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Research report

An animal model of disengagement: Temporary inactivation of the superior colliculus impairs attention disengagement in rats

Mariana Ferreira Pereira de Araujo [a,b,1], Jumpei Matsumoto [a,1], Taketoshi Ono [a], Hisao Nishijo [a,*]

[a] System Emotional Science, Graduate School of Medicine and Pharmaceutical Sciences, University of Toyama, Sugitani, 2630, Toyama 930-0194, Japan
[b] Edmond and Lily Safra International Institute of Neuroscience, Santos Dumont Institute, Rodovia RN 160, 3001 – Distrito Jundiaí, 59280-000 Macaíba, RN, Brazil

HIGHLIGHTS

- Rats were trained in a spatial choice task requiring attention disengagement.
- Inactivation of the superior colliculus (SC) impaired attentional disengagement.
- SC inactivation did not impair performance in non-disengagement trials.
- The SC is necessary for attentional disengagement.

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ABSTRACT

The orienting attention network is responsible for prioritizing sensory input through overt or covert shifts of attention among targets. The ability to disengage attention is essential for the proper functioning of this network. In addition to its importance for proper orienting, deficits in disengagement have been recently implicated in autism disorders. Despite its importance, the neural mechanisms underlying disengagement processing are still poorly understood. In this study, the involvement of the superior colliculus (SC) in disengagement was investigated in unrestrained rats that had been trained in a two-alternative light-guided spatial choice task. At each trial, the rats had to choose one of two paths, leading either to a large or a small reward, based on 1 (single-cue) or 2 (double-cue) lights. The task consisted of serial trials with single- and/or double-cue lights, and rats could acquire a large reward if the rats chose infrequent lights when infrequent cue lights were presented after preceding frequent cue lights. Experiment 1 included trials with either single- or double-cue lights, and infrequent trials with double-cue lights required both attentional disengagement and shift of attention from preceding frequent single-cue lights, while experiment 2 included only trials with single-cue lights requiring shifts of attention but not attentional disengagement. The results indicated that temporary inactivation of the SC by muscimol injections selectively impaired performance on trials requiring disengagement. No impairment was observed on the other trials, in which attention disengagement was not required. The results provide the first evidence that the SC is necessary for attentional disengagement.

1. Introduction

Attention is defined as a set of cognitive mechanisms that enable selective focus on a portion of the total information available in the environment for enhanced processing [1]. It can be divided into specialized subsystems, each performing different but interrelated functions [2,3]. The most intuitive, observable subsystem is the orienting network, which is responsible for prioritizing sensory input through overt (directing the sensory organs to a stimulus through changes in eye and head position) or covert (attending to stimulus location without such movements) shifts of attention among targets within or between modalities [2].

A fundamental operation for both overt and covert orienting is the ability to disengage attention from one focus before shifting and reengaging attention to a new target [2]. In classical disengage-

* Corresponding author. Fax: +81 764345012.
E-mail address: nishijo@med.u-toyama.ac.jp (H. Nishijo).
[1] These authors contributed equally.

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ment tasks, subjects must orient attention to a peripheral target that appears either in the presence of a central stimulus (overlap trials) or after its presentation (gap trials). In overlap trials, subjects must first disengage from the central stimulus before orienting to the target, and such processing results in longer response latencies. Response latencies are shorter in gap trials (gap effect), since there is no stimulus to disengage attention from when the target is presented. Recently, deficits in disengagement have been reported in patients with autism; they are slower at disengaging attention than normal subjects [4,5]. Clinical studies also indicate that disengagement impairments are one of the earliest symptoms of autism, detectable by 12 months of age [6]. It has been suggested that these deficits in disengaging attention are primary in the development of autism and that they underlie the social and communicative deficits that are typically observed in this disorder [1].

So far, however, the neural bases of attention disengagement are far from being completely understood. To date, a few studies have focused on the cortical mechanisms that are related to disengagement from a fixation point in gap paradigm tasks. These studies have suggested that the human frontal eye fields [7] and parietal lobes [8,9] are involved in disengaging attention. Patients with lesions in one of these brain regions were slower at disengaging attention in overlap trials [8,9]. Accordingly, an EEG study in normal subjects described that the activity in parietal lobe is prolonged in overlap trials [7]. Until very recently a possible role of subcortical structures, such as the superior colliculus (SC), had not been considered. In a recent single-unit recording study, the activity of SC neurons was recorded in rats while they performed an attention-shift task with and without attentional disengagement [10]. The activity of a group of SC neurons was specifically related to disengagement processing; their firing rate significantly increased in trials requiring disengagement compared to trials requiring no disengagement. This result suggests that, in addition to its well-known role in attention shifting and target selection [11–13], this structure also plays a role in attention disengagement.

In this study, we aimed at determining whether the rat SC activity is required for attentional disengagement. To this end, we developed an experimental design to study attention disengagement in rats. The procedures were adapted from a recent electrophysiology study published by our group [10], which is so far the only publication investigating attention disengagement in rats. We designed two experiments. In both, rats were trained in a two-alternative light-guided spatial choice task. Experiment 1 included trials requiring attentional disengagement and shift, while experiment 2 included trials requiring shift of attention without disengagement. The effects of unilateral temporary inactivation of SC in the rat's performance were then investigated. We predicted that SC functioning is necessary for attentional disengagement and therefore its inactivation would selectively impair performance on the trials of experiment 1 that required disengagement.

2. Material and methods

2.1. Subjects

Fourteen adult male Wistar rats weighing 250–350 g were used for this study. They were divided into 2 groups. Rats from group 1 ($n = 9$) were used in experiment 1 and rats from group 2 ($n = 5$) were used in experiment 2. The housing temperature was maintained at $23 \pm 1\,^{\circ}$C with a 12-h light/dark cycle. The rats were housed individually, with food available ad libitum. Water supply was restricted to 15 mL per day in their home cages because the reward given on the task was a solution of sucrose (0.3 M). The rats were weighed daily to ensure that they did not lose weight.

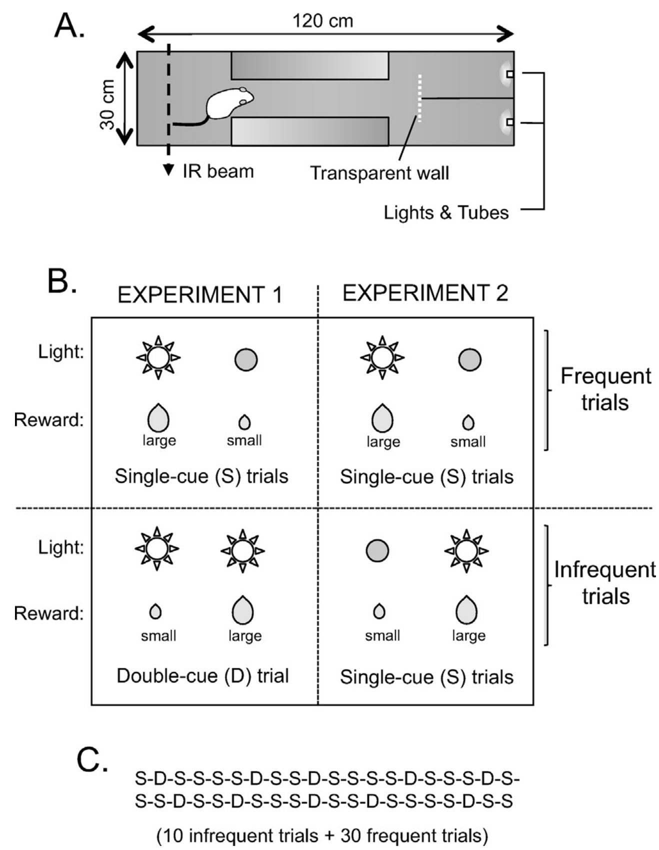

Fig. 1. Schematic representation of the study design. (A) Experimental setup. (B) Schematic illustration of the trial types of experiments 1 and 2. (C) An example of a sequence of trials in a session of experiment 1. S, single-cue trial; D, double-cue trial.

All rats were treated in strict compliance with the United States Public Health Service Policy on Humane Care and Use of Laboratory Animals, National Institutes of Health Guide for the Care and Use of Laboratory Animals, and Guidelines for the Care and Use of Laboratory Animals at the University of Toyama. All experimental procedures were approved by our institutional committee for experimental animal ethics.

2.2. Experimental setup

A testing chamber (120 cm × 30 cm × 30 cm) made from black acrylic was used in this study (Fig. 1A). This apparatus was positioned on the floor of the experimental room. At one end of the chamber, there was an infrared (IR) beam. When the rats passed through the IR beam, the trial started. There was a narrow corridor (10 cm wide) in front of the IR beam that ended in a transparent wall that delimited the entrance to two small paths, with one on the left and the other on the right. The transparent wall allowed the rats to see the wall at the end of the paths from the outside. This wall at the end of each path was equipped with a cue light above a hole, through which a retractable tube, attached outside the chambers, could extend inside the chamber to deliver reward. When the tubes were extended, the tips were positioned below the cue lights, and they were available to the rats. Both cue lights were identical. A touch sensor attached to each tube detected licking. When retracted, tips were located outside the chamber so that the rats could not lick them.