Tactile information from the vibrissal system modulates hippocampal functioning

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ABSTRACT

Most mammals have sensory tactile hairs, also known as whiskers or vibrissae. Traditionally, whiskers are associated with diverse survival skills, including tactile discrimination, distance assessment, food acquisition, gap crossing, and social interaction. Vibrissae functions are processed in the somatosensory cortex, commonly referred to as the barrel cortex. Hence, most of the whisker-related research has been focused on this cortical pathway. However, increasing evidence indicates that the vibrissal system modulates several aspects of hippocampal physiology. This graphical review aims to summarize cumulative evidence indicating that whiskers regulate the neural function and cellularity in several hippocampal subfields. Interestingly, lack of whiskers notably affects neuronal firing in CA1 and CA3 hippocampal subfields, alters spatial mapping, impairs navigational skills, modifies cytoarchitecture, and reduces the adult neurogenesis in the dentate gyrus. This evidence extends our understanding of how whiskers are related to hippocampal function and offers insights to explore novel associations between whisker functions and neural plasticity in the hippocampus.

1. Introduction

Rodents require exquisite navigational skills for environment exploration and, many of these abilities rely on their vibrissal system, also referred to as whiskers or facial hairs (Fig. 1A). Traditionally, whiskers are associated with tactile discrimination, gap crossing, and social behavior (Fig. 1B) (Adibi, 2019; Ahl, 1986; Brecht et al., 1997). However, increasing evidence indicates that the vibrissal system regulates hippocampal function, cytoarchitecture, and neurogenesis (Gonzalez-Perez et al., 2018; Milshtein-Parush et al., 2017; Pereira et al., 2007).

Whiskers are arranged in a five-row pad on each side of rodents’ snout and each row pad contains between five and nine whiskers 15–50 mm long (Fig. 1A). Whiskers are classified in macro-vibrissae, long hairs responsible for general object scanning and spatial navigation, and micro-vibrissae, short hairs responsible for exploring the specific properties of objects and texture recognition. Both types of whiskers work together to help animals with tactile discrimination, distance assessment, food acquisition, gap crossing, and social behavior (Fig. 1B) (Deschenes et al., 2005; Diamond et al., 2008). All whiskers are connected to structures, named follicles, innervated by the infraorbital nerve (ION) and, each follicle has mechanoreceptors that respond to the movement of whiskers to provide tactile sensitivity (Fig. 1A) (Diamond et al., 2008).

The tactile information obtained from vibrissal follicles projects via the ION to the principal sensory nucleus (Prv) and the spinal nucleus (Spv) (Fig. 2). After synapsing in the brainstem, axons from second-order neurons cross the midline and reach the contralateral ventral posteromedial nucleus (VPM) of the thalamus through the lemniscal pathway (Bisler et al., 2002; Diamond et al., 2008; Frangeul et al., 2014). Then, thalamic neurons project to layer IV of the somatosensory cortex, commonly known as the barrel cortex (BC) (Bisler et al., 2002). Subsequently, some of this tactile information processed in the somatosensory cortex projects to the entorhinal cortex (ENT) to finally reach the hippocampus (Fig. 2). Thus, the active use of whiskers elicits neuronal activity that promotes neuronal plasticity in the BC and helps create spatial maps in the adult hippocampus.

In the BC, each vibrissal follicle has a precise neuronal representation (Ahl, 1986; Grion et al., 2016). Each barrel processes information from a single whisker and, all of them, integrate a cortical map that replicates the vibrissal pad (Dimou and Gotz, 2012). During vibrissae stimulation, every barrel responds rapidly and modulates its neural activity...
depending on the nature of the stimulus (Woolsey and Van der Loos, 1970). Thus, vibrissae elimination produces a significant decrease in the activity of cytochrome oxidase (COX) enzyme in the BC (Fig. 3) (Kil-lackey et al., 1994; Wong-Riley and Welt, 1980). Whisker deprivation also produces a dramatic decrease in the expression of a calcium-dependent marker for neuronal activity (c-Fos protein) (Perrin-Terrin et al., 2016) in the BC (Filipkowski et al., 2001; Gonzalez-Perez et al., 2018). In contrast, tactile experience or stimulation enhances the c-Fos expression (Fig. 3) (Bisler et al., 2002; Filipkowski et al., 2000; LeCrux et al., 2017). Remarkably, some glial cells in the BC
are also modulated by tactile stimuli. Synaptic inputs from thalamocortical fibers derived from the vibrissal system regulate the number and proliferation of NG2 glia in the BC, which confirms that tactile inputs strongly modulate the neural activity of this region (Dimou and Goitz, 2012). Thus, research on sensorial information in the BC is extensive, but emerging evidence indicates that sensorial experience can modulate hippocampal function.

The hippocampus is an essential region for contextual learning,
memory consolidation, cognition, and novelty detection, which requires the integration of sensorial systems (visual, olfactory, and tactile) (Fig. 4 A – C) (Milshein-Parush et al., 2017; Pereira et al., 2007; Zeidman and Maguire, 2016). Electrically evoked tactile responses recorded in the CA1 hippocampus indicate that tactile inputs reach this region via the somatosensory cortex and contribute to acquire experience-dependent learning (Le Merre et al., 2018). Interestingly, trigeminal inputs from the vibrissae system send projections to CA1 and CA3 hippocampal regions and dentate gyrus (DG) to process this information and modulate neuronal spiking activity during discrimination tasks (Lee et al., 2004).

A recent report indicates that tactile experience enrichment improves memory and alleviates anxiety by inducing neuronal remodeling along the dorsoventral axis of the DG (Wang et al., 2020), which demonstrates that whisker activity strongly regulates the neuronal functioning in this neurogenic region (Fig. 4 D). In this regard, voluntary exercise, enriched environments, and cognitive processes can change hippocampal functioning in an activity-dependent manner that, in turn, can modify the adult neurogenesis (Kempermann et al., 1997; Ma et al., 2009; Pereira et al., 2007). Notably, whisker elimination reduces the number of c-Fos+ cells in the CA1, CA2, and CA3 hippocampal subfields and decreases calbindin expression in the DG. Intriguingly, these events are linked to a substantial reduction in the hippocampal neurogenesis, which affects the total number of newborn neurons produced in the adult subgranular zone (SGZ) and disrupts navigational skills that help solve a spatial memory task (Fig. 3) (Gonzalez-Perez et al., 2018). Altogether, these findings unveiled an important neurophysiological interaction among tactile information, hippocampal neurogenesis, and the creation of spatial maps in the postnatal brain. The biological meaning of this interaction is not clear, but recent evidence indicates that whisker-related sensory information is processed in the hippocampus to produce contextual, experience-dependent learning of rewarded sensory-motor associations (Le Merre et al., 2018). Thus, sensory responses elicited during contextual learning of goal-directed behaviors require the interaction among several cortical areas (prefrontal, entorhinal, S1, and S2 cortices) with the hippocampal circuitry (CA1 and CA3) and its neurogenic niche (Adibi, 2019; Aronoff et al., 2010; Cameron and Glover, 2015; Le Merre et al., 2018). Altogether, this evidence suggests that the tactile information processed in the hippocampus contributes to the learning of rewarded sensory-motor associations.

In summary, the tactile information processed through the vibrissal system is a crucial regulator of hippocampal functioning, neuronal remodeling, and neurogenesis, which unveils new associations between whisker activity and hippocampal homeostasis. Knowing the relationship between sensorial deprivation/stimulation and hippocampal plasticity may help understand processes of associative learning, cognitive decline, mental disorders, and neurodegeneration observed after long-lasting sensory deprivation.

CRediT authorship contribution statement

Nereida Ibarra-Castaneda: First draft, Writing – original draft, Formal analysis, figure design. Norma A. Moy-Lopez: Formal analysis. Oscar Gonzalez-Perez: Conception of the work, figure design, Writing – review & editing, final approval of the work.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crneur.2022.100034.

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