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WHICH FACTORS AFFECT THE ACCEPTABILITY OF BCIS FOR FUNCTIONAL REHABILITATION AFTER STROKE AMONG PATIENTS?

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ABSTRACT: Although motor imagery-based BCIs have been demonstrated to be relevant for improving motor recovery after stroke, they remain barely used in rehabilitation services. We hypohesise that *acceptability* (which is assessed in terms of perceived usefulness, ease of use and intention to use) could serve as a lever for fostering the adoption of BCIs through the improvement of their efficacy. More precisely, we suggest that improving the acceptability of BCIs could alleviate post-stroke patients' anxiety, stimulate their motivation and engagement in the BCI process, and thereby, favour skill acquisition (here self-regulation abilities), which will ultimately have positive effects on motor recovery. We created a model of acceptability of BCIs specifically for functional rehabilitation after stroke, and designed an associated questionnaire that was used to empirically assess the weight each factor of the model had on acceptability. Hereinafter, we introduce the methods and results obtained based on the responses received from 140 patients, and compare them with data collected in the general public (N=753). In a nutshell, for both the general public and patients perceived usefulness, scientific relevance and ease of learning emerge as the most influential factors.

INTRODUCTION

BCI-based functional rehabilitation procedures have demonstrated their efficacy to improve post-stroke patients' motor and cognitive abilities [1, 2]. In the coming years, they are expected to substantially improve the quality of life of those patients [2].

In classical functional rehabilitation procedures, when subjects have no residual movement, i.e., when they cannot voluntarily move their affected limb, physical practice is impossible and both subjects and therapists must mainly rely on mental practice alone. Mental practice includes motor imagery (MI) as well as attempted movements. In this context, BCIs are very relevant as they enable the detection of MI / attempted movements of the impaired limb, which are underlain by modulations of the so-called sensori-motor rhythms (SMRs)—as defined in the BCI field by a large band covering mu (μ) and beta (β) rhythms (8–30 Hz) [3]—, and provide the patient with a synchronised neurofeedback (NF), for instance using functional electrical stimulation that triggers an arm muscle contraction, or visual feedback (movement of a virtual hand on a screen [4]). Such a NF training enables the participants to train to voluntarily self-regulate their SMRs in a closed loop process, which should favour synaptic plasticity and motor recovery [5].

While this is encouraging, BCI efficiency is still far from the level required to achieve the clinical breakthrough expected by both clinicians and patients. Thus, BCIs remain barely used in clinical practice, outside laboratories [6]. BCI efficiency is known to be modulated by several factors. Many researchers are working on improving this efficiency either from a "technical" point of view (e.g., signal processing [7]), or from the human learning standpoint [8, 9]. Nonetheless, it might not be sufficient for those technologies to be actually used in a clinical setting: fully optimised BCIs (in terms of sensors, signal processing, and training procedures) are pointless if patients and clinicians are not able or do not want to use them, i.e., if BCIs are not accepted [10].

The concepts of acceptability and acceptance were introduced in order to understand what led users to adopt or not a new system [11]. The adoption of a technology refers to a use that is maintained over time, i.e., without abandonment. Acceptability and acceptance differ by the moment they are measured at: acceptability concerns the user's standpoint before any interaction with the system, while acceptance comes after at least one first use.

Misconceptions that patients and their entourage have regarding BCIs may have a detrimental effect on the acceptance of these technologies. For instance, BCI procedures are not often adapted to the general clinical guidelines and practices (e.g., organisational constraints, lack of training time), so caregivers are not engaged to use them [12]. BCI acceptance could also be altered by the fact that most stroke patients experience depression, and therefore high anxiety levels [13] that have detrimental effects on BCI acceptance and learning [14]. Thus, BCI acceptance is likely to have a major impact on patients' learning processes and therefore on the efficiency of BCI-based stroke rehabilitation procedures.

Among this clinical context, this article focuses on patients. We hypothesise that identifying acceptability and accep-

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tance factors will help us overcome these misconceptions and personalise the rehabilitation procedures, which will in turn result in reduced anxiety, and increased motivation and engagement levels for the patients. This should favour their learning and, ultimately, motor recovery. In other words, we expect that improving the acceptance levels of BCIs, through the design of personalised rehabilitation procedures, will result in an increased efficiency of these technologies and therefore be one step closer to their democratisation.

Yet, using acceptance to optimise BCI efficiency remains an aspect that has been little studied to date. To the best of our knowledge, only [15] for BCI-based stroke rehabilitation procedures, [16] with BCI training for elderly and [10, 17, 18] with BCIs for Amyotrophic Lateral Sclerosis patients assessed BCI in terms of acceptance. In addition, in the BCI field, acceptability is mostly assessed as an attribute of the user's satisfaction, itself being a dimension of user experience [6, 18]. It is possible that the reduced number of studies stems from the lack of proven methods to measure acceptability and acceptance (e.g., dedicated questionnaire or model). This is what we hope to remedy through our research.

To do this, we designed a general theoretical model of BCI acceptability [19] (under review) and a second one focused on BCI for functional rehabilitation after stroke. They are based on the *Technology acceptance model 3* (TAM3) [20], the *Unified theory of acceptance and use of technology 2* (UTAUT2) [21], and the *Components of user experience* (CUE) model [22]. In these existing models, acceptability measure is an evaluation of the user's behavioral intention (BI) i.e., their intention to use the studied technology. The main determinants of BI are perceived usefulness (PU) and perceived ease of use (PEOU). PU is the personal feeling about utility of the system, and PEOU the degree of belief to which using the system will require little or no effort. On the basis of our model, a questionnaire to assess the acceptability of BCI-based functional rehabilitation procedures among the general public was created and validated (N=753).

The aim of our paper is to study the acceptability of BCI-based functional rehabilitation procedures among post-stroke patients, in order to determine their most important acceptability factors and to compare the results to those of the general public. This paper details our methodology, then the results are presented, in addition to the data collected from the general public. Finally, the discussion includes a comparison of these two populations.

MATERIALS AND METHODS

In order to study the acceptability factors among patients, we used a questionnaire methodology — as we previously did for the general public.

Experimental paradigm:

Questionnaire: The questionnaire is inspired from a previous questionnaire developed to identify and weigh the factors influencing BCI acceptability for functional rehabilitation after stroke among the general public [23]. Detailed explanations regarding the design of this model are provided in [23]. In a nutshell, the BCI acceptability model for functional rehabilitation after stroke comprises four categories of factors: **(i)** ***System characteristics*** is a category related to the mental representation developed by the user to judge what the use of a technology can bring them in relation to their objective(s) (relevance of the system, perceived quality, etc.) [24]. **(ii)** ***Social influence*** is the influence of an individual's relatives and social group on their choice of whether or not to adopt a system. **(iii)** ***Individual differences*** is a category which groups the user personal characteristics (socio-demographic information, cognitive traits, etc.). Finally, **(iv)** ***Facilitating conditions*** brings together the factors related to the material, organisational and/or human conditions that facilitate the use of a technology [25] (Fig. 1).

We used the same questionnaire as the ones for the general public except that we added three factors into the ***individual differences*** category: *memory*, *attention* and *engagement in rehabilitation*. *Memory* [26] and *attention* [27] are both commonly affected after a stroke, and essential to learn to self-regulate brain patterns using a BCI (e.g., for memorising instructions and being able to stay focused on mental tasks [28]). The third factor was introduced in order to assess if the attitude towards BCI rehabilitation correlates with motivation in rehabilitation in general. All the questions are on the same scale in the patient and general public questionnaires.

The questionnaire was created on the Qualtrics tool, it was fully anonymous, and therefore not subject to the general data protection regulation (GDPR). It took between 20 min and 30 min to be completed, depending on the patients, and consisted of four parts: **(i)** Informed consent form; **(ii)** Questions regarding the participants' previous experience with BCIs; **(iii)** Questions related to each factor of the model (3-5 questions per factor). For example, for *subjective norm*, one of the question was *'People who are important to me would support the use of Brain-Computer Interfaces in post-stroke rehabilitation'*. The scale used was a visual analogue scale from 0 to 10 ("strongly disagree" to "strongly agree") for quantitative factors and a checkbox question for categorical factors. Two explanatory videos were also included in the questionnaire: one explaining BCIs in general (video 1) and the second more specific to BCI-based stroke rehabilitation procedures, presenting EEG-based BCIs with motor imagery tasks (video 2). **(iv)** Socio-demographic data (for each item of this category, the participants could choose the option " I do not wish to answer").

With regard to the factors, some were assessed before and others after the second video. PU and BI were measured twice (before video 2: PU1/BI1; after video 2: PU2/BI2), the questions being the same for both times. The aim was to observe whether respondents' scores were influenced by the information given in the video. The factors following video 2 required a more detailed view of these new reha-

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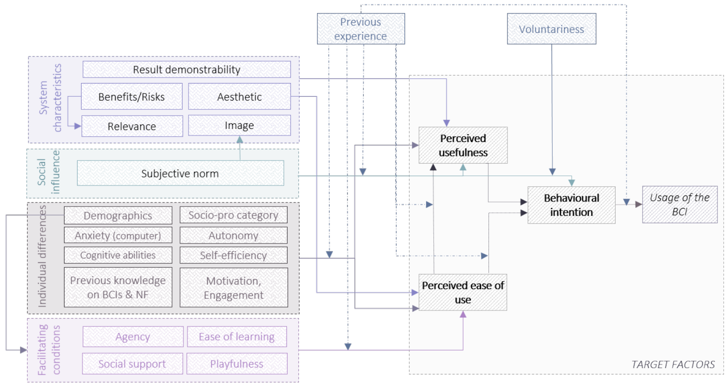

FIGURE 1: Representation of the model of acceptability of BCIs for functional rehabilitation after stroke. On the right are the target factors namely, PU, PEOU and BI. On the left are the four categories of factors that may influence the target factors. Finally, on top, two moderators are represented in blue. Those factors moderate the effect of the different categories on the target factors.

bilitation procedures (*result demonstrability*, *benefits/risks ratio* and scientific *relevance*).

For the added factors, we created the questions for *memory* and *attention*. Regarding *engagement in rehabilitation*, they come from the Treatment Self-Regulation Questionnaire (TSRQ) [29].

Distribution: The distribution of the questionnaire was done with two main methods: **(i) In hospital** (University hospitals of Bordeaux and Toulouse, France), with patients (N=40): experimenters visited stroke rehabilitation departments and helped patients to fill in the questionnaires. The experimenter read out the question and the patient was asked to answer orally or on a slate. The experimenters were medical students and a research engineer. **(ii) In autonomy, at home:** When the experimenters met patients in hospital, they always asked them whether they wished to complete the questionnaire on their own or accompanied by someone else. If the patient wished to take part independently, they gave their email address to the experimenter, and the anonymous link to the questionnaire was sent to them (N=52).The questionnaire link was also shared on social networks with the help of a patient who had a large online community concerned by stroke (N=48).

The exclusion criteria were people without experience of stroke and minors. The experimental protocol was carried out in accordance with the Declaration of Helsinki and was approved by the Research Ethics Committee of Bordeaux University (CER-BDX-AP-2022-14).

Data analysis:

We analysed the results in two stages. In both, the patient data was compared with the results for the general public.

Descriptive analysis: We measured the means and standard deviations (SD) of each quantitative factor, and the percentage distribution for the categorical factors. For the comparison, we used Welch t-tests (quantitative factors) and Chi² tests (categorical factors).

Quantitative analysis: We wanted to do observations that do not depend on the architecture of our proposed model. Three linear regressions were implemented to find the most important determinants of BI, PU and PEOU. To predict BI and PU, we used all the acceptability factors in our questionnaire (regression for BI included PU and PEOU, regression for PU included PEOU, as the arrows in Fig. 1). For PEOU, *result demonstrability*, *benefits/risks ratio* and *relevance* (i.e., factors after video 2) were not included, nor were BI and PU.

It is a different type of regression than the one used for the general public (random forest regressions) as the number of respondents was lower. The categorical data from the questionnaire were formatted in order to enable their inclusion in the regression analyses. These regressions were implemented on R.

RESULTS

Participants:

A set of N = 140 respondents was obtained to the questionnaire, all of them were post-stroke patients in France. Of these, 60% were men and 40% women. The age group most represented was 55-65. The questionnaire was completed in hospital, with an experimenter, for 40 patients, while the other 100 completed it independently on their computer, at home. The socio-demographic details are provided in Table 1.

Descriptive analysis:

In Table 2, are presented the mean scores of each quantitative factor, and the percentages for categorical factors. None of the factors was associated with a score below 5/10, which reflects globally positive feelings and well-perceived BCIs among the respondents. Indeed, regarding the target factors, for the patients, BI2 had a mean of 8.48/10 (SD = 2.03), for PU2 it was 8.34/10 (SD = 2.13) and for PEOU the mean was 6.43/10 (SD = 2.41).

These analyses show that certain factors differ significantly between the patients and the general public. Among target factors, only *PEOU* is significantly lower in the patient population. For ***system characteristics***, patients have a significantly higher *benefit/risk ratio* score and a lower

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		Number	%
AGE	18-24	2	1.43
	25-34	11	7.86
	35-44	31	22.14
	45-54	30	21.43
	55-65	32	22.86
	65-74	21	15.00
	74+	7	5.00
	Not know	6	4.29
GENDER	Male	84	60.00
	Female	56	40.00
POST-STROKE PERIOD	Acute *(< 15 days)*	2	1.43
	Subacute *(15 days - 6 months)*	21	14.00
	Chronic *(> 6 months)*	87	62.14
	No answer	30	21.43
SOCIO-PRO. CATEGORY	Students	2	1.43
	Craftsmen/shopkeepers	8	5.71
	Executives/Higher intellectual prof.	24	17.14
	Intermediate occupations	26	18.57
	Employees	32	22.86
	Manual workers	2	1.43
	Not in employment	7	5.00
	I do not wish to answer	3	2.14
	No answer	36	25.71
Questionnaire administration	With experimenter, at the hospital	40	28.57
	At home, recruited in hospital	52	37.14
	At home, recruited from social media	48	34.29

TABLE 1: Respondents' socio-demographic information. *Number:* number of respondents, *%:* percentage of respondents.

image score. Regarding ***social influence***, the *subjective norm* score is significantly higher among patients. In ***individual differences***, we found five significantly different factors. Perceived *autonomy* is higher among patients, and *computer anxiety* is lower (scores are inverted to be all negative to positive; a higher score means lower anxiety). Among the categorical factors, *self-efficacy*, *social support* and the *knowledge of BCIs* were significantly influenced by the group. For example, preferring to use a BCI with a human guidance is highly represented among patients.

Regressions:

Three linear regressions were performed in order to explain the main determinants of the three target factors: BI, PU and PEOU. Table 3 presents the variables with the most impact on these latter. The variables with significant p-values ($p <= 0.05$) were:
For BI2: *PU2*, *computer anxiety*, *socio-professional category* ("Students" and "No answer" categories), *autonomy*, *self-efficacy* ("I prefer to use the BCI alone, in autonomy" category) and *subjective norm*. Their coefficients were positive, except for *socio-professional category*. The quality of the prediction was good (adjusted R^2: 0.749, p-value $<$ 2.2e-16). **For PU2**: *Relevance* and *computer anxiety*. The quality of the prediction was medium (adjusted R^2: 0.648, p-value $<$ 2.2e-16). **For PEOU**: *Ease of learning* and *Playfulness*, but the prediction had a lower quality (adjusted R^2: 0.513, p-value = 3.178e-11).

DISCUSSION

We created a model of acceptability of BCIs specifically for functional rehabilitation after stroke, and designed an associated questionnaire. We collected responses from 140 post-stroke patients and compare them with data previously obtained from the general public (N=753).

FACTORS	MEAN PATIENTS	MEAN GEN. PUBLIC
	Scale from 0 to 10	
SYSTEM CHARACTERISTICS		
Result demonstrability	6.60 ± 1.93	6.84 ± 1.68
Benefits/Risks ***	7.80 ± 1.62	7.27 ± 1.51
Scientific relevance	8.09 ± 1.83	8.04 ± 1.48
Image *	5.54 ± 3.24	6.10 ± 2.18
Visual aesthetic	6.30 ± 2.47	6.62 ± 1.89
SOCIAL INFLUENCE		
Subjective norm **	7.80 ± 1.87	7.39 ± 1.71
INDIVIDUAL DIFFERENCES		
Engagement in rehabilitation	9.11 ± 1.52	/
Autonomy ***	7.99 ± 1.79	7.40 ± 1.46
General anxiety	5.23 ± 2.18	5.49 ± 1.87
Computer anxiety ***	7.40 ± 2.73	6.35 ± 2.51
Attention	6.16 ± 2.55	/
Memory	6.84 ± 2.52	/
BCI knowledge * **	Categorical variables *Chi²* residual	
No	70.7% $^{0.231}$	68.7% $^{-0.100}$
Yes (never used)	18.6% $^{-1.697}$	27.1% $^{0.732}$
Yes (already used)	10.7% $^{2.991}$	4.0% $^{-1.290}$
Self-efficacy * **		
Alone, in autonomy.	18.6% $^{-0.931}$	23.1% $^{0.401}$
Alone with a support function.	16.4% $^{-3.487}$	36.7% $^{1.504}$
Only with human guidance.	47.9% $^{3.457}$	28.3% $^{-1.491}$
Alone, if used similar technology before.	17.1% $^{1.449}$	12.0% $^{-0.625}$
Social support * **		
Independently at home.	22.1% $^{-1.906}$	32.8% $^{-1.906}$
With a healthcare professional.	67.1% $^{2.727}$	47.7% $^{-1.176}$
Alone, but in a healthcare establishment.	10.7% $^{-2.063}$	19.5% $^{0.890}$
FACILITATING CONDITIONS		
Playfulness	7.02 ± 2.41	6.90 ± 1.80
Ease of learning	6.06 ± 2.16	5.96 ± 1.62
Agency	6.25 ± 2.50	6.29 ± 1.65
TARGET FACTORS		
PEOU ***	6.43 ± 2.41	7.17 ± 1.57
PU	7.83 ± 2.00	7.87 ± 1.63
BI	8.11 ± 2.05	7.88 ± 1.73
PU2	8.34 ± 2.13	8.28 ± 1.57
BI2	8.48 ± 2.03	8.23 ± 1.69

TABLE 2: Results from post-stroke patients' questionnaire in comparison to the general public's questionnaire.
When a question was negative, the score was inverted (i.e., a high *general anxiety* score is in fact a low anxiety level).
For each factor, **Welch t-tests** (quantitative) and **Chi² tests** (categorical) were made. Factors in violet highlight significant differences between the two groups.'***' 0.001 '**' 0.01 '*' 0.05

Patients showed high acceptability levels, similarly to the general population (*behavioural intention*: 8.48/10 and 8.23/10, respectively and *perceived usefulness*: 8.34/10 and 8.28/10, respectively). Only the *perceived ease of use* was significantly lower in patients (6.43/10) than in the general public (7.17/10).

In addition to these target acceptability factors, descriptive analyses showed other significant differences between the two groups. Patients have a significantly higher *benefit/risk ratio* score (7.8/10), the advantages of BCI in functional rehabilitation seem greater to them than the disadvantages. Regarding *subjective norm* (7.8/10), compared with the general public, patients seem to consider that their close relatives and people who are important to them will have a more positive view of rehabilitation with BCI and will be more favourable to this type of rehabilitation. Nevertheless, they have a significantly lower *image* score (5.54/10): they think that the public image and the social status of people using BCI in rehabilitation will be less positive than respondents in the general population tend to expect. *Self-efficacy* and *social support* showed that the majority of pa-

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PATIENTS - N=140 Linear regressions					GENERAL PUBLIC - N=753 Random forest regressions	
	Estimate	**Std. Error**	**t value**	**Pr(>|t|)**		**Importance values**
BEHAVIOURAL INTENTION						
Residual Std. error: 1.016 - **R²**: 0.821 - **Adjusted R²**: 0.749					% Variance explained: 86.09	
(Intercept)	*-0.739*	*1.134*	*-0.652*	*0.516*		
Perceived usefulness	0.451	0.080	5.617	1.79 x 10^{-7} ***	Perceived usefulness	100
Computer anxiety	0.125	0.046	2.739	0.007 **	Scientific relevance	37.44
Socio-pro 1 (*"Students"*)	-2.543	0.952	-2.671	0.009 **	Benefits/Risks ratio	30.25
Socio-pro 3 (*"No answer"*)	-1.992	0.748	-2.665	0.009 **	Subjective norm	29.56
Autonomy	0.139	0.056	2.505	0.014 *	Result demonstrability	28.03
Self-efficacy 1 (*"Prefer to use BCI alone, at home"*)	0.758	0.339	2.234	0.028 *	Playfulness	27.67
Subjective norm	0.117	0.059	1.987	0.050 *	Perceived ease of use	24.94
PERCEIVED USEFULNESS						
Residual Std. error: 1.265 - **R²**: 0.746 - **Adjusted R²**: 0.648					% Variance explained: 79.64	
(Intercept)	*-0.306*	*1.413*	*-0.217*	*0.829*		
Scientific relevance	0.773	0.102	7.571	1.88 x 10^{-11} ***	Scientific relevance	100
Computer anxiety	0.125	0.055	2.250	0.027 *	Perceived ease of use	33.54
PERCEIVED EASE OF USE						
Residual Std. error: 1.682 - **R²**: 0.636 - **Adjusted R²**: 0.513					% Variance explained: 57.76	
(Intercept)	*1.947*	*1.799*	*1.082*	*0.282*		
Ease of learning	0.522	0.091	5.716	1.05 x 10^{-7} ***	Ease of learning	100
Playfulness	0.285	0.101	2.809	0.006 ***	Playfulness	83.21
					Subjective norm	80.86

TABLE 3: Regression results for the target factors (BI2, PU2, PEOU). For the patients, only the factors with significant p-value are displayed.
Pr(>|t|): probability of observing any value equal or larger than t (corresponds to p-value). **Estimate**: corresponds to the slope of the equation ("b" value). '***' 0.001 '**' 0.01 '*' 0.05. For the general public, random forest regressions (500 trees and 5-fold cross-validation), were used. Importance values are the mean decrease accuracy (%IncMSE), scaled from 0 to 100.

tients want human guidance and expect to be accompanied by a caregiver when using a BCI, unlike the general public, who prefer a help system integrated into the computer. It is also interesting to note that patients have significantly higher perceived *autonomy* and lower *computer anxiety* than the general public. This shows that therapists or patients' relatives should not consider these factors as obstacles to offering patients a new type of rehabilitation technology such as BCI (i.e. not thinking that it is a bad idea for patients because they would have a fear of technologies, for example).

Regression analyses revealed that the intention to use BCIs was mainly motivated by the *perceived usefulness* of the system, itself mainly influenced by *scientific relevance* of BCIs in functional rehabilitation. *Subjective norm* likewise had a small but significant influence on acceptability. These factors were also important for the general public.
In line with those of the descriptive analyses, these results highlight the importance of scientific evidence and scientific communication not only to patients, but also to clinicians and the general public, as social norms (i.e., *subjective norm* and *image*) play an important role among patients.

In addition, within patients, ***individual differences*** showed a significant impact on the intention to use BCIs (it was not the case in the general public): the weight of psychological variables is greater in people who have suffered a stroke, as shown by the importance of *computer anxiety* and *autonomy*. It appears also that patients who prefer to use the BCI alone, at home (i.e. higher level of *self-efficacy*), are more likely to want to use a BCI in their rehabilitation, which is coherent with existing recommendations [14]. Reducing patients' anxiety and taking into account their perceived autonomy and self-efficacy is also something that could be achieved by personalising BCI protocols. For example, by proposing training sessions where the degree of support provided by a therapist can be modulated.
As for the general public, among the patients, *ease of learning* and *playfulness* were the main determinants of *perceived ease of use*. Thus, with regard to the lower patients' *perceived ease of use* score, the aim is to improve this target factor by making it easier for patients to learn how to use the BCI. One way can be to personalise BCI protocols depending on patients' profiles, with the aim of making learning easier and more enjoyable for them. For instance, instructions must be clear and the feedback motivating. These findings are consistent with the guidelines for successful MI-BCI training [9] and with studies on gamified rehabilitation processes [30, 31].

CONCLUSION

This study provides insights on how to foster BCI acceptability, notably by better informing the patients and the general public on the scientific evidence related to BCIs and by personalising rehabilitation procedures to facilitate learning. One next step will consist in adopting the same approach with clinicians in order to understand the conditions for a high acceptability of BCIs, be they related to scientific, technical or organisational aspects.

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