Effects of dendritic compartmentalization on the property of spatial working memory

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In working memory tasks, pyramidal cells in the relevant cortical circuit receive both sensory feed-forward inputs and recurrent inputs to shape stimulus-selective sustained activity. Recent studies have revealed that each dendritic branch of pyramidal cells functions as a compartmentalized integration subunit [1]. Since significant part of the inputs are applied onto dendritic branches, such compartmentalization could affect the computational property of the memory circuit. We addressed this issue by constructing a model of neural circuit for spatial working memory, incorporating pyramidal dendritic arborization and branch-specific nonlinear input integration (Fig. A). Specifically, based on the architecture of existing models [2], we additionally incorporated multiple dendritic branches with the assumption that feed-forward inputs converge onto some portion of the branches in each pyramidal cell while recurrent inputs are evenly distributed. We show that the model forms accurate memory when the contrast of the feed-forward input exceeds a certain level, whereas memory is not induced when the contrast is low (Fig. Ba). Even when the input intensity is increased (Fig. Bb), low-contrast input does not induce inaccurate memory, which can be formed more easily in models without dendritic branching unless additional normalization process is explicitly incorporated. We explored how dendritic compartmentalization enables such contrast-dependent memory formation. When the low-contrast input is presented, majority of the dendritic branches that do not receive significant feed-forward input hardly contribute to somatic firing, because the total input in those branches does not reach the presumed branch-specific threshold, even in the cell receiving the strongest feed-forward inputs in total (Fig. C). Thereby cell-to-cell difference in the amount of feed-forward excitation is largely canceled at the level of somatic impact, preventing winner-take-all competition that leads to the formation of inaccurate memory. This mechanism holds in either case with somatically or dendritically mediated recurrent inhibition; however, for a wider range of conditions in the dendritic inhibition case. Provided the input contrast represents the certainty of stimulus location, such contrast-dependent accurate memory formation might serve for animal's appropriate decision making based on the memory. In terms of modeling, our results indicate the necessity and usefulness of considering a reduced neuron model with a few 'parallel' compartments, each of which receives inputs from different sources, instead of or in addition to tandem ones.

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References