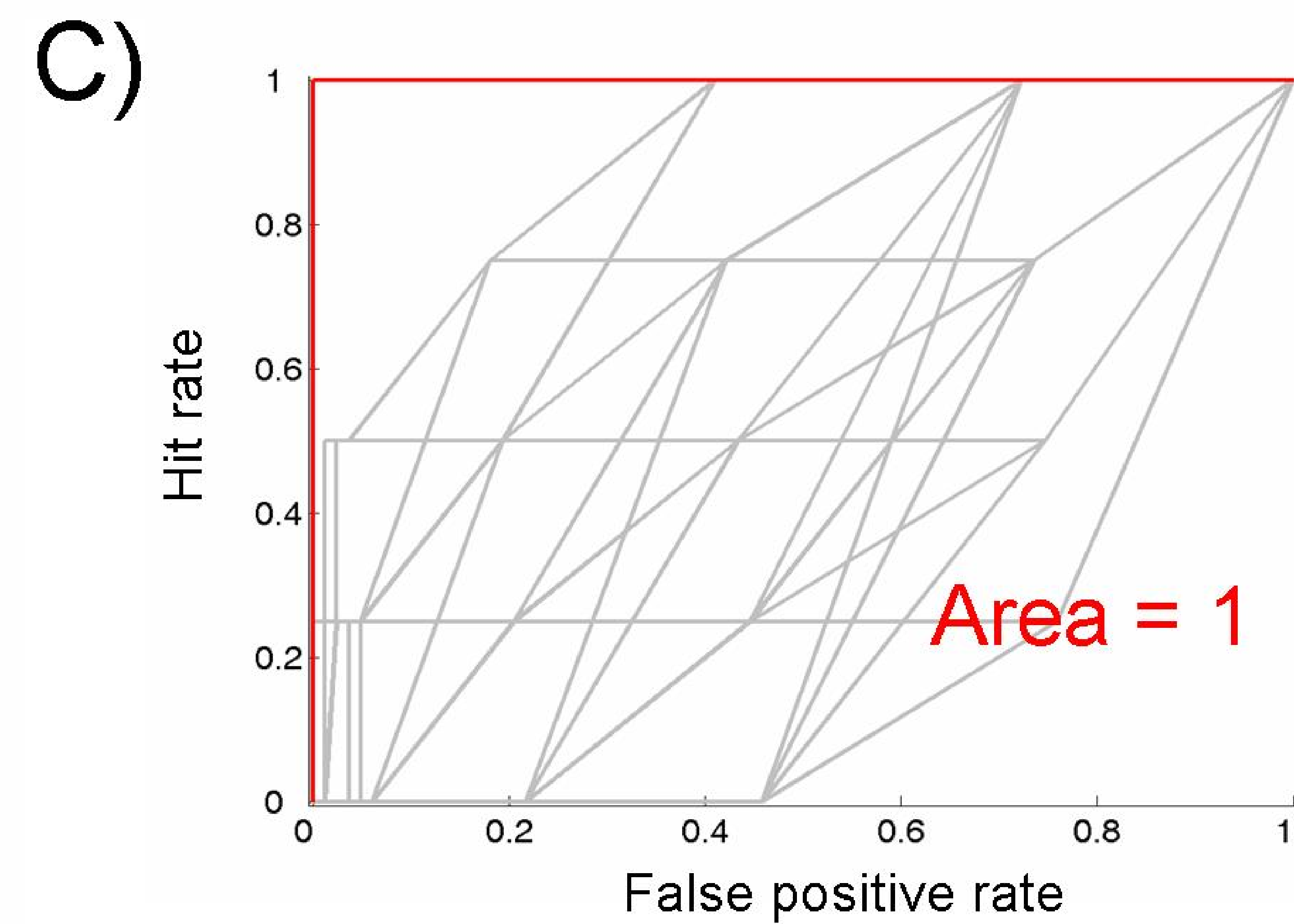
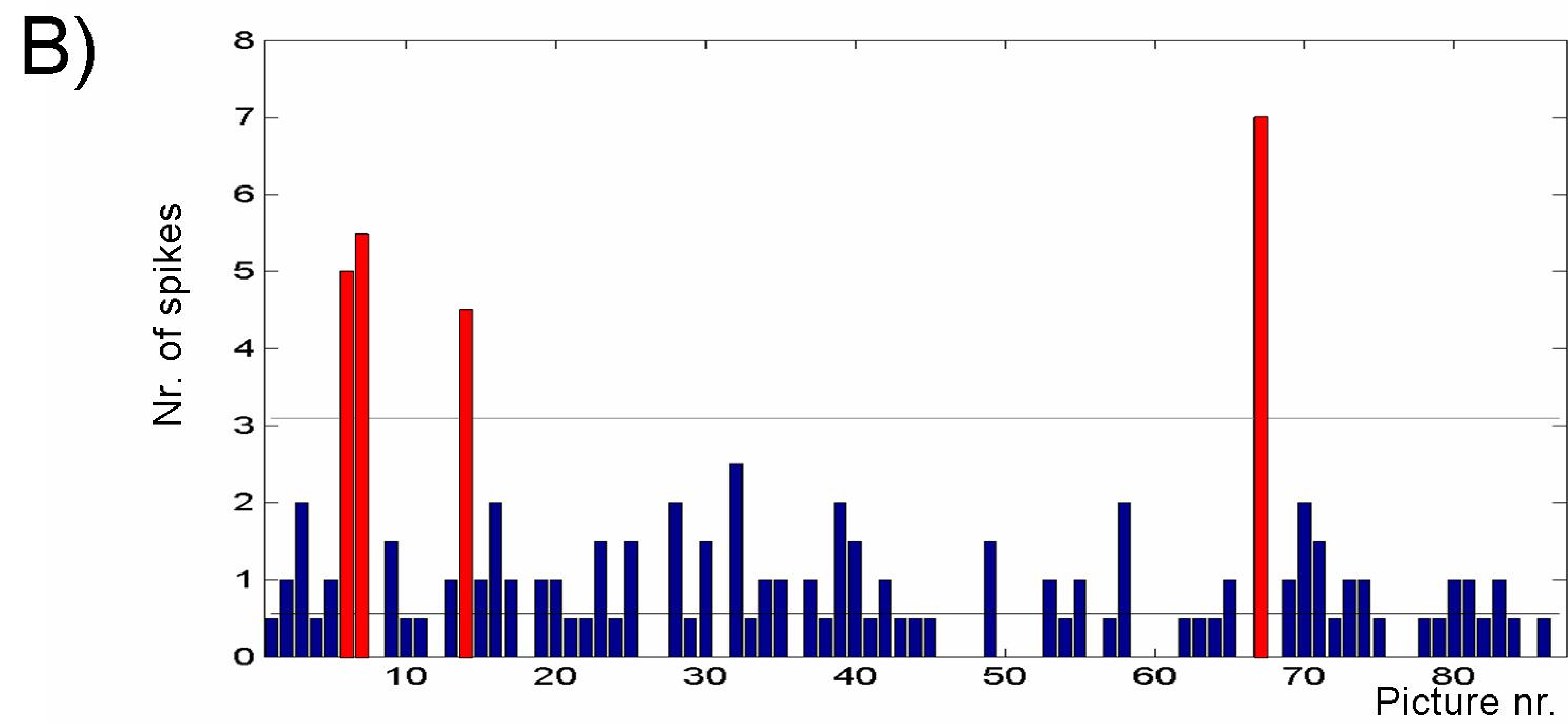
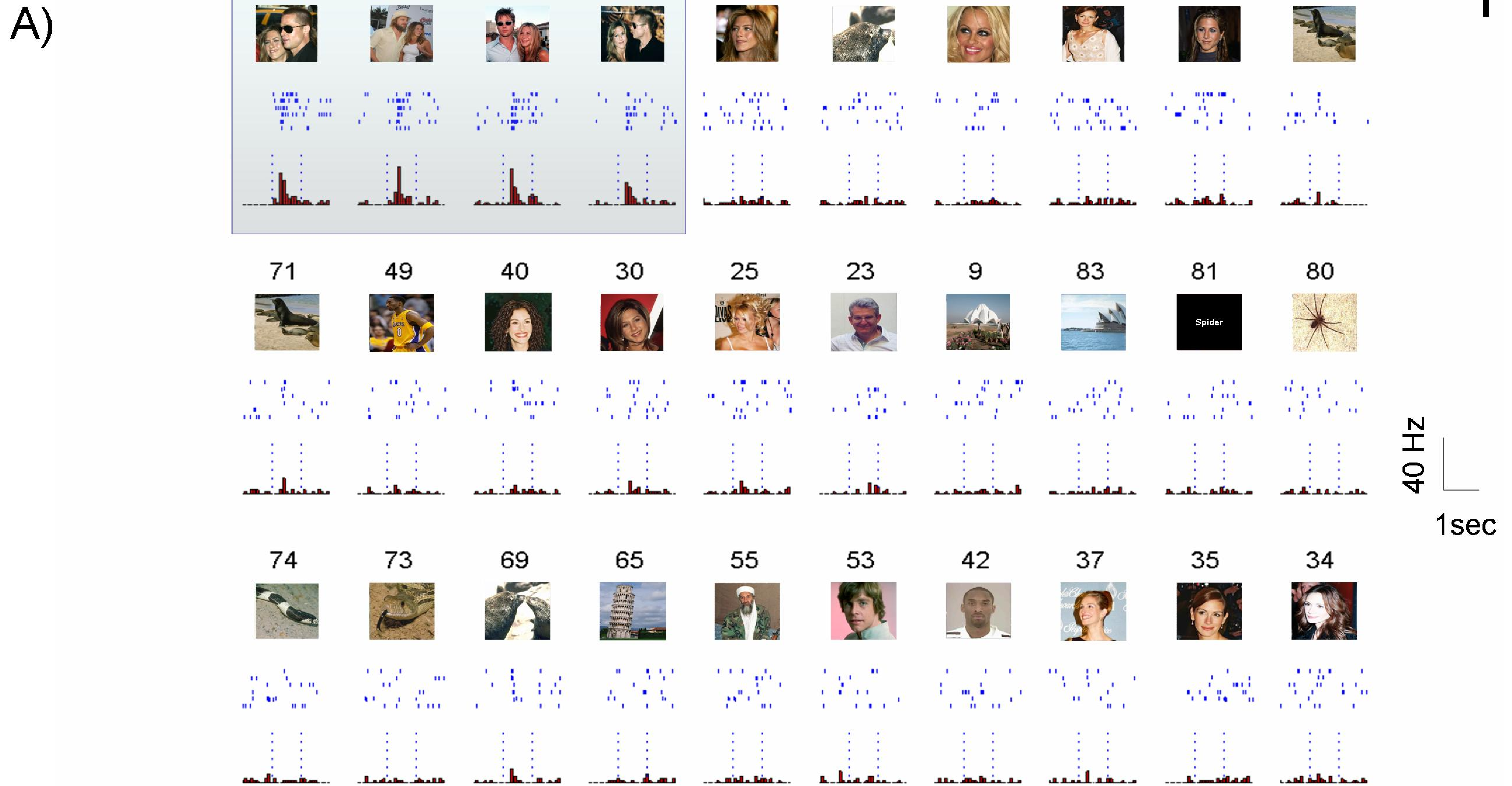
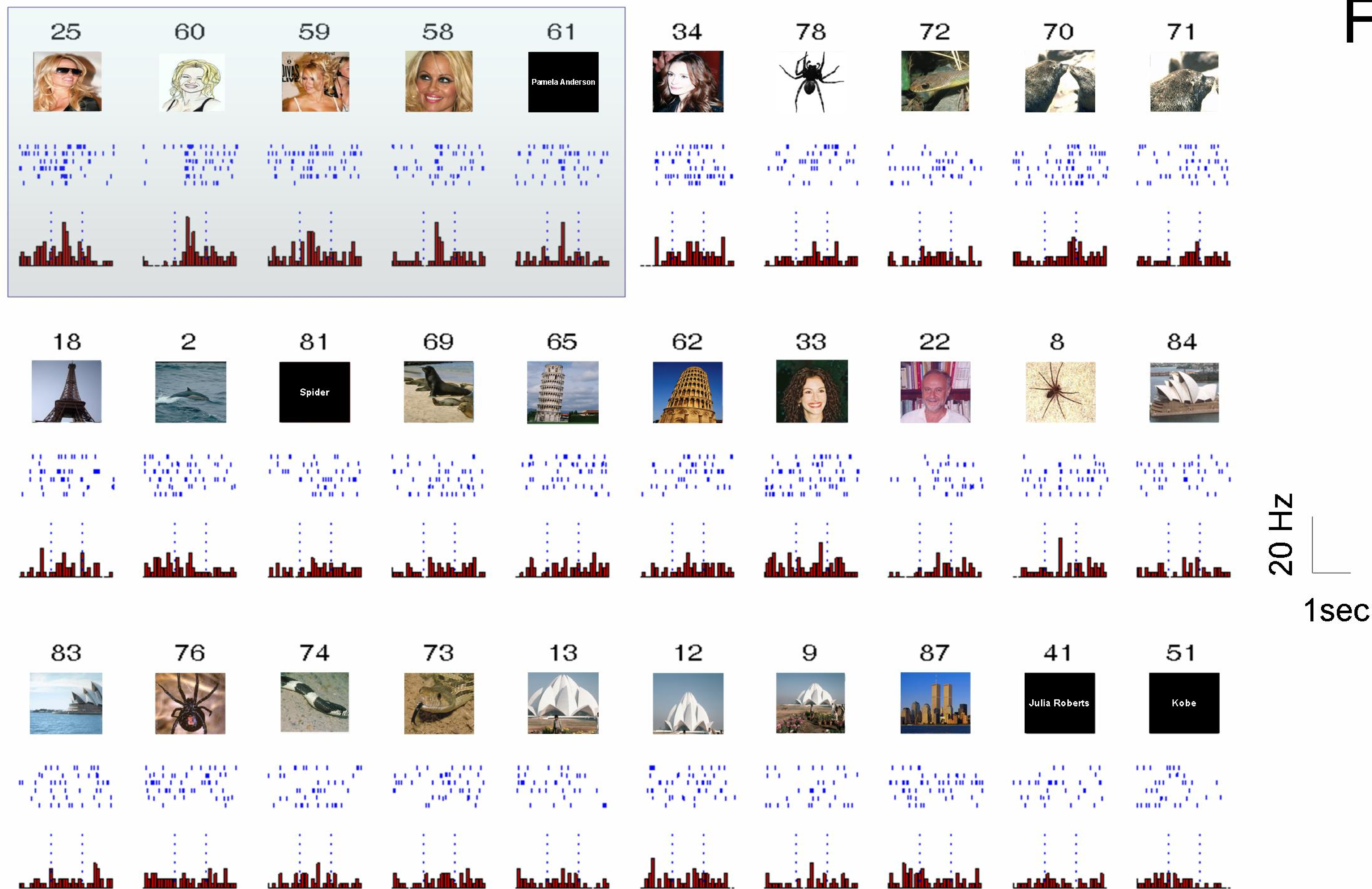


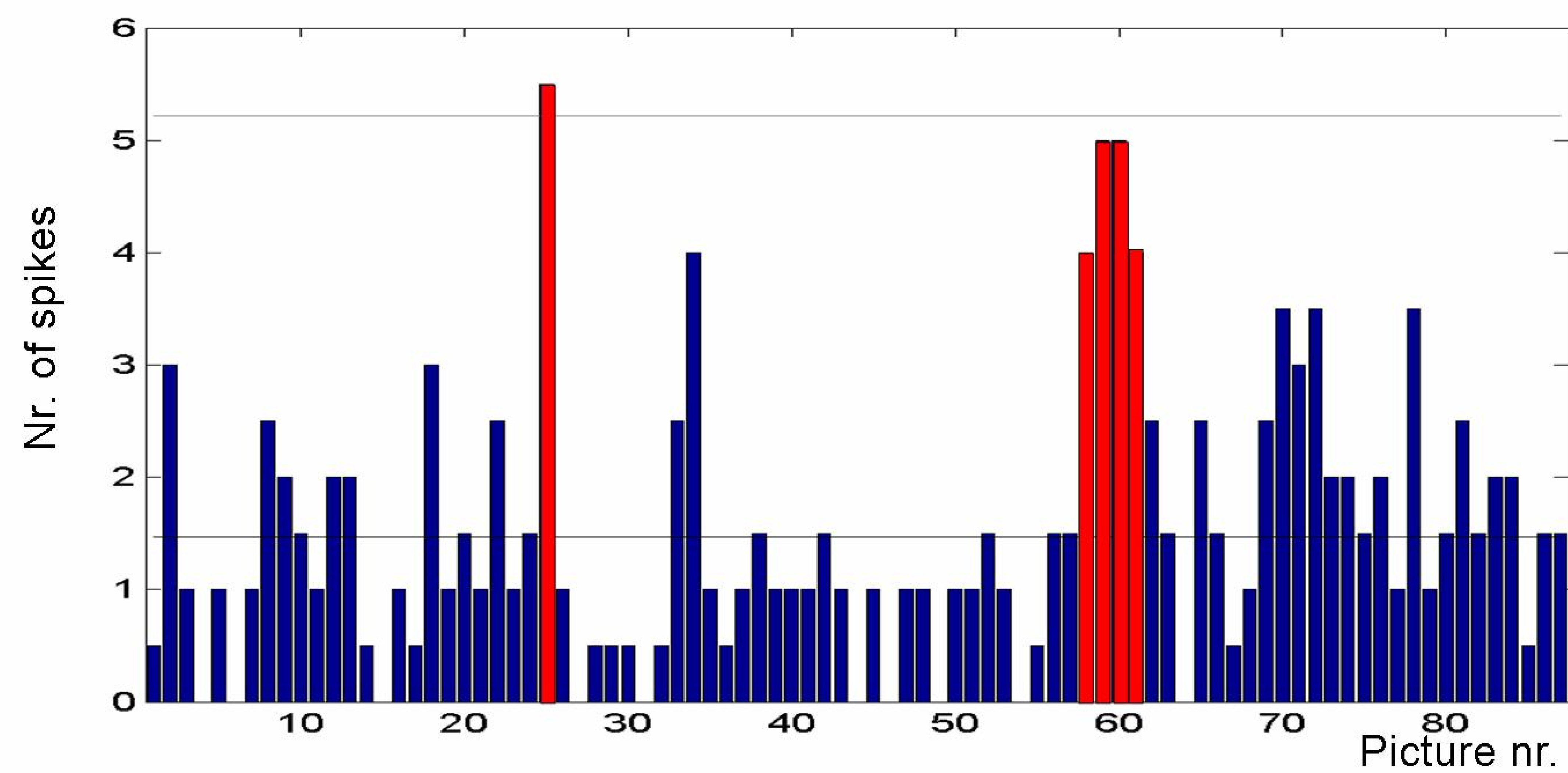
Fig. S2



A)



B)



C)

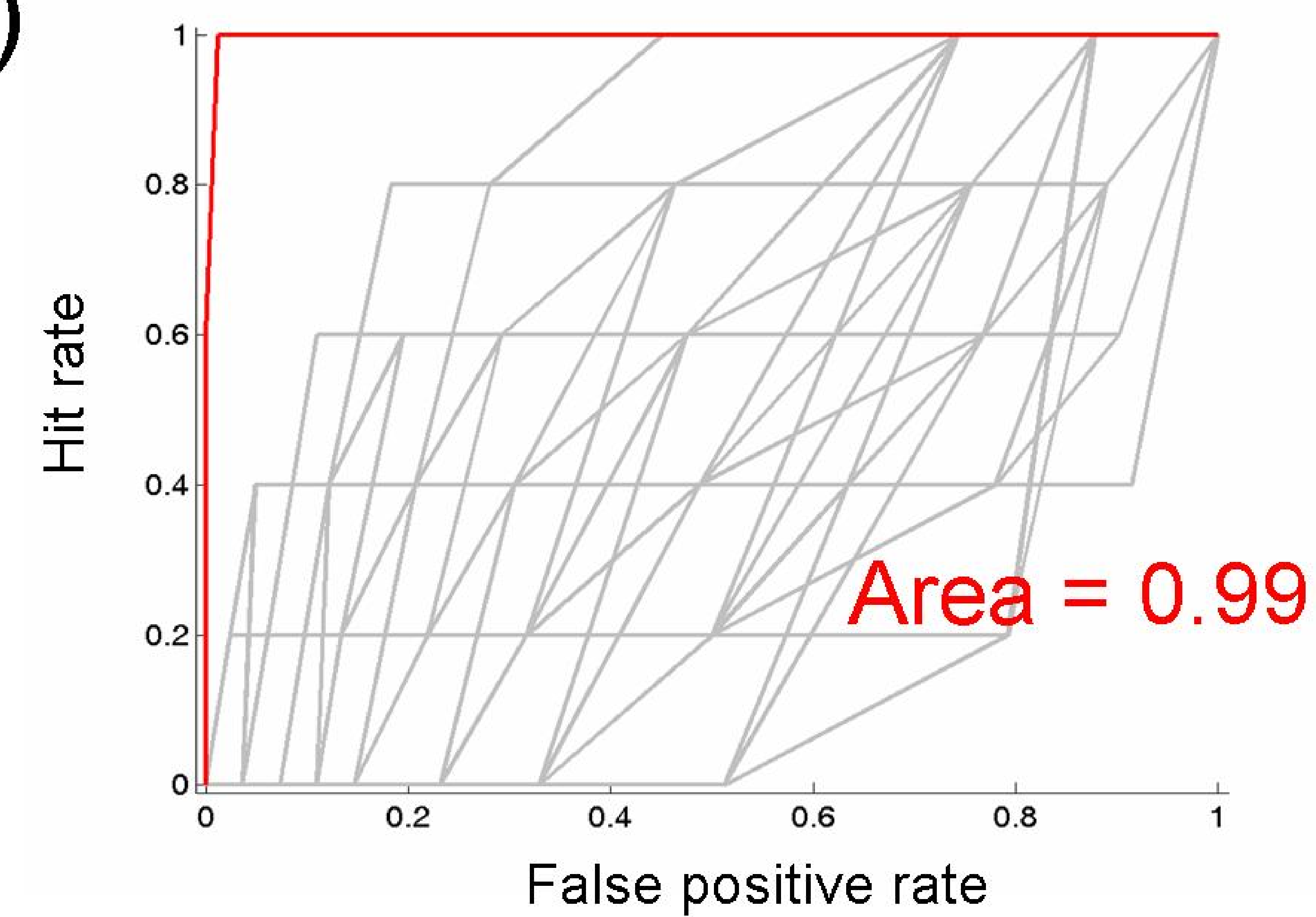
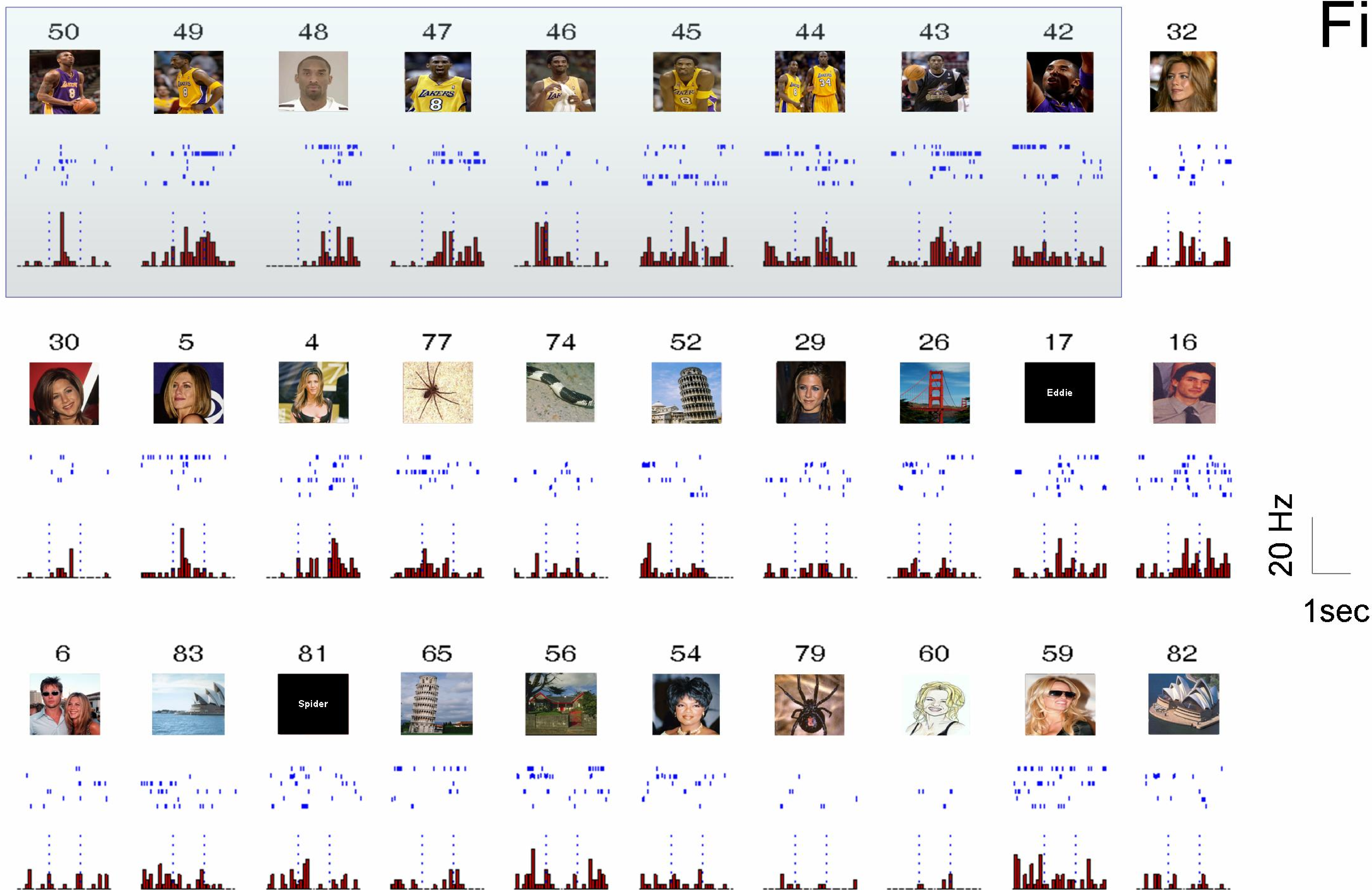
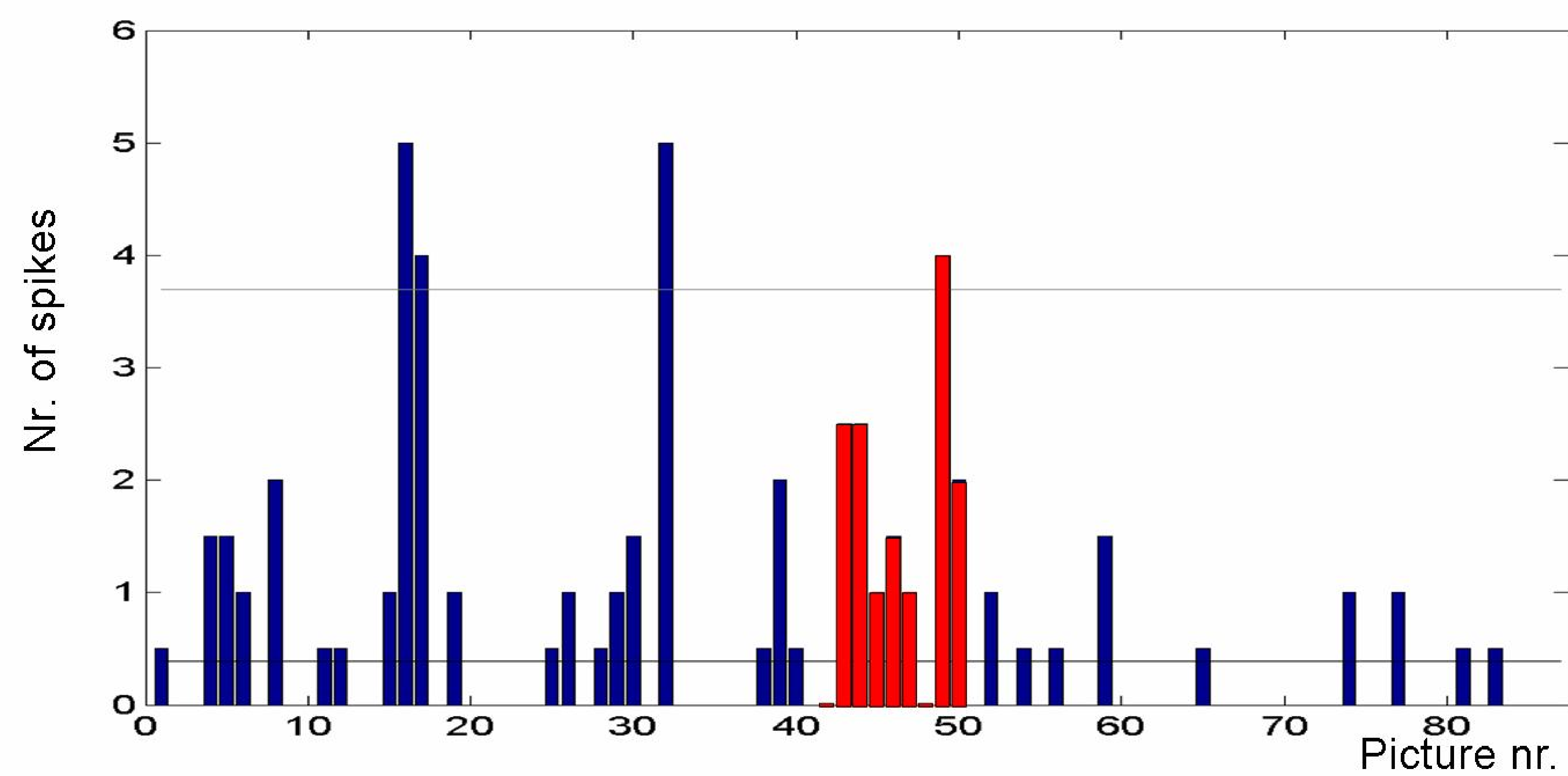


Fig. S4

A)



B)



C)

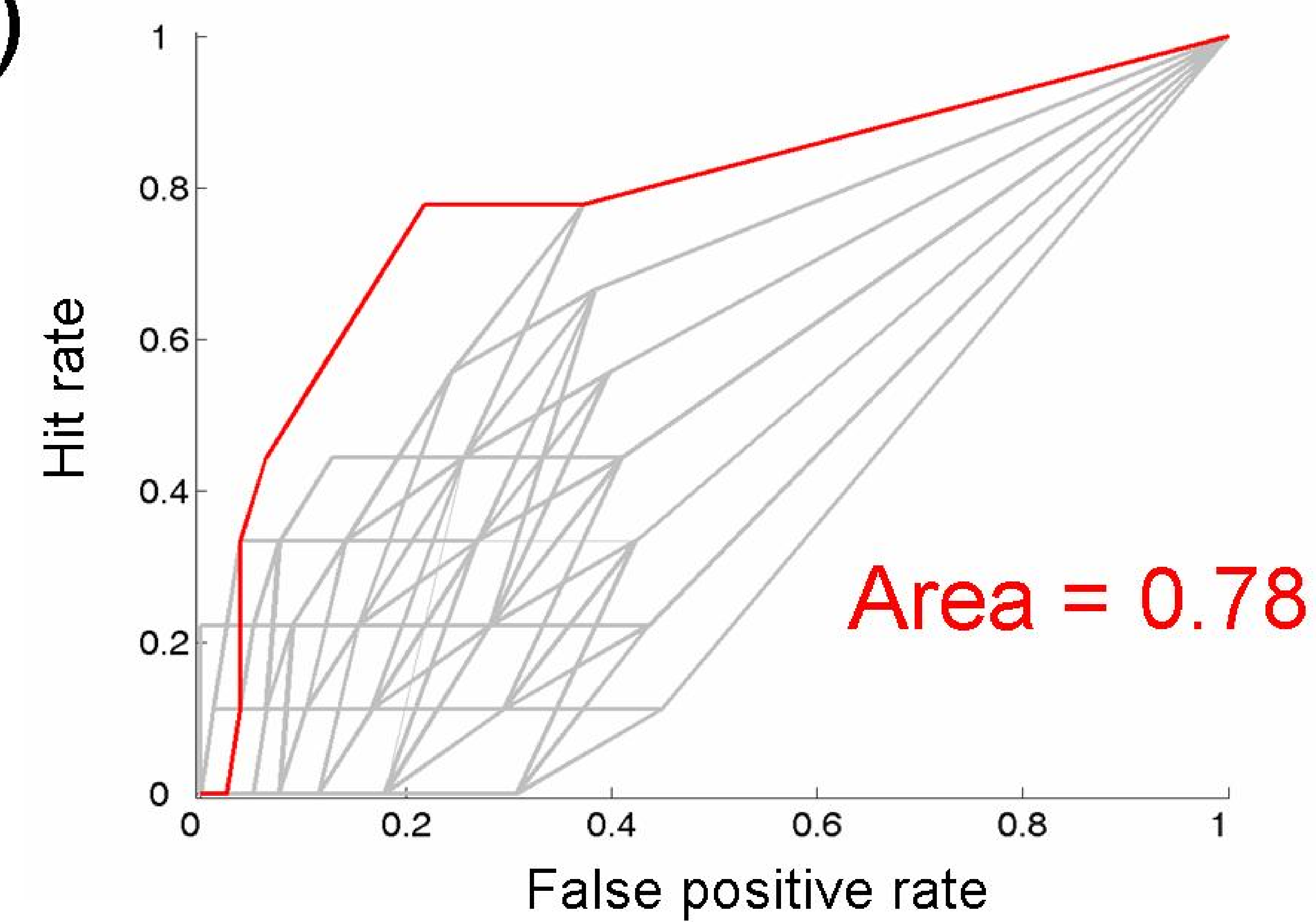
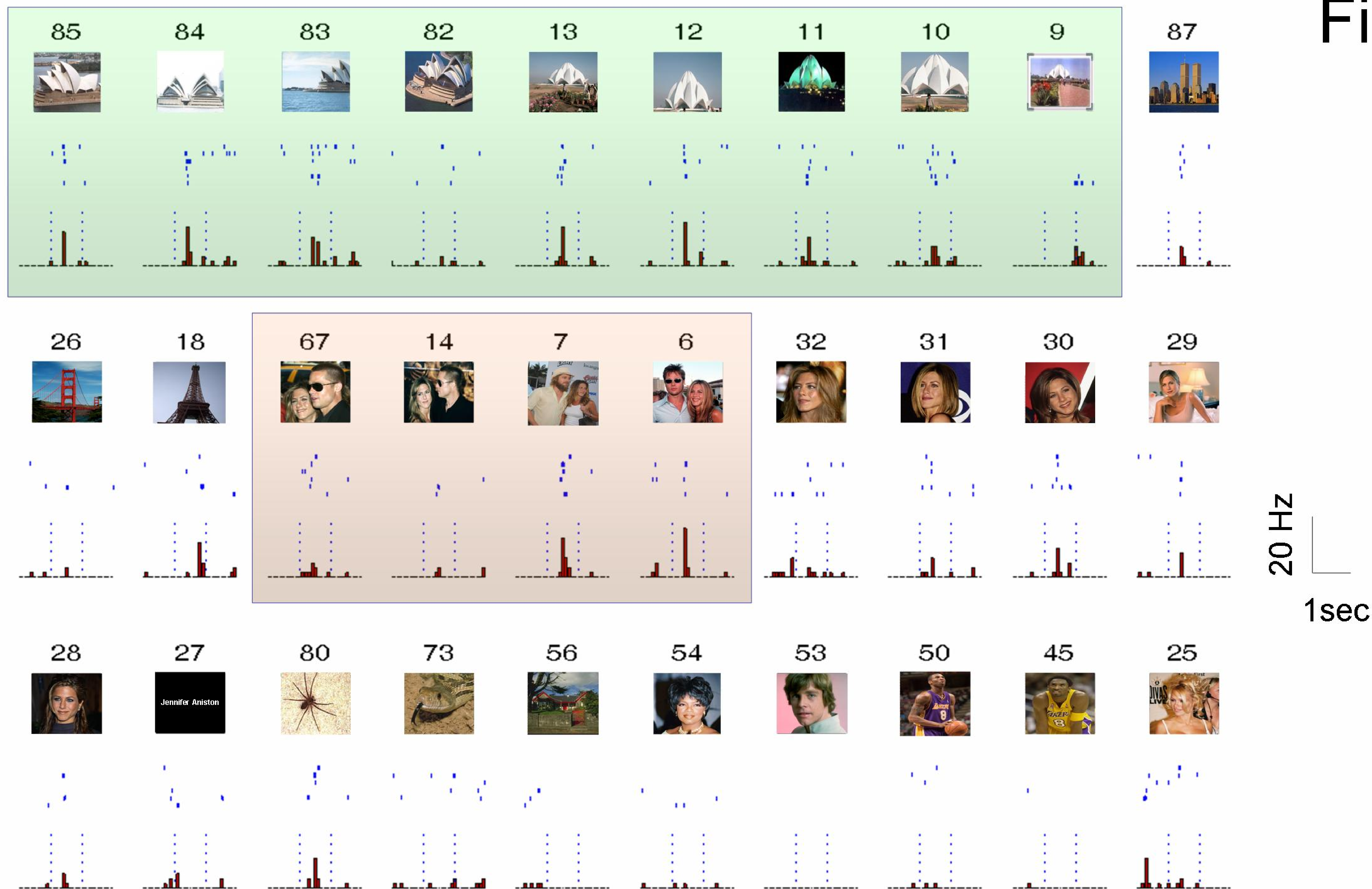
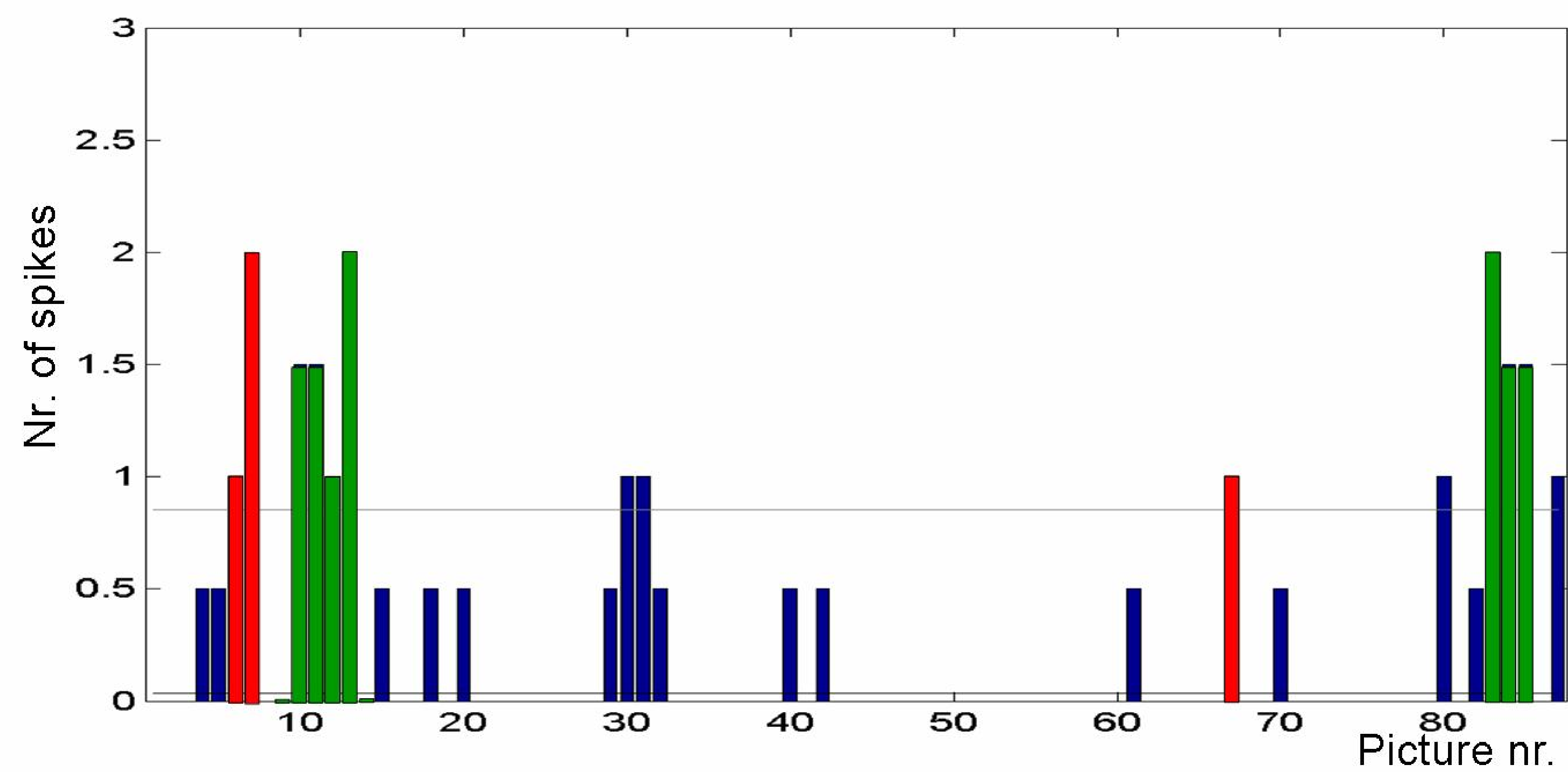


Fig. S5

A)



B)



C)

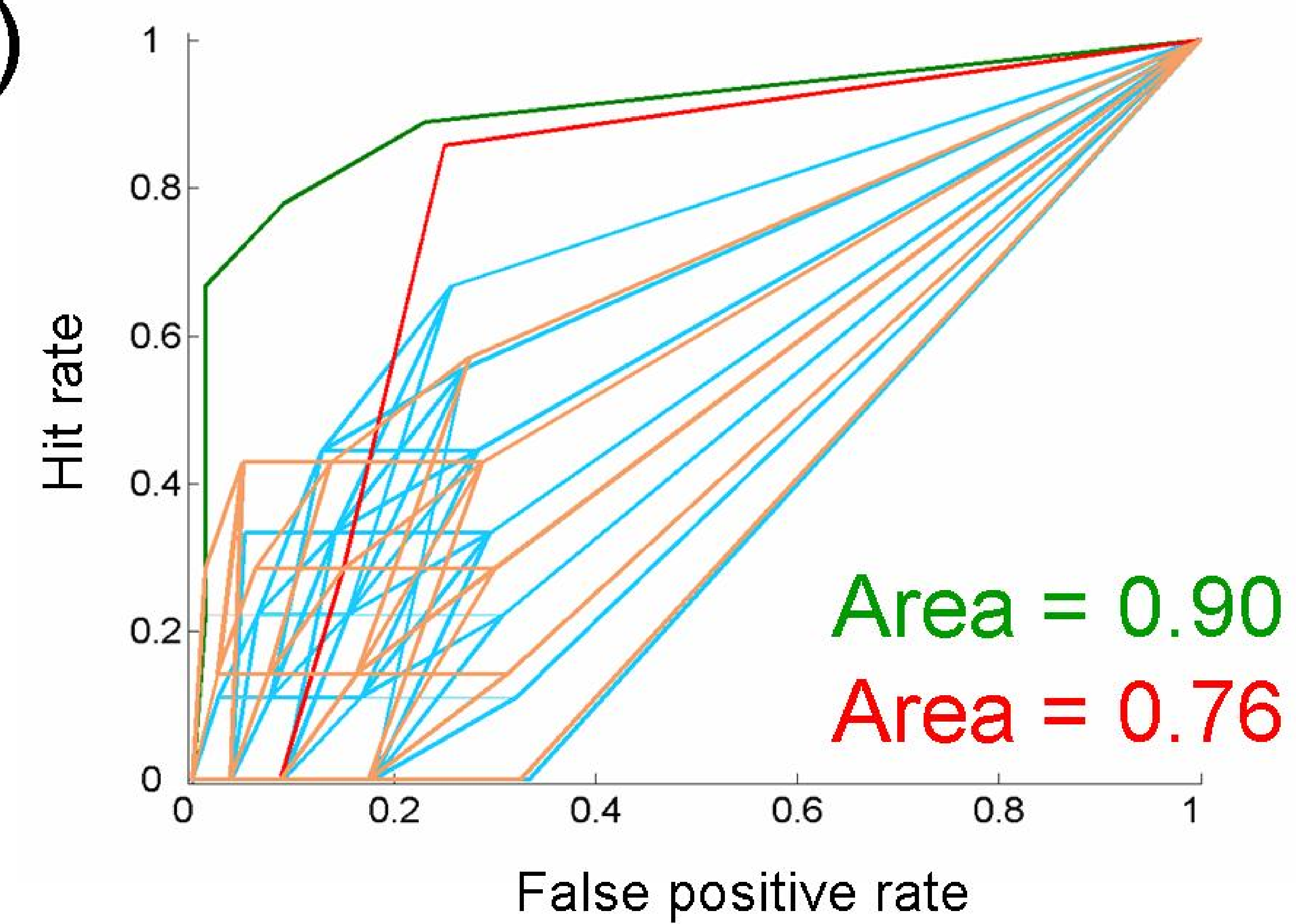
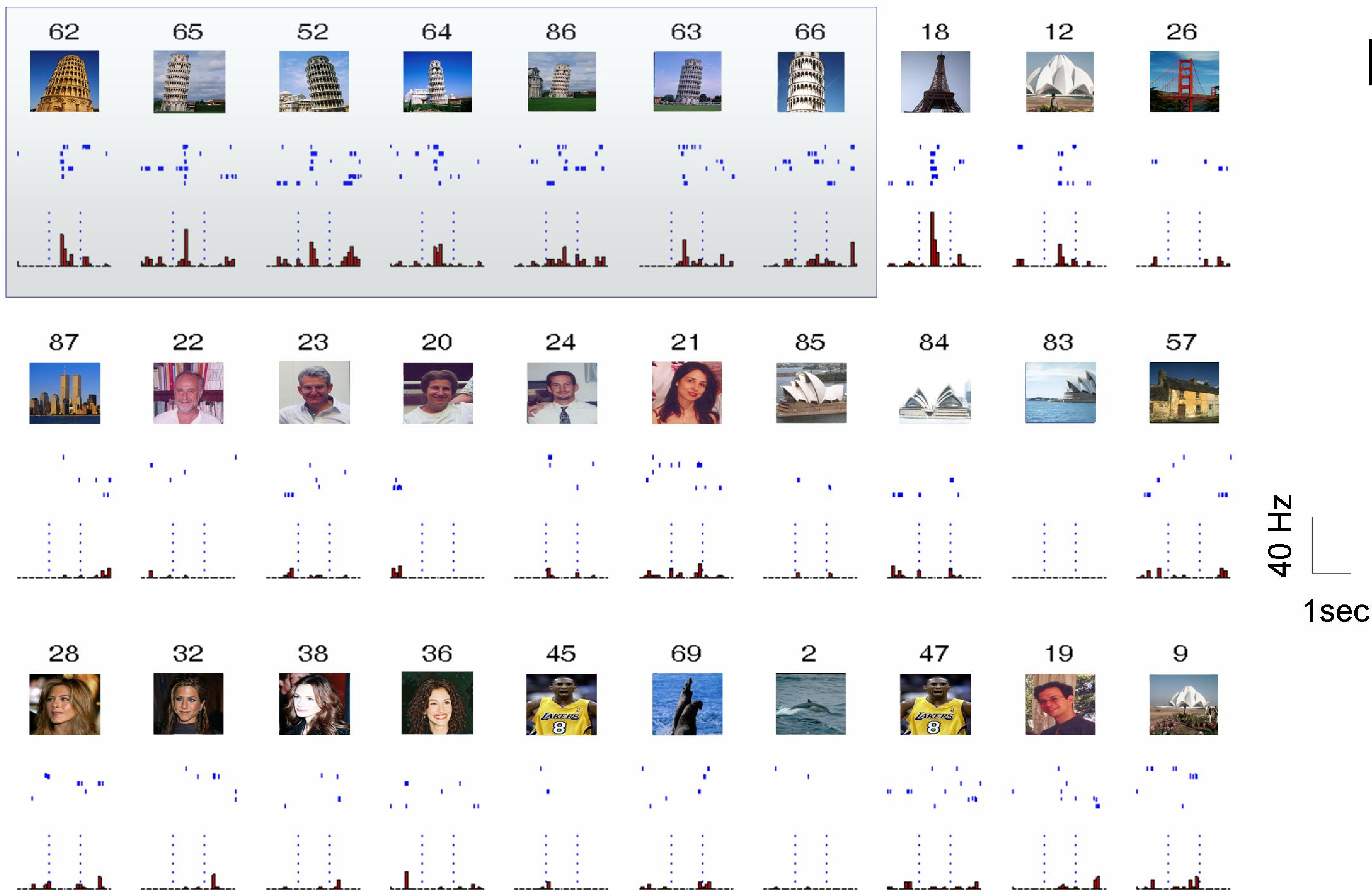
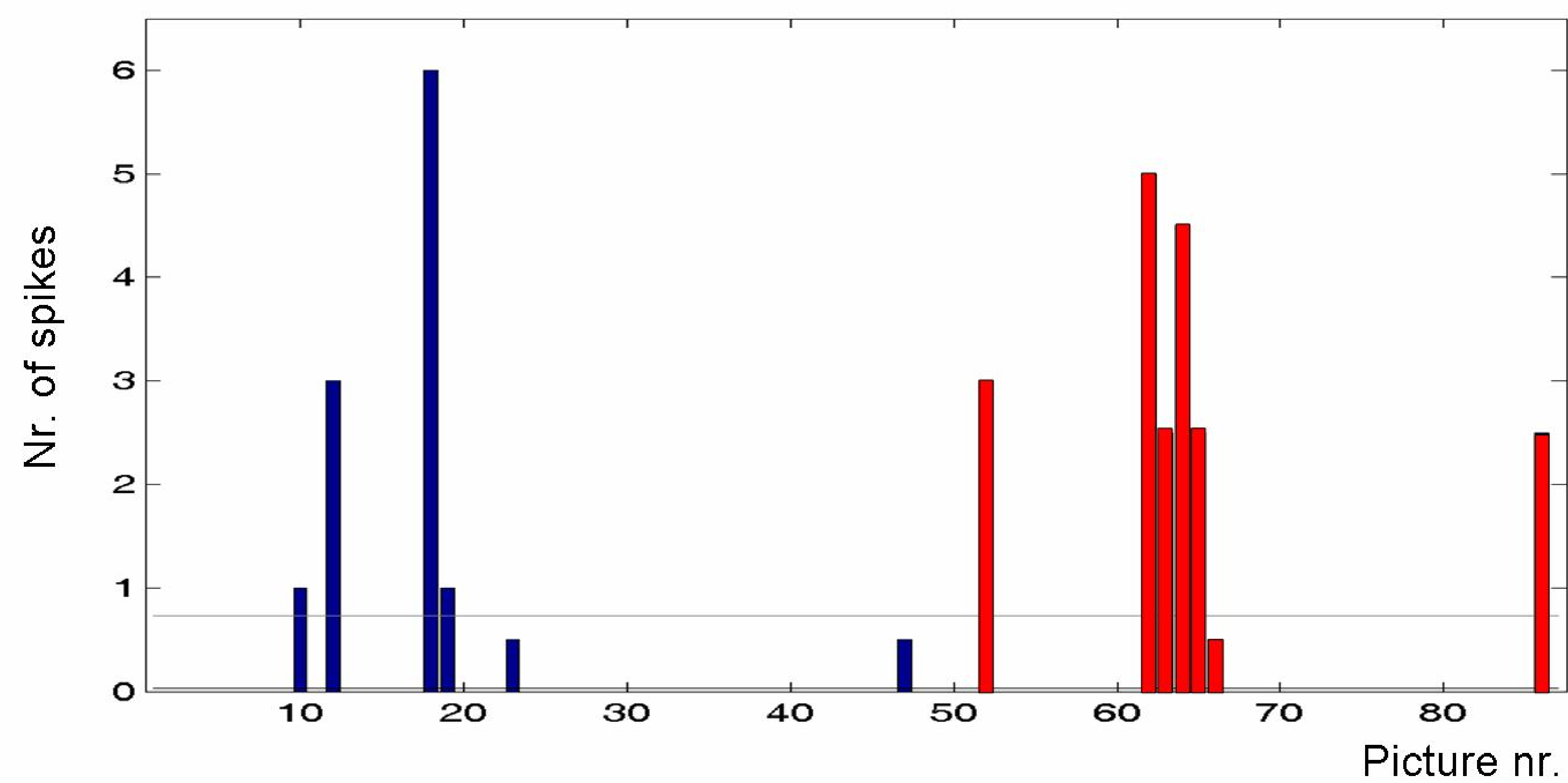


Fig.S6

A)



B)



C)

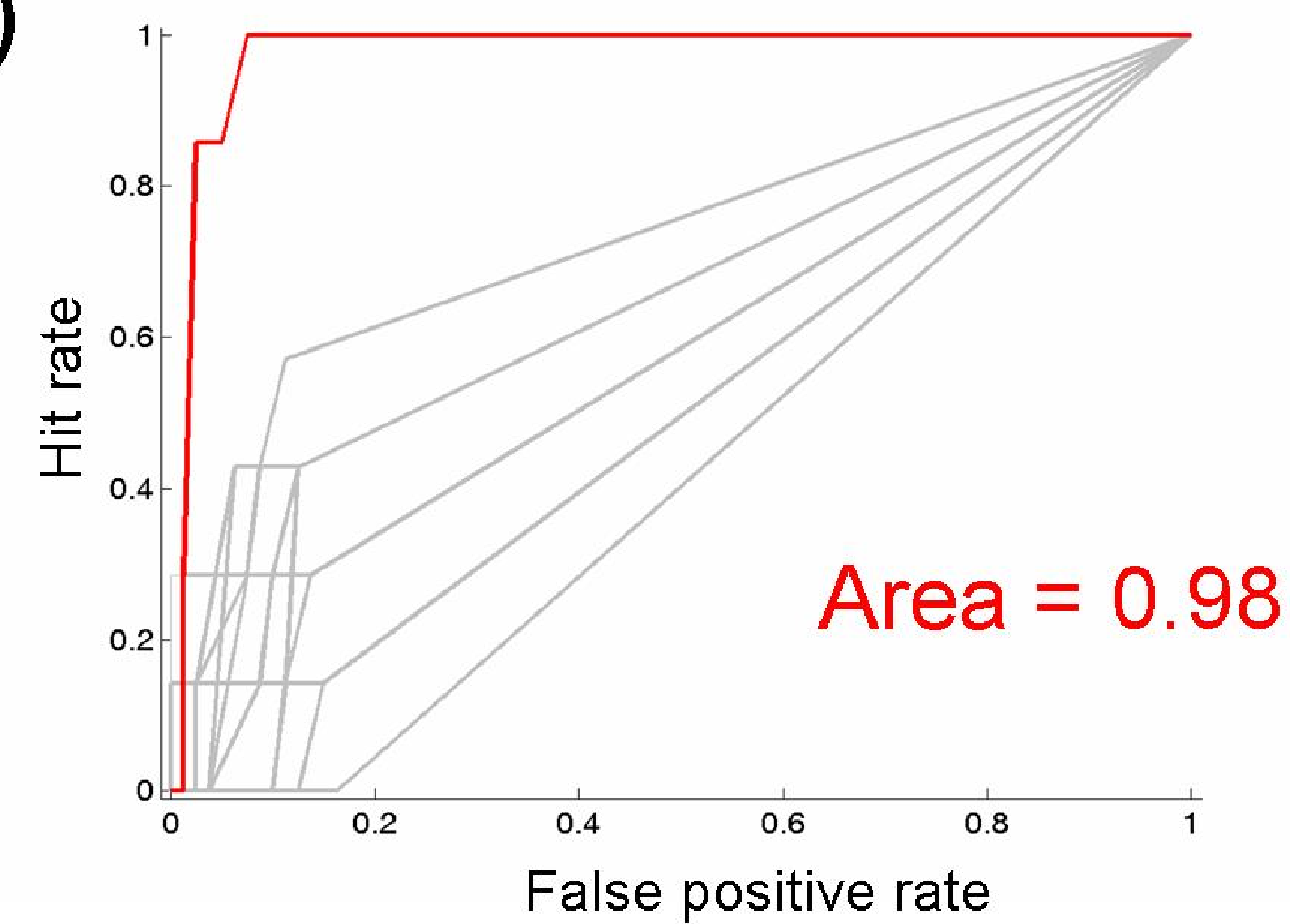
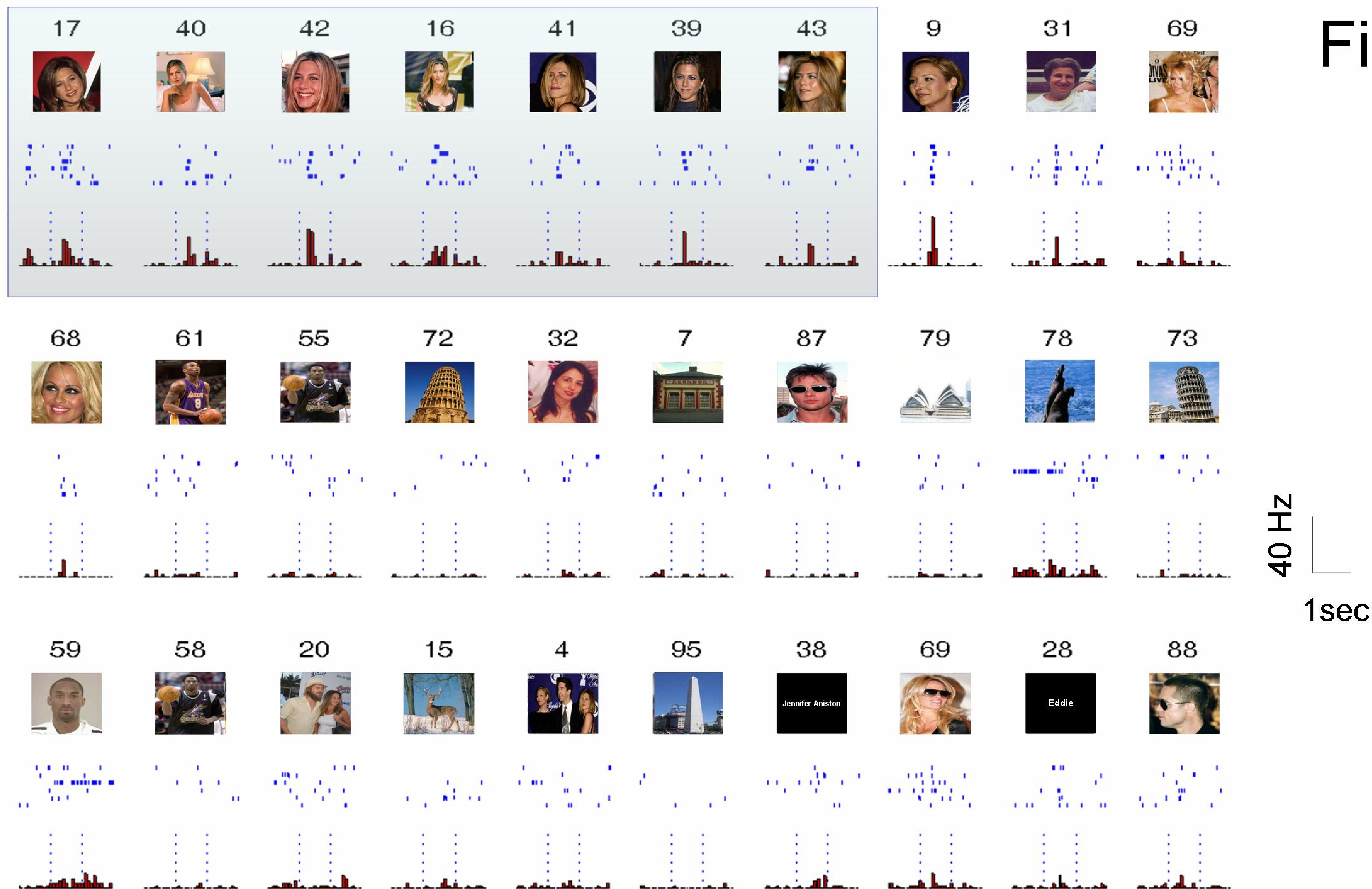
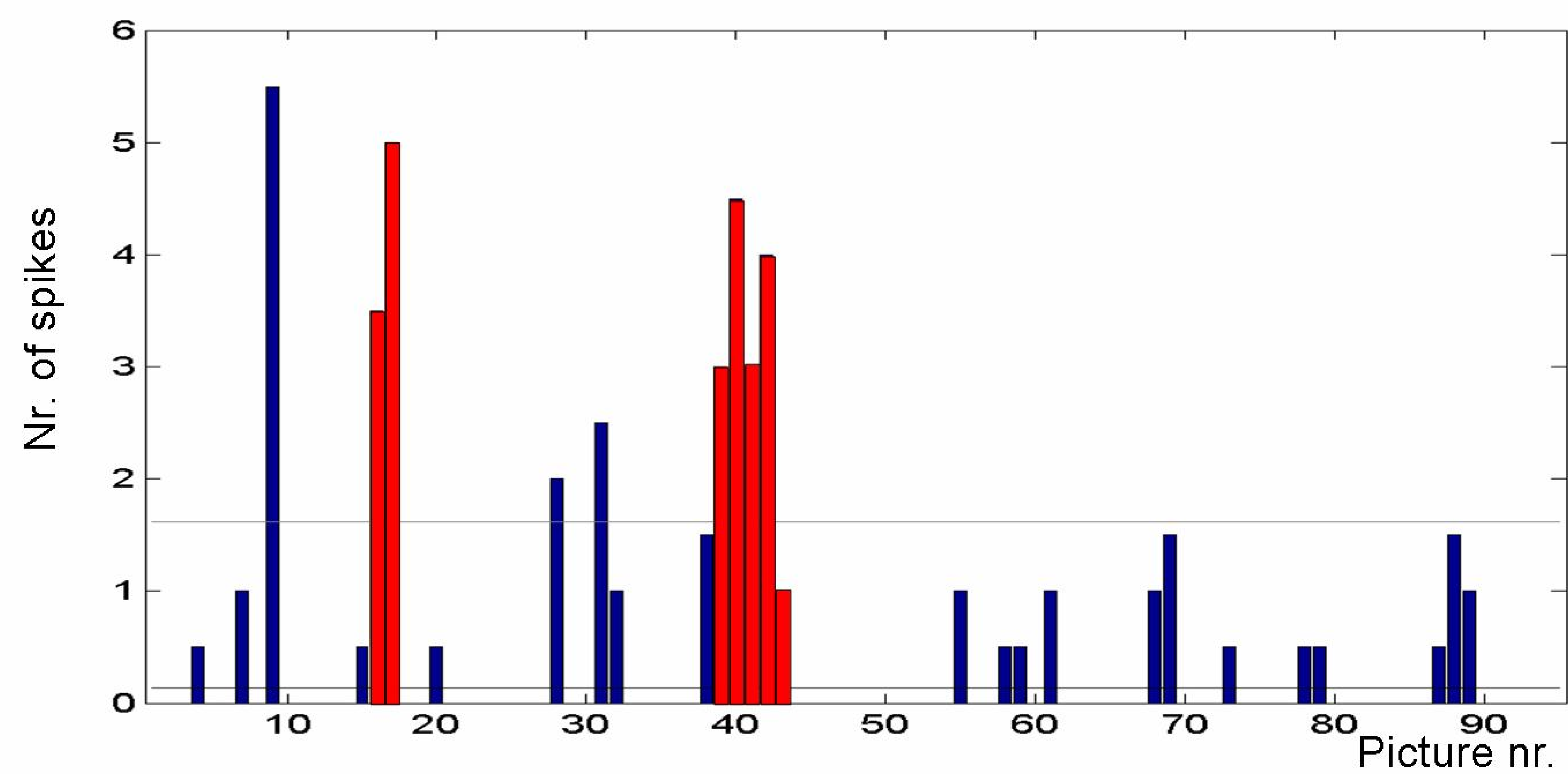


Fig. S7

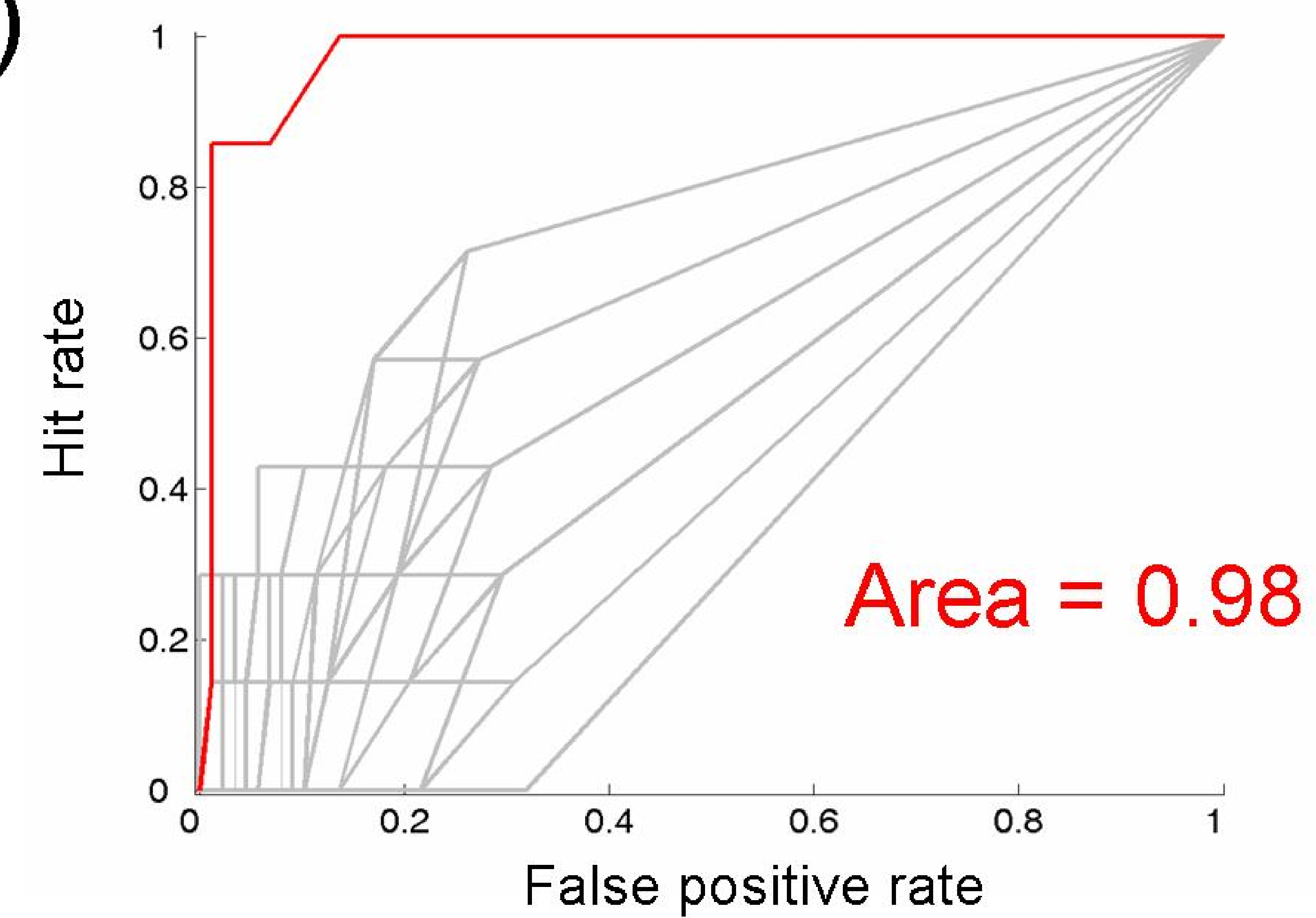
A)



B)



C)

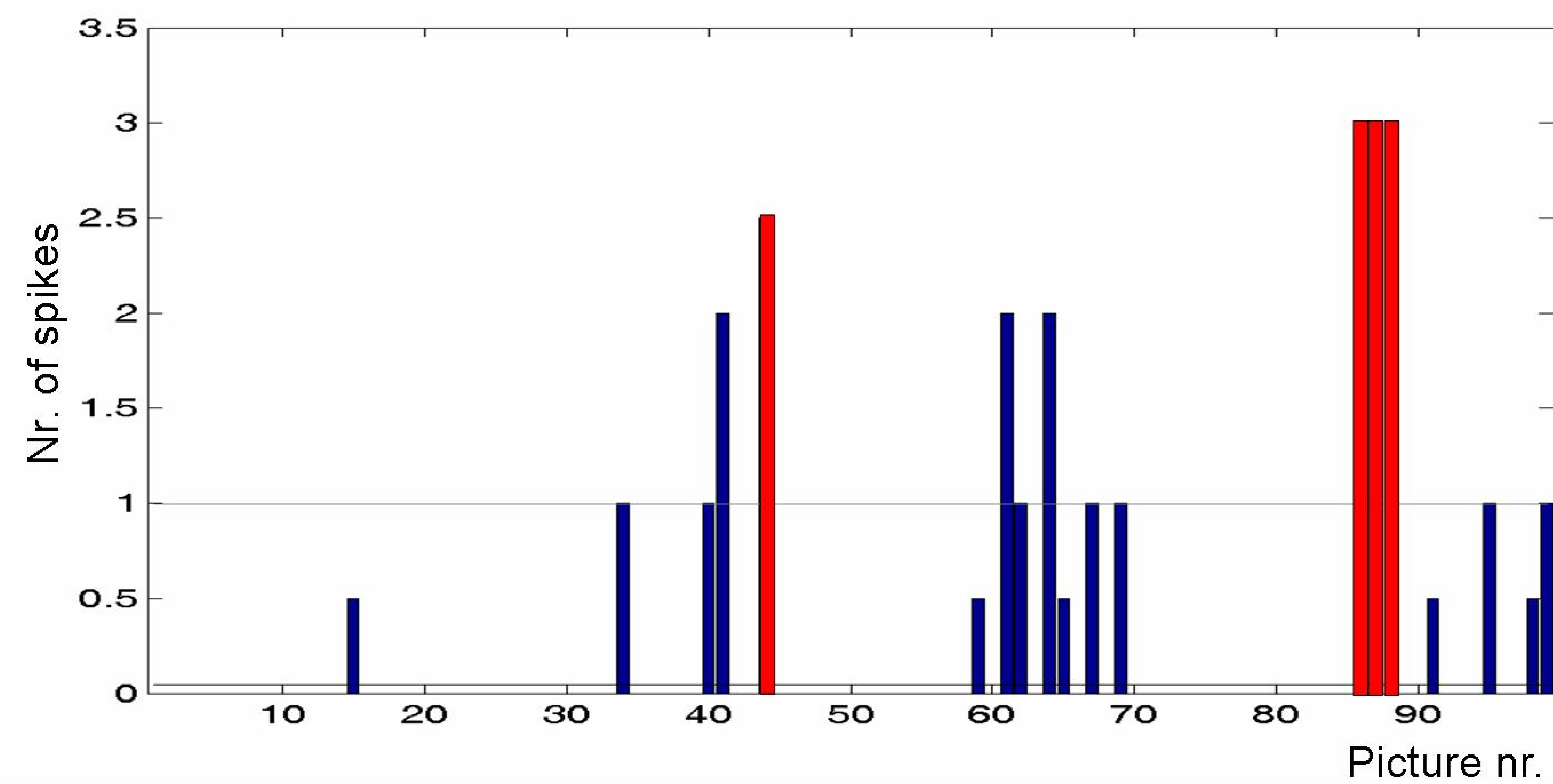


A)

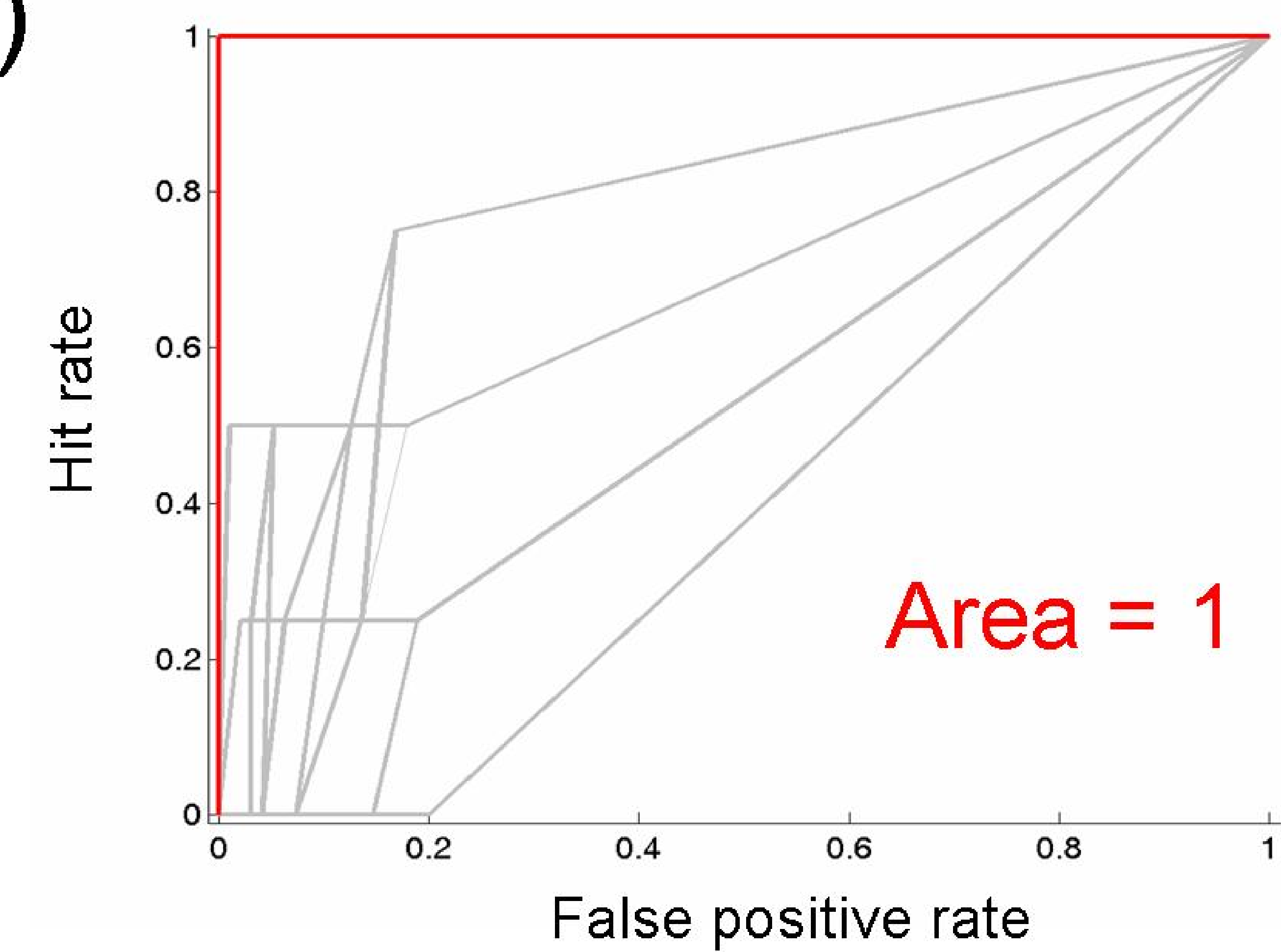


Fig. S8

B)



C)



A)

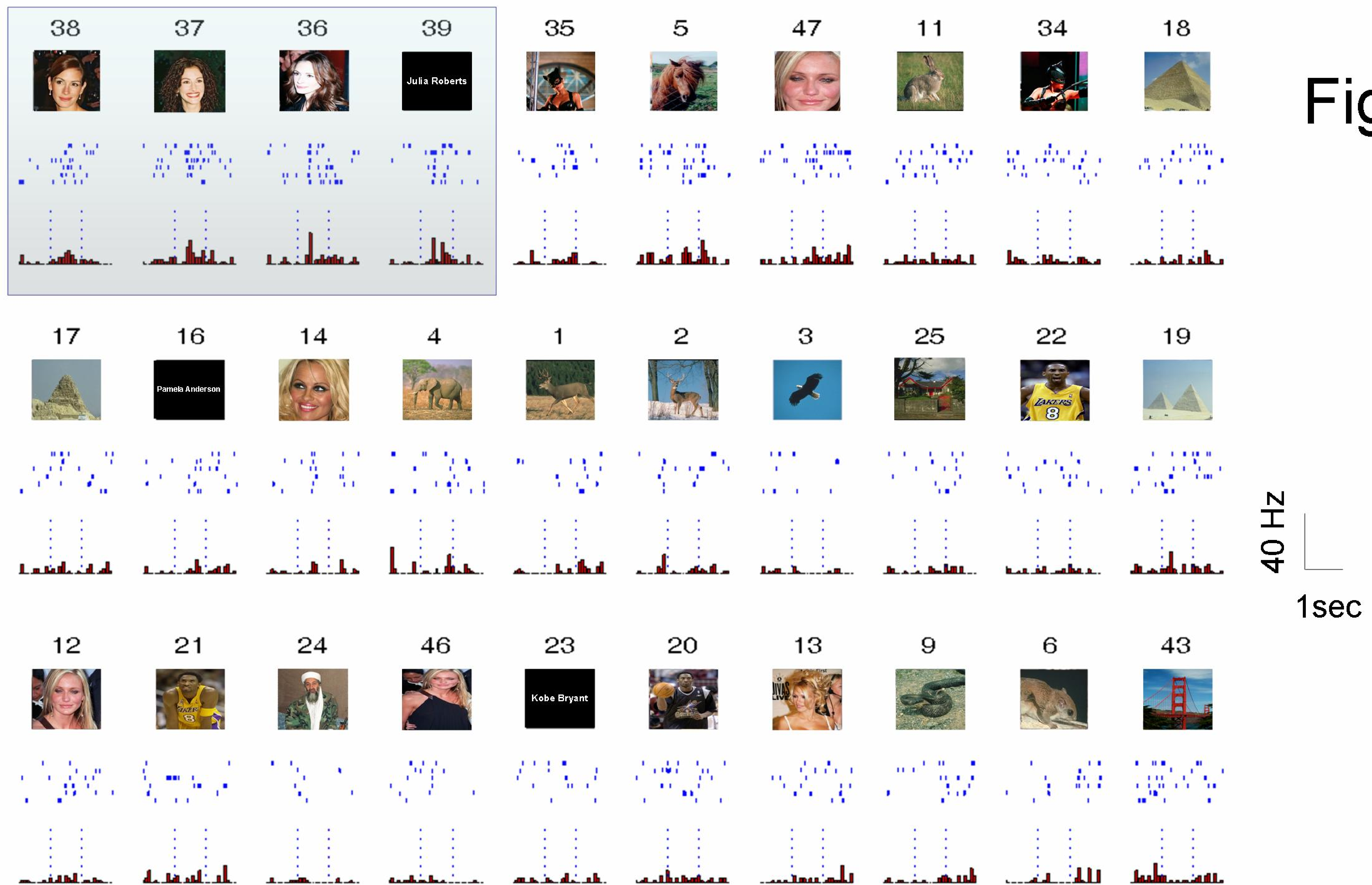
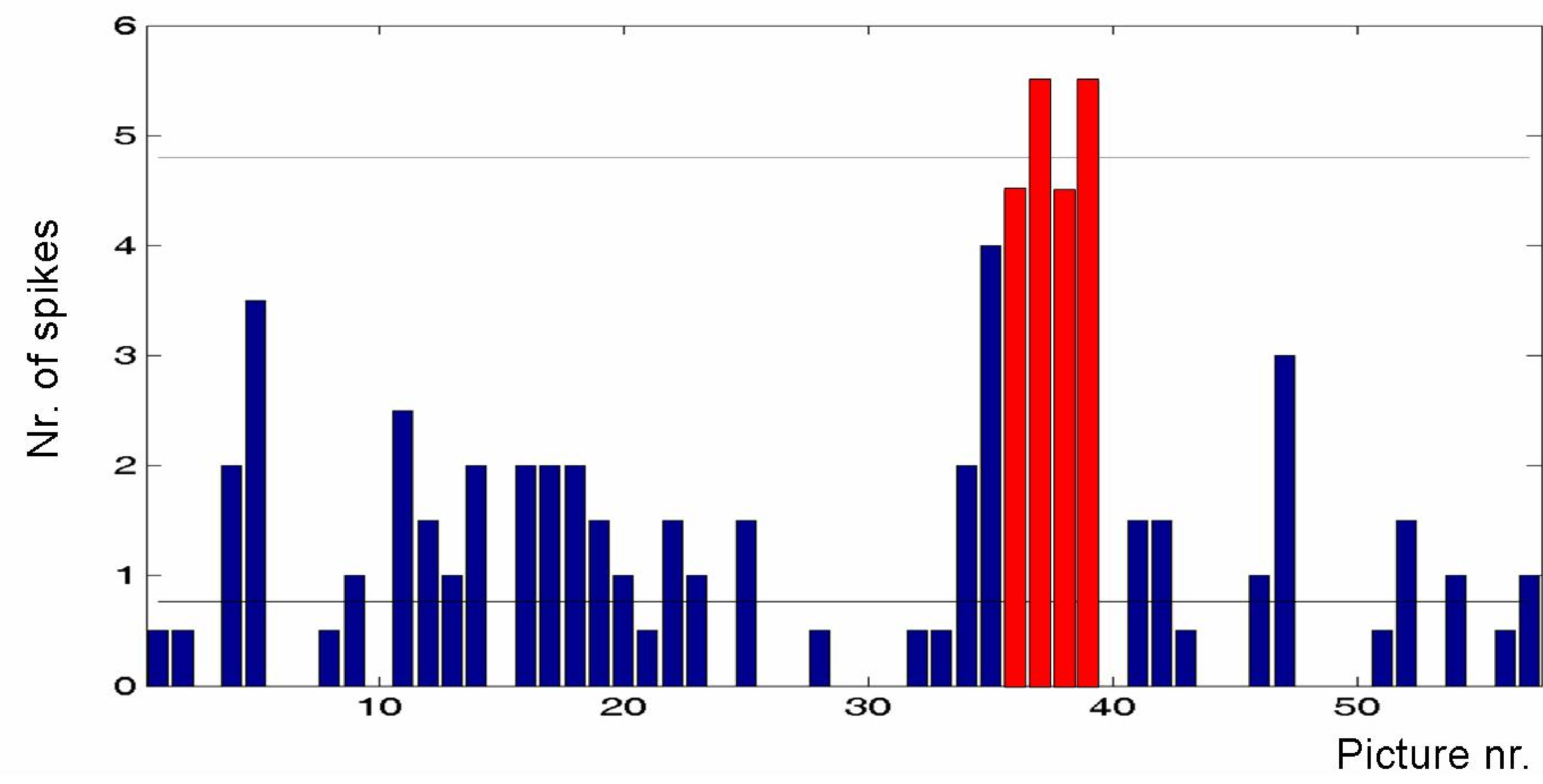
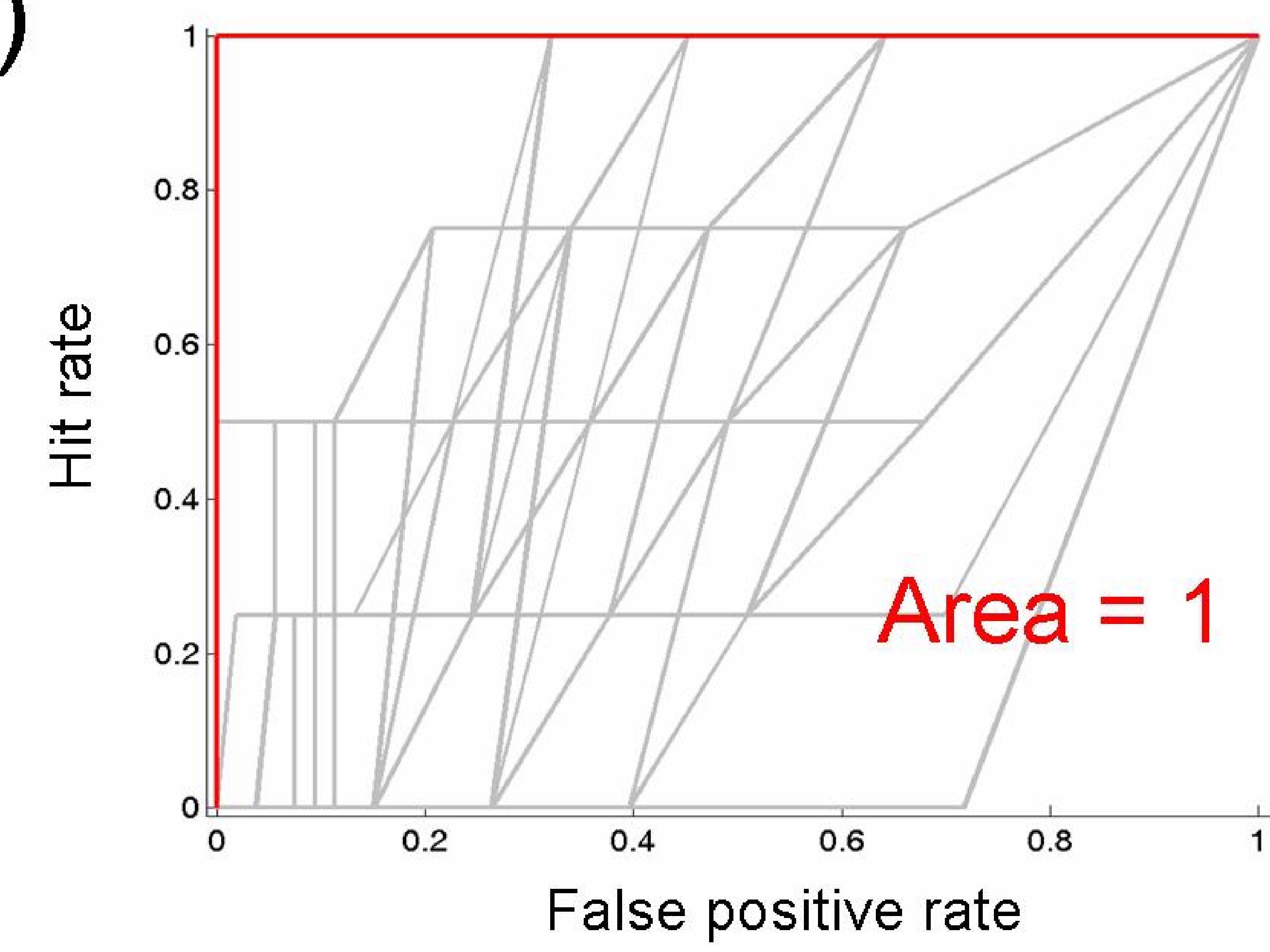


Fig.S9

B)



C)



A)

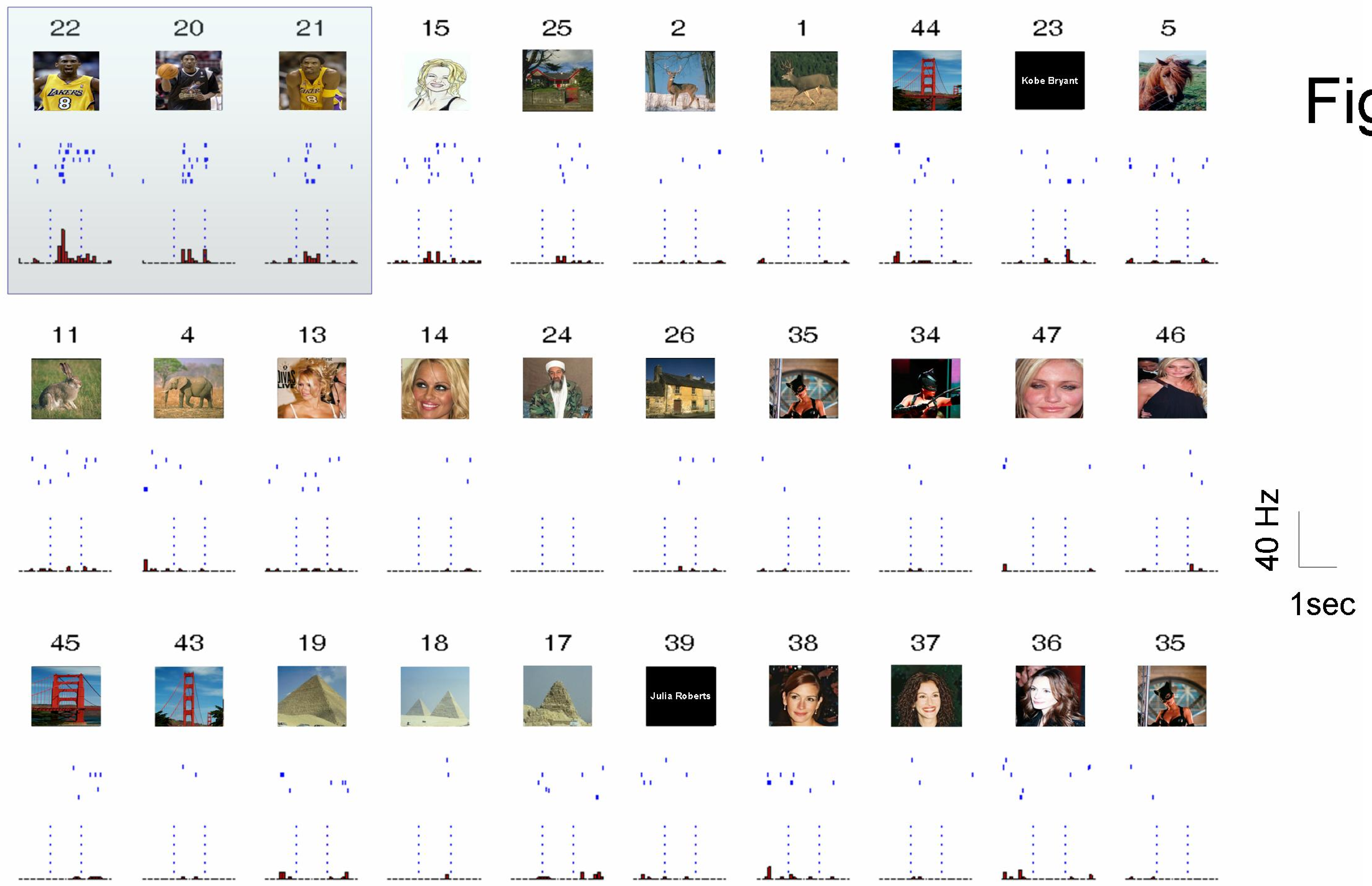
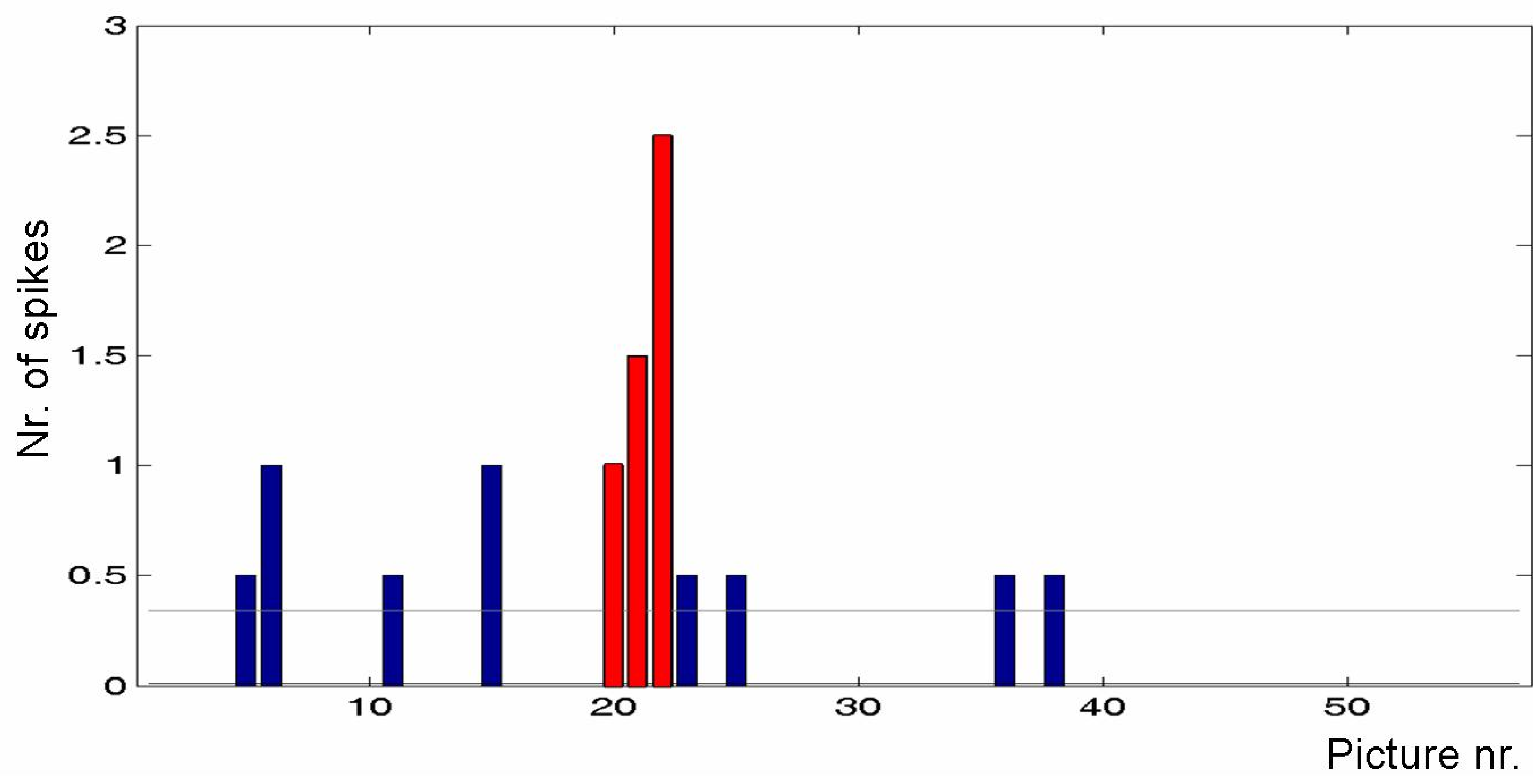
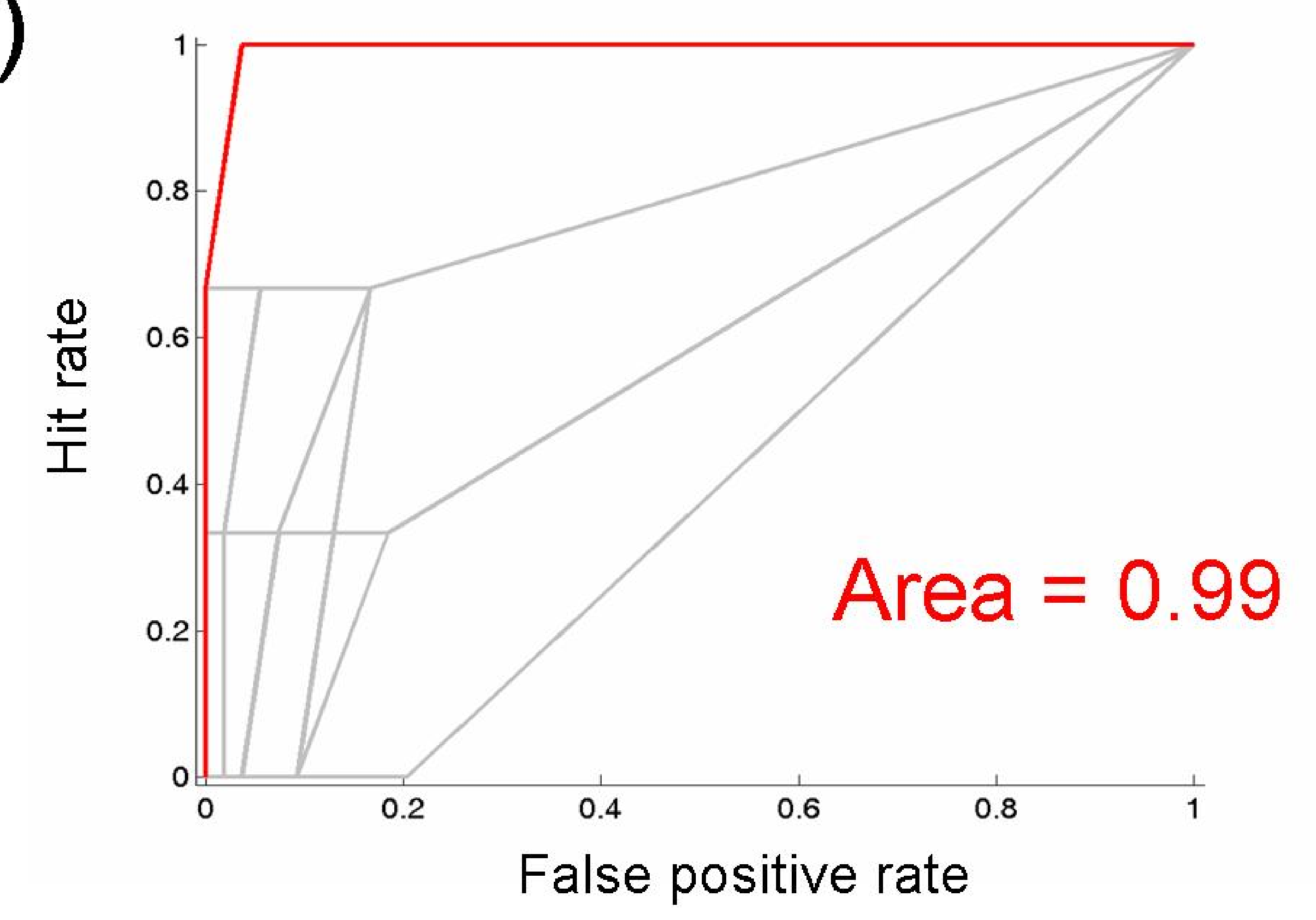


Fig.S10

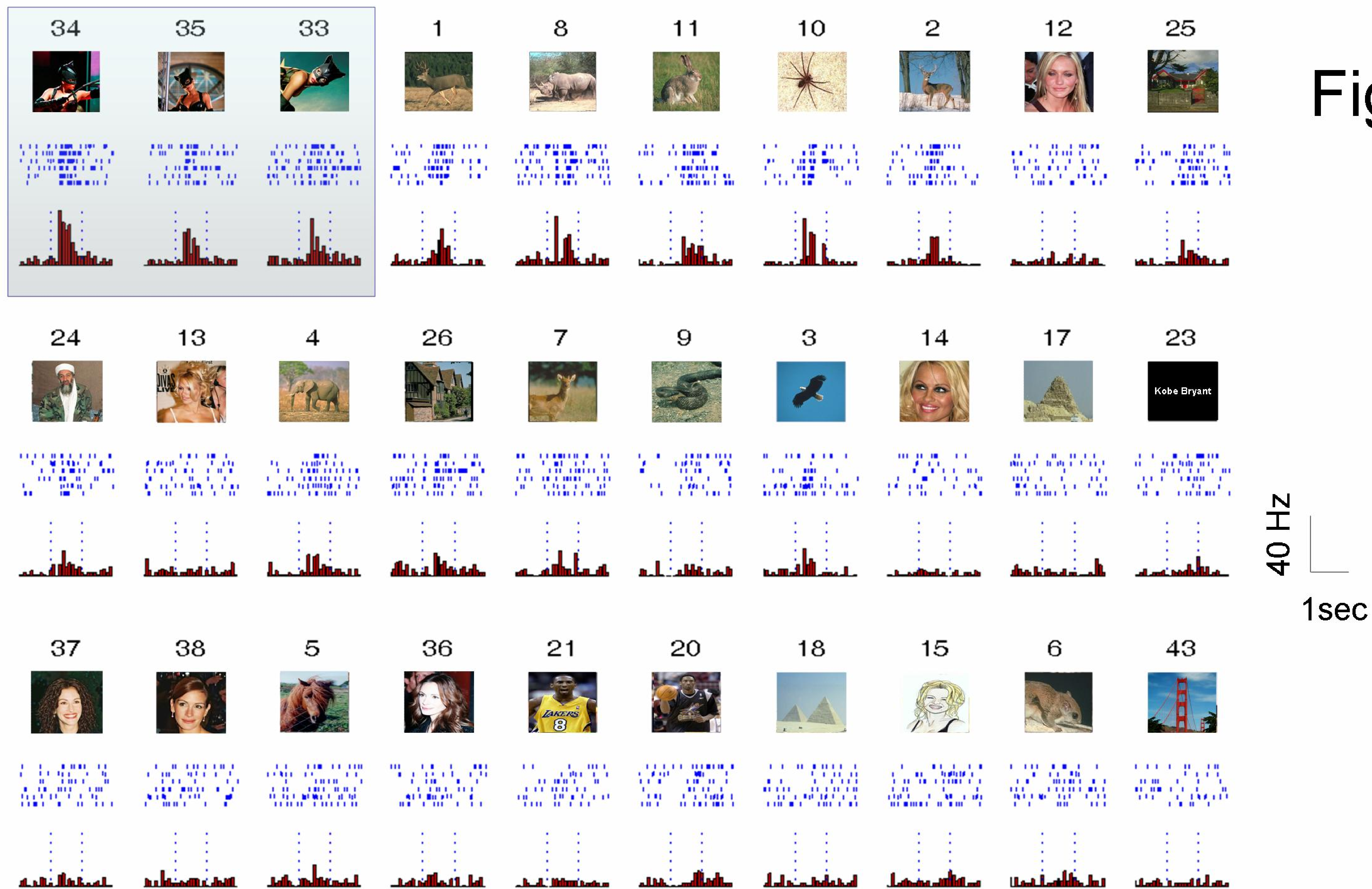
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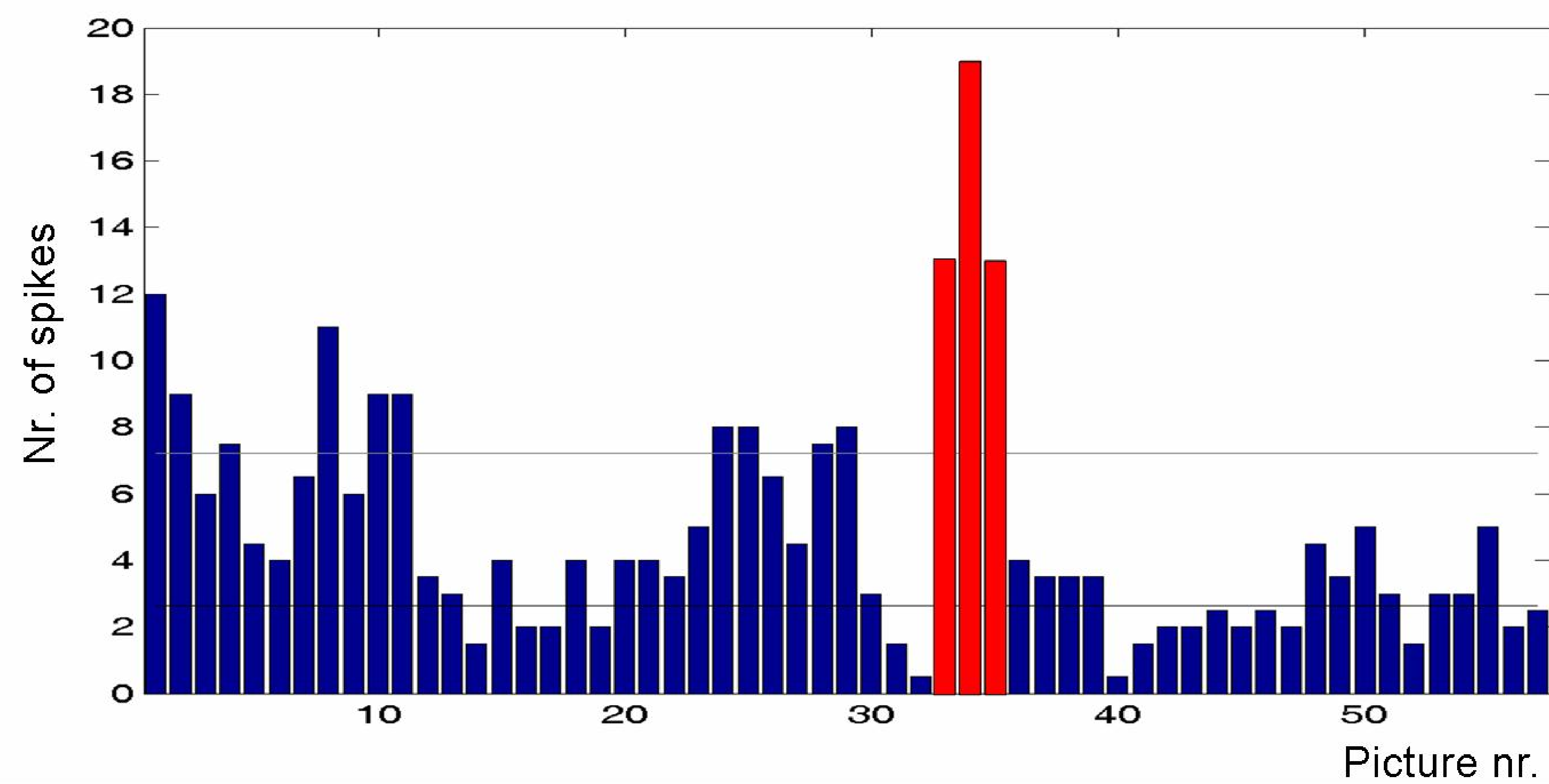
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A)



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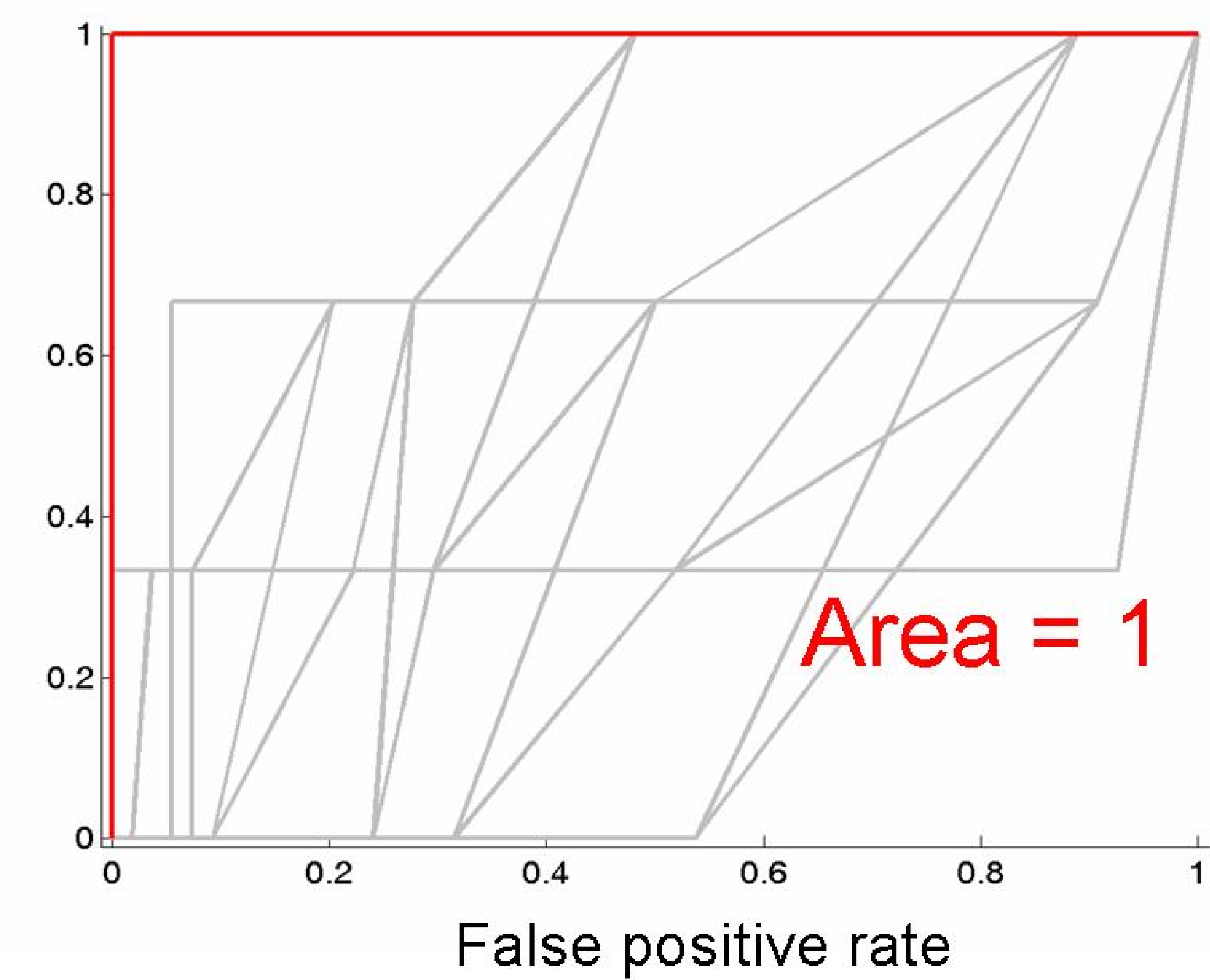


Fig.S11