Write to read: the brain's universal reading and writing network

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Do differences in writing systems translate into differences in the brain's reading network? Or is this network universal, relatively impervious to variation in writing systems? A new study adds intriguing evidence to these questions by showing that reading handwritten words activates a pre-motor area across writing systems.

Because the invention of writing is recent in human evolution, reading benefited from no special foothold on the human brain, which instead reorganized tissue that evolved for other purposes [1]. Accordingly, the idea of universals in reading has a distinctly different flavor from corresponding ideas of language or perceptual universals, which can be linked to specific neural foundations. To span across writing systems, orthographies, and scripts, which are highly variable in visual form, any universals in reading must be mainly inherited through the dependence of reading on language, especially a phonological system that is engaged by reading across writing systems [2].

The neuroscience of reading has yielded evidence for networks that are both universal and partly specific to language and writing system [3,4]. The universal network includes a left occipitotemporal (OT) region that becomes especially responsive to word-like forms in both alphabetic and nonalphabetic writing, thus earning the designation visual word form area (VWFA). This area, which links visual word recognition with more anterior and superior language areas in the temporal and frontal regions, is supplemented by the recruitment of areas that are especially responsive to the specific demands of the writing system, for example, a network of temporoparietal areas that support the conversion of alphabetic writing to phonology and distinctive parietal and frontal regions that are especially activated in reading non-alphabetic Chinese [3], which maps graphs to language at the morpheme and syllable level, rather than the phoneme level. Thus, reading can be characterized as supported by universals with writing system variations [4].

A new neuroimaging study adds highly original evidence concerning universals vs specialization [5]. Nakamura *et al*. demonstrate that for both French and Chinese two tightly linked neural subsystems together form a universal network that rapidly yields word meaning for handwritten words. The first of these subsystems comprises the left OT area, identified in many studies of reading. The second (Exner's area) is a left frontal pre-motor area that is involved in handwriting.

The study exploits the repetition priming effect, in which a target word is preceded by a briefly presented (for 50 ms) and masked prime word, either identical or unrelated to the target. Behaviorally, repetition priming produces faster decision times. Neuronally, it produces a lower level of brain activation (response adaptation). Critical is the visual presentation of the target word in cursive writing rather than print. The target (e.g., train) appears in all-at-once (static) form, in letter-at-a-time forward sequences that mimic normal handwriting, or in reversed sequences that violate the normal order. The prime is always in normal static cursive. Orthogonally, the target word appeared either normally spaced or distorted (Figure 1). The key result is a double dissociation between the brain areas responsive to the two stimulus factors. Distortion affected activation in the left OT/VWFA, but not in the left premotor Exner's area. Normal vs static and reversed cursive writing affected the left premotor Exner's area, but not the left OT/VWFA. These effects were the same for French and Chinese, leading to the central conclusion that there are two intimately connected subsystems for reading, one for word shape and one for handwriting gestures, and that these two subsystems are universal.

These intriguing results are important in two ways. First, they show a gestural component in reading hand written words, a reading analogue to gesture-based speech perception [6], which may involve specific articulatory motor activation [7]. This conclusion is consistent with behavioral experiments that suggest that written Chinese characters are perceived as sequences of strokes [8]. Writing-on-reading effects also are found in motor and pre-motor areas when English speakers learn Chinese characters through writing them [9].

A second conclusion is that the writing-responsive subsystem and the shape-responsive subsystem are universal.

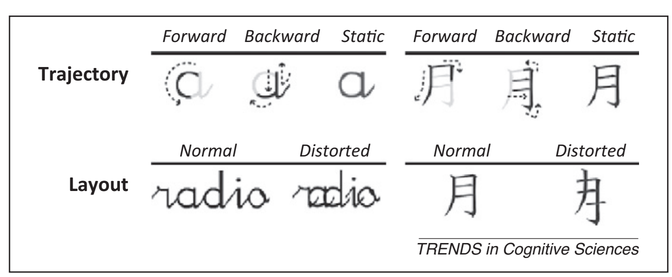

Figure 1. Each target word was displayed as a simulated handwriting sequence in a normal sequence of movements (forward direction) or in a reversed sequence of movements (backward) direction. Independently, the display could be in normal or distorted layout, in which the letters (French) or strokes (Chinese) are squeezed together. The distortion manipulation affects word shape recognition, and thus the processing in the Occipital–Temporal cortex and the VWFA. The trajectory manipulation affects the processing of hand–gesture cues produced by normal writing and thus the processing of writing gesture in Exner's area.
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There were hints of language differences, including stronger Chinese effects in areas of BA9 that overlap with those identified in previous research as more active during Chinese than alphabetic reading [3]. These language differences were downplayed because they did not survive a $p < 0.05$ threshold corrected for multiple comparisons in the whole brain-based comparison of Chinese and French subjects – perhaps a rather stringent test given prior results.

However, the general conclusion about universals does capture language differences: '. . .cultural effects in reading merely modulate a fixed set of invariant macroscopic brain circuits, depending on surface features of orthographies' ([5], abstract). This conclusion parallels the claim that all writing systems universally engage phonology, but orthographies shape important details that matter for reading [2].

Where does handwriting fit in this perspective? The identification of a gestural subsystem as universal is an exciting discovery. However, it does not reflect the theoretical bases of universal reading, which lie in the language constraint that all writing encodes language rather than meaning. Instead, it adds a gesture system that universally provides non-language motor support for reading handwriting, probably not functional across orthographic inputs, for example, computer type fonts. Its discovery does not directly address the systematic variations identified in other research [3,4,10]. These studies identified the LH word identification function (the 'shape' system of Nakamura *et al.*), without observing activation of Exner's area in the reading of computer printed fonts. They also identified some areas whose degree of involvement depends on the writing system. These distinctive areas seem to involve more than the visual appearance of the graphs, reflecting how the writing system maps graphs to linguistic objects, including phonology. Whether one considers these departures from universality as macroscopic or microscopic [5] seems a subjective matter for now. More research with more languages, orthographies, and scripts will help converge on a big picture that also has the little pieces right.

Intriguing beyond this question of universals is the implication that handwriting is a powerful procedure for establishing written word form knowledge in both native [5] and second language learning [9]. Whereas writing may be more integrally a part of Chinese literacy, it can play a role in alphabetic reading, at least as long as writing remains part of literacy practice. Indeed, it is remarkable that handwriting effects can be observed for alphabetic readers whose use of handwriting may be more a childhood memory than a regular feature of their adult literacy.

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A BOLD statement about the hippocampal-neocortical dialogue

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High speed and high spatial resolution are at the top of the wish list of every neuroscientist. An important step of progress in this direction has now been made by sampling throughout the brain fMRI signals that temporally surround important physiological patterns.

The wisdom that the combination of two methods is more than their sum is illustrated with 'grandeur' in a paper by Logothetis *et al.* published recently in Nature [1]. In it, the authors combined fast time-scale electrophysiological techniques with whole brain fMRI in anesthetized and awake monkeys at rest. The results provided a snapshot of the cooperative patterns of the large numbers of brain structures involved either leading to or responding to a specific physiological event, the so-called hippocampal sharp wave-ripple (SPW-R). Beyond the specific theoretical question the paper addresses, the combined method used, which the authors call 'neural-event-triggered functional magnetic resonance or NET-fMRI', provides a new method for examining the spatial embeddedness of *a priori* defined local brain patterns.

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