THE USE OF HAPTIC FEEDBACK FOR GRAPHOMOTRICITY ENHANCEMENT: A CASE STUDY

L'IMPIEGO DEL FEEDBACK APTICO PER IL POTENZIAMENTO DELLA GRAFOMOTRICITA': UNO STUDIO DI CASO

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ABSTRACT

Handwriting is crucial for children's development. The link between the writing and theories of Embodiment seems to be evident: writing can be considered as an action experience, a representational form of movement that involves physical qualities and influences cognitive processes. Writing involves a range of complex skills, making it a challenging task to learn, particularly for children with learning disabilities. Developed haptic guidance systems show potential in acquiring the skill of handwriting.

La scrittura a mano è fondamentale per lo sviluppo dei bambini: è un'esperienza d'azione, che coinvolge qualità fisiche e influenza i processi cognitivi. Il legame tra la scrittura e le teorie dell'Embodiment sembra essere evidente. La scrittura comporta una serie di abilità complesse, rendendolo un compito impegnativo da imparare, in particolare per i bambini con difficoltà di apprendimento. I sistemi di guida tattile sviluppati mostrano il potenziale nell'acquisizione dell'abilità della scrittura a mano.

KEYWORDS

Haptic interface, Handwriting, Special Education

Interfaccia aptica, Scrittura a mano, Educazione Speciale

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Introduction

Many studies described how students with specific learning disorders may have difficulty acquiring and controlling motor skills and having good handwriting (Tseng, & Chow, 2000; Smits-Engelsman, Niemeijern, & van Galen, 2001; Smits-Engelsman, Wilson, Westenberg, & Duysens 2003).

However, some studies (Summer E, Connelly V, Barnett A, 2012) suggest that difficulties in writing may occur in children with and without specific learning disorders or disabilities, as there may be both intrinsic factors related to the child, such as impaired motor function, and extrinsic factors such as ineffective handwriting teaching method in the literacy period (Cardoso, Capellini, 2015).

Handwriting skills are fundamental to children's overall development as they help improve their sensory, motor and cognitive abilities. The intentionality of the gesture involved in handwriting is an action experience in the form of representational movement involving physical qualities and cognitive processes (Capellini *et al.*, 2021ab; Hostetter, & Alibali, 2008; Goldin-Meadow, & Beilock, 2010; Kontra et al., 2012). So the link between the writing task and theories of Embodiment seems to be evident (Caldarelli *et al.*, 2021; Gomez Paloma, 2013; Anderson, 2001): handwriting can be regarded as an experience of action, a representational form of movement that involves physical qualities and influences cognitive processes, and as an experience of action it shapes the perception of context throughout life. (Kontra et al., 2012, Gomez Paloma, 2013; Anderson, 2001).

In order to understand the evolution of the acquisition of writing and writing skills, it is useful to understand how dysgraphia relates to motor coordination, and how both aspects are intertwined with the development of cognition (Biotteau et al., 2019). In this direction, the Embodied and Situated Cognition approach highlights the importance of physical interaction with the world for the development of cognitive skills (Mangen & Balsvik, 2016) and underlines how there is a fundamental difference between learning to write on paper and pencil (physical), typing on the keyboard (digital) and the use of tablets and digital stylus (a solution that we could call hybrid), which however implies a difference due to the writing surface (Gerth et al., 2016).

Technologies currently allow us to collect and digitize an important number of parameters and indicators during handwriting, such as acceleration, pressure

(Capellini et al., 2020), the inclination of the pen (Asselborn et al., 2020), and to focus on micro-movements (Simeoli et al., 2020), in particular grip, finger position, fine coordination, hand and shoulder movement, posture, pressure on the sheet/tablet, instead of on macro-movements (Rosenblum & Drog, 2016).

The use of haptic technology based on force-feedback have been explored to support children in: drawing emotions and geometric shapes (Park et al., 2019) and learning handwriting (Park et al., 2019; Fisackerly & Zedeh, 2010).

The main objective of this pilot study, which we will explain in the following paragraphs, is to better understand how the application of haptic technologies, can be a resource in formal and informal educational settings (Capellini *et al.* 2020; Rosenblum, Dror, 2016). The scientific literature of haptic devices focuses mainly on its implementation in the military, medical, and industrial fields, and this situation has led to a very limited supply of studies examining their potential in other research areas. However, thanks in part to the lowering of the costs of such devices, interesting studies are being conducted that use haptic devices specifically in the recovery of fine motor skills for stroke patients who have lost the ability of handwriting (Mullins, Mawson, Nahavandi, 2005) .

In particular, a case study conducted by the Teaching and Learning, Inclusion, Disability and Educational Technology Research Center (TIncTec) at the University of Macerata will be presented.

1. Writing, graphomotricity and haptic devices

Handwriting is a motor-praxic activity involving perceptual and motor skills (planning and execution of motor action), cognitive and linguistic processes (Bara e Gentaz, 2011; Overvelde e Hulstijn, 2011), and metacognitive skills (monitoring the handwriting activity).

The typical developmental pathway of the basic instrumentality of writing is characterized by four stages (Frith, 1985): logographic, alphabetic, orthographic and lexical. Thus, fine motor coordination follows a natural developmental sequence; however, it can be impaired by dysfunctions of various kinds. Impaired motor function or difficulties in motor coordination can affect the execution of the graphic stroke and grapho-motor pathways and, therefore, in handwriting learning (Giaconi, Capellini, 2015). This can also occur in pupils with good performance, as well as in pupils with learning disabilities. Many studies has already highlighted how sensory, perceptual and fine-motor coordination impairments can result in impairments in written expression and, therefore, in the framework of dysgraphia, as a Specific Learning Disorder (Trevisan et. al, 2008; Capellini e Souza, 2008; Vudarte et al., 2009; Coppede, Okuda e Capellini, 2012; Capellini, Coppede & Valle, 2010). Specialized literature defines dysgraphia as the impairment of handwriting, that is, the inability to copy or realize the sequence of letters in common words (Capellini & Souza, 2008). Lofiego (1995) distinguishes two different types of dysgraphia, which he calls ''ideomotor'' and ''ideographic''. The first is due to a dysfunction in the design of graphic actions procedures, which leads people to present an obvious difficulty in the organization of directional movements in writing. The second results in specific difficulty that is characterized by the lack of coordination of movements, presence of erasures, alterations in the direction of letters, errors in the proportion of letters, specular and inverted writing of letters and numbers, due to difficulties in copying a pattern. Several studies (Lousada, Santos, Lourencetti, Padula, Capellini, 2009; Okuda *et al.*, 2011; Coppede, Okuda, Capellini, 2012, Giaconi, Capellini, 2013) point out that students with dyslexia, or attention deficit disorder, or hyperactivity disorder, frequently show alterations in motor skills, thus in eye-hand coordination, manual dexterity, fine motor skills, which would justify the emergence of a dysgraphic picture in this population (Capellini *et al.*, 2022).

Primarily, programs specializing in the remediation of dysgraphia are based on the components, such as grapho-motor components, needed to accurately and with proper fluency execute graphical tracings, lettering, grapho-motor paths. Some programs are specific to strengthening the transition from printed to cursive through the promotion of grapho-motor fluency. Others aim at the consolidation of the order of execution and realization of graphic strokes and letters (e.g., from top to bottom) and the direction of the path (e.g., from left to right). As already explained (Giaconi, Capellini, 2015) we agree with those (Cornoldi, Zaccaria, 2011) who say that the purpose of dysgraphia interventions should not aim at ''beautiful handwriting,'' but rather at legibility of writing and, more generally, the enhancement of grapho-motor fluency. In view of the fact that the activities in which pupils with dysgraphia have the most difficulty are those based on movements with tridigital grip, modulation of force and pressure of objects, and synchronization of movement (Engel-Yeger, Nagauker-Yanuv & Rosenblum, 2009; Gvion & Friedmann, 2009; Pollock *et al.*, 2009; Lousada *et. al.*, 2009), haptic technology presents itself as an opportunity that offers the possibility to observe, monitor and support all these aspects referable to graphomotricity.

Scientific evidence, however, does not come from their use in educational pathways aimed at writing, but rather in intervention actions for the recovery of fine motor skills following events such as trauma. Mullins, Mawson and Nahavandi (2005) highlight the fact that, in many people , brain damage brought about by stroke phenomena, can result in the loss of the skill of writing (which we tend to take for granted), and that many are then unable to re-acquire it. The use of haptic technological devices, would make it possible to crucially implement traditional motor therapies, allowing impaired motor-praxic skills to be recovered more quickly and enabling greater personalization of the skill learning pathway. Haptic instrumentation, in fact, to the manipulation of elements and objects reconstructed in 3D, adds a tactile perception of them, with possibilities for attractive feedback and density.

In Mullins and collaborators using hardware that reflects tactile forces combined with intelligent control software, tactile writing systems have been found to help guide even users with limited motor skills through the letter formation process. Typing letters, words or sentences in the Haptic Handwriting Aid (HHA) helps stroke survivors remember useful words. This tactile training method has the potential to stimulate brain relearning in stroke victims, with obvious economic benefits for users and the medical industry.

This technology makes a wide variety of tactile devices available and can also be adapted to their purpose (Baxter et al., 2001; Jeng-sheng Yeh et al., 2002; Chu, Nelson & Tai, Chiew-Lan, 2004). Therefore, you should carefully consider which device to use and for what purpose. in Mullins et al. It has been shown that tactile writing aids can not only significantly increase sensory input in stroke patients at low cost, but more importantly, the system can also move the user's hand through motion control on one side. Tactile recording systems, on the other hand, can use the original handwriting of stroke victims as source material. This means that once the HHA has been recorded in the system, it can be trained for specific individuals.

In light of the above, in the following section we go on to illustrate a case study aimed at ascertaining the limitations and potential of haptic technologies currently on the market. In this specific case, the device that was used is Touch X by 3D system, using the 3D Systems Openhaptics Unity Plugin. Touch X is used for procedures that require a high degree of accuracy, such as 3D modeling and design, surgical training, virtual assembly. The current limits of this haptic technology based on force feedback in the exploration of shapes are two. The first one concerns the necessity of training the device, which one might find excessively time consuming. The second one is related to the risk of losing contact with the object while navigating the areas that present discontinuities in surface curving (for instance, sharp edges or small curving radiuses). It seems reasonable to question to which degree such limits influence the level of accessibility for people with disabilities and investigate their independence and autonomy in the use of haptic devices.

2. Case study

The purpose of this study is to understand whether the use of haptic devices can support people with disabilities and/or specific learning disorders to acquire and control motor skills, which are related to handwriting quality (Tseng, & Chow, 2000; Smits-Engelsman, Niemeijern, & van Galen, 2001; Smits-Engelsman, Wilson, Westenberg, & Duysens 2003). Smits-Engelsman et al. (2001) report that difficulties in the movements of students with specific learning disorders result from a reduced ability to automate motor skills. As a result, information for performing a task is not sufficiently stored, and thus motor program memories are not generated (D'Angelo, Capellini, 2020).

This study aims to preliminary evaluate the opportunity to use a force feedback haptic device to empower graphomotor skills, focusing on:

- the ease of learning of this technology by people with mild-to moderate intellectual disabilities;
- the improvement of the level of automation in performing "motor sequences" in the case of people with dysgraphia.

To this end, a case study was conducted within the Research Center on Teaching and Learning, Inclusion, Disability and Instructional Technology (TIncTec) at the University of Macerata, during Inclusion Lab week in July 2022, by a multidisciplinary team composed of experts in pedagogy and special education and experts in human factors and human-computer interaction.

This study was administered to a 16-year-old female student attending the third grade, with average intellectual retardation and also with pragmatic difficulties in grapho-motricity. We can observe in the female student an incorrect grasp of the graphic instrument and poor wrist fluency. The impairment of these two elements affect the ability to have fluent and legible writing.

2.1 Experimental procedure

This study was conducted in one week, conducting work sessions on non-consecutive days with each other, for a total of three meetings. The student was asked to perform several preparatory exercises for handwriting, which consisted in completing the three graphomotor paths represented in Figure 1 (i.e., A, B, C) , requiring different levels of motor control and graphomotor skills.

Figure 1 (A)

Figure 1 (B)

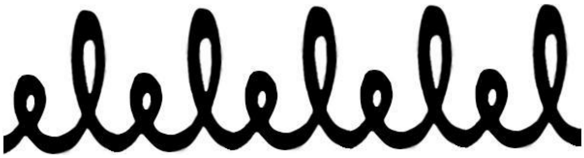

Figure 1 (C)

Each experimental session averaged about 7 to 8 minutes divided by session 1 and session 2.

Before the start of the working sessions, the following was presented how to interact with the virtual object through the haptic device and were asked to interact with it in order to become familiar with two basic operations: navigation and object manipulation.

Session 1 included the following activities:

- interaction with a digital trace on a VR application;
- reproduction of the digital trace by hand on paper.

Session 2 included the following activities:

- interaction with a carved trace on the surface of a classic wooden board for graphomotricity
- reproduction of the carved trace by hand on paper.

During the first experimental session, the student was asked to perform a few minutes training with the haptic instrument Touch X by 3D with one of the above-mentioned traces, and then go on to reproduce the same virtual tracing by hand on the paper.

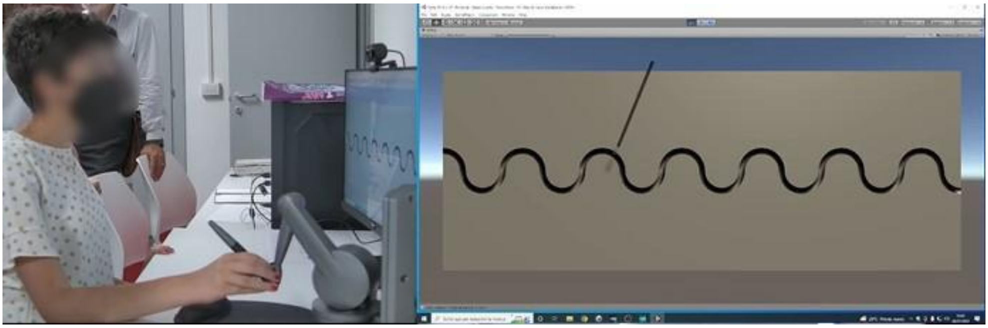

Fig. 2 (interaction with a digital trace on a VR application)

As a haptic device, we used the 6 DoF high fidelity force feedback Geomagic Touch X by 3D system[1]. The considered VR application, developed in Unity 3D[2], using the 3D Systems Openhaptics Unity Plugin[3], is displayed on a Philips Led 24'' full HD pc monitor while seated at a height-adjustable desk to ensure maximum comfort during interaction. It enables users to interact with virtual objects by means of a virtual probe: a virtual stylus that moves solid with the haptic device handpiece. The considered virtual objects, realized with a 3D modeling software (i.e., Inventor by Autodesk[4], are characterized by cavities on the surface of similar geometry to the grooves carved on wooden boards. The surface of the object with the cavities is displayed on the screen in orthogonal mode.

[1] 3D System, Touch X. https://www.3dsystems.com/haptics-devices/touch-x/specifications. Accessed on 09/04/2023.
[2] Unity 3D. https://unity.com/, Accessed on 09/04/2023.
[3] 3D Systems Openhaptics Unity Plugin. https://assetstore.unity.com/packages/tools/integration/3d-systems-openhaptics-unity-plugin-134024, Accessed on 09/04/2023.
[4] Autodesk Inventor. https://www.autodesk.com/products/inventor/overview?term=1-YEAR&tab=subscription, Accessed on 09/04/2023

Once the point of the virtual stylus comes into contact with the virtual object, the Touch X returns force feedback to the user who is holding the pen through the mechanical actuators of the device, thus simulating the "collision" of the stylus with the surface of the virtual object and the resistance that the virtual material itself opposes, based on the action-reaction principle.

In the second session, on the other hand, they were asked to train on the same tracing on a wooden graphomotor board, on which the tracing was performed with the use of a graphing tool. After a few minutes of training, the same tracing was again reproduced on the sheet of paper with the use of a pen.

2.2 Analysis of data

Data collection was done through audio and video recording of the training sessions. Video analysis was carried out by a team composed of experts in special pedagogy and Human Factor.

The video analysis focused on the analysis of the correctness of the grip of the handpiece, maintenance of posture, the mode of interaction with the virtual object, the execution of the exercise, and the level of autonomy, as well as the level of motivation and interest shown during use with the haptic device.

Specifically, the observation then focused on the following elements:

- handgrip correctness;
- level of autonomy of interaction with the virtual object;
- level of correctness of execution of the exercise;
- level of motivation and involvement manifested by the student.

The observation revealed that the student's ability to learn how to use the tool was poor. However, once addressed she was able to perform a short task independently.

Observation revealed a lack of learning ability on the part of the student on the use of the tool. However, once addressed she was able to perform a short task independently.

In fact, despite multiple training sessions, the student was not able to learn how to approach the haptic device so as to properly hold it independently; at the beginning of each session he needed support from the assistant in order to correctly place his hand on the handpiece. However, supported by the assistant, he was able to maintain the correct grip during almost the entire exercise session.

Regarding the interaction with the virtual object, the student demonstrated that she was unable to orient herself independently in the virtual space so as to interact with the virtual object independently, and in particular to place the probe on the surface of the track. However, once she received support from the assistant to correctly place the probe on the surface of the track, she was able to correctly complete the exercise sessions independently.

Instead, the student demonstrated an almost complete level of autonomy in interacting with the wooden board. This suggests how in part the considered technology may present initial barriers, but these can be easily overcome through the intervention of the assistant. While it is true that learning how to properly use the haptic device in general requires a period of training, in the case of a person with intellectual disabilities, such as the student considered, the training time may be considerably longer.

Making an analysis of the graphical tracings obtained after the trainings of the grapho-motor paths with the haptic device and with the wooden tablet, we cannot observe any substantial difference in the quality of the tracings found visually. Relevant, however, was the detection of the student's motivational level found while using the two media. She stated that she preferred performing the tracings in virtual reality over the real tablet. Despite this, the practitioners who attended the training on different days found a low motivational level in both the execution of the tracings with the haptic tool and the wooden tablet.

2.3 Discussion

In the last decades, there has been an increasing number of children with difficulties in the development of proper handwriting: an estimated 10% to 30% of students reports problems in handwriting that jeopardize their school career (Feder, Majnemer 2007).

Learning handwriting is a long, challenging and complex process (Tsai *et al.*, 2008) involving many components such as hand-eye coordination, visual capability to discriminate different elements, spatiality and orientation (Giaconi, & Capellini, 2015), and that requires planning and implementation of the gesture, involving cognitive and linguistic processes (Overvelde A, Hulstijn W, 2011).

Affordable and portable haptic systems could be a valid solution to deliver information and complement school-based therapist-directed interventions to improve functional handwriting outcomes (Palsb et al., 2011). However, the number of studies that have investigated the potential of such devices in educational settings is limited. In particular, no studies investigated the appropriateness of using force-feedback-based haptic devices with students with specific learning disabilities, intellectual disabilities, or reduced dexterity in manual tasks.

Concerning technology devices, haptic technology based on force-feedback is gaining rising interest as an assistive technology to improve the acquisition of handwriting skills for children with learning difficulties.

Handwriting is a complex skill, dependent on the maturation and integration of cognitive, visual-perceptual, and motor skills (Maeland, 1992; Rubin & Henderson, 1982; Sovik, 1975; Tseng & Murray, 1994; Weil & Amundson, 1994; Ziviani, Hayes, & Chant, 1990). It follows that before more systematic ways of teaching children to write can be developed, the constellation of skills needed for efficient writing will have to be better understood (Tseng M.H., Susanna M.K. Chow, 2000).

The ineffective method of teaching handwriting in the literacy period (Cardoso, Capellini, 2016) significantly affects the development of grapho-motor skills. Handwriting requires finely graded manipulation of graphical tools, such as pencils, pens, and markers of different hardness and size, to produce graphical tracings and letterforms, fluently and punctually, with a specific original and size, in a specific serial order, and in specific positions on a writing surface (van Galen, 1993). Fine motor skills are essential because accurately formed letters can be produced through proper control of timing and arm strength coordinated with hand and finger movements (Alston, Taylor, 1987; Thomassen *et al.*, 1983).

Conclusions

In the light of the above, it can be stated that haptic device could be one of the useful tools for improving graphomotor coordination. In fact, it has the ability to guide the hand in the execution of the trace with the virtual stylus (which actually has a three-digital grip like any pencil or pen) and for its simultaneous return of sensory and visual feedback. According to Sovik and Arntzen (1991), fluent writing is produced by an integrated pattern of coordinated movements subject to visual monitoring and sensorimotor feedback. The haptic device could also allow for greater motivation on the part of students in grapho-motor training because of its versatility and the possibility of developing more playful applications.

In future studies, it would be useful to integrate data collection, related to the processes of learning and practicing writing, by resorting to additional devices such as Wacom Intuos Pro. Such a device, in fact, thanks to a software SDK, enables the collection of otherwise unobservable handwriting dynamics information, specifically data related to pressure levels, slant and stroke speed.

Therefore, the use of technological devices such as those illustrated here (originally born neither with didactic purposes nor with the purpose of observing and surveying the ways in which they are used), allow us to delve into the analysis of fine motor (or precision) processes, such as those that relate to the use of small muscles for hand manipulation (Bruininks, Bruininks,2005), typical of writing, offering research the opportunity to plan increasingly customizable intervention strategies.

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