



Decreasing materiality from print to screen reading

by Theresa Schilhab, Gitte Balling, and Anežka Kuzmičová

Abstract

The shift from print to screen has bodily effects on how we read. We distinguish two dimensions of embodied reading: the spatio-temporal and the imaginary. The former relates to what the body does during the act of reading and the latter relates to the role of the body in the imagined scenarios we create from what we read. At the level of neurons, these two dimensions are related to how we make sense of the world. From this perspective, we explain how the bodily activity of reading changes from print to screen. Our focus is on the decreased material anchoring of memories.

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The embodiment of reading

In recent years, the transition from print to digital reading has accentuated reading as an embodied practice (Mangen and Schilhab, 2012). Literally speaking, the embodiment approach to reading assigns a role to the body in what is otherwise primarily a mental activity. Such a move is overdue (*e.g.*, Schilhab, *et al.*, 2008). The body has been off the radar in most treatments of human accomplishments for two millennia. Since ancient Greece, philosophers have tended to praise the achievements of the mind as if there was no body involved.

Embodiment in reading has two distinct dimensions: the 'spatio-temporal' that relates to what the body does during the act of reading and the 'imaginary', that relates to the role of the body in the imagined scenarios we create from what we read. The spatio-temporal dimension accentuates that, like the human body, all texts are material and exist in time and space. Hence, this dimension is about the presentation and tangibility of the text and how it is sensed through the body. The imaginary dimension accentuates that texts point to phenomena and events we imagine while reading. Especially literary texts elicit experiences in the reader that in so-called immersed reading feel like real experiences. Arguably, it is for that reason that literary reading appeals to most readers. But feelings of real life experiences may also arise as part of reading non-fiction. When reading expository texts like recipes and manuals, the reader imagines what is

the case in real life (Schilhab, 2015a). The bowl with eggs and sugar exists in time and space along with the whisk that fits the palm of the hand.

From a biological perspective, the two dimensions are related effects of how we make sense of the world. In biological terms, we incessantly interact with the environment. This applies not only to the macro level where we read books or tablets while seated in chairs or sofas. More surprisingly, perhaps, interactions apply especially to the micro level, the level of neurons. On that level, an action such as 'reading book A' becomes a distinct interaction as it connects with a particular location, such as 'a car', 'the living room', or on 'a mountain top'. Similarly, reading book B in a different location would lead to different connections. Therefore at this level it is clear that the act of reading becomes connected to what the body is doing while reading, thus influencing what (and how well) we remember the text we are reading.

In this article we explore what the incessant embodied interaction with the environment means for the embodiment of reading in the shift from print to screen. We ask whether the different materiality of the screen radically changes the connections formed between what we read and what the body does while reading.



The spatio-temporal dimension

Although texts have semantic meanings they are also material. The marked sensitivity to the materiality of the world is deeply ingrained in all organisms alive (Sheets-Johnstone, 1998; Schilhab, 2015b; 2015c). During reading we interact physically with the materiality of the reading substrate to decipher the text. Like a mountain top differs physically from the living room, different texts have distinct materialities. We react to the light conditions, the sensed weight of the platform and the physical touch of the substrate that holds the text. We engage with the strings of words in their quality of being a physical object with a certain appearance that takes up a particular part of space in time.

At both the macro and the micro level, the materiality is connected with the textual meaning. In attempts to unlock the meaning of the text, say the characterization of a culprit, or descriptions of an architectural masterpiece in town, concurrently we process where and when in the text we stumble across this information. The processing of time and space in our reading occurs in much the same way as we process objects and events on our walk to work. Processing of time and space also occurs while at rest in our living room, or while climbing the top of Matterhorn.

Hence, when reading we engage memory features supportive of ongoing cognitive events in general. This is not surprising. In the evolutionary perspective, reading is a much newer activity than walking and resting for which our memory features were developed.

Some of these features are known as so-called episodic memory, a concept introduced by Endel Tulving (1993). Episodic memory records a person's experience relating to personal spatio-temporal relations. Hence, among other things, episodic memory processing encodes events in the order of their occurrence and their sensory-perceptual-conceptual-affective characteristics, most often in the form of visual images. In other words, we process and store memories about events from how they are sensed, experienced, consciously understood and emotionally felt. Also, the memory always presents itself in a first-person perspective depicting encounters and events *as they are experienced* in time and space. Consequently, the reading substrate is important for the processing of the text and the subsequent recollection of the content of the text. How the body moves and interacts during reading is processed along with the unlocking of the meaning of the text.

Obviously, the solidity of the *printed* text fixed in size and space and anchored to, say, a distinct cover, renders it readily available to perceptual and sensual processing. By contrast, the digital text is fluid, often without fixation of font size, place in space or even anchorage to a particular substrate (e.g., a particular printed item with a particular cover). For example, an e-reader can contain a huge number of texts and is therefore not associated with any particular text. Rose (2011) describes how reading a continuing sentence is disrupted when the swap from one page to the next is done by scrolling in the text on screen during reading in portable document format (pdf). With printed text the swapping of pages would have had a coinciding recognisable feeling to it constrained by the feeling of the concrete pages.

In effect, whereas the description of a culprit's personality would automatically be linked to say, the left bottom corner of the page around 40 pages into the printed book, such concrete linkages are unavailable for the on-screen reader. Studies have shown that the transition from print to screen entails a shift in readers' spatio-temporal relation with the text (Hillesund, 2010), and

readers sometimes report a general sense of changed memory capacity in digitised reading (Kuzmičová, *et al.*, 2018).

How does research examine the differences between print and screen reading? Traditionally the differences have been associated with better memory for the content of the text in print readers. Mind, however, that cognitive processing during reading differs from that occurring while remembering the reading.

How exactly does the particular availability of printed text to the senses impact on readers' abilities to remember the content? At issue is to what extent momentary embodied processes are actually supporting the reading process and to what extent these are used later for remembering. Crudely put, it seems as if in the very course of reading, in the so-called encoding phase, the materiality of printed text increases one's ability to recall the content of the text. In the following we will expand on how the materiality impacts on encoding and recall when reading in print and on screen, respectively. To that end, we first address what happens at the micro level.



Biological sensitivity and multimodality

With printed text, the tangibility of the reading substrate lends itself to the kind of cognition that we are biologically adapted to and therefore comfortably employ. Most of these cognitive processes occur outside of our conscious mind. Crudely put, the reading activity 'speaks' to us at several levels: the sensory, perceptual, motor, conceptual and affective level. All of these levels participate in forming the so-called neural correlate, which is the bundle of neurons active during the reading (Schilhab, 2017a). To grasp how much is going on in each moment, imagine the simple act of holding a hot cup of coffee. In your mind's eye, go to the particular, combined sensation at your finger pads. Simultaneously, you may sense the heat from the porcelain; the smoothness of the surface and the weight of the cup. These sensations all point to further information. They help you deduce the hotness of the coffee, how much of it is left, and whether it is yours to drink in the first place.

In the words of Cashman [1], from whom this example is borrowed, the amount of neural activity is overwhelming:

When I hold a cup of hot coffee in my hand, my finger pads are physically made to curve in an iconic match to the curvature of the cup. Certain nerve endings embedded in the finger pads are triggered by this change of shape in the pads. At the same time, the skin of these finger pads is warming up because of the transfer of the heat (speed of molecules) from the porcelain cup to the fingers. Other specific neurons, that are unaffected by shape, are sensitive to changes of heat in the fingers. They are triggered to fire by the warming of the fingers. If, in addition, I squeeze the hand on the cup, still other neurons in the finger pads and in the joints of the hand are triggered in response to the increased pressure.

The question is what happens to the bundle of active neurons, when we switch the reading substrate from paper to screen?

With digital text, the tangibility that helps us literally navigate the text is markedly reduced. Accordingly there is a significant lack of so-called 'material anchors' with which the meaning of the text might become associated (Hutchins, 2005).

Barrett makes it clearer what changes with a switch from print to digital reading [2]:

Every moment of waking life, the human brain realizes mental states and actions by combining three sources of stimulation: sensory stimulation made available by and captured from the world outside the skin (the exteroceptive sensory array of light, vibrations, chemicals, etc.), sensory signals captured from within the body that holds the brain (somatovisceral stimulation, also called the interoceptive sensory array or the internal milieu), and prior experience that the brain makes available by the reactivation and reinhibition of sensory and motor neurons (*i.e.*, memory). These three sources — sensations from the world, sensations from

the body, and prior experience — are continually available, and they form three of the fundamental aspects of all mental life.

Two things become apparent. First, according to Barrett, at each instant our mental life is drawing on multiple sources. At any given moment, cognitive occurrences — be they ideas, desires, the needs for actions — are composed of many different processes. Hence, the three components: stimulations from the external and internal milieu, and memory. These comprise both conscious and unconscious processes. Some of the processes emerge 'bottom-up'. They are initiated and proceed without the individual recognising and controlling them.

The multimodality of every moment means that we habitually couple sensory knowledge with the concurrent mental processes. Clements (2000) refers to 'sensory-concrete' knowledge, which is knowledge that emerges from the association of sensory material to thought processes while grasping an idea. A typical example is when younger children can only perform mathematical operations such as count, addition and subtraction with the aid of material objects. Here, seemingly the concrete provides the child with 'external crutches' in the shape of material anchors.

Second, when we move from print to digital texts we rely less on what Barrett defines as sensory stimulation 'captured from the world outside'. When reading digitally, solid external crutches formed by different sensory processes are almost absent. Therefore, the unfolding meaning attribution to the text occurs without much material anchoring.

Digital reading compares to print reading as walking blindfolded compares to walking visually aware through a busy street. For the blindfolded pedestrian, the recollection of the content of conversations along the route must be processed and maintained entirely in the mind's eye. Conversations are memorised by their occurrence in time *in the string of conversations*, which are maintained without engaging perceptual qualities: that is, exclusively mentally. For the visually aware pedestrian, the conversations during the passing may be associated with a particular fence, zebra crossing or house facade. Space and time are now tangible and their impact on our bodily processes acts as anchors for later memories.



Material anchors in memory

When we neurally associate the processes that sustain abstract mental content with processes that sustain concurrent perceptual and sensory processes, the memory product is more easily re-enacted (e.g., Kontra, *et al.*, 2015). The effect of using the external world as anchor for otherwise abstract memories was exploited in the ancient mnemonic technique known as the 'mind palace technique', an established aid for recalling larger amounts of linguistic content. While rehearsing items to remember for, say, an important speech in the Roman senate or a festive birthday speech for a loved one, a sequence of visual images of a familiar environment can be used to prompt recall. Familiar rooms in your childhood home or the home of your grandparents are easy to re-enact because they are multimodal like the walk made while visually aware. You instantly visualise their atmosphere, odour, tactility, light conditions, sound pattern and so on, which can be used as material anchors while preparing the speech (see Fassbender, *et al.*, 2006). When performing the speech, all you have to do is to enter your well-known 'palace'. Now the associations with somewhat arbitrary strings of information are easily triggered, as if they were inhabiting the rooms recalled in memory.

Memory artists like Solomon Shereshevsky, Alexander Luria's famous patient, have also exploited how easily experiences with material objects come to mind and can form a background tapestry for memory. Shereshevsky, who showed extraordinary capabilities for memorising, often used a village street from his childhood. Here, he mentally dispersed the items to remember. In the recalling phase, he would stroll along the street and pick up the items mentally placed (Johnson, 2017; Foer, 2011).

We all outsource otherwise fragile and costly mental processes to the environment as we integrate the materiality of the text in our memory. The materiality of the printed book makes it a stable environment in the same sense as the familiar rooms. The features that made the familiar room in your mind palace so easily revived are shared by all concrete objects and environments. They repeatedly stir voluminous motor-sensory and emotional activity in us to which we can return later and very often in a kind of simulation. Concrete phenomena like coffee cups influence you in similar ways. They activate more or less the same neurons in much the same way. This explains why you can make reliable predictions about the temperature of the cup's content and the amount left. Similarly, the same printed book elicits neural activity in much the same way every time you leaf through its pages, whereas sensations that apply from

book to book leave you with the more general impression of 'bookness' (Barsalou, *et al.*, 2003).

The culprit's characterisation is invariably accessible on the fortieth page, whether you look up the text from the middle section or the last third. The number of pages you keep between your fingers in relation to the thickness of the book roughly correlates with the length of the story. And the distinct odour of dust and age and indents on the cover all add to the aura of that specific text. Hence, alongside the reading, the material anchors become stable non-arbitrary cues at work automatically and bottom-up. The arbitrary strings of words then become entangled with the stable and repeatable external world. Recollection of the content of the text may therefore occur by recalling the smell, the feel or the sensation of the weight of the book in your hands.

The encoding processes occurring during reading of the digital text, on the other hand, are very different. In comparison, they have very few and rather unstable anchoring points in time and space. Therefore, they are formed around solely mental associations controlled top-down by the individual. Completely mental processes without hooks into the material world emerge exclusively as meaningful conscious associations. Thus, we have no material entries, like the memory of a stained page or the feeling of a certain number of pages between the fingers, to re-enact them. All we have is the sheer remembrance of words. Surely, these are extremely fragile, whimsical and easy to forget. Think of how difficult it is to remember the name of someone you have never met and how much easier it is to remember the name of an acquaintance with a photo present. Facial characteristics, like specific pages in a book, are stable cues for arbitrary names (Goldberg, 2013).

With decreased materiality, is the spatio-temporal dimension of reading then irrelevant for on-screen reading? Certainly not, although the view on the spatio-temporal dimension is turned upside down. Cognition and metacognition researchers find that reading expository texts for learning on screen is typically associated with shallower processing as demonstrated by weakened effort regulation and test performance (Sidi, *et al.*, 2017). Since the reading of all texts occurs on the same physical substrate, the perceptual cues have no discriminative properties to anchor one's memory. Irrespective of the genre of the text, be it self-help medical entries, news, literary text or social media, there are no stable external features. Therefore, the mind is similarly rather than differentially attuned to all of them. According to the researchers, the perceptivity to the text on screen has decreased, simply because readers lack material anchors to guide their engagement with the text.



The imaginary dimension

The extensive neural coupling traversing the sensory, perceptual, motor and conceptual level also grounds the imaginary dimension of embodiment in reading (Kuzmičová, 2014). The imaginary dimension is based on the connections the reader has made in the spatio-temporal dimension when first learning to speak (*e.g.*, Schilhab, 2018; 2017a). From your first breath, your environment is both material and linguistic. Your environment is replete with concrete phenomena, events, processes or occurrences with tangible feels to them (*e.g.*, Wellsby and Pexman, 2014). We learn language in much the same way as we walk visually aware down a busy street. And we learn linguistic meanings by forming connections with linguistic practice. This is also why your grandparents' or your childhood home is so easily remembered. This fact pertains to most experiences of your childhood. Specific sensory feels and emotions are just beneath the surface of your memory. While your caretakers are quite keen on sharing the linguistic mastering of this world with you, concurrently you experience the physical setting. You perceive and interact with dogs, cutlery, daddy, liquid, clothes, apples and mosses, as well as sisters, insects, the globe, trees, stars and radio broadcasts (Schilhab, 2015c; 2011). This insight has come from studies that show activity in brain networks based on sensory experiences when readers passively encounter words with strong olfactory associations such as 'cinnamon' or 'garlic' (González, *et al.*, 2006).

Seemingly, meaning attribution during reading involves re-enactment of real-life experiences in memory (Schilhab, 2018; 2017a; 2015a; 2015b). Thus, mere reading of words that refer to real objects with sensory features recruits brain areas normally active during the actual experience of the object. Researchers propose that neurons activated as a result of real-life experiences with the referent of a word (*i.e.*, garlic) later participate in the bundle of neurons of the concept even without simultaneous presentation of the actual object (Pulvermüller, 2005). This bundle is then involved when we read the word referring to the object.

As infants, when we acquire language, simultaneously we perceive and talk. Hence, we associate the perceptual processes in the interaction with concrete phenomena and events with linguistic

processes of sounds, articulation, facial activity etc. (Glenberg, 2008; Öttl, *et al.*, 2017). In this process, the simultaneous exposure results in the co-wiring of perceptual and linguistic networks that will become active together during later recall. For example, when talking about bananas, infants are typically also perceptually engaged with concrete bananas (*e.g.*, Glenberg, *et al.*, 2008; Pecher, *et al.*, 2011). When children later hear or read about bananas they reactivate the sensory-motor areas active during perception. Comprehension of narratives, therefore, relies at least partly on simulations of sensory experiences (Speer, *et al.*, 2009; Engelen, *et al.*, 2011).

As a result, competent readers re-enact prior experiences when they read. Sadoski, *et al.* (1990), point to the many spontaneous imaginative responses associated with understanding and experiences of living through literature. When we imagine while reading we seem to reproduce images from memory that can be used to animate the text [3]. In the Sadoski study, students were exposed to differently paraphrased written instructions that emphasised either surface or deep reading. In spite of this, all participants seemed to engage in mental imagery when reading a 2,100-word typical adolescent adventure story. Students “formed powerful visual and affective images that were generally consistent with the text, and elaborated and synthesized portions of it, but also constructed images involving importations from other experiences” [4].

Deep reading

To engage prior experiences while reading is in a biological sense cognitively demanding. Biologically, cognitively demanding is used for imagery that is not supported by the surroundings (Schilhab, 2018). When we attribute meaning to a text, we rely less on sensory stimulation and more on memory. Reading where we are engaged in interaction with a text, either in the immersed/absorbed or the in-depth sense (Kovač and van der Weel, this issue) relies on such memory processes.

Birkerts coined the concept of ‘deep reading’ in 1994 as “the slow and meditative possession of a book” [5] which catches that we are engaged by a universe constructed by prior memories. Deep reading in this particular understanding, and not in the in-depth sense discussed by Kovač and van der Weel (this issue) relates to our ability to focus and sustain our attention for a longer period and on one task, and is especially related to the reading of longer literary texts such as novels or to following an argument in continuous reading of an academic book (see also Wolf and Barzillai, 2009).

Many scholars have pointed out the challenges of sustaining our attention when reading using a multifunctional digital substrate (Hayles, 2007; Baron, 2015; Lui, 2005; Hillesund, 2010; Mackey, 2011; Socken, 2013). Research shows that reading behaviour changes with the screen. We tend to read more selectively and shallowly when we read on screens. In an early survey study among academic staff (engineers, researchers teachers) and students Ziming Liu asked about time spent on sustained deep reading and shallow reading and on frequency of annotation in texts over a 10-year period. The result among the 113 participants showed a change in reading behaviour:

The screen-based reading behaviour is characterized by more time spent on browsing and scanning, keyword spotting, one-time reading, non-linear reading, and reading more selectively, while less time is spent on in-depth reading and concentrated reading. [6]

Other similar studies (Hillesund, 2010) support this picture. Screen reading such as reading on Web pages prompts searching for keywords and specific information, and a reading mode characterized by discontinuity and focus switching. When searching the Internet for information or gaming online this behaviour makes perfect sense. Certain reading modes require shallow reading. N. Katherine Hayles distinguishes between deep attention and hyper attention where deep attention is associated with concentrating on a single object for a longer period and hyper attention “is characterized by switching focus rapidly among different tasks, preferring multiple information streams, seeking a high level of stimulation, and having a low tolerance for boredom.” [7] Hayles points out that each cognitive mode has advantages and limitations. Still the above-mentioned research suggests that our time spent at screen activities influences our ability to engage deep attention and thus our deep reading ability.

One way to explain this change in reading mode is the affordances of digital substrates. Affordance theory (Gibson, 1986) states that we not only perceive the world in terms of object shapes and spatial relationships, but also in terms of object possibilities (affordance). Affordance

points at the transactions that are possible between an individual and their environment. A printed book requires one type of interaction whereas a tablet requires another. For example, it is possible when reading on your smartphone, to swipe between pages and press on hyperlinks with one hand. Thus, different reading substrates and different forms of reading require different forms of interaction and different forms of attention.

The paper book is characterized by a high level of stability, deriving from its materiality. The codex format as we know it has more or less looked the same since it outcompeted the scroll in Late Antiquity (Manguel, 1996). The substrate, in the form of the paper book, has become such an ingrown part of reading that it has become transparent to a degree where we almost forget the existence of the container and focus solely on the content (Bolter and Grusin, 1999). This is due to the fact that a physical book is a unique reading machine whose single function is to hold a text. It is not of much other use. The printed book therefore seems perfect to motivate to contemplation. A tablet or a computer on the other hand is a multimodal and multifunctional machine. Our laptops, our tablets or our smartphones hold potentially all our communication and interactions with friends and work, our banking business, our entertainment channels (gaming, music television), our food recipes, holiday plans and tickets, our self-monitoring in relation to sport, health etc. As we read we might be tempted to click to other sites, to open other apps, or we are interrupted by notifications, social media etc. (Hillesund, 2010). This is exactly why many point at the paper book as more suitable for contemplation and deep reading (Birkets, 1994; Hayles, 2007; Baron, 2015; Mackey, 2011; Socken, 2013). This is also why the imaginary dimension of reading is better served by paper than by screens: if the reading is shallower, as it is in the case of screens, then the reproduction of images and what we can do with them cognitively is shallower too.



How to deep-read on screen?

The question we would like to raise is how to combat the negative impact of the decreased and unstable materiality of the screen on deep reading. Given the multifunctionality of digital reading substrates, how may we stimulate the practice of deep reading for future readers? Are there any obvious biological quick fixes?

One option is to reserve particular reading substrates for particular reading modes. This approach acknowledges the finetuned neural sensitivity to the materiality. Dedicating a specific device to, say, academic texts will ensure the stability of external cues for that genre and thus at least to some extent improve memory processes. However, more conscious actions are also available. In studies showing shallower reading of expository texts on screen, engaging in concrete memorizing procedures such as generating key words seemed to counteract screen inferiority (Lauterman and Ackerman, 2014). Hence, encouraging in-depth cognitive interaction with the text overcame the cruder qualities of the reading substrate. Shallow reading is also counteracted if readers improve their self-regulation abilities to sustain their attention on the text (Schilhab, 2017b).

The problem that remains then is how to stimulate better self-regulation when it comes to securing deep attention. When a reading technology also affords watching videos, gaming or establishing social contact online, the reader's attention is likely to float (Hayles, 2007). We must then counter the distracting effects by learning entirely new habits such as how to actively restore our self-regulatory abilities (*e.g.*, Schilhab, *et al.*, 2018).

Screen use affords new ways of reading and therefore calls for new kinds of behaviour and attention regulation, as also suggested by studies emphasizing risks of addiction (Wei, *et al.*, 2012; Tarafdar, *et al.*, 2013). We must learn to control the habit of checking for messages and updates (Lee, *et al.*, 2014) when engaged in activities that need our full attention like deep reading and the company of others (Radesky, *et al.*, 2014; Turkle, 2015).

Here, another challenge calls for future research, since people seem to differ in their abilities to self-regulate as viewed from the perspective of multitasking (Ie, *et al.*, 2012; Alzhabi and Becker, 2013).




Concluding remarks

The shift from print to screen has physical effects on how we engage the body while reading. This has led to a general awareness about the embodiment of reading. We have suggested that

two distinct dimensions of the embodiment, the spatio-temporal and the imaginary, result from the same biological principle. Together they show that reading depends on direct experiences in the moment as well as in the past.

At the neural level the change from print to digital reading is obvious. Whereas printed text affords numerous stable material anchors in the moment for memorizing, digital texts are much reduced in this respect. This may change how we encode and remember reading content. Also digital reading substrates impact on how easily we re-activate past experiences when we read. The multifunctionality of the device threatens the cognitively demanding engagement with a text while increasing shallow and fragmentary reading.

If we wish to keep supporting deep reading, the lack of material anchors and the inclination to engage in selective reading on screen must be addressed.

We suggest that future research should explore what readers do to secure room for deep reading. Do they mute notifications, use dedicated e-readers, or in other ways solicit time spent alone with the text? Maybe we will find that experienced readers excel in abilities to switch off or ignore distractions that depend on the full attention of the conscious mind. Such studies would shed light on whether self-regulatory abilities are in high demand in literary readers in a world of technology-induced quick fixes. 

About the authors

Theresa Schilhab is Associate Professor, Future Technologies, Culture and Learning, Danish School of Education, University of Aarhus (Denmark).
Direct comments to: tsc [at] edu [dot] au [dot] dk

Gitte Balling is Associate Professor in the Department of Information Studies, University of Copenhagen (Denmark).
E-mail: Gitte [dot] balling [at] hum [dot] ku [dot] dk

Anežka Kuzmičová is a postdoctoral research fellow in the Department of Culture and Aesthetics, Stockholm University (Sweden).
E-mail: anezka [dot] kuzmikova [at] littvet [dot] su [dot] se

Notes

1. Cashman, 2008, p. 51.
2. Barrett, 2009, p. 330.
3. Sadoski, *et al.*, 1990, p. 56; see also Burke, *et al.*, 2016; Kuzmičová, 2014.
4. Sadoski, *et al.*, 1990, p. 69.
5. Birkerts, 1994, p. 146.
6. Liu, 2005, p. 700.
7. Hayles, 2007, p. 187.

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