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Metacognition and sensorimotor components underlying the process of handwriting and keyboarding and their impact on learning. An analysis from the perspective of embodied psychology.

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Abstract

Digital writing devices such as the computer or the personal digital assistant are inundating the higher education classrooms around the globe. They have developed to indispensable learning tools and consequently the use of longhand in the education context is in continual detriment.
From the perspective of cognitive science the processes of typing and handwriting differ considerably. This paper firstly analyzes the highly complex nature of handwriting, further highlights the psycho neurological mechanisms involved in acquiring and practising this skill and points out the differences to typewriting. Finally, the author deliberates about how the use of the two different writing techniques may affect the learning outcome of students.

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Keywords: learning efficiency; cognitive effort; handwriting; keyboarding; note taking; working memory.

1. Introduction

For the millennial generation as well as for the digital immigrants daily use of information technology devices is a matter of course which does not require further reflection. The confidence in electronic instruments to register and store information, to communicate and to handle daily business is so deeply rooted in everyday life that rarely an alternative modus operandi is considered.

The widespread maxim “the more digitalized a process or instrument is, the more reliable and professional is its output ” meets the current zeitgeist. In the framework of education, this belief affects the behavior of our students in the classroom and the way they are taught and learn.

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This paper, firstly, analyzes one of the aspects which has been deeply influenced by the introduction of new technologies in education: the nature of writing. Oatley & Djikic (2008) postulate in an article the idea of "writing as thinking"; following the statement of Richards (1925) "a book is a machine to think with" Oatley et al. (2008) go further and predicate that "a pen is machine to think". Miró Juliá (1999) while exposing his teaching methodology in higher education makes the observation that "handwriting is a tool to learn reasoning". Taking into account statements like the previous mentioned it is worth to consider the impact of the ever-increasingly adoption of keyboarding as writing alternative among the students community. The new Common Core State Standard, the standardized education benchmark for USA public schools adopted by 45 U.S. states, does not require school districts to teach cursive writing and it omits it as a graduate requirement. This implies that the state does not check schools on covering handwriting in their programs; keyboarding skills, on the other hand, are specifically required. However, the acquisition of the cursive writing skill has always been considered as a milestone of child development and a big step toward the intellectual maturity of human beings.

Secondly, this work examines the concept of metacognition and the different cognitive processes involved in handwriting and keyboarding with special focus on the activity of notes taking in the classroom. Even from the perspective of a neophyte in the writing topic it can be attested that the two writing modalities imply different sensorimotor processes. The impact of both writing modalities in the learning outcome is analyzed taking into account the principles of the embodied psychology. Additionally, an insight in the neuropsychological processes activated while practicing writing and their role in memorizing and comprehending learning material is offered.

Finally, a reflection about the future role of longhand in the context of education is given. The author, conform to the proposal of Mueller & Oppenheimer (2014), advocates for a combination of writing techniques by taking into consideration that they support and strengthen different skills, necessary firstly for cognition development, secondly for learning efficiently and lastly for successful performing in a progressively more digitalized workplace.

2. The nature of writing

In order to understand the interconnection between writing and other cognitive processes the relation between handwriting and letter cognition will be exposed as prior development skill for acquiring reading proficiency.

In an early experiment conducted by Hulme (1979) visual recognition was studied by comparing the memorization of abstract graphics with children who had to learn the forms just by looking at them or by tracing them with the index finger. The tracing modality entails a higher memorization of the abstract items than the activity of looking at them. Hence, consequently, it is legitimated to suppose that visual and motor information are allied. The great body of research devoted to analyze the role of handwriting in the categorization of letters conducted by James in cooperation with other researches offers as well sufficient evidence of how the sensorimotor experience during the process of acquiring writing and reading proficiency has developed in a complex neural network. In a study undertaken by James & Engelhardt (2011) preliterate five years old children were instructed in the visual motor task of printing by hand, tracing and typing in a keyboard different letters. Posteriorly, children underwent a functional imaging session (fMIR) and were instructed in a task of letter recognition. Results show that after a self-generated letter printing letter perception recruits brain areas involved in letter processing and reading system, concretely in the visual areas involved in letter processing and the motor areas engaged in letter production, in a higher degree than doing other kind of sensorimotor activities. The motor task involved in tracing and free printing may appear the same, but the prior and posterior processes underlying the motoric performance differ considerably. When writing by hand, stroke after stroke, children learn the different variations of a letter and consequently deal with an ambiguous and demanding task of categorizing, the free creation of letters allows children to understand the perceptual properties and the variations on shape from the prototype; in the process of tracing they are not confronted with such a challenge. The highly demanding process of categorization recruits brain areas involved also in letter identification, concretely the fusiform gyrus which is responsible for within-category identification and, at the same time, for letter recognition. Children who had undergone the printing practice by hand show a neural activity more enhanced and "mature -like" than those who were instructed just in looking at the letters.

Studies conducted with adults corroborate as well how both processes are strongly interconnected. Longcamp, Anton, Roth & Velay (2003) explored to what extend motor-perceptual brain areas may be activated while reading; subjects underwent the task of looking at letters and letter-like stimuli, pseudo-letters, and then copying the

characters. Brain imaging shows an activation of the left premotor cortex while looking at the letters as well as when writing them, when dealing with pseudo-letters the passive exposure to them did not activate the premotor context. The authors conclude that there must be a relation between the subjacent processes of reading and writing, being the ability to write a support for reading. James & Gauhtier (2006) corroborated with some studies the results of Longcamp et al. (2003). Further James & Atwood (2009) aimed to find out how the specialized response pattern seen during letter perception may be caused partially by the experience in writing letters. Participants were trained to recognize pseudo-letters by writing, typing, or visual practice. The aim was to investigate whether or not different types of experience with letter-like stimuli ("pseudo-letters") led to functional specialization similar to that which exists for letters. Results suggested that only after writing practice did neural activation patterns to pseudo-letters coincide with the patterns observed for letters. That is, neural activation in the left fusiform and dorsal precentral gyrus was higher when participants observed pseudo-letters than other similar stimuli, but only after writing experience. Neural activation also increased after typing practice in the right fusiform and left precentral gyrus, suggesting that in some areas any motor experience may change visual processing.

In a study of Longcamp, Boucard, Gilhodes, Anton,Roth, Nazarian, & Velay (2008) adults had to learn unfamiliar letters. The modalities were two: handwriting and keyboarding. The group learning by handwriting performed better than the experimental group which was learning the new characters via typing. Brain imagines acknowledge, once again, that the test persons who learned by hand recruited motor function areas of the brain. The mere physical act of shaping letters activates the motor memory in the sensorimotor zones of the brain and reinforces the learning process.

Thus, this body of studies leads to consider the facilitator role which the handwriting experience plays in acquiring reading proficiency and the neural interconnection between handwriting and letter recognition. Learning cursive is an important tool for cognitive development, which enhances the functional specialization of the brain. The results of these experiments indicate a strong interaction between perceptual and motor systems during pseudo-letter and letter perception. The decreasing commitment of parents and educators in instructing longhand in favour of other writing modalities may generate disadvantages in the children´s development process like for instance slowing down the reading proficiency. The substitution of longhand by typing needs further exploration in order to determine the impact this course may have in our education systems.

3. Writing modalities

J. Willis, in a plea for handwriting, declares: *"when writing is embedded throughout the curriculum, it promotes the brain´s attentive focus to class and homework, boosts long-term memory, illuminates patters, gives the brain time for reflection, and when well guided is a source of conceptual development and stimulus of the brain´s highest cognition"* (Willis, 2011).

The majority of psychological studies of writing focuses on mental processes but, as Mangen & Velay (2010) depict, scarce research has been done about the bodily experience of writing, and writing by nature is a physical experience. Writing means using a technology to create a text, by switching technologies the bodily experience, and subsequently its interconnected cognitive processes, must necessarily suffer alterations. Hence, it is of capital importance to scrutinize how the changeover to a new writing technology may impact the embodied cognition experience.

3.1. Differences between handwriting and keyboarding from the perspective of embodied cognition

Based on the article published in advances in haptics "reflections on the haptics of writing" of Mangen et al. (2010), the first and more obvious aspect which differentiates between handwriting and the use of digitalized devices is the tool. While by longhand the pen, hand (as haptic input) and the written result (as output) are in the same visual field; in keyboarding the visual effort has to be divided between two physically separated fields: keypad and screen. This fact may diminish the quality/quantity of devoted attention.

Another evident difference is the involvement of hands. Whereas longhand implies the use of a single hand, keyboarding is bimanual. This fact carries several implications. The use of only one hand slows down the process of

writing compared to keyboarding and hence has consequences in the information processing. Handwriting enables more time for reflection and gives the memory a greater chance to store the information which is writing down. Contrariwise, writing down information via keyboarding goes so rapidly that the required retention is minimal. Writing stimulates the reticular activating system (RAS) in the brain. The RAS operates as a filter for what should be processed; this may explain why the retention is higher by handwriting.

Research headed by Berninger (Berninger, Augsburger, & García, 2009) underlines the previous statement. Berninger and her team conducted a study to analyze children´s ability to write the alphabet, sentences and essays using the pen or the keyboard in the second, fourth and six school grades. While writing the alphabet, the keyboard went faster than the pen. On the other hand, children writing by hand wrote more and faster essays. With reference to sentences the results were ambiguous, although fourth and six graders wrote more complete sentences when using the pen. The aim of the study was to compare methods of transcription (cognitive process which allows translating thoughts into written language).The sequential character of finger movements activates regions involved in thinking, language and working memory; subsequently, it reinforces the short and long term memory. In this study even children with disabilities performed better with a pen. Nevertheless, a part of the scientific community dedicated to the study of cerebral lateralization supports the advantages which the bimanual nature of keyboarding may have in the neurological development (Gómez Guardado, 2013).

A further different aspect, according to Mangen et al. (2010), between writing technologies is linked to the production of characters. In handwriting each letter has to be graphomotorically formed, in typewriting there is not such a graphomotor component, the computer keys offer already formed letters and the writing action consists of deciding which key to press; evidently, the writing pace cannot be the same. Related to this idea, the inner voice in writing (subvocal articulatory rehearsal process) and its implications in the working memory differ in both modalities. Since handwriting is slower, pace of the inner voice allows more time for rehearsal and facilitates in a greater scale the retention (Chenoweth & Hayes, 2003).

The National Association of State Boards of Education in the USA (NASBE), which recently compiled evidence about the benefits of instruction in handwriting, listed the following facets stimulated by handwriting (Kysilko, 2012):

- Cognitive and motor skills development
- Literacy development
- Memory
- Written expression
- Learning disabilities improvement t point

The implications of the switchover, from book to image, from pen to keypad, have for some contemporary thinkers consequences far beyond the above exposed, but which exceed the boundaries of this paper. In terms of Kress (Kress, 2003) this phenomenon will have an impact not only in the cognition process, the education and the communication, but also in widest areas, from socio-cultural paradigm changes to shifts in term of power.

3.2. Note taking. Implications on learning

Even those who can afford greatly relying on memory may catch themselves taking notes with the most different purposes. From the banal act of writing the shopping-list to crucial issues, we need to remember, we use notes. Taking notes, apart from ensuring the possibility to remember information, allows us to concentrate, comprehend and reconsider information as well as to reorganize intentions and plans. Generally speaking, note taking is a complex activity which requires an effort; this effort, however, pays off in form of efficiency.

The process of note taking demands auditive, sensorimotor, visual and cognitive perceptive tasks (Piolat, Olive, & Kellogg, 2005) which additionally must be performed simultaneously and under time pressure. Piolat et al. (2005) argued that the act of selecting the relevant information from the incoming continuous flow (which implicates a process of decision making), retaining the information in the working memory long enough to be processed and comprehend it while interacting with already stored knowledge for finally transcription taxes the sensorimotor and cognitive capacity fairly high. In other words, it requires the principle proclaimed by the embodied cognition of

learning since it implies comprehension (van Dijk & Klintsch, 1983) and written production (Daneman & Merikler,1996).

Empirical studies confirm the use of note taking as a highly effective way of learning in the educational context, and therefore it is important to consider if the switch of writing modalities may affect the learning process while note taking. Students take notes in order to record information they should posteriorly read and learn, however, the benefit goes beyond the initial intention; taking notes is per se and act of memorization which leads to the creation of an "internal" storage (Kiewra,1987), the act of taking notes intrinsically fosters learning. Note taking is a fundamental skill for exam performance, accounting higher than other predictors as verbal ability (Kiewra, Dubois, Christian, McShane, Meyerhoffer, & Roskelley, 1991). "*Taking notes involves active listening, as well as connecting and relating information to already available knowledge. It also involves seeking answers to questions that arise from the material* "(O'Hara, 2005). Moreover, the capabilities of the note taker, the student, influence decisively the learning achievement; aspects like the mastery of the language, the body of previous knowledge related to the subjects as well as the transcription speed affect the quality of the notes and consequently the learning efficiency (Peverly, 2006).

In a study carried out by Makany, Kemp, & Dror, (2008), the authors conducted a comparative analysis of two different note taking modalities: traditional linear and non-linear SmartWisdom; after the exposition to a lecture or a conference discussion, participants were measured in the following cognitive processes:

- Comprehension
- Accuracy
- Complexity
- Metacognition
- Memory

Students taking non-linear notes statistically outperformed in comprehension and metacognition. Although the central executive functions of the working memory are highly demanded by note taking and while some studies reported a correlation with learning efficiency, some experts, like the exposed above, plead that the academic excellence behind note taking is rather generated from an advance information management technique (restructuration of the information), able to deal with the continuous flow of information, than on the prominent short memory skills (Makany et al., 2008).

The quality of notes taken depends on the cognitive load which the students can handle in the process (Baddeley, Chincotta, & Adlam, 2001); following Titsworth (Titsworth, 2004) students record more details and organizational points when listening to lectures with strong organizational cues, therefore note taking techniques which stimulate the creation of organizational cues may as well reinforce academic performance by reducing the cognitive demand. However, future studies should analyze to what extent short memory skills are a fundamental prerequisite to manage the information and if it possible to outstandingly manage information without a firstly high performance of the working memory.

Metacognitive knowledge is often regarded as a strategy for efficient self- regulated learning (Sperling, Howard, Staley, & DuBois, 2004) and consequently as a key factor in academic performance (Hacker, Dunlosky, & Graesser, 1998);note takers need to be reflective and aware of their own abilities to registering and comprehending the written information. Besides, while taking notes students become firstly conscious of what they are learning, monitor the efficiency of their own taking notes competence and estimate their understanding by having to transcript thoughts into written words, "*learning to monitor the quality of one's thought and the products of one's effort is the hallmark of what is mean by cognition*"(White & Frederiksen,1998).

Once accepted the great benefits of note taking for students it seems worthwhile to consider how the replacement of paper and pen by digital devices may affect the sensorimotor and cognitive processes and the learning benefits underlying note taking.

The findings of a set of research studies conducted by Mueller and at. (2014) evidence that note taking via laptop generates nearly verbatim records of the teaching material while longhand note takers record less information. 65 students were exposed to a lecture about an interesting but not common knowledge topic. Part of the students was

asked to take notes by hand, part by laptop. One and a half hour after the presentation students were tested on the teaching material in factual records and in higher order conceptual learning. In factual records students scored very similar while in conceptual and inferences learning students taking notes with the computer performed poorer. In a further study students went under the same kind of probe, but were additionally tested one week later. Interestingly students who took notes handwriting performed significantly better in factual as well as in comprehension questions.

One of the plausible explanations for this result may be caused by the nature of writing. Students using keyboard registered a much higher verbatim overlap with the lecture, this modality of writing allows a higher speed production and therefore leads to "mindless transcription". The high amount of registered information inhibits its management by overloading the cognitive processes. On the other hand, students writing are using a slow and arduous method and are forced to select thoroughly the information to be recorded; consequently they become deeper engaged with the material, which enables additionally the storage of the new learning material in a deeper and more interconnected way with existing knowledge.

In consonance with the findings of Makany et al. (2008) it is tempting to explain the lower performance of keyboarding note taking in the study of Mueller et al. (2014) as an extreme form of a linear note taking technique; considering a continuum from the most efficient learning form of note taking to the poorest one which implicates just the ability to record the maximum amount of words , keyboarding will be positioned in the opposite extreme of non-linear techniques, concretely in the one which less enhance academic performance.

According to the revised taxonomy of Bloom (Anderson, Krathwohl, & Airasian, 2001) the necessary information filter given by the nature of handwriting involves a higher level in the Bloom' s proposed learning hierarchy, namely the levels of understanding , analyzing and evaluating the given information which facilitate a deep learning. Parallel, from the perspective of information sciences and the data-wisdom chain model, it can be assumed that note taking by keyboarding can be located in the scale of generation of information while handwriting implies a process and reframing of information which results in knowledge.

4. Conclusion

The dissimilar learning output of the two taking notes modalities should not conduct us to dismiss one in favor of the other. Even explaining to our students the benefit of handwriting is not likely they will refuse to use digital devices as a learning instrument. The amount of students making use of a laptop in the classroom is increasing and the trend is irreversible. According to Mueller at al. (2014), it is recommendable to try to combine both methods and to make students aware of the benefits of handwriting; for many, a quite unfashionable writing way.

The combination of methods could be the key to optimize academic performance while taking notes. Technology advances speedily and it may come the day when digital writing can include more of the idiosyncracy of longhand, including so many of the cognitive benefits implicated in it.

Trying to strengthen first the longhand practice in the higher education context will result in a lost cause. It is much earlier, in the elementary school, when children should be enhanced in handwriting proficiency and in the awareness of the importance to write and to have a personal and legible calligraphy and a good orthography.

There is an inherent joy in the human nature to create and to have an individual hallmark difficult to imitate. Handwriting implies a creative process and leaves a unique personal seal on paper. Children in the school are most eager to accept the challenge to learn to write dually and it is the environment, parents and school community, who may support children to develop the necessary skills for outstanding proficiency in both techniques without forcing them to prioritize or to choose one of the two methods.

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Metacognition and Sensorimotor Components Underlying the Process of Handwriting and Keyboarding and Their Impact on Learning. An Analysis from the Perspective of Embodied Psychology. MarÃa Antonia PÃ©rez Alonso. Psychology. 2015. VIEW 1 EXCERPT. Improving automated source code summarization via an eye-tracking study of programmers. The processes of planning, monitoring, and regulating thoughts are generally known as executive processes, which involve the interaction of two levels: At one level is the creative, associative, wandering mind and above it is the executive, trying to keep it on task.Â Despite the multitude of studies about the role of metacognition in learning and teaching, several gaps are apparent. First, while studies on the effects of metacognitive instructional methods in reading and mathematics are relatively extensive, not much work has been done in everyday problem solving.Â These 13 components of Metacognition have the following subscales: For knowledge of cognition we have: Declarative knowledge (DK), Procedural knowledge (PK), and Conditional knowledge (CK). Metacognition is a key component of musical performance. Metacognitive knowledge and skills are fundamental for musicians at all stages of their academic and professional career to allow them to structure, monitor, assess and, if needed, revise practice sessions toward specific performance goals. Research in music education has highlighted the impact that metacognition has on enhancing musical performance and the learning processes that characterize it.Â This research interest is supported by a new pedagogical perspective that considers the processes of learning and practicing just as important as performance outcomes for evaluating and understanding success and failure in music learning (Leon-Guerrero, 2008; Wise et al., 2017).