Summary

We present simulations of a model of visual working memory in prefrontal cortex (PFC). The model consists of a 'feature layer' which is activated by specific features (shape, color, location), and a 'blackboard' layer [1]. The 'blackboard' serves to bind the features of the objects stored in memory, so that the features belonging to a selected object are correctly combined. In our simulations, we tested the prediction [1] that the success of binding depends on the number of objects stored in working memory. In particular, when too many objects are stored, their representations in the 'blackboard' will interfere, which results in loss of feature binding.

For the simulations, we linked the working memory neural model with a (trained) neural network model of the ventral pathway in the visual cortex, that is used in the simulation of object-based attention in the visual cortex [2]. This model consists of a feedforward network that includes the areas V1, V2, V4, PIT and AIT, and a feedback network that carries information about the identity of the objects to the lower areas in the visual cortex (V1 - PIT). During the simulations, displays consisting of N (different shaped) objects, with N ranging from 2 to 9, are presented to V1. Objects in a display are placed on separate, non-overlapping, positions. After the presentation of a display, the representations developed in the layer PIT of the feedforward network activate the 'blackboard' in the working memory model. The PIT layer in the feedback network, as activated by a feature in AIT, served as the feature layer in the working memory (PFC) model.

The simulation of storing a display of objects runs as follows. First, the visual cortex processes the display. The representations of the objects in PIT also activate the representations in the blackboard layer of PFC. This layer stores the objects in the display. Then, one of the stored objects is selected, e.g., by activating its shape representation in the feature layer. If the representation of the selected object in the blackboard layer of PFC is not severely affected by the representations of other objects, the interaction between the blackboard layer and feature layer selects (enhances) the activations of the selected object in the blackboard layer. In turn, this will result in the selective activation of the other features of the selected object in the feature layer. However, when the representations of the objects in the blackboard layer interfere too much, they make each other's representations ‘fuzzy’, so that the interaction between the feature layer and the blackboard layer cannot uniquely enhance the activations of the selected object anymore. Instead, it might wrongly enhance the activations of other objects. Feature binding of the selected object then fails. We tested whether the chance of this happening will rise as the number of objects stored in memory increases.

In the simulations, we selected a feature of one object in the feature layer and investigated the interaction of the feature layer with the blackboard layer. In particular, we investigated whether the information about the object could be retrieved from the blackboard layer by this interaction.
We simulated this interaction by computing the covariance in activation between the blackboard layer and the feature layer. This gives a match (positive covariance) or a mismatch (negative covariance). After every presentation of a display with N objects, the positive covariance for every possible position of an object in the blackboard layer was summed and subsequently standardized by the average positive covariance per position during that trial. The same was done for the negative covariance. In every trial, one position in the blackboard layer corresponds to the position of the selected object, and N - 1 positions in this layer correspond to positions of nonselected

objects. The remaining positions in the blackboard layer (9 - N) correspond to positions where no object was stored.

We computed the probability distribution of (mis)match for positions in the blackboard layer for selected objects and for nonselected objects. For each number of objects in working memory, data of 5 instances of the model were averaged over all relevant trials. For successful binding to occur, the match should be high on the position of the selected object and low on positions of nonselected objects (and the mismatch should be low and high, respectively), so that the position of the selected object is clearly distinguished from the positions of nonselected objects. The results show that this occurs if the number of objects held in working memory is low (for $N < 4$). However, the probability distribution of (mis)match for the positions of selected and nonselected objects start to overlap more and more as the number of objects in working memory increases. This means that the information about the selected object cannot be retrieved reliably from the blackboard layer anymore. As the load on memory gets higher, nonselected objects will more frequently be selected instead. In other words, the binding process starts to break down.

The simulations point out that the model of visual working memory that we presented [1] is limited in the number of objects that it can maintain in memory without interference (i.e., loss of information). With too many objects, the level of (mis)match that can be detected in the blackboard layer related to the selected object is more and more similar to the level of (mis)match for other objects. Thus, in line with experimental findings [3], our model cannot successfully bind the feature(s) of the selected object anymore as it gets loaded with more objects.

References

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