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Brain Research



Research Report

An investigation of the white matter microstructure in motion detection using diffusion MRI



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ARTICLE INFO

Article history:

Accepted 4 May 2014

Available online 14 May 2014

Keywords:

Motion detection

Vision

White matter microstructure

DTI

MRI

ABSTRACT

One of the most widely investigated functions of the brain is vision. Whereas special attention is often paid to motion detection and its modulation by attention, comparatively still little is known about the structural background of this function. We therefore, examined the white matter microstructural background of coherent motion detection. A random-dot kinematogram paradigm was used to measure the sensitivity of healthy individuals' to movement coherence. The potential correlation was investigated between the motion detection threshold and the white matter microstructure as measured by high angular resolution diffusion MRI. The Track Based Spatial Statistics method was used to address this correlation and probabilistic tractography to reveal the connection between identified regions. A significant positive correlation was found between the behavioural data and the local fractional anisotropy in the posterior part of the right superior frontal gyrus, the right juxta-cortical superior parietal lobule, the left parietal white matter, the left superior temporal gyrus and the left optic radiation. Probabilistic tractography identified pathways that are highly similar to the segregated attention networks, which have a crucial role in the paradigm. This study draws attention to the structural determinant of a behavioural function.

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1. Introduction

The neural substrates of motion sensitivity are located at different levels of the visual system. Electrophysiological investigations have revealed that in the retina subgroups of ganglion cells react differently to moving lights some responding with activation and others with decreased firing (Sivyer et al., 2010). Similarly, the lateral geniculate nucleus (LGN) (Stanley et al., 2012), the striate cortex (Beckett et al., 2012) and some peri- and parastriate areas (Sary et al., 1995; Larsson et al., 2010) respond to a dot moving across the receptive fields of the neurons. The higher levels of perception, such as global motion recognition seems to be located in the middle temporal area (MT), medial superior temporal cortex (MST), and the fundus of the superior temporal cortex (FST), that are similar in monkeys and humans (Morrone et al., 2000), and was suggested to make up a complex: V5/MT+ (Boussaoud et al., 1990; Morrone et al., 2000). This area receives direct input from the primary visual cortex (V1) (Maunsell and van Essen, 1983; Felleman and Van Essen, 1991), LGN (Sincich et al., 2004), and also extrastriate regions, such as V2 (Lewis and Van Essen, 2000). These neurons with a broadly binocular representation and a relatively large receptive field (~15–20°), (Angelucci et al., 2002), have a principal role in motion and directional sensitivity (Chawla et al., 1998).

Motion transparency (e.g. two motions superimposed on each other) as applied in the form of a random-dot kinematogram is frequently used to identify motion-sensitive cortical regions in functional imaging (Friston et al., 1997) and electrophysiological experiments (Antal et al., 2005; Braunitzer et al., 2012). It affords an opportunity for the analysis of integrated action vision in close-to-real situations. Moreover, through modulation of the attention to the various components of the task the mechanism by which attentional networks interacts with motion detection areas can be revealed (Buchel et al., 1998; Kellermann et al., 2012).

Although functional imaging experiments offer a unique opportunity for the examination of functional activation in various behavioural conditions, it was recently suggested that behavioural performance is also strongly influenced by the underlying brain structure. It was shown that the correlation between the individual structural variability and the behavioural performance can identify the neuroanatomical structures involved (Maguire et al., 2000). Moreover, if white matter structure-related parameters are investigated, this approach provides a unique opportunity for the identification of the white matter tracts associated with the certain functions (Floel et al.,

2009). Such parameters can be defined by diffusion tensor imaging that may address the integrity of the white matter microstructure. The relationship between the locally measured diffusion parameters and the behavioural data is capable of revealing the coupling of structure and function (Johansen-Berg, 2010). Human studies have implied that short-term visuo-motor learning enhances the fractional anisotropy in the cortico-spinal tract (Landi et al., 2011). Plastic brain changes were found in a sequence-learning task as a correlation between the local FA and steeper learning curves (Tomassini et al., 2011). Recent combined imaging and histological studies demonstrated that spatial learning and motor learning result in locally enhanced myelination (Blumenfeld-Katzir et al., 2011; Sampaio-Baptista et al., 2013), which is reflected in enhanced FA in the diffusion MRI.

Most of the available information on the V5/MT+ stems from monkey experiments, human fMRI and positron emission tomography (PET) studies. Such knowledge is mostly functional in nature, but the structural background of motion detection is not sufficiently well known, especially that regarding the white matter pathways. In the current study, we set out to identify the white matter structural background of motion detection. We investigated the correlation between the white matter diffusion parameters and the intersubject variability for the threshold of detection for coherent motion in a random-dot kinematogram paradigm.

2. Results

2.1. Correlation of the white matter integrity and the motion detection threshold

The mean motion detection threshold was $18.87 \pm 5.79\%$ coherent motions. A significant positive correlation was found between the motion detection threshold and the local FA in the right frontal cortex in the posterior part of the right superior frontal gyrus ($p < 0.0032$, non-corrected), the right juxta-cortical superior parietal lobule ($p < 0.0032$, non-corrected), the left parietal white matter ($p < 0.001$, non-corrected), the left superior temporal gyrus ($p < 0.0026$, non-corrected) and the left optic radiation ($p < 0.0036$, non-corrected) (Table 1, Figs. 2 and 3).

2.2. Connectivity of the white matter region having correlated microstructure with behavioural data

The right frontal cluster showed strong connections to the identical region in the left hemisphere and to the right

Table 1 – Regions correlating with the white matter structural integrity.

Anatomical structure	Side	Size (voxel)	Peak p value	x (mm)	y (mm)	z (mm)
Deep intraparietal white matter under the parieto-occipito-temporal junction	Left	21	0.001	–42	–48	29
Juxtacortical white matter in the superior temporal gyrus	Left	16	0.0026	–51	–33	8
Juxtacortical superior parietal lobule	Right	6	0.0032	36	–64	32
Juxtacortical white matter under the posterior part of the right superior frontal gyrus	Right	4	0.0032	16	–15	58
White matter in the occipital pole	Left	4	0.0036	–18	–86	12

The locations and sizes of the associated regions and the standard MNI-based coordinates are shown.

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