Data for Brain Reference Architecture of NM24VestibuloOcularReflex

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Abstract

Computational models have been proposed for the vestibulo-ocular reflex (VOR), one of the key components of eye movements. To realize brain-inspired software , it is necessary to comprehensively describe and organize the functions of brainstem nuclei related to VOR in alignment with other types of eye movements. In this paper, we introduced the concept of "network motifs" , which are repeatedly occurring circuit patterns consisting of multiple nodes with input-output transformations that can be interpreted as computational functions. Based on this concept, we organized the functions of the nuclei. Furthermore, based on the hierarchical functional decomposition, we propose hypotheses for new anatomical structures in some nuclei. Also, we will discuss the details and validity of these proposals, as well as the issues with the currently proposed information-processing structure of neural nuclei involved in VOR.

Keywords: Brain Reference Architecture ;Vestibulo-Ocular Reflex ; Brain Stem

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1 Context

Brain Reference Architecture (BRA) is the reference architecture for software that realizes cognitive and behavioral functions in a brain-like manner. The architecture primarily consists of the mesoscopic-level anatomical data of the brain and the data of one or more functional mechanisms that are consistent with that knowledge (Yamakawa, 2021). BRA consists of Brain Information Flow (BIF), which represents structural knowledge of the brain, and Hypothetical Component Diagram (HCD)/Funciton Realization Graph (FRG), which represent brain functionality.

In this paper, we describe the data explaining the vestibulo-ocular reflex (VOR), one of the key components of eye movements. The functions of brainstem nuclei related to VOR are organized in the data. Furthermore, several hypotheses are established based on the hierarchical functional decomposition, which are about new anatomical structures in some nuclei.

Table 1: Abbreviations and Full Names of Brainstem Nuclei and Extraocular Muscles used in this study

Abbreviations	Full Names
MVe	medial vestibular nucleus
PrH	prepositus hypoglossal nucleus
3N	oculomotor nucleus
4N	trochlear nucleus
6N	abducens nucleus
AIN	abducens internuclear neurons
MNs	motoneurons
LR	lateral rectus
MR	medial rectus
IO	inferior oblique
SO	superior oblique
SR	superior rectus
IR	inferior rectus

Table 2: Abbreviations and Full Names of other terms used in this study

Abbreviations	Full Names
l	left
r	right
h	horizontal
v	vertical
NI	neural integrator
1	type I neurons
2	type II neurons

Based on multiple detailed anatomical studies about the brainstem nuclei associated with VOR, Brain Information Flow (BIF) data is created. This study focuses on seven regions of interest (ROIs) within the brainstem nuclei: MVe, PrH, 3N, 4N, 6N, AIN, and MNs. Table 1 shows the abbreviations and full names of the brainstem nuclei regions and extraocular muscles addressed in this study. Tables 2 provides those of directions as well as other terms related to this research. For example, MVe1h_r stands for right medial vestibular nucleus type I neurons innervating horizontal motoneurons.

Hypothetical connections To accomplish VOR, we considered the following hypotheses to be essential.

Connections within 6N Examination of the internal connections within 6N reveals a neural circuit that regulates horizontal eye movements in both directions. 6N is divided into MNs and AINs (Baker & Highstein, 1975). Traditionally, it is understood that projections from MVe targeting to 6N, where AINs subsequently project to the contralateral 3N and MR, while MNs innervate ipsilateral LR (review (Takahashi & Shinoda, 2018)). However, this conventional model implies a temporal discrepancy in the regulation of MR and LR due to the differing number of processing steps. Therefore, it is reasonable to hypothesize that the regulation circuits for MR and LR have an equal number of processing steps within 6N, suggesting the presence of a direct AIN-to-MNs connection, with AIN occupying an upstream position. This proposed architecture eliminates the temporal lag between MR and LR adjustments, thereby maintaining stable horizontal eye movements.

Anatomical structures within MVe MVe plays a crucial role in VOR by converting head velocity input from the semicircular canals (Highstein & Holstein, 2006) into eye velocity in the opposite direction. Downstream nuclei from MVe are not involved in performing directional selection, since PrH is suggested to function as a neural integrator (Fukushima, Kaneko, & Fuchs, 1992) and 6N only regulates extraocular muscles as well as 3N or 4N, suggesting that MVe possesses the function of direction switching for both horizontal and vertical movements. It is known that commissural inhibition occurs within MVe (Curthoys, 2020), which is thought to facilitate the mechanism of direction switching. Consequently, we hypothesize that MVe is divided into two separate components for horizontal and vertical directions, respectively. These subdivisions can be further classified into excitatory and inhibitory nuclei, as supported by latest anatomical studies.

Moreover, the current HCD lacks a neural integrator for converting eye velocity to eyeball position in the vertical direction. Thus, we propose the existence of an integrator-equivalent region within MVe for vertical eye movements, implying two additional neural nuclei corresponding to upward and downward directions.

To summarize, MVe can be hypothesized to be divided into six distinct regions. This proposed division enables the coherent realization of the critical function of VOR, which is to move the eyeballs in the direction opposite to head movement.

2 Method

SCID method The series of procedures followed to produce the dataset according to structure-constrained interface decomposition (SCID) method (Yamakawa, 2021).

The brief introduction of three steps of SCID method is given as follows:

Step 1. Brain Information Flow (BIF) registering and provisonary creation of Hypothetical Component Diagram. This steps include (a) surveying anatomical knowledge in specific brain region (ROI: region of interest), (b) following determination of ROI and TLF (top-level function) consistently and (c) creation of a provisionary component diagram (called HCD)

Step 2. Enumerating candidate component diagram.

Step 3. Rejecting diagram that are inconsistent with scientific knowledge.

You can see more details about these steps in (Yamakawa, 2021).

Sampling strategy The dataset was created by the authors, including experts in the field of computational neuroscience, through the collection and integration of data from multiple publications. The selection criteria for the referenced publications were based on their inclusion in major academic journals related to anatomy. Detailed information about the referenced publications, such as titles, authors, journals, and publication years, is provided in the "References" sheet of the dataset.

3 Dataset Description

Repository location BRA Editorial System (BRAES) https://sites.google.com/wba-initiative.org/braes/data

Object name and versions Please refer to the "Project" sheet in the BRA data for the more detail of data summary.

Table 3: BRA DATA SUMMARY

BRA Data			
Object Name	Template	Including Content(s)	
		BIF	HCD/FRG
ProjectID.bra	*version 2.0*	√	√

Table 4: BRA IMAGE SUMMARY

Graphic Files: BIF Image, HCD Image, FRG Image	
File Type	Object Name
BIF Image	NM24VestibuloOcularReflexBIF.xml
HCD Image	NM24VestibuloOcularReflexHCD.xml
FRG Image	NM24VestibuloOcularReflexFRG.xml

Creation dates 2024-02-14 to 2024-06-1

Language English.

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4 Caveats for Data Usage

This data includes several hypotheses for anatomical structures and functions relating to some nuclei such as MVe and 6N, thus requiring careful considerations when used.

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Competing interests

The author(s) has/have no competing interests to declare.

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