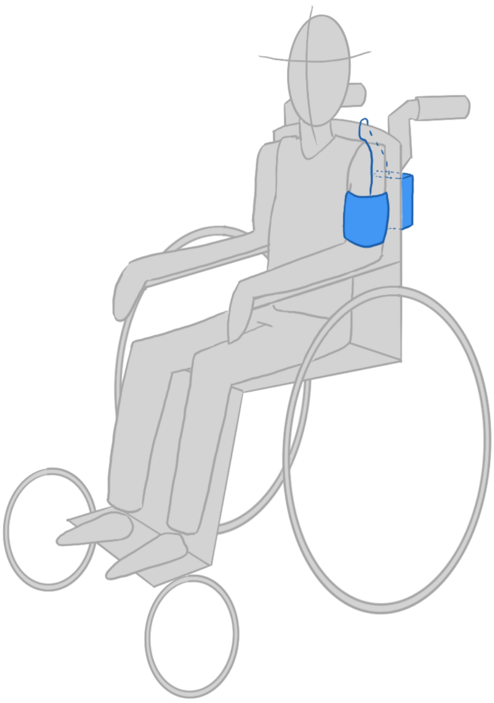
EPFL

Spasm and voluntary movement detection

Neural interface

Report 1



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General context and proposed device

In many neurological conditions, a certain amount of physiotherapy is needed for neuro-rehabilitation. We're focusing on the patients lacking the ability to differentiate between voluntary movements and involuntary movements who, through physiotherapy, attempt to learn to distinguish them in order to have better motor control. To illustrate such a neurological disorder, we're applying our project to a 5 year old girl, Laura [1], who suffered from a meningitis infection at the age of 7 months leading to an incomplete tetraplegia with proprioception limitations. As Laura is still young, there is a lot of room for her to learn motor control, as her neurorehabilitation therapist has informed us. The current system used for her physiotherapy sessions are electrodes coupled with an *Arduino*, a rudimentary system we would like to improve and implement for long term usage, so that Laura can wear the device daily.
We are suggesting a wearable EMG device using dry electrodes optimized to effectively differentiate between voluntary and involuntary movements, which have different signal amplitudes. As we can see on Figure 1 the device would be connected to a feedback system allowing the patient to improve movement coordination with physiotherapy.
Laura's therapist has emphasised that other children suffering from different proprioception and motor disorders could benefit from such a device for neurorehabilitation.

Design concept, specifications and building blocks

The device contains different building blocks presented in Figure 2. Electrodes, that are in direct contact with the skin of the arm (number and placement should be clearly defined for efficient muscle targeting), are held in place thanks to an electrode placement system [3]. The electrodes (active or passive) will send the data to a processing unit, that also contains batteries [1] through cables [2]. The processing unit can be fixed on the wheelchair or on a belt, depending on the patient's needs. Ultimately, the goal is for the device to give a feedback [5] to the patient, which can be in multiple forms such as sound indicators, or through lights that can be placed on the placement system.

Finally, you can find a first draft of the device specifications in Table 1. Through further research, these specification will become more precise and may change.

Feasibility assessment

Electrodes: The choice of dry electrodes arises from the fact that the traditional Ag/AgCl wet electrodes present challenges in our application such as discomfort for the young patients (hair removal, grinding of the horny layer of skin, presence of gel), as well as gel evaporation during long sessions.
The main issues in Laura's current electrode system are high noise levels and poor signal quality. We have therefore chosen to proceed with common-contact dry electrodes, discarding capacitive and invasive microneedle dry electrodes.(capacitive electrodes have high interface resistance, microneedle electrodes cause discomfort as well as infections to the patient.)
The challenge now is to make a common-contact dry electrode that has good adhesion to the skin (it will be subjected to normal movement spasms, and to sweat), to ensure a continuous measurement at a constant location on the muscle (for calibration of the different thresholds of amplitude to identify the movement, the measurement must be taken from a constant location). Research has been made on both ultra-thin dry electrodes as well as on micro-structured electrodes to best answer the mentioned challenges [1]. These are our current candidates for electrodes.
Super stretchability and flexibility are the ideal components of the dry electrodes to ensure conformal adhesion. The materials selected as well as the overall electrode should have a young modulus closely matched to that of the skin as possible. Elastomers, gels and semiconductors polymers are good candidates to be the substrate of the electrode and ensure such requirements. Conductivity is another important feature of our device and can be enhanced by using metals as fillers [1]. To ensure biocompatibility with the skin, preventing the risk of infection, the utilisation of natural materials like silk protein (SF) and dopamine can be employed.[1].
The choice of electrode type needs to yet be made before choosing more specifically the materials as well as defining a manufacturing process.
Electrode placement system: To be wearable daily and work efficiently we have to take into account several requirements in the design of the system. The support needs to maintain the electrodes, even when subjected to sweat, spasms, chocks or movements. The device must be easy to set up and work properly even if not placed perfectly (re-calibration for each usage). In this context, individual electrode patches, as discussed in the study by Liu et al [4], are excluded due to the time-consuming nature of their placement, even when there is no intention to reposition them. We thought about a regular armband [6], but it could be uncomfortable to wear throughout the entire day, additionally this system can slide. Furthermore, we have to target multiple muscles covering a broad area when the armband is local. To overcome this problem multiple bands could be used in parallel [2] but we will have to find a solution to avoid multiple wires from getting entangled. Finally, the electrodes

[1]Laura's project was part of the Hackathealth'hackaton [3] edition 2022 and the rudimentary set-up mentioned correspond to what the team managed to build and was later refined as the project went on thanks to founding. Currently, the team lacks people experienced in the domain of electronics and signal processing and would therefore highly benefit from a course such as this one. Therefore we contacted Laura's therapist to have his consent and she agreed mentioning that it would even if it's only theoretical.

could be placed along arm-sleeves, avoiding complex wiring and allowing to shape the sleeve to fit the arm and facilitate the placement of the electrode on the muscles.
Acquisition signal processing: The signal recorded by the electrodes could be processed at the level of the wearable device or on an external processing unit. Pros and cons of the two methods are developed in Table 2.

Conclusion

Several decisions are still pending, especially concerning the electrodes (type, materials, manufacturing), the placement system, connectors, battery, power consumption and data processing. Further research will allow to answer this. As this project involves young patients, there are many additional challenges concerning non-invasivess, long-term monitoring and high signal-to noise ratio. The will to use research material not yet marketed is an additional one but also open the doors of new devices. Special care will have to be given to the manufacturing to achieve the results expected and special recipes of microfabrication will have to be designed. Tradeoffs will certainly have to be made as well.

Table 1: Specifications

required function	criteria of appreciation	flexibility
weight	lightest possible	max 80g (based on smartwatch)
wearable daily	comfort (minimise sweat)	not warm, no friction
	support movements	without displacement
	long battery life time	min 15h autonomy
	water resistant	IP67 resistant (norm)
	breathable material	enable evaporation of sweat and skin-gaz
	installed quickly	max 3minutes. No wire entanglement
recording quality	signal-to-noise ratio	Allow differentiation involuntary/voluntary
	continuous skin-contact	match skin Young's modulus (1MPa)
bio-compatibility	no adverse reaction	not abrasive/toxic
recording range	correct frequency range	50 to 150 Hz [5]
	correct voltage thresholds	(additional research needed)
feedback	comprehensive/didactic feedback for rehabilitation	visual or auditory feedback when involuntary movement detected
aesthetics	Yong-user friendly	subjective

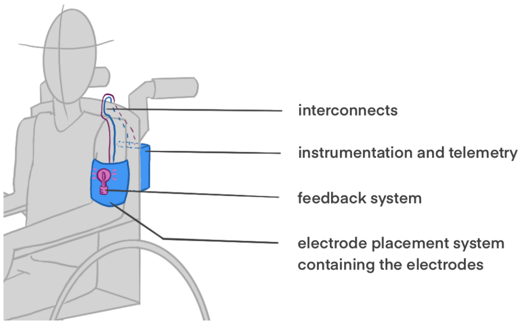

Figure 1: General device concept

	pros (+)	cons (-)
signal processing in the device	wearable (no exterior cables management) handy (less parts, quick installation) no noise du to wire movement	carry battery (bigger & heavier) no in-depth signal processing slack
signal processing on exterior device	smaller device on body (lighter) can be second-skin-like more precise data processing can be done	cable management cables source of noise

Table 2: acquisition signal processing

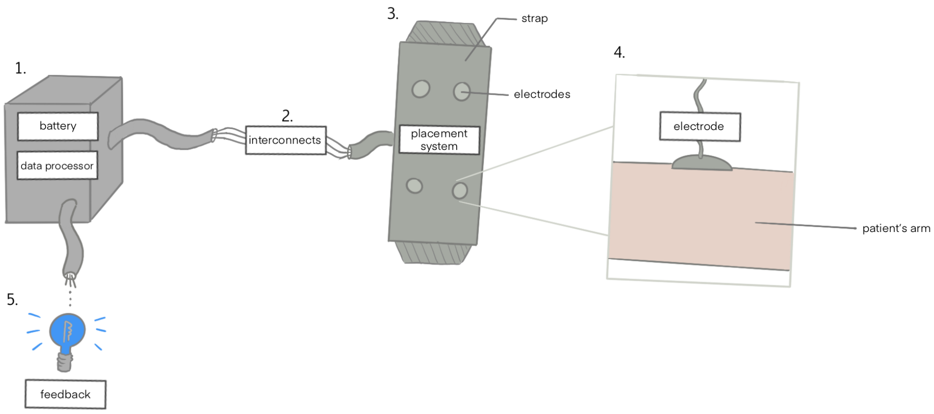

Figure 2: Building blocks

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