論文の内容の要旨

Abstract of Dissertation

論文題目　The Contribution of Dorsal and Ventral Pathways to Visual Object Recognition that Subserves Reading
（読字に寄与する視覚的物体認識への背側及び腹側経路の貢献について）

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Literacy, especially the ability to read, is essential in our contemporary life, and a considerable amount of research has been conducted concerning the neural mechanisms that subserve it. As a result, it is now known that visual information concerning the form of letters is transformed into linguistic information in the left lateralized regions that house both the visual and the verbal system. Both neuroimaging and lesion studies have identified the left lateralized ventral regions—including the occipital temporal gyrus, inferior frontal gyrus, and inferior parietal lobule—as the regions that play a substantial role in the transformation of visual information concerning the form of letters into phonological, syntactic, and semantic information.

Recently, however, a line of research on reading and word recognition has revealed that the mechanism that takes in and analyzes the purely visual properties of letters is as important for the ability to read as the mechanism that converts visual information into linguistic information. For instance, some authors have suggested that impairment in visual recognition of letters can be one of the causes of the inability to acquire orthography-to-phonology correspondences. Reading involves integration of visual, attentional, and oculomotor processes in addition to linguistic information processing. This thesis is an attempt to determine what effect impairment in these non-linguistic processes involved in reading can have on the ability to read. More specifically, we attempted to study the contribution of the ventral and dorsal pathways to visual object recognition that subserves reading, by examining how letters and letter-like shapes are processed in the brain. Inclusion of non-letters in the experimental material allowed us to make inferences regarding whether the ventral and the dorsal pathway are activated during reading to perform linguistic processing alone or to perform non-linguistic, as well as linguistic processing.

We conducted three experiments to test the hypothesis that the dorsal pathway makes an important contribution to the process of letter recognition by (i) processing the kinesthetic information related to writing of each individual letter or letter-like shape even when one is reading rather than writing something and (ii) processing visual information about the spatial location of successive letters and words and programming and controlling eye movements. The primary goal of this thesis was to provide evidence for or against this hypothesis.

After outlining the structure of the thesis and introducing the reader to what is now known regarding the distinct neural pathways that process the output of the primary visual area in the first chapter, I present in Chapter 2 our first experiment, which was a functional magnetic resonance imaging (fMRI) experiment using healthy young adults whose purpose was to investigate whether the motor-related areas and some other particular areas on the dorsal pathway respond to mere visual presentation of the subjects' own handwriting and others' handwriting. Contrary to our expectation that objects associated with more familiar movements based on previous experience would elicit stronger activation of the motor-related areas on the dorsal pathway, the recognition of others' handwriting induced stronger activation in the dorsal motor-related region than the subjects' recognition of their own handwriting. In line with previous findings that the dorsal motor-related regions are responsible for online visuo-motor control of visually guided movements, we submit that this response occurs because the recognition of others' handwriting involves online movement tracing (i.e., mental reconstruction of the movements that must have produced the object being perceived) that automatically accompanies visual perception of unfamiliar graphomotor images, rather than access to stored kinesthetic knowledge of overlearned actions located in more ventral regions.

In Chapter 3, I report on our second experiment, which was an electroencephalography (EEG) experiment conducted to examine why the dorsal pathway was activated to a greater degree during observation of others' handwriting than during observation of subjects' own handwriting. In this experiment, we had 16 adult participants with normal reading comprehension copy various letters and letter-like shapes while we obtained EEG recordings. This second experiment also yielded results that arguably indicate that letter recognition engages the motor-related function of the dorsal parieto-frontal pathway especially when the visual stimuli are presented in an unfamiliar configuration, namely when what is visually presented is others' handwriting or pseudo letters.

In Chapter 4, I report on an experiment whose purpose was to investigate whether children with reading disorders differ from typically developing children in their ability to program and control eye movements so as to efficiently receive visual information from letters

and words in the peripheral spatial location. The participants in this experiment were typically developing children and children with reading disorders such as developmental dyslexia, which is often defined as a deficit in reading and spelling despite normal intelligence and access to conventional instruction and sociocultural opportunity. This third experiment, employing electrooculography (EOG), revealed that children with reading disorders tend to have a problem not only in deciding how to make a saccade to direct their visual attention onto an appropriate region but also in one of the motor-related functions of the dorsal pathway, namely the function that is responsible for generating saccades. This result arguably indicates that children with reading disorders have some problem not only in processing in the ventral pathway but also in processing in the dorsal pathway.

In Chapter 5, I recapitulate the main findings described in this thesis, discuss possible interpretations of the experimental results, and reflect on interesting future follow-up studies or applications.

The results of our three experiments show that the dorsal pathway plays a larger role in letter recognition than has previously been thought, although it remains true that the ventral pathway is the main locus of letter recognition. The dorsal pathway seems to play two distinct functions during reading, namely an attention-related function and a visuo-motor function.

The view that the dorsal pathway plays an attention-related function in reading has already been expressed in the previous literature, and our results were consistent with this view. The process of planning and performing saccades requires intricate regulation of attention, which is one of the tasks known to be carried out in the dorsal pathway. As had been expected, the attention-related region in the dorsal pathway was found to be activated to a greater degree when handwriting was being seen than it was when printed graphemes were being seen.

At the same time, the dorsal pathway seems to play some visuo-motor function as well during reading. This is what we consider to be the main finding of this work. There are four considerations that lead us to this conclusion.

First, it was found in our experiments that the motor-related region in the dorsal pathway was activated to a greater extent when an unfamiliar type of handwriting (i.e., either others' handwriting or a handwritten pseudo-grapheme) was being seen, compared to when a familiar type of handwriting was being seen. This result can be taken to indicate that an unfamiliar type of handwriting does not elicit a recall of specific memorized movements (which is thought to be stored in the ventral pathway), but rather activates a type of automatic simulation of movements that was first hypothesized by Goodale and Milner (1992).

Second, children with reading disorders showed a significantly weaker cue effect in the visual matching task involving saccades, compared to those in the control group; children with reading disorders did not initiate saccades as quickly as those in the control group when a cue was available. This result points to the possibility that children with reading disorders tend to have impairment in the visuo-motor function of the dorsal pathway, since saccades are a typical instance of visually guided movements, and there are reasons to believe that execution of visually guided movements are controlled mainly by the intraparietal sulcus, part of the dorsal pathway.

Third, it has been known that the dorsal pathway is one of the areas that are employed to process kinesthetic information. It is claimed in existing literature that the dorsal pathway contributes to recognition of tools by processing the kinesthetic information related to the use of tools. It is natural to expect that recognition of handwritten strokes is likewise accompanied by activation of the dorsal pathway to process kinesthetic information associated with handwritten strokes.

Fourth, there are some everyday observations that suggest that a s pecific type of kinesthetic information, namely information concerning how one moves one's hand to write each specific letter, is utilized in reading, at least under certain circumstances and possibly quite generally. For instance, it has long been observed that people with reading impairment can sometimes help themselves read letters that they initially have trouble with by tracing those letters with their fingers or by observing others' writing actions. A lso, when a Japanese speaker attempts to recall the form of a Chinese character that she finds difficult to write, she sometimes tries to write that letter in the air by actually moving her hand in midair. Such hand movements are felt by many to aid their effort in recalling the details of Chinese characters.

It is possible that the findings reported in this study will prove useful in developing strategies for supporting those children with reading disorders for whom interventions aimed at developing their phonological processing have not been very effective. Those children may be under the influence of impairment in a non-linguistic mechanism involved in reading, and our findings will help us to understand the problem they are experiencing and to develop more effective strategies for remediation and educational support for them.