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Digitizing literacy: reflections on the haptics of writing

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How utterly bound to the physical world of bodies is writing, one of the most awesome products of the human mind. (Haas 1998)

1. Introduction

Writing is a complex cognitive process relying on intricate perceptual-sensorimotor combinations. The process and skill of writing is studied on several levels and in many disciplines, from neurophysiological research on the shaping of each letter to studies on stylistic and compositional features of authors and poets. In studies of writing and literacy overall, the role of the physically tangible writing device (pen on paper; computer mouse and keyboard; digital stylus pen and writing tablet; etc.) is rarely addressed. By and large, the (relatively young) field of writing research is dominated by cognitive approaches predominantly focusing on the visual component of the writing process, hence maintaining a separation between (visual) perception and motor action (e.g., haptics[1]). However, recent theoretical currents in psychology, phenomenology & philosophy of mind, and neuroscience – commonly referred to as "embodied cognition" – indicate that perception and motor action are closely connected and, indeed, reciprocally dependent.

Today, most of our writing is done with digital writing devices (the computer, the mobile phone, the PDA [i.e., Personal Digital Assistant]), rather than writing by hand. The switch from pen and paper to mouse, keyboard and screen entails major differences in the haptics of writing, at several distinct but intersecting levels. Handwriting is by essence a unimanual activity, whereas typewriting is bimanual. Typically, handwriting is also a slower process than typewriting. Moreover, the visual attention of the writer is strongly concentrated during handwriting; the attentional focus of the writer is dedicated to the tip of the pen, while during typewriting the visual attention is detached from the haptic input, namely the

[1]Haptics is defined as a combination of tactile perception associated with active movements (i.e. voluntary movements generated by central motor commands which, in turn, induced proprioceptive feedback). Haptic perception is involved in exploratory hand movements and object manipulation.

process of hitting the keys. Hence, typewriting is divided into two distinct, and spatiotemporally separated, spaces: the motor space (e.g., the keyboard), and the visual space (e.g., the screen). Another major difference pertains to the production of each character during the two writing modes. In handwriting, the writer has to graphomotorically form each letter – i.e., produce a graphic shape resembling as much as possible the standard shape of the specific letter. In typewriting, obviously, there is no graphomotor component involved; the letters are "readymades" and the task of the writer is to spatially locate the specific letters on the keyboard. Finally, word processing software provides a number of features all of which might radically alter the process of writing for professional as well as for beginning writers.

A large body of research in neuroscience, biopsychology and evolutionary biology demonstrates that our use of hands for purposive manipulation of tools plays a constitutive role in learning and cognitive development, and may even be a significant building block in language development. Furthermore, brain imaging studies (using fMRI, i.e., functional Magnetic Resonance Imaging) show that the specific hand movements involved in handwriting support the visual recognition of letters. Considering the fact that children today or in the near future may learn to write on the computer before they master the skill of handwriting, such findings are increasingly important. In this article we present evidence from experiments in neuroscience and experimental psychology that show how the bodily, sensorimotor – e.g., haptic – dimension might be a defining feature of not only the skill of writing but may in fact be an intrinsic factor contributing to low-level reading skills (e.g., letter recognition) as well, and we discuss what a shift from handwriting to keyboard writing might entail in this regard. In addition, we discuss the ramifications of the recent interdisciplinary paradigm of embodied cognition for the field of literacy studies in general, and for writing research in particular. Specifically, we intend to address the following questions:

- Why, in what ways and with what implications is keyboard writing different than writing by hand?
- What implications might these differences have for children's learning, and for our reading and writing behavior and experience? Entailed in this question complex are, moreover, the wider implications surrounding the role of the hand-brain relationship in learning and cognitive development overall.

2. Reclaiming the haptics of embodied writing

Writing is an immensely important and equally complex and sophisticated human skill commonly ascribed a fundamental role in children's cognitive and language development, and a milestone on the path to literacy. Nevertheless, compared to the vast field of reading research, there has been less scientific attention devoted to the act and skill of writing. As new technologies complement and eventually replace old ones, and we increasingly type and click rather than write with a pen in our hand, however, the distinctive sensorimotor properties of this skill reveal themselves. Writing has always been dependent on technology; indeed, in a very literal sense, writing *is* technology, for "[…] without the crayon or the stylus or the laptop, writing simply is not possible." (Haas, 1996; preface) From using clay tablets and animal skins via the medieval manuscript and the ancient papyrus roll, to the mechanization of writing with the printing press and the current digitization, writers have always had to handle physical devices and then applying these to some substrate. The outcome of the writing process has always relied on the skilful combination of technical/manual skill and intellectual/aesthetic aptitude (Bolter, 2001; Ong, 1982).

However, at least outside the domain of ergonomics, the role and impact of the different technologies employed in the writing process is rarely addressed. Whether focusing on the cognitive aspects of writing, the semiotics of different codes and sign systems of writing, or studying emergent writing skills within a sociocultural paradigm, the technologies in question are by and large – and deliberately or not – treated as transparent. Hence, arguably important questions of how technologies and devices are physically (e.g., haptically) handled during the act of writing, and how these sensorimotor acts might interplay with, and impact, cognition, seem not to be considered scientifically interesting. The haptics of writing is a curiously ignored area of research, both in the field of literacy studies at large, as well as within the field of writing research in particular.

In the theoretically-methodologically inhomogeneous field commonly referred to as digital (or new) literacies, (digital; multimodal) writing is commonly considered a meaning making process situated in specific social and cultural contexts (Barton, 2007; Barton, Hamilton, & Ivanic, 2000; Buckingham, 2003, 2007; Coiro, 2008; Jewitt, 2006; Kress, 2003; Lankshear, 2006; Säljö, 2006). As such, it is argued, it is most appropriately studied within a theoretical-methodological framework defined mainly, if not exclusively, by sociocultural and/or semiotic perspectives. Within such a framework, reflections on the impact of digital technologies on reading, writing and literacy limit themselves to discussing the changing (semiotic; structural; semantic; aesthetic) relations between different sign systems (e.g., image, text, and sound) when displayed on screen.

A major digital literacy scholar, semiotician Günther Kress readily acknowledges the radical changes to writing brought about by digital technology:

The combined effects on writing of the dominance of the mode of image and of the medium of screen will produce deep changes in the forms and functions of writing. This in turn will have profound effects on human, cognitive/affective, cultural and bodily engagement with the world, and on forms and shapes of knowledge. (Kress, 2003, p. 3)

Such changes, argues Kress, forces "an insistence on the very materiality of writing […], its *stuff* […]" (p. 32), hence indicating that it is time, after all, for literacy studies to focus on our sensorimotor, bodily engagement with the materialities of reading and writing – e.g., with the technologies involved. According to Kress, we need a new theory of meaning and meaning making that takes into account the materiality of the different semiotic modes (text, image, sound, etc.) and how they relate differently to bodily reception of meaning. What Kress terms the *affective affordances* of sound are very different from those of sight or those of touch, in that "[…] sound is more immediately tangibly felt in the body than is sight, and certainly different felt. A theory of meaning that is inattentive to these will no be able to provide fully satisfactory accounts of the new communicational forms." (p. 46) Such promising foundations notwithstanding, Kress never goes beyond a semiotic perspective which seems, somehow, to be incompatible with a focus on what goes on in the writer's mind and body during writing in different technologies. In order for the field of digital literacies to be able to address the role and potential impact of changing devices of writing, the field would arguably benefit from opening up to recent research on the embodied aspect of digital writing emerging in fields such as cognitive neuroscience, experimental psychology, phenomenology and philosophy of mind. Keyboards and computer mice transform the process and experience of writing to such an extent that we might – indeed, *should* – ask ourselves what such a shift might entail in terms of cognitive and phenomenological implications for the act and skill of writing. Further, we should ask what epistemological implications this shift might have for the field of writing research, and what pedagogical implications it might hold for the teaching of writing both inside and outside of classrooms. Considering the speed and rate at which the technological environments of literacy develop and change, we can no longer afford to ignore the haptics of writing. This article intends to contribute to these vital reflections.

The purpose of this article is twofold. The first purpose pertains to the field of writing research and instruction: by exploring and explicating the critical role of haptics in writing, we discuss and reflect on how new writing technologies and devices, by radically altering the hand movements and hence the haptic feedback, might have an impact on future writing skills. As a corollary, if the technologies of writing do in fact radically alter the acquisition of writing skills, this ought to be reflected in the pedagogies of writing instruction. In the light of emerging knowledge about the implications of the digitization of writing on emergent literacy and early writing acquisition, how can and should writing instruction adjust accordingly? A closely related issue is the current theoretical-methodological state of the art of writing research. The second purpose of this article has to do with an unfortunate but persistent scientific schism between fields such as literacy and media studies on the one side, and on the other side, philosophy of mind, neurophenomenology,[2] and research in the natural sciences dealing with questions that are obviously relevant to the field of literacy, such as cognitive neuroscience and experimental psychology. Considering what we now know about embodied cognition and the role of the body in learning and cognitive development, what theoretical-methodological challenges does this entail for the fields of literacy, reading and writing research? And how might these challenges be met?

3. The neurophysiology and phenomenology of writing

The act of writing is a complex cognitive process relying on intricate perceptual-sensorimotor combinations. As a highly sophisticated and comprehensive way of externalizing our thoughts, giving shape to past memories as well as future plans and dreams, sharing our stories and communicating our emotions and affections, writing always involves the skillful handling of some mechanical/technical device, and necessarily results in a visuographic representation – some kind of (more or less) readable text, in the form of a

[2] Usually applied to the works of the late neurobiologist Francisco Varela et al. (Varela, Thompson, & Rosch, 1991), neurophenomenology is an attempt at combining phenomenology and neuroscience, emphasizing the corporeally embodied nature of cognition and mental experience. Specifically, neurophenomenology explores "the relevance of first-person methods for producing more refined first-person reports in experimental psychology and cognitive neuroscience." (Thompson, 2007, p. 20)

string of letters or symbols. As mentioned, in studies of literacy in general, and of writing (as well as of reading) in particular, the role and potential impact of the technologies employed – whether pen and paper, or keyboard and computer screen – is rarely addressed. A cursory and cross-disciplinary glance at the current state of writing research yields the impression that writing is mainly, if not exclusively, a mental (e.g., cognitive) process (MacArthur, Graham, & Fitzgerald, 2006; Torrance, van Waes, & Galbraith, 2007; Van Waes, Leijten, & Neuwirth, 2006). Cognitive approaches to the study of writing focus predominantly on the visual component of the process, and how it relates to cognitive processing. However, as evidenced by research in neuroscience, and as phenomenologically experienced by the writer him- or herself, writing is a process that requires the integration of visual, proprioceptive (haptic/kinaesthetic), and tactile information in order to be accomplished (Fogassi & Gallese, 2004). In other words, the acquisition of writing skills involves a perceptual component (learning the shape of the letter) and a graphomotor component (learning the trajectory producing the letter's shape) (van Galen, 1991). Research has shown that sensory modalities involved in handwriting, e.g., vision and proprioception, are so intimately entwined that strong neural connections have been revealed between perceiving, reading, and writing letters in different languages and symbol/writing systems. (James & Gauthier, 2006; Kato et al., 1999; Longcamp, Anton, Roth, & Velay, 2003, 2005a; Matsuo et al., 2003; Vinter & Chartrel, 2008; Wolf, 2007) Current brain imaging techniques show how neural pathways can be differentially activated from handling different writing systems: logographic writing systems seem to activate very distinctive parts of the frontal and temporal areas of the brain, particularly regions involved in what is called motor perception. For instance, experiments using fMRI have revealed how Japanese readers use different pathways – when reading kana (an efficient syllabary used mainly for foreign and/or newer words, and for names of cities and persons), the activated pathways are similar to those used by English readers. In contrast, when reading kanji – an older logographic script influenced by Chinese – Japanese readers use pathways that come close to those used by the Chinese. (Wolf, 2007) Our knowledge about the writing body and brain is steadily increasing, and it is unfortunate – and strange – if such knowledge cannot find accommodation in the field of literary and writing studies.

More and more of our current writing is writing with a digital device, whether it is a laptop, a PDA, or a mobile phone. Computers and keyboards are replacing pen and paper at an ever-increasing rate, and children are increasingly being introduced to writing with computers in addition to, and even at the expense of, writing by hand. With new technologies, we are changing the role of the hands, as the haptic affordances of digital technologies are distinctly different than earlier technologies such as pen and paper, the print book, and even the typewriter. We click and scroll with computer mice and tap keys on a keyboard, instead of putting pen to paper. This switch from pen and paper to mouse, keyboard and screen entails major differences in the haptics of writing, at several distinct but intersecting levels. When writing by hand, we use only one hand, whereas typewriting typically involves both hands; handwriting is commonly experienced as a slower and more laborious process than writing with a keyboard. Writing by hand requires the writer to shape each letter, whereas in typewriting, obviously, there is no such graphomotor component involved. Moreover, our visual attention is commonly restricted to precisely the point where the pen hits the paper during handwriting, while during typewriting there is a distinct spatiotemporal decoupling between the visual attention and the haptic input.

Finally, word processing software provides a number of features all of which might radically alter the process of writing for professional as well as for beginning writers – from autocorrect and spell-check options to large-scale genre templates and stylistic features.
Generally speaking, the process of text production, sensomotorically as well as cognitively and phenomenologically, is radically different in a print writing environment compared to a digital environment. Such a change might plausibly have considerable educational implications, the understanding of which mandates a thorough investigation of the currently changing role of haptics in writing. In order to understand why and to what extent the process, skill, and art of writing is being transformed by digital technologies, we must reconceptualize our understanding of writing as incorporating – literally speaking – sensory modalities not commonly addressed in educational research on writing and literacy, such as haptics. Considering the major ongoing changes in how we write, and – perhaps even more importantly – how children, in our age of digital technology, learn to write (and might learn to write in the near future), the haptics of writing is an aspect in urgent need of scientific scrutiny.

4. Writing, body, and technologies

Writing is, by definition, the production of some kind of text on some kind of surface or display, employing some kind of technical device. As mentioned, the role of this technical device – how it is employed and implemented in the writing process, and how it thus impacts the process of writing – has not been the subject of much attention in the field of writing research. Describing writing in the very early years of word processors, Christina Haas observed:

Changing the technologies of writing has profound implications, at least in part, because different technologies are materially configured in profoundly different ways. That is, different writing technologies set up radically different spatial, tactile, visual, and even temporal relations between the writer's material body and his or her material text. […] Hence, the body […] is the mechanism by which the mediation of the mental and the material occurs. (Haas, 1996, p. 5)

More than a decade later, Haas' claim still holds. Overall, contemporary theoretical discussions on writing tend to treat technology as transparent, or simply not interesting in and by itself. However, phenomenological accounts of writing provide some insight into the fundamental *bodiliness* of the writing process, and the role of the material device in the process, and illustrate how writing is inextricably bound to the entire human sensorium – in which our fingers and hands play a vital part. In his early writings, Martin Heidegger (1982 [1942]) underscores the phenomenological impact of, precisely, the physical inscriptions on some tangible material entailed in handwriting, by contrasting handwriting with the impersonalized mechanization of writing introduced by the (mechanical) typewriter. When writing with a typewriter, Heidegger says,

the word no longer passes through the hand as it writes and acts authentically but through the mechanized pressure of the hand. The typewriter snatches script from the essential realm of the hand – and this means the hand is removed from the essential realm of the word. The word becomes something 'typed.' [...] Mechanized writing deprives the hand of dignity in the realm of the written word and degrades the word into a mere means for the traffic of communication. Besides, mechanized writing offers the advantage of covering up one's handwriting and therewith one's character. (1982 [1942], pp. 118-119)

Replacing the mechanical typewriter with the digital computer and its word processing software introduces new features of equally impersonalized and disembodied writing – a writing modality, moreover, that is undoubtedly more phenomenologically monotonous than handwriting.[3] Although digital word processing does provide features intended to resemble a more "personalized" and idiosyncratic mode of writing (e.g., fonts that are supposed to look like handwriting) and thereby attempting to reintroduce the "aura" or "felt origination" (Benjamin, 1969; Heim, 1999) that authentic handwriting entails, the paradoxical experiential outcome of such digital attempts at reproducing *the trace of the tangible* is to even further detach the embodied relation to the inscribing efforts – the writing – from the displayed outcome, thereby adding yet another layer of phenomenological disembodiment. When writing by hand, we experience a direct and phenomenologically unambiguous relation between the act of inscription and the phenomenological correlate of the pen moving across the paper (cf. Mangen, 2009). In the words of neuroscientists, in handwriting, motor commands and kinesthetic feedback are closely linked to visual information at a spatial as well as a temporal level, while this is not the case with typewriting. For instance, neuropsychologist Alexander R. Lurija uses handwriting as an example par excellence of a "kinetic melody" – e.g., an embodied, automatized incorporated skill:

In the initial stages […] writing depends on memorizing the graphic form of every letter. It takes place through a chain of isolated motor impulses, each of which is responsible for the performance of only one element of the graphic structure; with practice, this structure of the process is radically altered and writing is converted into a single 'kinetic melody', no longer requiring the memorizing of the visual form of each isolated letter or individual motor impulses for making every stroke. The same situation applies to the process in which the change to write a highly automatized engram (such as a signature) ceases to depend on analysis of the acoustic complex of the word or the visual form of its individual letters, but begins to be performed as a single "kinetic melody" […] The participation of the auditory and visual areas of the cortex, essential in the early stages of the formation of the activity, no longer is necessary in its later stages, and *the activity starts to depend on a different system of concertedly working zones*. (Lurija, 1973, p. 32)

Luria's kinetic melody thus refers to the neurological role of the hand in writing. In *Physical Eloquence and the Biology of Writing*, Robert Ochsner extends Luria's melody to include two additional neurophysiological functions, namely, visual melodies and auditory melodies. These correspond, respectively, to the roles of the eye and the ear in the handwriting process. The visual melody determines how much of the text the eye takes in as feedback, and the auditory melody regulates the inner voice of the writer as it matches vocally

[3] For instance, consider how handwriting might entail and display visible traces – however subtle – of different sensory traits of the writer, such as temper, stress, or nervousness.

subpressed language with the language of a written text. Basic to these functions of the eye and the ear, however, is nevertheless the kinetic melody, which innervates muscles in the hand, wrist, arm and shoulder to produce graphic shapes. (Ochsner, 1990, p. 55)

The increasing disembodiment of writing currently taking place should not be reduced to a matter of interest primarily for philosophers, nostalgics and neo-Luddites,[4] as it points to the importance of acknowledging the vital role of haptics, and the profound and fundamental links between haptics and cognition, in writing. Our body, and in particular our hands, are inscribed in, and defining, the writing process in ways that have not been adequately dealt with in the research literature. The current radical shift in writing environments mandates an increased focus on the role of our hands in the writing process, and – even more importantly – how the movements and performance of the hand relate to what goes on in the brain.

5. Haptics and learning

In his landmark volume *The Hand* – succinctly described by some scholars as "one of the wisest books of recent decades" (Singer & Singer, 2005, p. 113) – neurologist Frank Wilson vigorously claims that "any theory of human intelligence which ignores the interdependence of hand and brain function, the historical origins of that relationship, or the impact of that history on developmental dynamics in modern humans, is grossly misleading and sterile." (Wilson, 1998, p. 7) Nevertheless, the importance of the hand-brain relationship and of the haptic sense modality for learning, and for our experience of and interaction with the lifeworld in general, is not commonly acknowledged or understood.[5] This widespread and largely internalized neglect becomes obvious when we are reminded of how fundamental haptics and the rest of our tactile sensorium were in our life from the moment we are born:

As infants, we tend to learn as much, if not more, about our environment by touching as well as looking, smelling, or listening. Only gradually, and after many warnings by our parents not to touch this or that, we do finally manage to drive the tactile sense underground. But the many do-not-touch signs in stores and especially in museums suggest that apparently we still would like to touch objects in order to get to know them better and to enrich our experience. (Zettl, 1973, p. 25)

Research in experimental psychology, evolutionary psychology, and cognitive anthropology (Bara, Gentaz, & Colé, 2007; Greenfield, 1991; Hatwell, Streri, & Gentaz, 2003; Klatzky, Lederman, & Mankinen, 2005; Klatzky, Lederman, & Matula, 1993; Wilson, 1998) has convincingly demonstrated the vital role of haptic exploration of tangible objects in human learning and cognitive development. In a very literal way, the sense of touch incorporates

[4] Neo-Luddite is a label commonly attached to people who are considered overly sceptical or resistant of technological change.

[5] The pedagogies of Montessori and Steiner might be considered as exceptions in this regard, with their focus on holistic education, eurythmy (a pedagogical program focusing on awakening and strengthening the expressive capacities of children through movement) and on seeing children as sensorial explorers. (Palmer, 2002)

human nature, as eloquently described by Brian O'Shaughnessy: "Touch is in a certain respect the most important and certainly the most primordial of the senses. The reason is, that it is scarcely to be distinguished from the having of a body that can act in physical space." (O'Shaughnessy, 2002, p. 658) During infancy and early childhood, haptic exploration is very important; however, as we grow up, we tend to lose some of the strength and clarity of the sense of touch (and smell, it is argued), so that we somehow have to re-learn how to make use of it.

Metaphors and colloquialisms are additional indicators of the importance of the haptic modality in cognition. Numerous expressions for understanding and comprehension consist of terms and concepts referring to *dexterity*: expressions such as "to get a hold of someone," "to handle a situation," "to grasp a concept" all point to (pun intended) the paramount influence of our hands and fingers in dealing with the environment. Such an intimate connection between the human body – for example, our hands – the lifeworld, and cognition is a hallmark of phenomenology, in particular the somatosensory phenomenology of Maurice Merleau-Ponty:

It is the body that 'catches' […] 'and 'comprehends' movement. The acquisition of a habit is indeed the grasping of a significance, but it is the motor grasping a motor significance. […] If habit is neither a form of knowledge nor any involuntary action, then what is it? It is a *knowledge in the hands* [Merleau-Ponty's example is knowing how to use a typewriter], which is forthcoming only when bodily effort is made, and cannot be formulated in detachment from that effort. (Merleau-Ponty, 1962 [1945], pp. 143-144)

Our fingers and hands are highly active and important means of perception and exploration, representing an access to our lifeworld which in some cases could not have been established by any other sense modality. In our everyday whereabouts, however, we are just not used to thinking of the hands as sensory organs significantly contributing to cognitive processing, because most of our day-to-day manipulation is *performatory*, not *exploratory*: "[T]hat is, we grasp, push, pull, lift, carry, insert, or assemble for practical purposes, and the manipulation is usually guided by visual as well as by haptic feedback." (Gibson, 1979, p. 123) Because of this, the perceptual capacity of the hands, and the vital role it plays in cognition, is often ignored – both because we pay more attention to their motor capacities, and because the visual modality dominates the haptic in our awareness.

6. Writing and embodied cognition

During the past decade, intriguing and influential interdisciplinary perspectives have been established between biology, cognitive neuroscience, psychology and philosophy. Jointly advocated by philosophers, biologists, and neuroscientists,[6] the embodied cognition paradigm emphasizes the importance of embodiment to cognitive processes, hence

[6] The most prominent philosophers are Andy Clark, Evan Thompson, Alva Noë, and the late Susan Hurley; Francisco Varela and Humberto Maturana are the biologists most frequently associated with embodied cognition, whereas the best known neuroscientists are Antonio Damasio, V. S. Ramachandran, Alain Berthoz and J.Kevin O'Regan.

countering Cartesian dualism[7] and focusing instead on human cognition as inextricably and intimately bound to and shaped by its corporeal foundation – its embodiment. In this current of thought, cognition is no longer viewed as abstract and symbolic information processing with the brain as a disembodied CPU. It is becoming increasingly clear that the body is an active component that adds uniquely and indispensably to cognition, and that human cognition is grounded in distinct and fundamental ways to embodied experience and hence is closely intertwined with and mutually dependent on both sensory perception and motor action. A number of theoretical contributions from adjacent fields can be subsumed under the heading of embodied cognition:

- Motor theories of perception (initially developed for the perception of spoken language by Liberman et al. [1985]): Until fairly recently, perception and action were studied as quite separate entities in the disciplines involved. Now, converging research data from neuroscience and experimental psychology show how our perception is closely correlated with motor actions, to active explorations of our lifeworld, mainly through the always active and intriguingly complex collaboration of sensory modalities. Commonly referred to as *motor theories of perception*, these theories indicate that we mentally simulate movements and actions even though we only see (or only hear; or only touch) them. Research data from cognitive neuroscience and neurophysiology (Fogassi & Gallese, 2004; Jensenius, 2008; Olivier & Velay, 2009) show how motor areas in the brain (e.g., premotor and parietal area; Broca's area) are activated when subjects are watching someone else performing an action, when they are watching images of tools requiring certain actions (e.g., a hammer; a pair of scissors; a pen, or a keyboard; cf. Chao & Martin, 2000), and when action verbs are being read out loud (e.g.; kick; run; shake hands; write; cf. Pulvermüller, 2005), even when no action or movement is actually required from the subjects themselves. Motor theories of perception hence support the so-called sandwich theory of the human mind, which suggests that human cognition is "sandwiched" between perception as input from the world to the mind, and action as output from the mind to the external environment – also called an "action-perception loop".

- The *enactive approach* to cognition and conscious experience (Varela et al., 1991) argues that experience does not take place inside the human being (whether in a "biological brain" or in a "phenomenological mind"), but is something humans actively – e.g., physically; sensorimotorically – enact as we explore the environment in which we are situated. Building in part on J. J. Gibson's ecological psychology (Gibson, 1966, 1979), Varela et al. emphasize the importance of sensorimotor patterns inherent in different acts of exploration of the environment, and they argue that perception and action supply structure to cognition: "Perception consists in perceptually guided action and […] cognitive structures emerge from the recurrent sensorimotor patterns that enable action to be perceptually guided." (Varela et al., 1991, p. 173)

[7] Cartesian dualism refers to the conception of mind and body as distinct, separate entities and treating mental phenomena (e.g., perceptual experience; cognition; reasoning) as being purely matters of mind.

- The theory of *sensorimotor contingency* (Noë, 2004; O'Regan & Noë, 2001). According to the sensorimotor contingency theory, each sensory modality – audio, vision, touch, smell, taste, haptics, kinesthetics – are modes of exploration of the world that are mediated by knowledge of sensorimotor contingencies, e.g., practical and embodied knowledge of sets of structured laws pertaining to the sensory changes brought about by one's movement and/or manipulation of objects. For instance, visual experience depends on one's knowledge of the sensory effects of, say, our eye-contingent operations – e.g., the fact that closing our eyes will yield no visual input. In contrast, closing our eyes will not change the tactile input of experience. This practical, bodily knowledge of sensorimotor contingencies makes us effective in our exploration.

These theoretical developments all have similarities with the by now classical, ecological psychology of J. J. Gibson, in particular his concept of affordances, which are functional, meaningful, and persistent properties of the environment for activity. (Gibson, 1979) Hence, Gibson would say, we attend to the properties and the opportunities for actions implied by these objects, rather than to the physical properties of objects in the environment *per se*. In other words, we see the world as we can exploit it, not "as it is." (ibid.) Embodied cognition, in other words, is theorized as an active, multisensory probing of the surrounding lifeworld. A central and far-reaching corollary of these conceptualizations is that learning and cognitive development is about developing representations about how to physically – haptically – interact with the environment, e.g., how to explore our surroundings by means of all our sensory modalities, rather than about making internal representations – a quasi-photographic "snapshot" – of the environment itself. Thus, learning and cognition are inextricably tied to and dependent upon our audiovisual, tactile, haptic, *probing* of our surroundings. In other words, it is time, as S. Goldin-Meadow claims, "to acknowledge that the hands have a role to play in teaching and learning" (Goldin-Meadow, 2003) – not only in gestures and non-verbal communication, but also, and more specifically, in the haptic interaction with different technologies.

7. From pen and paper to keyboard, mouse and screen: explicating the differences between handwriting vs typing

The important role of the motor component during handwriting can be deduced from experimental data in neuroscience. There is some evidence strongly suggesting that writing movements are involved in letter memorization. For instance, repeated writing by hand is an aid that is commonly used in school to help Japanese children memorize kanji characters. In the same vein, Japanese adults report that they often write with their finger in the air to identify complex characters (a well-known phenomenon, referred to as "Ku Sho"). In fact, it has been reported that learning by handwriting facilitated subjects' memorization of graphic forms (Naka & Naoi, 1995). Visual recognition was also studied by Hulme (1979), who compared children's learning of a series of abstract graphic forms, depending on whether they simply looked at the forms or looked at them as well as traced the forms with their index finger. The tracing movements seemed to improve the children's memorization of the graphic items. Thus, it was suggested that the visual and motor information might undergo a common representation process.

Various data converge to indicate that the cerebral representation of letters might not be strictly visual, but might be based on a complex neural network including a sensorimotor component acquired while learning concomitantly to read and write (James & Gauthier, 2006; Kato et al., 1999; Longcamp et al., 2003; 2005a; Matsuo et al., 2003). Close functional relationships between the reading and writing processes might hence occur at a basic sensorimotor level, in addition to the interactions that have been described at a more cognitive level (e.g., Fitzgerald & Shanahan, 2000).

If the cerebral representation of letters includes a sensorimotor component elaborated when learning how to write letters, how might changes in writing movements affect/impact the subsequent recognition of letters? More precisely, what are the potential consequences of replacing the pen with the keyboard? Both handwriting and typewriting involve movements but there are several differences – some evident, others not so evident– between them. Handwriting is by essence unimanual; however, as evidenced by for instance Yves Guiard (1987), the non-writing hand plays a complementary, though largely covert, role by continuously repositioning the paper in anticipation of pen movement. Even when no movement seems needed (as for instance, in dart throwing), the passive hand and arm play a crucial role in counterbalancing the move of the active arm and hand. The nondominant hand, says Guiard, "frames" the movement of the dominant hand and "sets and confines the spatial context in which the 'skilled' movement will take place." (ibid.) This strong manual asymmetry is connected to a cerebral lateralization of language and motor processes. Typewriting is, as mentioned, a bimanual activity; in right-handers, the left hand which is activated by the right motor areas is involved in writing. Since the left hemisphere is mainly responsible for linguistic processes (in righthanders), this implies inter-hemispheric relationships in typewriting.

A next major difference between the movements involved in handwriting and typewriting, pertains to the speed of the processes. Handwriting is typically slower and more laborious than typewriting. Each stroke (or letter) is drawn in about 100 ms. In typing, letter appearance is immediate and the mean time between the two touches is about 100 ms (in experts). (Gentner, 1983) Moreover handwriting takes place in a very limited space, literally, at the endpoint of the pen, where ink flows out of the pen. The attention of the writer is concentrated onto this particular point in space and time. By comparison, typewriting is divided into two distinct spaces: the motor space, e.g., the keyboard, where the writer acts, and the visual space, e.g., the screen, where the writer perceives the results of his inscription process. Hence, attention is continuously oscillating between these two spatiotemporally distinct spaces which are, by contrast, conjoined in handwriting.

In handwriting, the writer has to form a letter, e.g., to produce a graphic shape which is as close as possible to the standard visual shape of the letter. Each letter is thus associated to a given, very specific movement. There is a strict and unequivocal relationship between the visual shape and the motor program that is used to produce this shape. This relationship has to be learnt during childhood and it can deteriorate due to cerebral damage, or simply with age. On the other hand, typing is a complex form of spatial learning in which the beginner has to build a "keypress schema" transforming the visual form of each character into the position of a given key in keyboard centered coordinates, and specify the movement required to reach this location (Gentner, 1983; Logan, 1999). Therefore, learning how to type also creates an association between a pointing movement and a character. However, since the trajectory of the finger to a given key – e.g., letter – largely depends on its position on the keyboard rather than on the movement of the hand, the relationship between the pointing and the character cannot be very specific. The same key can be hit with different movements, different fingers and even a different hand. This relationship can also deteriorate but with very different consequences than those pertaining to handwriting. For instance, if a key is pressed in error, a spelling error will occur but the visual shape of the letter is preserved in perfect condition. The visuomotor association involved in typewriting should therefore have little contribution to its visual recognition.

Thus, replacing handwriting by typing during learning might have an impact on the cerebral representation of letters and thus on letter memorization. In two behavioral studies, Longcamp et al. investigated the handwriting/typing distinction, one in pre-readers (Longcamp, Zerbato-Poudou et al., 2005b) and one in adults (Longcamp, Boucard, Gilhodes, & Velay, 2006). Both studies confirmed that letters or characters learned through typing were subsequently recognized less accurately than letters or characters written by hand. In a subsequent study (Longcamp et al., 2008), fMRI data showed that processing the orientation of handwritten and typed characters did not rely on the same brain areas. Greater activity related to handwriting learning was observed in several brain regions known to be involved in the execution, imagery, and observation of actions, in particular, the left Broca's area and bilateral inferior parietal lobules. Writing movements may thus contribute to memorizing the shape and/or orientation of characters. However, this advantage of learning by handwriting versus typewriting was not always observed when words were considered instead of letters. In one study (Cunningham & Stanovich, 1990), children spelled words which were learned by writing them by hand better than those learned by typing them on a computer. However, subsequent studies did not confirm the advantage of the handwriting method (e.g., Vaughn, Schumm, & Gordon, 1992).

8. Implications for the fields of literacy and writing research

During the act of writing, then, there is a strong relation between the cognitive processing and the sensorimotor interaction with the physical device. Hence, it seems reasonable to say that theories of writing and literacy currently dominant in the fields of writing research and literacy studies are, if not misguided, so at least markedly incomplete: on the one hand, currently dominant paradigms in (new) literacy studies (e.g., semiotics and sociocultural theory) commonly fail to acknowledge the crucial ways in which different technologies and material interfaces afford, require and structure sensorimotor processes and how these in turn relate to, indeed, how they *shape*, cognition. On the other hand, the cognitive paradigm in writing research commonly fails to acknowledge the important ways in which cognition is embodied, i.e., intimately entwined with perception and motor action. Moreover, media and technology researchers, software developers and computer designers often seem more or less oblivious to the recent findings from philosophy, psychology and neuroscience, as indicated by Allen et al. (2004): "If new media are to support the development and use of our uniquely human capabilities, we must acknowledge that the most widely distributed human asset is the ability to learn in everyday situations through a tight coupling of action and perception." (p. 229) In light of this perspective, the decoupling of motor input and haptic and visual output enforced by the computer keyboard as a writing device, then, is seriously ill-advised.

Judging from the above, there is ample reason to argue for the accommodation of perspectives from neuroscience, psychology, and phenomenology, in the field of writing and literacy. At the same time, it is worth noticing how the field of neuroscience might benefit from being complemented by more holistic, top-down approaches such as phenomenology and ecological psychology. Neurologist Wilson deplores the legacy of the Decade of the Brain, where "something akin to the Tower of Babel" has come into existence:

We now insist that we will never understand what intelligence is unless we can establish how bipedality, brachiation, social interaction, grooming, ambidexterity, language and tool use, the saddle joint at the base of the fifth metacarpal, "reaching" neurons in the brain's parietal cortex, inhibitory neurotransmitters, clades, codons, amino acid sequences etc., etc. are interconnected. But this is a delusion. How can we possibly connect such disparate facts and ideas, or indeed how could we possibly imagine doing so when each discipline is its own private domain of multiple infinite regressions – knowledge or pieces of knowledge under which are smaller pieces under which are smaller pieces still (and so on). The enterprise as it is now ordered is well nigh hopeless. (Wilson, 1998, p. 164)

Finally, it seems as if Wilson's call is being heard, and that time has come to repair what he terms "our prevailing, perversely one-sided – shall I call them cephalocentric – theories of brain, mind, language, and action." (ibid.; p. 69) The perspective of embodied cognition presents itself as an adequate and timely remedy to the disembodied study of cognition and, hence, writing. At the same time it might aid in forging new and promising paths between neuroscience, psychology, and philosophy – and, eventually, education? At any rate, a richer and more nuanced, trans-disciplinary understanding of the processes of reading and writing helps us see what they entail and how they actually work. Understanding how they work, in turn, might make us realize the full scope and true complexity of the skills we possess and, hence, what we might want to make an extra effort to preserve. In our times of steadily increasing digitization of classrooms from preschool to lifelong learning, it is worth pausing for a minute to reflect upon some questions raised by Wilson:

How does, or should, the educational system accommodate for the fact that the hand is not merely a metaphor or an icon for humanness, but often the real-life focal point – the lever or the launching pad – of a successful and genuinely fulfilling life? […] The hand is as much at the core of human life as the brain itself. The hand is involved in human learning. What is there in our theories of education that respects the biologic principles governing cognitive processing in the brain and behavioral change in the individual? […] Could anything we have learned about the hand be used to improve the teaching of children? (ibid.; pp. 13-14; pp. 277-278)

As we hope to have shown during this article, recent theoretical findings from a range of adjacent disciplines now put us in a privileged position to at least begin answering such vital questions. The future of education – and with it, future generations' handling of the skill of writing – depend on how and to what extent we continue to address them.

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Advances in Haptics
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Haptic interfaces are divided into two main categories: force feedback and tactile. Force feedback interfaces are used to explore and modify remote/virtual objects in three physical dimensions in applications including computer-aided design, computer-assisted surgery, and computer-aided assembly. Tactile interfaces deal with surface properties such as roughness, smoothness, and temperature. Haptic research is intrinsically multi-disciplinary, incorporating computer science/engineering, control, robotics, psychophysics, and human motor control. By extending the scope of research in haptics, advances can be achieved in existing applications such as computer-aided design (CAD), tele-surgery, rehabilitation, scientific visualization, robot-assisted surgery, authentication, and graphical user interfaces (GUI), to name a few. Advances in Haptics presents a number of recent contributions to the field of haptics. Authors from around the world present the results of their research on various issues in the field of haptics.