Rehabilitation for Dysphagia in Children with Cerebral Palsy

Project EEN205

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Contents

1 Introduction

Cerebral palsy (CP) is a term used to describe a group of permanent movement disorders caused by neurological factors early in life [1]. These disorders originate from brain damage that occurs in the womb, during, or shortly after birth. In addition to motor impairments, these disorders are often accompanied by additional challenges. One of the most common is the difficulty in chewing and swallowing, also known as dysphagia.

To address this case, this project proposes an innovative, interactive rehabilitation therapy system aimed at supporting CP children with dysphagia. The proposal is a Human-Computer Interface (HCI) that combines three key modalities: Electroencephalography (EEG), Electromyography (EMG), and Functional Electrical Stimulation (FES). By fully integrating these modalities in an EEG cap, the goal is to detect the intention to chew, measure muscle activity, and assist the chewing motion with electrical stimulation. The target population includes children aged 4 to 12 years with CP who are classified at levels I to III on the Eating and Drinking Ability Classification System (EDACS), that have some voluntary control of the masticatory muscles and are able to eat and drink safely, with or without limitations [2]. This age range is chosen because children at this stage are typically able to understand what is happening and participate meaningfully in the therapy process. Children with severe cognitive impairments are not included, as they may be unable to be engaged in the rehabilitation therapy [3]. Since the interactive aspect is especially important when working with children and promoting motivation and learning, the system will be designed with child-specific needs in mind, using playful interfaces as well as child-friendly, auditory feedback in real time.

This report presents an initial concept for the development of a rehabilitation system. The focus is on exploring the integration of multiple modalities (EEG, EMG, and FES) into a single wearable system, such as a cap. Additionally, the project investigates how to provide effective visual and auditory feedback through a user-friendly interface tailored to children. Although the system will include several components, this first idea concentrates on the core integration and interaction aspects, to create a meaningful proposal for the rehabilitation of CP children with eating dysphagia.

2 Background

In order to develop this rehabilitation system, anatomy involved in dysphagia along with existing solutions were studied. The relevant findings are presented in the following section.

2.1 Masseter muscle

The masseter muscle is one of the four muscles involved in chewing and jaw movement [4]. It is located on the side of the face, connecting the cheekbone to the lower jaw. Its primary function is to elevate the jaw, allowing the mouth to close during biting and chewing. Due to its high strength relative to its size, the masseter muscle plays a crucial role in producing the force required for effective chewing and food breakdown.

2.2 Impact of Cerebral Palsy on Chewing Muscles

In individuals with CP, especially those with more severe motor impairments, oral motor dysfunction is highly prevalent [5]. This affects the control and coordination of muscles involved in chewing, such as the masseter. This dysfunction can result in difficulties with chewing efficiency, jaw stability, and the ability to break down food properly. As reported, over 90% of children with CP exhibit clinically significant oral motor dysfunction, which includes challenges with muscle tone, reflexes, and coordination necessary for effective chewing.

2.3 State of the art

EEG–fNIRS (functional near-infrared spectroscopy) systems have already been applied in infant studies to understand and monitor neuroplasticity [6]. These technologies are non-invasive, portable, and well-suited for long-term monitoring, making them especially valuable in pediatric rehabilitation settings. Several commercial solutions provide inspiration for further development in this area, two examples include the g.Nautilus by NIRx and the actiCAP by Brain Products GmbH [7] [8].

EEG can be used to record brain activity related to specific masticatory muscles, such as during jaw-biting movements. A study investigated movement-related cortical potentials (MRCPs) in patients with oral cancer and found that these signals, which originate from motor areas like the supplementary motor area and primary motor cortex, were present during jaw-biting tasks [9]. These findings suggest that EEG can capture neural activity involved in the motor planning of chewing.

EEG and EMG are used during research in the field of neuromotor rehabilitation to measure brain and muscle activity, respectively [10]. Although these modalities have traditionally been applied independently, studies increasingly explore their combined use, offering a more comprehensive understanding of neurophysiological processes and potentially improving the design and evaluation of rehabilitation interventions. Studies have shown that combining EMG and FES enables intention-driven motor rehabilitation by using voluntary EMG to modulate stimulation intensity [11] .

In general, in eating and chewing rehabilitation, EMG signals are often combined with feedback systems to regulate eating behaviour. One approach uses haptic feedback, such as wristband vibrations, to help patients control chewing speed [12]. Another method involves auditory cues, where rhythmic sounds guide patients to chew at a steady pace. Studies have found that following an auditory cue reduces variability in chewing, leading to more consistent chewing cycles [13].

Research focusing on children with CP has explored various ways to enhance their functional abilities through engaging interventions [14]. This has led to the use of playful, interactive elements such as music, sound effects, and game-like features, which make the therapy feel more like a fun activity rather than a serious training session. Such feedback approaches have proven successful in various motor learning contexts, like improving walking patterns.

An existing solution for dysphagia rehabilitation is a gamified user interface designed for a swallowing exercise called the submandibular push exercise, which involves pushing the muscles under the jaw upward [15]. The interface uses three concentric bubbles to guide the patient, each representing a type of muscle exercise: isotonic (moving with steady force), isokinetic (moving at a constant speed), and isometric (holding a position without moving). The size, color, and transparency of the bubbles reflect how challenging each level is. A pressure sensor placed under the jaw measures the upward force during the exercise. The bubbles move up and down, just like the natural motion during swallowing. The interface has intuitive symbols and buttons and logs data and observations.

2.4 Requirements

When putting a rehabilitation device on the market there are a lot of requirements that needs to be fulfilled, both functional and legal. The key factors for recovery can be divided into the following topics: intensity, psychological factors, manner and information [16]. The intensity includes factors like, repetitions, distribution, duration, difficulty and effort. The psychological factors refers to motivation and manner incorporates specificity, task segmentation, variability, shaping and initiation. The information topic covers instructions and feedback.

Previous studies on electrical stimulation in CP children with dysphagia has adjusted the intensity of the therapy to each patient, in order to for it to be long enough to engage neuroplasticity and at the same time avoid fatigue [17].

To motivate children with dysphagia, it is important to make the therapy a positive experience [18]. This can be done by using playfully designed utensils and plates, offering tasty food, letting the child touch and smell the food in advance, and customizing equipment to the child's interest.

For instructions and feedback for child-focused dysphagia management it is important that the rehabilitation professionals in the communication with the children and caregivers, uses a non-technical language when describing how to utilize the rehabilitation device safely [19]. They should ensure that the caregivers understand as well as make them how to observe and respond to signs of loss of attention and fatigue. The caregivers role is to integrate therapy exercises into daily routines in order to build consistency, engage the child by using playful language and create stories or games around the therapy.

Legal requirements varies depending on which market the rehabilitation device is put on, for the EU market MDR has to be followed [20]. There are different categories under MDR, a category relevant for rehabilitation is category of active therapeutic devices and neurostimulation devices. As well as different risk classifications, a device falls under IIa if stimulation is low-risk and reversible or class IIb, if stimulation poses a higher risk to vital functions. There are ISO standards regarding process standards for quality, risk, biocompatibility and clinical studies that should be followed. As well IEC standards to ensure electrical safety, electromagnetic compatibility and performance.

3 Methods

To design a rehabilitation system for children with CP and associated dysphagia, the project began with an extensive literature review. This included studies on the neurological and muscular impairments caused by CP, the mechanisms of chewing and swallowing, and existing technologies for motor rehabilitation such as EEG, EMG, and FES. Additionally, best practices in user interface design for pediatric therapy tools were investigated to ensure accessibility, intuitiveness, and sustained engagement for young users.

Based on this literature research, a set of functional and technical requirements was defined. These included the need for a non-invasive, wearable system capable of real-time signal acquisition and processing, the use of adaptive FES, and a multimodal feedback interface that combines interactive visuals and motivational audio prompts to maintain the child's attention and support motor learning. A comparison with the current state of the art highlighted that, while EEG, EMG, and FES are used independently in various rehabilitation contexts, no existing solution integrates all three in a closed-loop system specifically aimed at masticatory muscle training in children with CP.

The development process included weekly presentations and feedback sessions with supervisors and peers, which supported refinement of the concept.

4 Result

Based on the reviewed state-of-the-art solutions and the functional and user-specific requirements identified, a rehabilitation system was developed to support chewing in CP children with dysphagia.

4.1 System overview

The rehabilitation system integrates an 8-channel EEG-fNIRS cap with surface EMG electrodes placed on the masseter muscles on the right and left sides. Separate electrodes are used for detection and stimulation to minimize signal interference and ensure reliable measurements. Brain and muscle signals are measured and transmitted wirelessly to a processing unit, which analyzes EEG data to detect the intention to chew or swallow, and EMG data to assess masticatory muscle activation. When the system detects an intention to chew but finds insufficient muscle activation, it activates FES to the masseter muscle to assist the movement. The stimulation is adaptive, based on real-time EEG and EMG signals to either support or initiate the chewing action. The system overview can be observed in Figure 1.

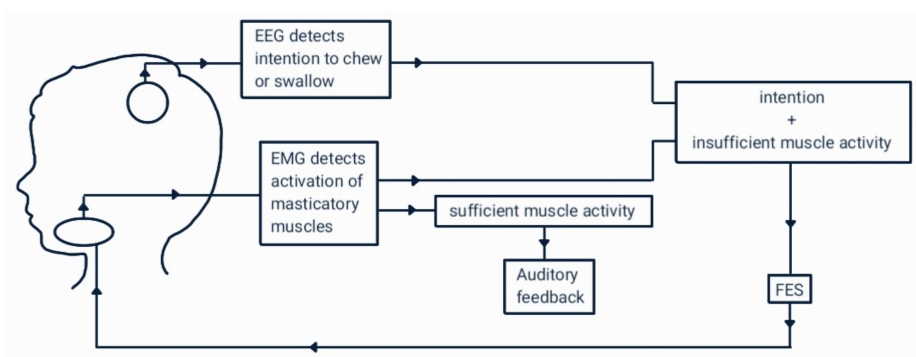

Figure 1: Flow of the rehabilitation system (image created by the author).

The rehabilitation system, shown in Figure 2, is intended for use during guided therapy sessions to reinforce sensorimotor pathways through repetitive, structured training. As muscle control improves, FES support can be gradually reduced, promoting neuroplasticity and the development of independent chewing and swallowing. Throughout the session, EMG sensors continue to monitor muscle responses, and when a predefined activation threshold is reached, acoustic feedback is delivered to reinforce successful movement. In parallel, visual and audio feedback is provided through an engaging bubble game interface, designed to maintain motivation and support motor learning. In this game, the child can blow virtual bubbles and when their muscle activity reaches a certain level based on the EMG signal, a bubble pops and a popping sound is played as a reward.

Figure 2: Overview of the rehabilitation system. Image generated using ChatGPT for illustrative purposes.

4.2 Novelty

A fully integrated, wireless, and wearable device is proposed for dysphagia therapy, with all electrodes embedded in a cap. The system combines FES, EMG, and EEG to monitor and stimulate the masseter muscle. Our novel contribution lies in designing this integrated device and combining it with the game-based feedback system.

4.3 Requirements

To fulfil the functional and legal requirements of the device, the intensity of the therapy sessions are going to be approximately 30-45 minutes per day, 5 days a week for 4 weeks but adapted to each patients needs which aligns with other previous similar studies. The sessions will not include actual eating. There will be a first appointment where the rehabilitation professional informs caregivers how to carry through a therapy session at home as well as get the cap and electrodes fitted and intensity set. The sessions will then mainly be carried out in the patients home but with follow-up appointments where the rehabilitation professional adapts the intensity parameters. EMG threshold will over time increase (first soft and then hard food), FES stimulation will decreased. The first appointment is also when the design of the equipment is determined, by finding out what the child likes and could motivate them.

The game in the interface is inspired by the earlier mentioned gamified rehabilitation study using the same bubble concept. In order to make it more motivating for a child, the character in the game is supposed to be relatable and is therefore wearing the cap as shown in Figure 2.

MDR has to be followed to be able to put the device on the EU market, it falls under the category of active therapeutic devices and neurostimulation devices. Depending on the intensity of the FES stimulation the device should be classified as risk class IIa or IIb. All applicable ISO and IEC standards should be followed.

5 Discussion

EEG caps are already used to measure brain activity, sEMG electrodes are widely adopted to monitor muscle activation, and FES is commonly applied in neuromuscular rehabilitation. However, there are no existing technologies available on the market that combine the three modalities into a single integrated system.

As presented, the integration of EEG, EMG, and FES into one device aimed at pediatric rehabilitation, particularly for children with cerebral palsy and eating dysphagia is technically promising. However, there are several limitations.

First, biological signals are weak and susceptible to noise. EEG signals, in particular, are extremely weak due to the presence of an air gap between the scalp and dry electrodes, which reduces signal quality. Additionally, interference between signals becomes a major issue, especially from the electrical stimulation pulses, which can overlap and distort the EEG recordings. One possible way to reduce this interference is through windowed signal analysis but this is an area that leaves room for a lot of future development. However, this approach introduces delays and prevents real-time synchronization, essential for providing immediate feedback during therapy.

Cost represents a significant concern, as the system includes many components, such as the EEG cap, EMG electrodes, and FES units. However, most of these elements can be reused across different patients by simply adapting the EMG electrode placement, which helps reduce long-term costs. Still, the complexity and number of components introduce another limitation: the system is difficult to implement with children. The quantity of equipment and time required to prepare each session makes it harder to implement with children, who may have limited patience or tolerance for long setups. Additionally, children often do not recognize the goal of the therapy and may lose interest quickly. Therefore, even though the interface is designed to be playful, maintaining attention over repeated sessions remains a key difficulty.

6 Conclusion

This work represents a proof of concept and an initial step toward developing a more complex and usable rehabilitation system. There are plenty of limitations to account for when combining the three modalities, and more investigation is required to realize this in a clinical setting. Future efforts should focus on expanding the number of muscles monitored and stimulated, as well as refining the design and integration of all system components. In the long term, the ultimate goal is to enable the use of this system during actual meals, allowing the integration of structured therapy into daily eating activities.

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