Problem Statement / Research Question and Background

Movement disorders at the upper limbs can lead to incapacity to write. These difficulties can be linked to tremors, osteoarthritis, involuntary muscle contractions, spasticity, ataxia, fine motor difficulties with spasticity, dyspraxia, dysgraphia, agraphia, apraxia or developmental coordination disorder.

The impact of handwriting difficulties can be important, mainly for children at school where learning activities are often focused toward motor activities [1]. Children living with movement disorders during handwriting may need to make serious efforts [2], experience repeated failure [2] and suffer from reduced self-esteem [3], [4]. Nowadays, in a world where digital technology is omnipresent, handwriting is still really important. There are many advantages to writing by hand, e.g., facilitating the expression of ideas [5], increasing the capacity of critical thinking and problem solving, and managing emotions [6]. It has been demonstrated that the fact of writing by hand activates the sensory-motor network responsible for the visual recognition of letters [7]–[9] and leads to a better recognition of letters compared to passive observation, typing on a computer or writing on a tablet [7], [10]. Handwriting also improves reading capacities [11], memorization and assimilation of information [12], [13] and capability of learning mathematics [14].

There are different types of commercially available writing aids. These include bigger pencil grips, elastics to hold the pen in the hand and Y-shaped pens. A roundtable with occupational therapists revealed that none of the existing writing aids provides good support in the writing process for children living with movement disorders and spasticity. Most of the aids are too simple for people living with developmental coordination disorder, fine motor difficulties with spasticity or any of the other pathologies aforementioned.

The objective of this project is to develop a writing assistive device for children living with difficulties to control movements, in order to promote their development and learning. The hypothesis is that the device will help them to write and draw by reducing the execution time, increasing movement fluidity, and increasing the ease of writing, or allow someone who is usually not capable of writing to do so on his/her own. This project presents technical challenges due to the design of the mechanism and the fact that potential user's capabilities may highly vary. The design should also consider accessibility issues (i.e., cost) and acceptability considerations.

Methods/Approach/Solutions Considered

This project uses an interdisciplinary, iterative and user-centred methodology, and is decomposed into fours major steps:

1) <u>Establishing the actual situation related to handwriting amongst the target population:</u> A formal focus group with six occupational therapists, one researcher in occupational therapy and two researchers in engineering was conducted to evaluate the handwriting challenges faced by those living with movement disorders. The objective was to better understand the current situation and the relevance of developing a new assistive device for those persons.

2) <u>Performing a review of the commercially available products and the solutions presented in scientific literature:</u> The review was performed through three sources: a) the devices suggested by

occupational therapists during the focus group in step 1, b) the commercially available solutions for handwriting aids found on the website of assistive technology manufacturers, c) a review of the scientific literature. The last two solutions were presented to the focus group to ensure a clearer understanding of the advantages and drawbacks of the different solutions.

3) Developing a functional prototype: Different solutions (i.e., arm support, external mechanism) were considered. A device that would be fixed to the table and external to the user (i.e., not worn by the user) was selected for its simplicity and because it is easier to develop a device adaptable to each user. A first solution was inspired by the eating assistive device developed by Turgeon [15], [16] and was presented to occupational therapists. The position of the device relative to the user (i.e., in front, on the side) was also an important point of discussion. After some experiments with the prototype, it has been decided that the mechanism should be fixed on the opposite side of the user's writing hand to facilitate the movements and improve ergonomics. Prototypes of the device were then built and presented iteratively to occupational therapists and potential users to propose future improvements.

4) Evaluating the prototype: Six participants completed the evaluation. One is living with cerebral palsy and the rest are experiencing coordination or movement disorders. Participants were admitted if they had difficulty writing by hand on their own. Each person took part in an individual testing session which lasted approximately 45 minutes. First, participants had to draw simple lines and forms (from a predetermined set) on their own using their usual pencil. The required set of drawings was, in order of complexity, a vertical line, a horizontal line, a circle, a vertical cross, a diagonal line, a square, a triangle, a simple drawing up to the participant's choice and a word, such as their name. Afterwards, the handwriting assistive device prototype was installed on the table in front of the participant and the configuration (damping, handle form and position) was verified to fit each participant. They were given time to manipulate the device. Each participant then had to draw the lines and forms using the prototype of the assistive device. At the beginning of each session, sociodemographic and clinical data such as age, gender and diagnosis were collected. The completion time and quality of the drawing remain to be analyzed to quantify the improvements using the prototype.

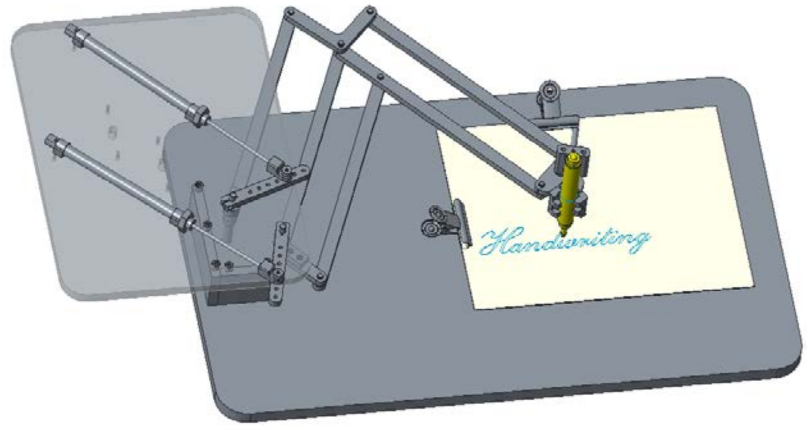

Figure 1 – Mechanism tested with potential users.

Description of Final Approach and Design

1) General overview: The final system proposed has two degrees of freedom (DoF) and is shown in Figure 1. It is designed to be installed on a table with a sheet of paper located in front of the user. To control the pencil, the user can either grab the actual pencil or a customizable handle placed on the side of the pen. As a result of the mechanism design, the pen holder always remains perpendicular to the table. Mechanical inertia and dampers allow stabilization of the user's motion as these actions are carried out.

2) Mechanism: Figure 2 presents three variations of the potential mechanism, in order of increasing complexity, all of which have the same two DoFs. Figure 2a shows a simple system with two pivots (J_1 and J_2). As shown, the handle changes direction depending on its position over the paper. This is not undesirable since the user would have to change the orientation of his/her hand during the process of writing or drawing. In order for the end-effector orientation to remain the same all along the trajectory, two parallelograms were added—one for each joint—as shown in Figure 2b. This modification allows the mechanism to be controlled in a Cartesian plane with angular joints. Damps were added to each joint to control the movements and limit the effects of spasticity. The mechanism presented in Figure 2b has the two DoF in series, which means that they are placed one after the other. Joint J_2 supports the end effector, and joint J_1 supports joint J_2 and the end effector. This induces more stress on J_1 than on J_2. To distribute the effort evenly between the two joints, a third parallelogram was added as presented in Figure 2c to report the control of J_2 to the base. This allows the two joints to work in parallel instead of in series. The article [17] explains the design of the mechanism in detail.

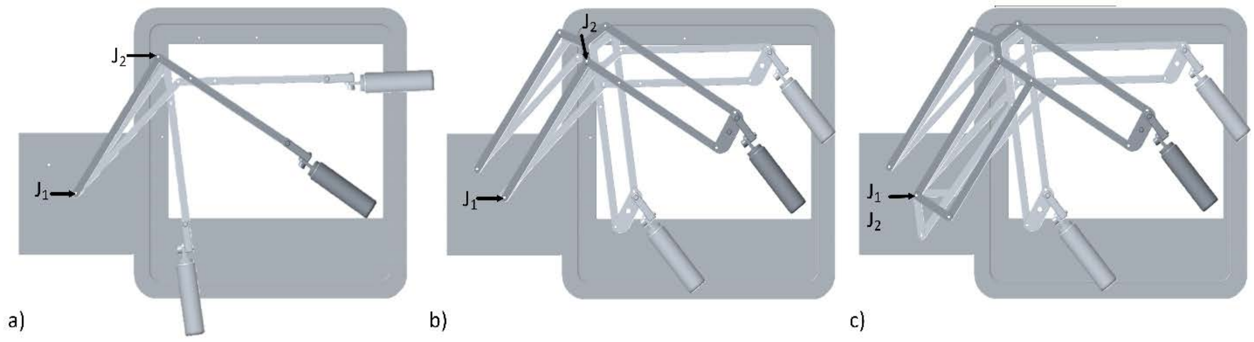

Figure 2 – Presentation of the mechanism. a) basic mechanism, b) adding 2 parallelograms so the end effector stays in the same orientation with respect to the base in all positions, c) adding a third parallelogram to control the second rotation, J_2, from the base.

The external dimensions of the mechanism are 440 mm x 725 mm. The working space is designed to have a letter size sheet in landscape or portrait orientation.

3) Stabilizing the movements: At first, we used angular dampers as it was easy to add them in the design. It turned out that there was too much dry friction, which means that the damping effect was not dependant of the speed of the effector. We then tried to include linear dampers as presented in Figure 3 to damp or absorb abrupt motions. Each of the two dampers controls one DoF. As the desired damping may change between users, a simple four-bar mechanism was added to link the dampers to the handwriting mechanism shown in red. It is possible to modify

the length of the first bar represented in purple so the ratio between the actual damping felt by the user and the real damping induced by the dampers is somewhere between 10% to 100% of the damper capacity.

The position and orientation of the dampers are set so their effects are maximized. Many simulations were conducted to optimize the efficiency of the mechanism as angular movement is transformed into linear movement at the effector.

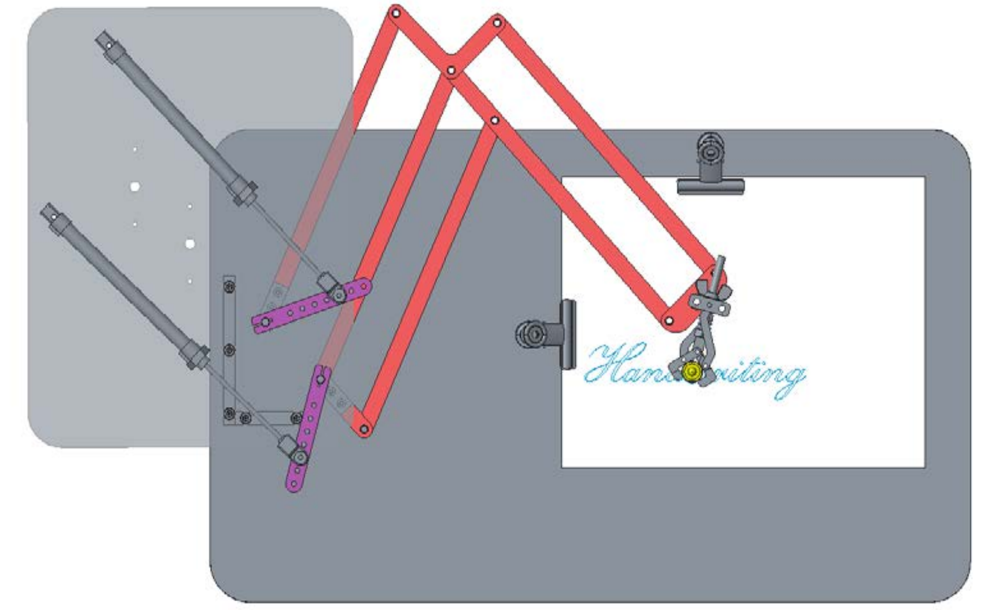

Figure 3 – Damping mechanism (left) and handwriting mechanism (right).

For users who need high damping to assist their movements, it is still possible to use the angular dampers along with a modified four-bar mechanism. This allows users to benefit from some resistance at all times. The linear dampers have a linear effect, which means that the force induced by the dampers is stronger as the speed increases. The angular dampers have a high dry friction, which means that they create a constant resistance to movement (even for slow movements) and the resulting resistance is almost the same at every speed. They were thus counteracting both slow voluntary movements and abrupt undesired movements.

4) Pen holder design: At the end effector, a pen holder mechanism was added to hold the pencil in place. It is possible to fit any writing instrument, from 7 mm diameter pens to 22 mm diameter highlighters, for instance. The angle of the pen relative to the mechanism can also be adjusted easily with a screw. A wing nut allows changing the pencil in a few seconds.

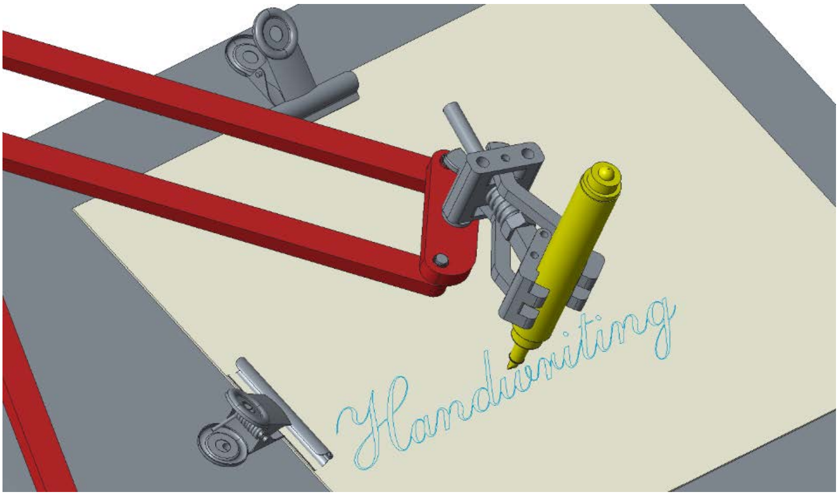

Figure 4 – Pen holder mechanism fixed to the end effector.

Since the attachment to the pencil is small (only 25 mm high), it is possible for the user to hold the actual pen. If this is not possible, a handle can be added on the side of the pen to control the mechanism. The position relative to the pen of the handle can be modified to fit the user's needs, and the handle is fully customizable. New handles can be designed if necessary.

In a future version of the prototype, it would be relevant to change the angle of the pencil relative to the sheet. Currently, it is almost perpendicular, but it would be pertinent to be able to modify it so the user can hold the pen the same way he or she holds a pencil without the mechanism. This would also allow some progress in the learning process, as users can start using the handle and progressively control the device with the pencil.

Outcome (results of any outcome testing and/or user feedback)

Results from the testing sessions with six participants living with upper arm disabilities show that the use of the prototype helps them write.

The first participant lives with cerebral palsy and is not able to write on his own due to spasticity and uncoordinated movements. He used the mechanism with the angular dampers at 100% level and a T-shape handle to control the pen. The damping helped to stabilize his movements. He was able to draw all the required forms (horizontal and vertical lines, square, circle and triangle). He was also capable of writing down his name ("Seb") even though he had never learned to write. The results show that all the drawings and writing were done faster and with more fluidity (qualitative measurement) using the writing assistive device. He mentioned he would have liked to use such a device when he was young, so he could have learned how to write on his own. Figure 5 shows the difference in the writing of the user with and without the assistive device. The writing is more legible when the assistive device is used.

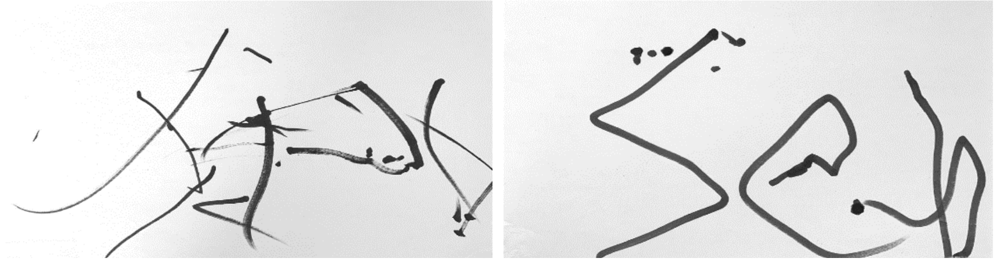

Figure 5 – Handwriting of the word "Seb" without the assistive device (left) and with the assistive device (right)

The five other participants were children (age 7 to 12) from a school in Quebec City living with language and motor difficulties. They were all able to hold a pen but had difficulty to write words or draw different forms on their own. The children were all able to use the device and it helped them to draw the required forms. The lines were better defined and some children were also able to trace the first letter of their name. The children had relatively fair gross motor control but they had difficulty to hold the pen straight. The damping was thus not necessary, but the device helped them to hold the pen straight up.

Cost (cost to produce and expected price)

The handwriting assistive device has been designed to develop an affordable solution for accessibility issues. The production cost of the prototype is US$830 and is detailed in Table 1.

Table 1 – Handwriting assistive device prototype production cost versus cost per unit for a 10-unit production.

	Prototype price (US$)	Unit price for 10 (US$)
Materials (aluminum, plastic, steel, etc.)	20	20
Machining	750	400
Parts	60	60
TOTAL	830	480

These estimations do not include engineering development time and consultations with clinicians. Several improvements could be brought to reduce the production cost. The machining cost was high because only one instance of the device was built; most of the machining labour was attributable to the preparation of the first part (preparing the machining strategy and setting up). A larger production quantity (even small numbers such as 10 devices) would significantly reduce the cost since the preparation and setup would only be required once. It would also be possible to improve the design based on what we have learned to reduce the costs. Keeping in mind the current design but with the hypothesis that 10 devices would be built, the unit production cost of 10 of the current prototypes would be US$480. The expected pricing would be US$960, which is exactly what occupational therapists expect for a device like that.

Significance

The current prototype was developed as a preliminary proof of concept with the objective of evaluating the potential use of this technology by individuals living with movement disorders such as spasticity and dysgraphia. Evaluations of the prototype have shown that the mechanism was already able to help users to write and draw simple forms, and to improve movement fluidity. It is expected that improvements to the device that were all identified during the evaluations will help in assisting many potential users. The main target population would be a portion of people living with cerebral palsy, estimated at 764,000 in the US [18]. In the end, the device should help people living with movement disorders to learn and practise handwriting and drawing.

As there are many advantages to handwriting, this device will help children and adults have the possibility to write on their own and facilitate the learning process.

Acknowledgements

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