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Research report

Neural representations of novel objects associated with olfactory experience

Marta Ghio[a,*], Patrick Schulze[b], Boris Suchan[b], Christian Bellebaum[a]

[a] Institute of Experimental Psychology, Heinrich Heine University, Universitätstrasse, 1, 40225, Düsseldorf, Germany
[b] Department of Neuropsychology, Institute of Cognitive Neuroscience, Faculty of Psychology, Ruhr University Bochum, Universitätstrasse, 150, 44801, Bochum, Germany

HIGHLIGHTS

- Role of olfactory experience in the formation of novel object concepts.
- Recognition of objects paired with odors activates the right anterior hippocampus.
- We do not find any activations in primary olfactory areas.
- Different functional roles of the hippocampus in olfactory processes are discussed.

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ABSTRACT

Object conceptual knowledge comprises information related to several motor and sensory modalities (e.g. for tools, how they look like, how to manipulate them). Whether and to which extent conceptual object knowledge is represented in the same sensory and motor systems recruited during object-specific learning experience is still a controversial question. A direct approach to assess the experience-dependence of conceptual object representations is based on training with novel objects. The present study extended previous research, which focused mainly on the role of manipulation experience for tool-like stimuli, by considering sensory experience only. Specifically, we examined the impact of experience in the non-dominant olfactory modality on the neural representation of novel objects. Sixteen healthy participants visually explored a set of novel objects during the training phase while for each object an odor (e.g., peppermint) was presented (olfactory-visual training). As control conditions, a second set of objects was only visually explored (visual-only training), and a third set was not part of the training. In a post-training fMRI session, participants performed an old/new task with pictures of objects associated with olfactory-visual and visual-only training (old) and no training objects (new). Although we did not find any evidence of activations in primary olfactory areas, the processing of olfactory-visual versus visual-only training objects elicited greater activation in the right anterior hippocampus, a region included in the extended olfactory network. This finding is discussed in terms of different functional roles of the hippocampus in olfactory processes.

1. Introduction

We accumulate knowledge about the world (e.g., objects, people, places, and word meanings) throughout the entire life and we flexibly use and modify it in all our interactions with the world. A shared assumption of current neuroscientific accounts is that this knowledge, which comprises our semantic memory, relies on a distributed neural network, including areas coding for different types of experience (sensory, motor, emotion systems) and heteromodal areas in the anterior temporal lobe and the inferior parietal cortex (for a review, see Ref. [4]). This network seems to be constrained by multiple dimensions of organization, such as semantic domains (e.g., animals, tools) and different types of experience-based knowledge (e.g., visual, motor knowledge; for a review see Ref. [6]). Theoretical accounts differ, however, in how they explain

* Corresponding author at: Institute of Experimental Psychology, Heinrich Heine University, Universitätstrasse, 1, 40225 Düsseldorf, Germany.
E-mail addresses: Marta.Ghio@hhu.de (M. Ghio), patrick.schulze@rub.de (P. Schulze), boris.suchan@ruhr-uni-bochum.de (B. Suchan), Christian.Bellebaum@hhu.de (C. Bellebaum).

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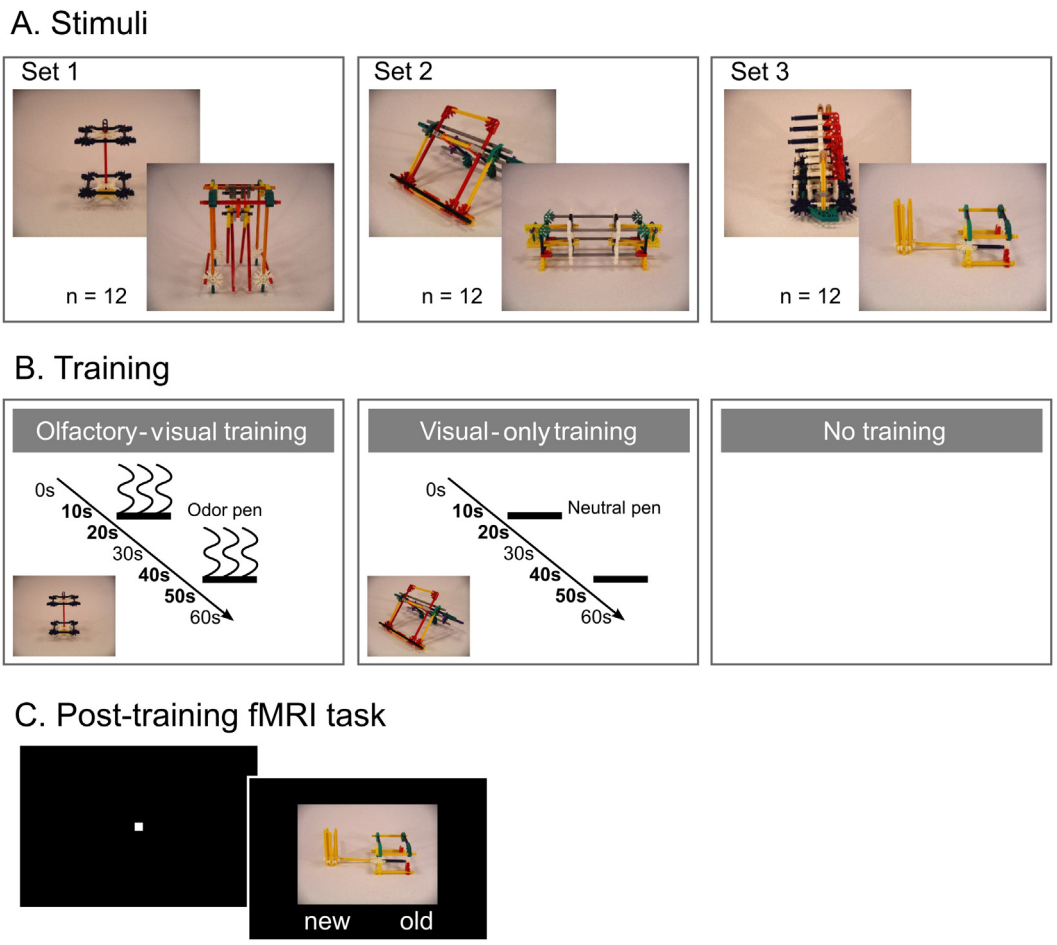

Fig. 1. Experimental procedure: (A) Stimuli; (B) Training; (C) Post-training fMRI task.

these organizational dimensions and especially in the role they ascribe to experience-based knowledge.

According to the domain-specific hypothesis, evolutionary pressures rather than individual experience yielded domain-specific neural representations stored in distinct brain areas, innately connected with experiential brain systems [31,32]. In turn, sensorimotor-based theories and grounded cognition accounts claim that different semantic categories are represented in experiential brain systems in a way that reflects the individual history of experience with the concepts' referents (for reviews, see Refs. [1,50]). Considering, for example, the semantic category of tools (e.g., hammer), visual (e.g., how a hammer looks like), manipulation (e.g., how to manipulate a hammer), and functional (e.g., to hammer a nail) experience is usually engaged during concept acquisition and might contribute to shaping their representation at the neural level (for reviews see Refs. [4,25,26]).

Consistently with the latter theoretical accounts, several neuroimaging studies have shown that the processing of familiar tool words or pictures engages left-hemispheric motor-related areas in the premotor cortex and the intraparietal sulcus, motion-related areas in the posterior middle temporal gyrus and shape-related areas in the medial fusiform gyrus (for reviews, see Refs. [6,34]). Lesion data from neuropsychological patients and virtual lesion data obtained with transcranial magnetic stimulation, however, are not conclusive as they indicate that dysfunctions in experiential brain areas are not detrimental for semantic processing of conceptual object knowledge (for reviews see Refs. [25,33]). Furthermore, this line of research on familiar object concepts suffers from the limitation that the individual history of experience with the objects was not controlled.

A direct approach to test the role of experience in shaping conceptual knowledge is based on training with novel objects since it allows to experimentally control and manipulate the modalities of individual experience with objects [2,11,26,40,41,47]. For example, in the study by Weisberg et al. [47], participants underwent three training sessions in which they learned how to manipulate tool-like novel objects. Brain activation during an object-matching task was measured by using fMRI before and after the training. Results showed increased post-training activity in left hemispheric motor (premotor cortex, intraparietal sulcus) and motion areas (middle temporal gyrus) for the processing of pictures of manipulated objects. In a later study, Bellebaum et al. [2] found post-training activations in the left middle/inferior frontal gyrus and parietal lobule for the processing of novel objects associated with manipulation vs. visual experience, with also increased effective connectivity between these regions.

So far, the role of experience in shaping conceptual object knowledge has been addressed mainly by considering manipulation and visual experience. In particular, the novel objects used in these previous studies were introduced as artefacts, for which manipulation and functional features can be considered particularly relevant. At the same time, motor and manipulation experience dominates our interactions with familiar artefacts. It is as yet unknown, in what way representations of novel objects are influenced by mere sensory experience through different modalities, also including those that are usually non-dominant channels of experience with familiar tools. A strong interpretation of grounded