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The prospects of brain – computer interface applications in children

Mini-Review

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Abstract: The restoring of motor functions in adults through brain-computer interface applications is widely studied in the contemporary literature. But there is a lack of similar analyses and research on the application of brain-computer interfaces in the neurorehabilitation of children. There is a need for expanded knowledge in the aforementioned area. This article aims at investigating the extent to which the available opportunities in the area of neurorehabilitation and neurological physiotherapy of children with severe neurological deficits using brain-computer interfaces are being applied, including our own concepts, research and observations.

Keywords: *Children • Neurological disorder • Brain-computer interface • Neuroprosthesis • Quality of life*

1. Introduction

Reported incidence rates of severe neurological disorders in children are not low, e.g. the prevalence of pediatric stroke is estimated to be 2-3/100 000 [1]. The problem of pediatric neurorehabilitation in severe neurological conditions (e.g. post-stroke, after spinal cord injuries – SCI, muscular dystrophies, cerebral palsy, cerebral malformations, etc.) seems to be underscored. There is a necessity to search for the newest, most effective therapeutic approaches. There is a need to adapt effective solutions from the neurorehabilitation of adults if possible. One of the most advanced technical solutions is represented by brain-computer intefaces (BCIs), which utilize signals recorded directly from the patient's brain for communication, control, diagnostics, and rehabilitation purposes.

It is rather difficult to determine the possible disorders at which BCIs could be applied in children. The knowledge of scientists and clinicians in the area of indications and contraindications is limited and requires further research. Moreover, medical, technical, ethical and legal issues should be taken into consideration in every individual case. Despite the aforementioned problems, the authors strongly believe the application of BCIs in children with neurological disorders may constitute another breakthrough and needs deeper research and support. This article aims at investigating the extent to which the available opportunities in the area of neurorehabilitation and neurological physiotherapy of children with severe neurological deficits using BCIs are being applied, including our own concepts, research and observations.

2. EEG-based BCI

A brain-computer interface (BCI) may be regarded as a "linking device" (or even a "bypass") between the human brain and the computer, usually where the normal flow

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and/or execution of commands from the brain (e.g. to the peripheral muscles for motor purposes) has been disturbed or interrupted. BCIs record cortical signals with the objective of:

- diagnosis (e.g. in patients with disorders of consciousness);
- communication (e.g. using word processor);
- controlling artificial limbs (or other neuroprosthetic devices), powered wheelchairs, exoskeletons, smart home systems, etc.;
- other applications (e.g. supplementary channel for neurorehabilitation purposes) [2].

Thanks to BCI recorded signals, (originating from the brain) reflecting a patient's intent can be analyzed (usually in real-time processing) and transformed into messages (for communication purposes) or commands compatible with controlled devices. BCI solutions may be divided into:

1. electrode arrays implanted directly in the brain (e.g. BrainGate2);
2. non-invasive electrodes placed directly on the scalp (e.g. Wadsworth BCI System), mainly (approx. 60%) based on one of the three following BCIs paradigms:

- P300;
- steady-state visual evoked potentials (SSVEP);
- event-related desynchronization/synchronization (ERD/ERS) [2].

Of course there are a lot of other signals that are regarded as useful in BCIs. Each of them has its own advantages and disadvantages. The use of a particular solution depends on many factors. (Figure 1).

Despite the rapid development of BCIs, there may be problems with their use in children [2]. The following may play a significant role:

1. a lack of indications and contraindications (including e.g. epilepsy);
2. a lack of procedures, guidelines, and recommendations according to the evidence based medicine (EBM) paradigm;
3. a slower development of brain-signal analysis in children – mainly due to:

- increased neural plasticity,
- problems with focal localization of the cortical activity,
- lesion modified activations,
- possible poor correlation of the behaviorally-associated cortical activations,

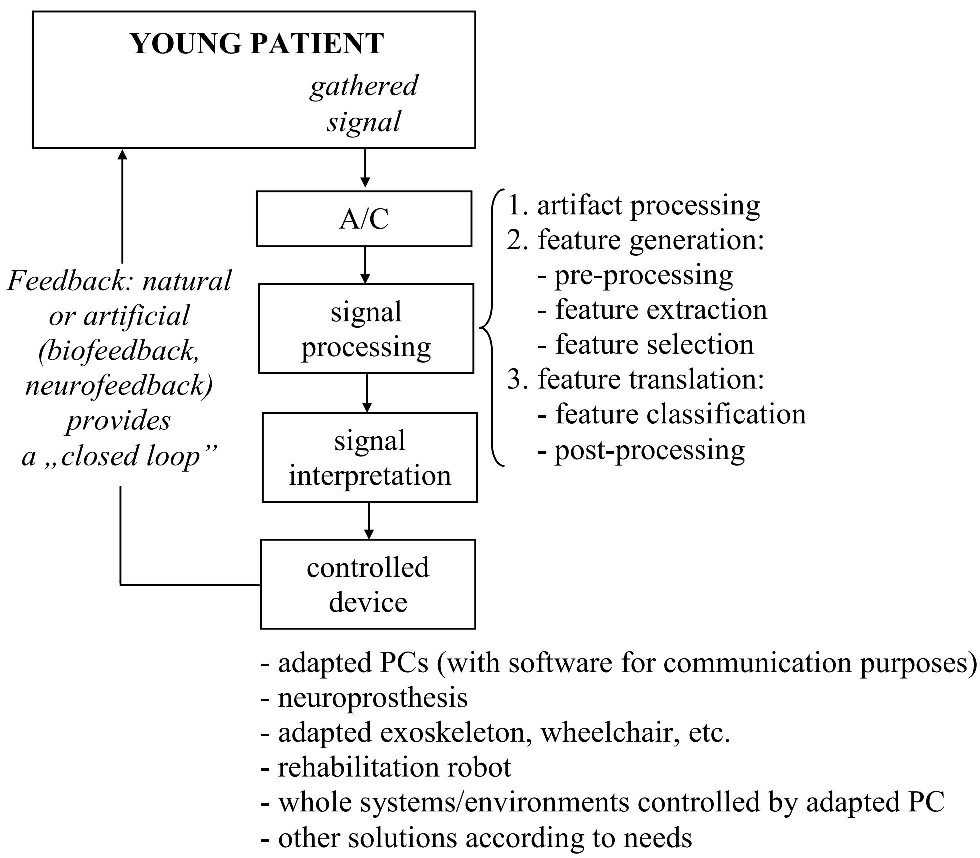

Figure 1. The general brain-computer interface concept [2]

- random stochastic activity,
- a need for correlation with distinguishing cognitive tasks, etc. [3].

3. The specificity of EEG use in children

EEG testing in children needs additional preparations in the areas of:

- personnel selection towards the cooperation with children and their parents based on the psychology of child development;
- nice/pleasant room decor, kids' room arrangement, a lot of toys, pictures, books, etc.;
- the comfort of children with severe neurological disorders, including the possibility of sleep, particularly in newborns and infants;
- avoiding fearful situations, e.g. the lack of invasive assessment just before EEG investigation,
- proper positioning of the child (especially with neurodisabilities) both for optimized safety and comfort, and to prevent movement artifacts;
- proper electrodes' positioning and montage;
- the proper preparation of children, including talk, games, fairy tales, feeding (low glucose level may change EEG findings), etc. [4].

The interpretation of EEG findings in children needs particular knowledge, experience, and awareness of possible difficulties. Moreover, signals useful for BCI applications should meet the following requirements:

- easy to recognize in (almost) every patient;
- easy to learn how to intentionally influence their features;
- easy to acquire and interpret the control of devices in real-time;
- impervious to errors and distortions;
- safe for common use [2].

Thus, BCI selection and fitting procedures, patient assessment and preparation, and BCI everyday use in children may significantly differ from the previous experiences in adults. Continuous development of the young nervous system may change its features, and make continuous adjustments of the BCI device necessary, including not only upgrades, but even replacement. Moreover, all tools for assessment, self-diagnosis, and training have to be attractive enough for children (e.g. compared with current computer games), and easily adapted to the child's age, deficits, needs, and preferences. Cooperation with very young patients may be the most challenging part of the clinical BCI's use in children.

4. Research

A critical review of bibliographic databases showed publications concerning BCI application in children very rarely. Research by Breshears et al. aimed at studying if brain-derived computer control in children may be comparable to the performance previously reported for adults. This study proved the usefulness of the pediatric brain electrocortical signals as a source for BCI operation (including neuroprosthetic control). Moreover, very quick adaptation was possible: all six children achieved accuracies of 70-99% within nine minutes of training (using the same tasks). This result was similar to that achieved by adult patients [3]. There is need for further research on bigger samples of young patients, especially to assess if children's computer control is comparable to the performance in adults in a way allowing for the use of the same or similar devices.

Brain-derived signals may change with age, disturbing long-term BCI use. Thus, the use of electrocorticography (ECoG) with high gamma rhythm (76-100 Hz) may be an important solution due to the unchanged (with age) and focused localization. The rest of the cortical bands: delta (<4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and low gamma (30-50 Hz) are regarded as changing (e.g. broadening localization) with age [5,6]. ECoG-based BCIs have shown significant promise for clinical application due to the high level of information that can be derived from the ECoG signal, the signal's stability, and its intermediate nature of surgical invasiveness [5].

A survey by Cincotti et al. included four teens: one twelve y. o., and three sixteen y. o. Various disorders and associated residual abilities may require various solutions – thus the need for flexible systems integrating several different assistive technologies including i.a. BCIs [7].

According to research by Ehler et al. [8], describing the use of SSVEP-based BCI mean accuracy rates depends both on the age of the patients and the frequency of stimulation (where low frequency: 7-11 Hz, medium frequency: 13-17 Hz, high frequency: 30-48 Hz). The best mean accuracy independent from the applied frequency showed a group of adult patients – respectively: approx. 78%, 78%, and 62%. On the other end, the two youngest groups of children showed a mean accuracy below 60% independent from the applied frequency of stimulation. Among the children, the worst mean accuracy (below 40%) was achieved by the youngest group with high frequency stimulation, and the best mean accuracy (approx. 76%, while mean accuracy in adults was approx. 78%) was achieved by the oldest group of children. The aforementioned results may support the evidence that there are significant differences in the use of SSVEP-based BCIs in children and in adults. Moreover, the study showed the potential direction for further research in the area of the smaller frequency differences between adults and children. The use of the SSVEP paradigm in children may be regarded as possible to the limited extent described by the required mean accuracy. What is more, the use of SSVEP-based BCI in children above approx. eight y. o. is possible, while the use of it in children below the aforementioned age needs particular attention and further research aimed at more efficient solutions, due to i.a. visual annoyance and users' fatigue. Scientists and clinicians do not know if these results are strictly development-dependent. Moreover, Ehler et al. have some research data unpublished – we hope they will be published in the near future (Table 1).

The quality of life of people suffering from severe motor disabilities can benefit from the use of current assistive technology capable of ameliorating communication, house-environment management and mobility, according to the user's residual motor abilities. Brain-computer interfaces (BCIs) are systems that can translate brain activity into signals that control external devices. Thus, they can represent the only technology for severely paralyzed patients to increase or maintain their communication and control options [7].

Results of long-term BCI use in children are not known and need further research assessing chances of success and threats. Its influence to the young developing nervous systems may be perceived as at least debatable so far. No doubt the mental workload during BCI use may be an important issue [9]. Contemporary outcomes from the use of BCI-based games (e.g. MindBall), BCIs in ADHD treatment [10], and biofeedback may be useful, but we do not know if previous experiences in this area may be generalized. Contemporary neurofeedback aims at:

- support of the other therapeutic methods, e.g. rehabilitation robots, for better patient motivation purposes,
- therapeutic EEG signal optimization,
- brain enhancement,
- entertainment (game BrainGame, device BrainWave TV, etc.).

5. Discussion

BCIs may be regarded as a good diagnostic and, in selected cases, therapeutic tool, even in very young children, including children with disorders of consciousness. In this area, Egeth [11] described the concept of the BCIs' application in locked-in children and adults based on previous research on auditory attention in children by Gomez et al. [12] and Sanders et al. [13]. Further studies in the area of auditory event-related potentials (ERPs) in 4- and 5-year-old children by Sanders et al. [14] showed auditory processing quite similar in young children and adults. These findings may constitute promise towards further use of auditory ERPs in ERP-based BCIs in the youngest children with neurological disorders.

Table 1. Available data from the literature concerning BCIs' application in children

Author	Population and sample	Diagnosis	Technique of BCI
Breshears et al. [3]	n=6, aged 9-15 years	Intractable epilepsy	ECoG, implanted electrode array, 48-64 electrodes
Cincotti et al. [7]	n=14 aged 12-35 years (including two patients 12 y.o. and three 16 y.o.), additional control group n=14	Healthy subjects vs. patients with severe motor disabilities due to progressive neurodegenerative disorders: Spinal Muscular Atrophy type II (SMA II) or Duchenne Muscular Dystrophy (DMD), unable to walk	EEG, motor imagery
Ehlers et al. [8]	n=51, adults and children aged 6-33 divided into four groups: group 1: n=11, mean age=6.73, group 2: n=12, mean age=8.08, group 3: n=14, mean age=9.86, group 1: n=14, mean age=22.36	Healthy right handed, with normal or corrected-to-normal vision, no prior experience with BCIs, no obvious somatic disease, no history of head injury, no neurological or psychiatric disorder, and no drug-related illness, no medication taking during the research	SSVEP
Lim et al. [10]	n=20, mean age=7.80	Children with inattentive or combined subtypes of ADHD	EEG-based attention training game system

Both structural and functional nervous system development is a long-term process reflected in changing EEG. The associated predominance of various EEG signal features (frequencies, amplitudes) depends on the age, artifacts, asymmetries, etc.. Responses to stimulus change in a similar way. There are significant individual differences observed. Thus normal values of the EEG parameters change with age, and EEG interpretation depends on both children's age and level of maturity. Even EEG investigation in premature babies differs significantly [4]. All this presents a challenge for the designers of BCIs for children. Signal selection and preprocessing should be limited to signals beyond all doubt.

There is the possibility of disturbing proper BCI operation as a result of a bad mood, fear, fever, drugs, etc. Functional adaptation of the human-machine system may be significantly different in children, so there is a need for additional research.

No doubt contraindications to active BCI use (for communication and control purposes) in children should be mental illnesses, severe uncontrolled tics, and lack of understanding of the BCI's application and functioning. There is still discussion if epilepsy may be regarded as contraindication to BCI use. Moreover, BCI use may have repercussions that will be more significant on the neurorehabilitation of children than on adults.

Contemporary knowledge of scientists and clinicians seems to be incomplete, and not all issues are clear. There is a need for a deep awareness of the ethical issues and possible long-term influence of BCIs on a young developing nervous system. Moreover, there is a lot of BCI devices used for entertainment purposes – no doubt children apply them despite the lack of research in the area of their long-term use. There is a need to pay particular attention to threats in this aforementioned area. Scientists do not know exactly how the use of the human-machine interface, including lack of particular senses or external stimulus, influences a young developing nervous system. In addition, the ethical and legal considerations associated with more common BCI use may significantly change our society. The impact of the long-term use of BCI-controlled neuroprostheses in children is not known – their temporary use may not be possible due to changes associated with young motor control systems. This kind of proposed BCI-controlled recovery (shaping) of the nervous system and the return (even partial) to the natural tissues' use may not be possible. Thus, we should differentiate between controlled recovery and function replacement, and be aware of its results and limitations. Recent research by Dominici et al. [15] and van den Brandt et al. [16] on remodeling of cortical projections, and restoration of control over electrochemically enabled spinal cord structures may be very important in the aforementioned area.

There is a strong need for more research on the clinical application of BCIs in children. This article may be regarded as an introduction to further studies by the authors.

6. Conclusions

To conclude, rational use of BCIs may provide a new effective tool in contemporary healthcare in children with neurological disorders, despite well known differences in the cortical maturation and (neuro) physiology between children and adults. In selected severe cases of children with neurological deficits, BCIs' application may be the only solution for communication and/or control purposes.

References

[1] Mikołajewska E. Neurorehabilitation in pediatric stroke. J Health Sci, 2012, 2, 23-31

[2] Mikołajewska E., Mikołajewski D. Neuroprostheses for increasing disabled patients' mobility and control. Adv Clin Exp Med, 2012, 21, 263-272

[3] Breshears J. D., Gaona C. M., Roland J. L., et al. Decoding motor signals from the pediatric cortex: implications for brain-computer interfaces in children. Pediatrics, 2011, 128, e160-168

[4] Artemowicz B., Sobaniec P. Badanie EEG w neuropediatrii [EEG investigation in neuropediatrics (article in Polish)]. Neurologia Dziecięca, 2011, 20, 89-95

[5] Roland J., Miller K., Freudenburg Z., et al. The effect of age on human motor electrocorticographic signals and implications for brain-computer interface applications. J Neural Eng, 2011, 8, 046013

[6] Kellis S. S., House P. A., Thomson K. E., et al. Human neocortical electrical activity recorded on nonpenetrating microwire arrays: applicability for neuroprostheses. Neurosurg Focus, 2009, 27, E9

[7] Cincotti F., Mattia D., Aloise F., et al. Non-invasive brain-computer interface system: towards its application as assistive technology. Brain Res Bull, 2008, 75, 796-803

[8] Ehlers J., Valbuena D., Stiller A., Gräser A.

Age-specific mechanisms in an SSVEP-based BCI scenario: evidences from spontaneous rhythms and neuronal oscillators. Comput Intell Neurosci, 2012, 967305

[9] Felton E. A., Williams J. C., Vanderheiden G. C., Radwin R. G. Mental workload during brain-computer interface training. Ergonomics, 2012, 55, 526-537

[10] Lim C. G., Lee T. S., Guan C., et al. A brain-computer interface based attention training program for treating attention deficit hyperactivity disorder. PLoS One, 2012, 7, e46692

[11] Egeth M. A. „Turing Test" and BCI for locked-in children and adults. Med Hypotheses, 2008, 70, 1067

[12] Gomes H., Duff M., Barnhardt J., et al. Development of auditory selective attention: event-related potential measures of channel selection and target detection. Psychophysiology, 2007, 44, 711-727

[13] Sanders L. D., Stevens C., Coch D., et al. Selective auditory attention in 3- to 5-year-old children: an event-related potential study. Neuropsychologia, 2006, 44, 2126-2138

[14] Sanders L. D., Zobel B. H. Nonverbal spatially selective attention in 4- and 5-year-old children. Dev Cogn Neurosci, 2012, 2, 317-328

[15] van den Brand R., Heutschi J., Barraud Q., et al. Restoring voluntary control of locomotion after paralyzing spinal cord injury. Science, 2012, 336, 1182-1185

[16] Dominici N., Keller U., Vallery H., et al. Versatile robotic interface to evaluate, enable and train locomotion and balance after neuromotor disorders. Nature Medicine, 2012, 18, 1142-1147