

Rehabilitation after Stroke: Practicable Functionalities and Benefiting Patients of Brain-computer Interfaces in Combination with Functional Electrical Stimulation – A Qualitative Interview Study

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Abstract

Introduction: Brain-computer interfaces in combination with functional electrical stimulation (BCI-FES) is currently researched whether it is a viable approach for post-stroke rehabilitation, but it is important to know which patient groups can benefit from such systems and what features it should have to be accepted and used in a clinical context.

Materials and Methods: A qualitative interview study with eight staff members from a regional hospital with a supraregional stroke unit was conducted. Categories were independently extracted from the answers.

Results: The results indicate that such systems must be easy to operate, quick to setup, and should possibly be usable at home. The interviewees state that Phases A and B patients (acute rehabilitation and early rehabilitation) may not benefit from such systems as they usually do not have the cognitive abilities to understand and implement the instruction.

Conclusion: BCI-FES system is currently not useful for inpatient rehabilitation routine of a stroke unit due to the lack of time and complexity of such systems. Furthermore, it should be evaluated how Phases C and D patients (follow-up rehabilitation) can benefit from such systems.

Key words: Brain-computer interfaces, Electrical stimulation, Electroencephalography, Rehabilitation, Stroke

INTRODUCTION

Stroke is the second leading cause of death worldwide and one of the most common causes of severe disability in adulthood.^[1] Up to three-quarters of those affected survive the stroke and must then be provided with specific drug therapies and rehabilitative or nursing services.^[2]

In Germany, a phase model (A-G) exists for the different stages of stroke rehabilitation. Phase A includes acute care, in which the patient is treated in a stroke unit, intensive

care unit, or normal ward. Phase B is the beginning of early rehabilitation, in which intensive treatment and rehabilitation with medical and therapeutic focus is carried out. In Phase C, the patient needs much less help in coping with everyday life, so that mobilization and the restoration of independence are the main focus here. The purely medical rehabilitation ends with Phase D, the follow-up rehabilitation treatment, in which the main focus is the reduction of existing disability.^[3]

However, up to 40% of the surviving stroke patients have long-term limitations in the activities of daily living and thus suffer from problems with mobility, personal hygiene, independent dressing, and eating.^[4] For this reason, early, effective rehabilitation is crucial for the long-term quality of life of those affected.^[5] Consequently, there is a constant need for the development of new therapeutic strategies that will enable a significant improvement in rehabilitation procedures.^[6]

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At present, brain-computer interfaces (BCIs) are increasingly important in rehabilitation therapy after stroke. BCIs aim to create a new communication channel between the brain and external devices without any neuromuscular intervention.^[7] They may fill the gap between patient expectations and therapy results. BCIs capture, analyze, and use electroencephalography (EEG) activity in real-time. Patients imagine a certain movement and the corresponding brain activity is recorded by EEG electrodes and sent to an amplifier. When the correct movement is interpreted by the classification algorithm of the BCI, sensory feedback is provided by external devices.^[8]

Based on this, BCIs are currently being researched in combination with functional electrical stimulation (FES) in post-stroke patients.^[9-11] FES is a technique in which electrical currents are applied to produce artificially controlled muscle contractions.^[12] The main advantage of rehabilitation based on BCI-FES over conventional therapies is that it is based on the patient's active intention to move, which simultaneously activates sensory and motor pathways and thus promotes neuroplasticity.^[9] The enhancement of neuronal plasticity after a stroke by BCI-FES is a sustainable approach that opens up new possibilities for stroke rehabilitation.^[13] However, according to a systematic review, a positive effect of BCI and FES is only marginally detectable and has to be compared to a very high therapy effort. None of the studies conducted to date have provided clinically convincing results with regard to improved motor rehabilitation.^[13]

For this reason, it is important to know in which phase and for what patient groups the application of BCI in combination with FES should be considered. It is also necessary to check which functions a system must have to be used sensibly in everyday rehabilitation practice.

To elaborate these questions, a qualitative interview study at a regional hospital with a supraregional stroke unit was conducted. The aim of the study was to ask employed neurologists and non-medical staff about rehabilitation therapy after stroke. The survey focused on the question of which patient groups, according to the experts, can benefit from BCIs in combination with FES, what weaknesses such systems currently have, and what functionality it should have in order to be used in practice. The interview took place in the overall project "Technische Innovation in der Schlaganfall Rehabilitation" (Technical innovation in stroke rehabilitation) (04/2019–12/2021), where a BCI-FES device is developed.

MATERIALS AND METHODS

The present study is based on eight guideline-based expert interviews with neurologists ($n = 5$), physiotherapists ($n = 2$)

and a nurse from the neurology department of a stroke unit [Table 1] and was approved by the ethics committee of the University of Applied Sciences Zwickau. A guideline was developed, which was used as a basis for all interviews. Thus, individual interviews are easily comparable, since the survey situation is similar and the same questions were asked.^[14] The guideline was divided into six topics:

1. Current forms of therapy
2. Wishes and requirements for stroke rehabilitation
3. Experiences with BCI and FES
4. How the system should work in practical application
5. Concerns about the use of BCI and FES
6. Benefiting patient group.

Interviewees were referred in 2020 by the head of the participating hospital using the gatekeeper method, where the gatekeeper provides pre-selected interview partners.^[15] Following common qualitative sampling strategies, the selection of the interview partners aimed at a composition of the group that was as heterogeneous as possible.^[16] The target groups were experts from the professional groups of medicine, physiotherapy, and nursing. The experts had different hierarchical levels. The fields of work of the professional groups are accordingly heterogeneous and range from medical care and therapeutic procedures to basic and treatment care. After the pre-selection process, the respondents who had agreed in principle to participate received information material on the topic of the interview. All interviewees gave their consent to participate in the study after having been informed in advance.

The interviews were conducted by a nursing and a computer scientist and recorded with a tape recorder and transcribed according to the rules of transcription. During transcription, all personal data were anonymized. The evaluation of the data was carried out according to the systematic and rule-guided procedure of Mayring.^[17] The focus was on the development of a category system. Categories are developed in a reciprocal relationship between the question and the concrete material, defined by construction and assignment rules, and revised and re-examined during the analysis. Through the inductive category definition, the categories were derived directly from the material without referring to previously defined theoretical concepts.^[17] The categories were created independently by two scientists and then compared

Table 1: Sample structure with regard to assignment and duration of activity

Assigned professional role	Duration of activity
Neurologists ($n=5$)	Mean 19.8 (± 7.02) years
Physiotherapists ($n=2$)	Mean 14 (± 4) years
Nurse ($n=1$)	15 years

with each other. The deductively formed categories and inductively formed subcategories that were found out by both scientists were coded during the analysis of the interview material [Table 2].

RESULTS

On behalf of the interview material, it could be determined that the most frequently used therapy after a stroke is physiotherapy. In the following occupational therapy, speech therapy and neuropsychology are used as rehabilitation therapy in the first phases after the stroke, depending on the type of stroke. In the field of outpatient rehabilitation, occupational therapy and sports therapy were also mentioned.

In the beginning, it was of interest to find out what wishes and requirements result from the view of the hospital staff for the stroke rehabilitation. Half of the respondents stated that the therapies should be patient-oriented and individualized. Three of eight also had the opinion that it would be useful to implement digitization in stroke rehabilitation. With reference to this, one member of the physiotherapy staff (T/P1, personal interview, July 15, 2020) expressed the following opinion:

- We need modern, contemporary tools ... adapted ... electronically controlled through apps, adaptable to the patient.

BCI in combination with FES is unknown to all respondents. Only one physiotherapists and two neurologists are familiar with similar procedures, mainly from Parkinson disease rehabilitation therapy. Brain stimulators have been named

Table 2: Categories and subcategories ordered by importance (how often it was named)

Categories	Subcategories
Stroke therapy wishes and requirements (WR)	WR1 – Patient-oriented therapy (4)
	WR2 – Digitalization (3)
	WR3 – Longer therapy sessions (3)
	WR4 – Interdisciplinary collaboration (2)
Requirement for BCI-FES Systems (RS)	RS1 – Quick to set up (6)
	RS2 – Easy to operate (5)
	RS3 – Usable at home (4)
	RS4 – Useful movements (2)
	RS5 – Entertainment value for patients (1)
	RS6 – Evidence based (1)
Concerns BCI-FES Rehabilitation Systems (CBF)	CBF1 – Lack of effect (4)
	CBF2 – Comprehension problems (3)
	CBF3 – Risk of falling (2)
	CBF4 – Damage by current (2)
	CBF5 – Therapist substitution (1)
Patient group (PG)	PG1 – Adequate, cognitively fit patients (5)
	PG2 – Patients with affinity for technology (2)

BCI-FES: Brain-computer interfaces in combination with functional electrical stimulation

for this purpose, which are invasive and should lead to improved mobility.

In spite of the limited experience, all respondents can imagine working with a BCI in combination with FES. To design therapy units in a meaningful way, however, the systems should be easy and quick to set up and operate. One neurologist (A4, personal interview, July 23, 2020) summarized the following functions:

- It must be quick to put on. It does not make sense that it takes half an hour of preparation time to put on the hood, etc. This is not possible in the general therapy concept.

In terms of ease of use, several respondents could imagine that the device would also have to be operable at home by the patient himself or a relative. For this purpose, however, an exact electrode placement would have to be defined. However, this is not easy to implement, since the correct electrode location is different for each person with regard to anthropometric data, such as length and mass of the forearm.^[18] A physiotherapist (T/P2, personal interview, July 15, 2020) expressed the following functionalities:

- It should have the ability that the electrodes stay where they are or set a marker where they have to go ... so that you can use it at home.... It has to be constructed so simply that the patient or the relatives can understand what they have to do with three switches..., otherwise it quickly leads to frustration.

According to several interviewees, another major benefit of this system lies in the area of motivation. Especially for cognitively unrestricted patients, the additional feedback triggered by the electrical muscle stimulation can lead to an increased feeling of therapeutic success. For many patients, it is sufficient to stimulate a movement to standardize it.

The application should be wireless, so that the risk of falling is minimized and ease of use is simplified. In addition to the therapeutic benefits, all those involved have sometimes very different concerns about such systems. According to the respondents, this system cannot be used for every stroke patient.

According to the interviewees, it is mainly patients who belong to Phases C and D who benefit from the system, that is, who can have a certain mobility and alertness.

Participation in the therapy requires not only motivation but also certain cognitive abilities of the patient. For example, old age, multimorbidity, depression, and fatigue often play a decisive role.^[13]

One neurologist (A4, personal interview, July 23, 2020) summarized the concerns as follows:

- I am concerned that patients simply do not understand this in the acute phase. After all, patients are asked to actively cooperate. I think that this is difficult in the acute phase. In the end, it is mainly about the severely affected patients. Those who have mild paresis are more likely to benefit from active therapy. It is more about the patients who have severe paresis. They are usually also severely affected. They simply have to have the cognitive abilities to implement this at all.

A member of the physiotherapy staff had the opinion that the system should not be seen as the only sensible therapy. Only in combination with classical rehabilitation methods, it could be an asset for the practice. These applications must not suggest to the patient that these are the only rehabilitation options.

DISCUSSION

One of the main concern against using a BCI System in a clinical context is the technical complexity^[19] which our interviewees stated indirectly with RS1 and RS2. BCI in combination with FES is not feasible for every stroke patient as Hashimoto *et al.* state that “patients with early stroke are not able to activate the sensorimotorcortex enough to affect their EEGs”^[10] which correlates to PG1 and is also supported by Hernandez-Rojas *et al.*^[11] A meta-analysis of different clinical trials indicates a positive effect using BCI and FES in a clinical context;^[20] however, the effect in contrast to the effort was not evaluated. Other literature state that it can be difficult for clinicians to select a beneficial BCI method as “the specific mechanisms underlying functional improvements remain largely unknown”^[21] which can lead to frustration because of a lack of effect. Despite the fact that interviewees were naive about BCI in combination with FES, they gave valuable information that is supported by literature and contain new aspects that should be considered in designing a BCI-FES therapy.

CONCLUSION

Post-stroke rehabilitation through BCI-FES can open up new possibilities for stroke rehabilitation. However, the results of the survey and Simon *et al.*^[21] indicate that the system is not practicable in its current application for use in the inpatient rehabilitation routine of a stroke unit. A too long preparation time disturbs an efficient flow of the therapy units. Due to the complex location of the electrode placement and the time limited therapy units, the therapy is difficult to implement. This is also reflected in a systematic review: The application of BCI and FES means

a high therapy effort, which is opposed by a so far only marginally demonstrable therapy success.^[13]

Furthermore, from the perspective of physical therapists, finding the correct location of the electrodes prevents a quick and easy therapy session. Furthermore, according to a systematic literature review, this has been identified as a problem in the use of BCI in conjunction with FES. Most of the research studies reviewed did not accurately define the exact electrical placements.^[18] Patients who are hospitalized shortly after a stroke often belong to Phases A and B, where medical care and early rehabilitation are generally the first priority. In many cases, the severely affected patients are not able to understand and implement instructions. Therefore, it should be investigated to what extent patients of Phases C and D benefit from the therapy compared to Phases A and B patients which is also supported in the literature.^[10,11]

Furthermore, the use of therapy at home by relatives or outpatient physiotherapy would also be conceivable. However, even in this case, the system should follow simple structures in its application and usability.

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