Endogenous Cognitive Tasks for Brain-Computer Interface: A Mini-Review and a New Proposal

Endogenous Cognitive Tasks for Brain-Computer Interface: A Mini-Review and a New Proposal

Dize Hilviu[1][a], Stefano Vincenzi[2], Giovanni Chiarion[3][b], Claudio Mattutino[2][c], Silvestro Roatta[4][d], Andrea Calvo[5,6,7][e], Francesca M. Bosco[1,7][f] and Cristina Gena[2][g]

[1]*Department of Psychology, University of Turin, Via Verdi 10, 10124, Turin, Italy*

[2]*Department of Computer Science, University of Turin, Corso Svizzera 185, 10149, Turin, Italy*

[3]*Department of Electronics and Telecommunications, Polytechnic of Turin, Corso Duca degli Abruzzi 24, 10129, Turin, Italy*

[4]*Rita Levi Montalcini Department of Neuroscience, University of Turin, Corso Raffaello 30, 10125, Turin, Italy*

[5]*Rita Levi Montalcini Department of Neuroscience, University of Turin, Via Cherasco 15, 10126, Turin, Italy*

[6]*Neurology, Hospital Department of Neuroscience and Mental Health, Città della Salute e della Scienza Hospital of Turin, Corso Bramante 88, 10126, Turin, Italy*

[7]*Neuroscience Institute of Turin, University of Turin, Regione Gonzole 10, 10043, Orbassano, Italy*

Keywords: Human-Computer Interaction, Brain-Computer Interaction, Brain-Computer Interface, Electroencephalography, EEG-based BCI, Cognitive Task, Endogenous Task.

Abstract: Brain-Computer Interfaces allow interaction between the voluntarily produced human cerebral activity and a computer. The output produced by the user's performance can serve as an input to the technologic device that can decode this information and transform it to a command. Literature has usually focused on processing and classification often neglecting the importance of the mental tasks used to elicit and modulate the cerebral activity. In this paper, we review previous mental tasks used in literature: motor imagery, spatial navigation, geometric figure rotation, imagery of familiar faces, auditory imagery and math imagery. Then, we propose a set of these tasks modified to maximize the user's performance during the execution of mental tasks.

1 INTRODUCTION

Brain-Computer Interaction is a scientific approach offering various opportunities of empirical research in the neuroscience domain. This technique uses special interfaces (Brain Computer Interfaces, BCIs) allowing the interaction between the human cerebral activity and an electronic device (Wolpaw et al., 2002). There are several types of BCIs, each one based on different methods to detect brain signals (e.g., Electrocorticography, Functional Magnetic Resonance Imaging, Positron Emission Tomography, etc.). Among them the Electroencephalography-based (EEG) method is one of the less invasive. EEG-based interfaces use a change in brain electrical activity as an input signal, which is usually defined as event-related synchronization or desynchronization (for a comprehensive review on EEG-based BCI paradigms see Abiri et al., 2019). The change may be caused by exogenous stimuli (triggered by external events) or endogenous stimuli (voluntarily produced by the subject while imagining a movement for instance) (Tan & Nijholt, 2010). The possibility to use exogenous stimuli is reduced since they are less likely to be used by some clinical populations. For example, persons with complete locked-in syndrome,

[a] https://orcid.org/0000-0002-4312-2206
[b] https://orcid.org/0000-0001-5588-5633
[c] https://orcid.org/0000-0002-0413-2436
[d] https://orcid.org/0000-0001-7370-2271
[e] https://orcid.org/0000-0002-5122-7243
[f] https://orcid.org/0000-0001-6101-8587
[g] https://orcid.org/0000-0003-0049-6213

Hilviu, D., Vincenzi, S., Chiarion, G., Mattutino, C., Roatta, S., Calvo, A., Bosco, F. and Gena, C.
Endogenous Cognitive Tasks for Brain-Computer Interface: A Mini-Review and a New Proposal.
DOI: 10.5220/0010661500003060
In *Proceedings of the 5th International Conference on Computer-Human Interaction Research and Applications (CHIRA 2021)*, pages 174-180
ISBN: 978-989-758-538-8; ISSN: 2184-3244

i.e., a neurological disorder that causes the complete paralysis of all voluntarily muscles but spares the cognitive functionality, could not perform a visual task but instead will use a somatosensory paradigm, such as vibro-tactile or auditory (De Massari et al., 2013; Guger et al., 2017; Halder et al., 2016). Therefore, endogenous stimuli are more suitable to involve a larger sample of subjects that could benefit of this technology. Specifically, cognitive tasks are the most used and they consist in mental tasks where the user is asked to imagine something or doing something.

Cognitive tasks must be selected considering several aspects, since high individual differences in responsiveness to the task have been reported (Friedrich et al., 2012).

The first element to consider is the preferences of the users: based on their personal past experiences, users may find easier to perform some tasks than others (Kleih & Kubler, 2016; Lotte et al., 2013).

Second, since BCI technology is mostly used in medical/rehabilitative contexts, another aspect that should be considered is the residual cognitive ability possessed by participants (De Massari et al., 2013; Kübler & Birbaumer, 2008). Several pathologies can impact on the cognitive functioning, thus patients in locked-in condition may find difficult to imagine body movements (Birbaumer & Cohen, 2007).

Third, another crucial aspect is the set of psychological variables that could affect the task performance (Kleih & Kubler, 2016), as for example, the fatigue and frustration that may come from the effort of the task realization, or mood and motivation in performing the task (Kleih et al., 2010).

Finally, the self-regulatory skills, i.e., the ability to be concentrated, focused and the ability to decide how much attention direct towards some activities by ignoring other distracting stimuli must as well be considered (Kleih & Kubler, 2016). All these cognitive abilities (i.e., *updating*, *shifting*, *attention* and *inhibition*), known as Executive Functions, allow people to perform goal-directed behaviours and reside in the prefrontal cortex (Miyake et al., 2000), which is reported to be damaged in some pathological cases, e.g. Alzheimer disease.

Chances to perform a fine classification of the acquired cerebral signal are increased further when a training precedes the recording sessions (Lotte et al., 2013). During the training users learn how to control and regulate their performance (EEG signals). The training session is particularly important in the experiments involving patients with a pathological condition that may aggravate in time, such as patients with amyotrophic lateral sclerosis that may be in a locked-in condition and, after the worsening of the disease, may move to a complete locked-in condition where muscular abilities are permanently impaired (Neumann & Kübler, 2003).

Literature has focused mainly on the elaboration and classification processes often neglecting the cognitive task design or selection process which can promote an optimization of the BCI performance by selecting the most appropriate strategy for each user (Curran & Stokes, 2003; Friedrich et al., 2012; Lazarou et al., 2018). The aim of the present study is: first to provide a short review of the cognitive endogenous tasks used in previous research (motor imagery, spatial navigation, geometric figure rotation, imagery of familiar faces, auditory imagery and math imagery) and then to propose some revisions to these tasks, based on the literature available for empirical investigation in this domain.

2 COGNITIVE TASKS

2.1 Motor Imagery

Motor imagery is the most widespread paradigm used to elicit a change in the cerebral activity. Subjects have to imagine repetitive movements of their own arms, hands, legs or feet. Movements can involve the imaginary use of objects (e.g., shift an object, squeeze a ball) or they can simply be a movement of the body. This paradigm is largely used because its results are more reliable than those produced by other tasks (Attallah et al., 2020; Curran et al., 2004; Friedrich et al., 2013; Lu et al., 2020; Togha et al., 2019). This high statistical discrimination is easily explained since the planning of a motor movement, activates brain areas (primary motor cortex, supplementary motor area and premotor cortex) clearly identified in the neuropsychological literature (Moran & O'Shea, 2020). See Table 1.

However, as already mentioned, motor imagery tasks may not be suitable in some cases, e.g., in locked-in syndrome, where patients are not able to perform movements and may find difficult to imagine how to program and execute a movement.

2.2 Spatial Navigation

Another cognitive task often used in literature is the spatial navigation (Cabrera & Dremstrup, 2008; Lugo et al., 2020): subjects have to imagine being in a familiar place, such as their own house, and to move from a room to another. Specifically, the task requires participants to focus on surrounding objects and not on walking, otherwise an overlapping with the motor activity may take place (Curran et al., 2004). However, some other studies asked participants to focus on orientation (Friedrich et al., 2013). Differently from the motor imagery task, which activates a specific brain area, spatial navigation imagery activates several brain regions, i.e., the dorsal fronto-parietal regions, presupplementary motor area, anterior insula, and frontal operculum (Cona & Scarpazza, 2019). See Table 1.

2.3 Geometric Figure Rotation

In the geometric figure rotation task, participants are asked to think about the rotation of an object (such as a cube) on a specific axe. In certain cases, the task can be hard to perform, therefore an example of rotation is provided, i.e., participants are provided for few seconds with a video where an object is rotating and then asked to imagine the movement (Anderson & Sijercic, 1996; Huan & Palaniappan, 2000; Lee & Tan, 2008; Rahman & Fattah, 2017). A general consensus exists in neuropsychological literature in considering the parietal cortex as the core region of activation for this task (Jäncke & Jordan, 2007). See Table 1.

2.4 Imagery of Familiar Faces

Another task quite often used in literature to stimulate cerebral activity involves the imagination of the face of a dear person or a famous celebrity (Başar et al., 2007; Friedrich et al., 2012; Özgören et al., 2005). This task recruits several brain regions (e.g., parahippocampal gyrus, middle superior temporal gyri, middle frontal gyrus) depending on the type of stimulus (faces of parents, partners etc.). This task usually activates the fusiform gyrus (Taylor et al., 2009). See Table 1.

2.5 Auditory Imagery

Thinking to a familiar tune or song has also been proposed and used as cognitive task. Here, subjects are usually instructed to “sing” in their head the song without moving the mouth or any other body parts (to avoid an overlapping of the motor activity) (Cabrera & Dremstrup, 2008; Curran et al., 2004; Gonzalez & Yu, 2016). This task activates the auditory cortex (Kraemer et al., 2005). However, many elements of the task might recruit other areas such as the left hemisphere if the user is imagining songs with words or the supplementary motor area if the songs includes humming (Halpern, 2003). See Table1.

2.6 Math Imagery

Math imagery includes two different types of tasks: math calculations tasks and visual counting tasks.

In math calculations, subjects are given the instruction to think of some additions, subtractions or multiplications and are asked to solve the calculations without producing vocalisations or muscular movements (Han et al., 2019; Roberts & Penny, 2000).

In visual counting tasks, participants are asked to imagine numbers written sequentially on a blackboard. They are specifically instructed to think of a number, then erase the number, and image the next one being written on the blackboard. As for the others tasks, subjects are not allowed to produce verbalizations or muscular movements (such as lips counting) (Huan & Palaniappan, 2000; Rahman & Fattah, 2017).

Math calculations tasks involve both frontal and parietal areas (Arsalidou et al., 2018). See Table 1.

Table 1: Brain areas activated in function of the cognitive task.

Cognitive task	Brain areas
Motor imagery	Primary motor cortex, supplementary motor area, premotor cortex
Spatial navigation	Dorsal fronto-parietal regions, presupplementary motor area, anterior insula, frontal operculum
Geometric figure rotation	Parietal cortex
Familiar faces imagery	Parahippocampal gyrus, middle superior temporal gyri, middle frontal gyrus, fusiform gyrus
Auditory imagery	Auditory cortex
Math imagery	Frontal and parietal areas

3 A PROPOSAL OF REVISED TASKS

The short review described in the previous section briefly summarizes the type of tasks that are currently used in EEG-based BCI literature.

On this basis, we propose a list of tasks inspired by those present in the literature but with some modifications in order to overcome the problems that could negatively affect the participant’s performance as the indecision and stress that the user may experience while choosing what kind of movement to perform. On the other hand, such tasks proposal promotes and encourage attention and concentration and can be considered as specifically tailored since users can select the one they prefer.

There are several other aspects of novelty that characterize the tasks that will be described in the next section. First of all, the proposed tasks are preceded by the description of training sessions that help the user exercising and controlling her/his output. Although there is no specific indication on the duration of trainings (Roc et al., 2021), we grounded our proposal on the existing and previously cited literature and empirical research. Therefore, we suggest to perform at least 3 sessions of training, until users report to feel confident in mentally executing the task. Secondly, the execution of each task is followed by a questionnaire where users have to indicate, using a Likert scale (from 1 to 5), how confident they felt during the task and how easy they found to imagine that specific task (1 = not comfortable/very hard to imagine; 5 = very comfortable/ very easy to imagine).

3.1 Motor Imagery Task

The user is asked to imagine doing a hand movement without any muscular movements, specifically to imagine her/his left hand moving to the left or the right hand to the right. In the training, users sit in front of a computer screen and see two hands, right and left, with palms down from a self-centred perspective. Subjects have to imagine moving one hand at a time, depending on how it will be requested and indicated by an arrow: the right hand will move towards the outside of the display to the right and the opposite for the left. After 1 second of image presentation (hand + arrow indicating direction of movement), the user has to imagine the movement of her/his hand and then, in order to strengthen the imagination, the participant sees the movement on the screen (the duration of the movement is 6 seconds). Each trial of the training lasts 10 seconds, and the complete training comprises 8 runs with 18 trials each.

3.2 Spatial Navigation Imagery Task

Differently than the existing tasks based on navigation imagery, the spatial navigation task consists of 2 subtasks, based on the participant's preference: a navigation with an egocentric perspective and one with an allocentric perspective (Tversky, 1991).

The egocentric perspective (also called *route*) refers to the point of view of the participant as she/he is inside an environment and has to move to the left or the right. Here users have to imagine themselves while moving within a familiar environment from their point of view, e.g., their house or the hospital. In the training session, users sit in front of a computer screen and look at some videos (video games mode). Videos show an environment for few seconds (still image) and, in this fraction of time, users have to imagine themselves moving forward according to the path suggested from time to time by the images, e.g., the image shows a room with only one door to the right. After that, the video shows the movement (e.g., entering thorough the door to the right, the only one visible).

The allocentric condition (also called *survey*) refers to the perspective from above, such as when looking at a map/labyrinth. In this task, users have to imagine a cursor moving in a map where only a path is visible and therefore possible. In the training session, users sit in front of a computer screen and visualize a video showing a map with a cursor moving step by step. The user is asked to imagine the movement of the cursor through the path.

The training of both sub-tasks consists of 8 runs with 10 trials each. Each trial is characterised by 6 seconds of movement imagination and 3 seconds of movement visualization. Each run lasts 90 seconds and turns (left and right) are balanced in order to avoid any kind of bias. After training, users are requested to use this kind of spatial navigation task during the recording session.

3.3 Object Rotation Imagery Task

In this task, users have to imagine a familiar object rotating. Unlike previous tasks, we introduced a real object to be used in the training session, i.e., an hourglass, because we believe that movement of the sand can help the user to imagine the rotation. The user sits in front of a computer screen and visualizes the hourglass rotating clockwise or counter clockwise. The training session is characterised by a series of images, in each of them an indication of the future rotating movement is placed. Three seconds are provided to the user to imagine the movement and then the rotation is shown and lasts 6 seconds. The training comprises 8 runs with 18 trials (rotations) each.

3.4 Face Imagery Task

In this task, subjects have to imagine the face of a celebrity. They have to imagine with attention the eyes, the mouth, the nose etc. The user can choose the celebrity from a list of famous people. For our proposal, we have selected 6 (3 females) national and international persons (such as Roberto Benigni, Lady Diana, etc.). This task can be preceded by a training session where the user sits in front of a computer screen, images are shown for 10 seconds and then the participant is asked to recall the face of the celebrity during the recording session. This process is repeated 6 times. We suggest to propose the celebrities in line with the age of the participant since young celebrities may not be familiar to older persons. If the user is unable to choose due to a pathology, the celebrity can be chosen by a family member.

3.5 Music Tune Imagery Task

In this task, users have to imagine a music tune but since the elaboration of the output produced by this task is highly subjective and perhaps complicated, we propose to present a list of very famous songs based on the cultural context (e.g., for the Italian context we propose "Volare" by Domenico Modugno or "Azzurro" by Adriano Celentano) among which the user can choose the preferred one. In the training session, the user can familiarize with the song by hearing it 3 times with the lyrics. Then, the user has to imagine the song without verbalisations or muscles' movements.

3.6 Math Counting Task

In the present task, participants have to perform calculations, without verbalizations or muscular movements. Users can imagine a number and then starting to subtract or add a specific number as many times as requested in the recording process. This task can be preceded by a training where the user sits in front of a computer screen and visualizes very simple math operations: by starting from a specific number presented on the screen, the user has to add or subtract a unit (such as 2 or 3), e.g., 9+3 = 12 + 3 =15 etc. The kind of operation (subtraction or addition) is indicated before the start of the training session. After carrying out the operation mentally in 4 seconds, the user sees the result. The training session is made up of 6 runs, with 20 trials (calculations) each (the starting number and the number to add or subtract can change).

4 CONCLUSIONS

EEG-based BCI is a recent technology using brain activity to allow communicative interactions. In several cases, there is the need to code for numerous information therefore different tasks that convey information are implemented. In the present study we have summarized the main endogenous cognitive tasks used in literature: motor imagery, spatial navigation imagery, geometric figure rotation imagery, familiar face imagery, auditory imagery and math calculations imagery. We have then proposed some adjustments to them, in order to improve the user's performance, i.e., the generation of the EEG signal. First of all, we have added a training before all the tasks. Second, we propose to ask users using a questionnaire, the perceived level of confidence and ease they felt while imagining each task. The information gathered with the questionnaire will be useful to direct the future use and application of mental tasks. Third, the tasks are enriched with details that users can find more suitable for them and therefore improve their performance.

Cognitive tasks represent a great resource in this research area. BCI technology combined with the availability of several tasks can also contribute to the cognitive assessment of subjects who are not completely responsive without involving verbalizations or muscular movements (Cipresso et al., 2012; Lugo et al., 2020).

In conclusion, the possibility to choose among different types of cognitive tasks (and also a preferred mode such as route vs survey or the face of the celebrity or the song) provides many benefits to the cognitive performance of the users. Users can indeed choose the one they consider most suitable for them. Furthermore, the high number of tasks can also be used to code different answers.

Future empirical research should evaluate the validity of these modified tasks, and should compare these tasks on the same group of subjects in order to verify which one maximizes the participant's performance also considering the goodness of the underlying algorithm.

ACKNOWLEDGEMENTS

This work has been funded by the project BciAi4Sla, Brain computer interfaces and Artificial intelligence for amyotrophic lateral Sclerosis, funded by Fondazione CRT, Torino, Italy.

REFERENCES

Abiri, R., Borhani, S., Sellers, E. W., Jiang, Y., & Zhao, X. (2019). A comprehensive review of EEG-based brain-computer interface paradigms. *Journal of Neural Engineering*, *16*(1). https://doi.org/10.1088/1741-2552/aaf12e

Anderson, C. W., & Sijercic, Z. (1996). Classification of EEG signals from four subjects during five mental tasks. *Advances*, 407–414. http://sce.uhcl.edu/boetticher/CSCI5931 Computer Human Interaction/Classification of EEG signals from four subjects during five mental tasks.pdf

Arsalidou, M., Pawliw-Levac, M., Sadeghi, M., & Pascual-Leone, J. (2018). Brain areas associated with numbers and calculations in children: Meta-analyses of fMRI studies. *Developmental Cognitive Neuroscience*, *30*(August 2017), 239–250. https://doi.org/10.1016/j.dcn.2017.08.002

Attallah, O., Abougharbia, J., Tamazin, M., & Nasser, A. A. (2020). A BCI system based on motor imagery for assisting people with motor deficiencies in the limbs. *Brain Sciences*, *10*(11), 1–25. https://doi.org/10.3390/brainsci10110864

Başar, E., Özgören, M., Öniz, A., Schmiedt, C., & Başar-Eroğlu, C. (2007). Brain oscillations differentiate the picture of one's own grandmother. *International Journal of Psychophysiology*, *64*(1), 81–90. https://doi.org/10.1016/j.ijpsycho.2006.07.002

Birbaumer, N., & Cohen, L. G. (2007). Brain-computer interfaces: Communication and restoration of movement in paralysis. *Journal of Physiology*, *579*(3), 621–636. https://doi.org/10.1113/jphysiol.2006.125633

Cabrera, A. F., & Dremstrup, K. (2008). Auditory and spatial navigation imagery in Brain-Computer Interface using optimized wavelets. *Journal of Neuroscience Methods*, *174*(1), 135–146. https://doi.org/10.1016/j.jneumeth.2008.06.026

Cipresso, P., Carelli, L., Solca, F., Meazzi, D., Meriggi, P., Poletti, B., Lulé, D., Ludolph, A. C., Silani, V., & Riva, G. (2012). The use of P300-based BCIs in amyotrophic lateral sclerosis: From augmentative and alternative communication to cognitive assessment. *Brain and Behavior*, *2*(4), 479–498. https://doi.org/10.1002/brb3.57

Cona, G., & Scarpazza, C. (2019). Where is the "where" in the brain? A meta-analysis of neuroimaging studies on spatial cognition. *Human Brain Mapping*, *40*(6), 1867–1886. https://doi.org/10.1002/hbm.24496

Curran, E. A., & Stokes, M. J. (2003). Learning to control brain activity: A review of the production and control of EEG components for driving brain-computer interface (BCI) systems. *Brain and Cognition*, *51*(3), 326–336. https://doi.org/10.1016/S0278-2626(03)00036-8

Curran, E. A., Sykacek, P., Stokes, M. J., Roberts, S. J., Penny, W., Johnsrude, I., & Owen, A. M. (2004). Cognitive Tasks for Driving a Brain-Computer Interfacing System: A Pilot Study. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *12*(1), 48–54. https://doi.org/10.1109/TNSRE.2003.821372

De Massari, D., Ruf, C. A., Furdea, A., Matuz, T., Van Der Heiden, L., Halder, S., Silvoni, S., & Birbaumer, N. (2013). Brain communication in the locked-in state. *Brain*, *136*(6), 1989–2000. https://doi.org/10.1093/brain/awt102

Friedrich, E. V. C., Scherer, R., & Neuper, C. (2012). The effect of distinct mental strategies on classification performance for brain-computer interfaces. *International Journal of Psychophysiology*, *84*(1), 86–94. https://doi.org/10.1016/j.ijpsycho.2012.01.014

Friedrich, E. V. C., Scherer, R., & Neuper, C. (2013). Long-term evaluation of a 4-class imagery-based brain-computer interface. *Clinical Neurophysiology*, *124*(5), 916–927. https://doi.org/10.1016/j.clinph.2012.11.010

Gonzalez, M., & Yu, L. (2016). Auditory imagery classification with a non-invasive BCI. *2016 IEEE 36th Central American and Panama Convention, CONCAPAN 2016*. https://doi.org/10.1109/CONCAPAN.2016.7942369

Guger, C., Spataro, R., Allison, B. Z., Heilinger, A., Ortner, R., Cho, W., & La Bella, V. (2017). Complete locked-in and locked-in patients: Command following assessment and communication with vibro-tactile P300 and motor imagery brain-computer interface tools. *Frontiers in Neuroscience*, *11*(MAY), 1–11. https://doi.org/10.3389/fnins.2017.00251

Halder, S., Käthner, I., & Kübler, A. (2016). Training leads to increased auditory brain-computer interface performance of end-users with motor impairments. *Clinical Neurophysiology*, *127*(2), 1288–1296. https://doi.org/10.1016/j.clinph.2015.08.007

Halpern, A. R. (2003). Cerebral Substrates of Musical Imagery. In I. Peretz & R. Zatorre (Eds.), *The cognitive neuroscience of music* (Vol. 930, pp. 2017–2230). New York, NY: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198525202.003.0015

Han, C. H., Kim, Y. W., Kim, D. Y., Kim, S. H., Nenadic, Z., & Im, C. H. (2019). Electroencephalography-based endogenous brain-computer interface for online communication with a completely locked-in patient. *Journal of NeuroEngineering and Rehabilitation*, *16*(1), 1–13. https://doi.org/10.1186/s12984-019-0493-0

Huan, N., & Palaniappan, R. (2000). *Brain Computer Interface Design Using Mental Task Classification*. 1–9.

Jäncke, L., & Jordan, K. (2007). Functional Neuroanatomy of mental rotation performance. In *Spatial processing in navigation, imagery and perception* (pp. 183–207). Boston, MA: Springer.

Kleih, S. C., & Kubler, A. (2016). Psychological Factors Influencing Brain-Computer Interface (BCI) Performance. *Proceedings - 2015 IEEE International Conference on Systems, Man, and Cybernetics, SMC 2015*, 3192–3196. https://doi.org/10.1109/SMC.2015.554

Kleih, S. C., Nijboer, F., Halder, S., & Kübler, A. (2010). Motivation modulates the P300 amplitude during brain-computer interface use. *Clinical Neurophysiology*, *121*(7), 1023–1031. https://doi.org/10.1016/j.clinph.2010.01.034

Kraemer, D. J. M., Macrae, C. N., Green, A. E., & Kelley, W. M. (2005). Sound of silence activates auditory cortex. *Nature*, *434*(7030), 158. https://doi.org/10.1038/434158a

Kübler, A., & Birbaumer, N. (2008). Brain-computer interfaces and communication in paralysis: Extinction of goal directed thinking in completely paralysed patients? *Clinical Neurophysiology*, *119*(11), 2658–2666. https://doi.org/10.1016/j.clinph.2008.06.019

Lazarou, I., Nikolopoulos, S., Petrantonakis, P. C., Kompatsiaris, I., & Tsolaki, M. (2018). EEG-based brain–computer interfaces for communication and rehabilitation of people with motor impairment: A novel approach of the 21st century. *Frontiers in Human Neuroscience*, *12*(January), 1–18. https://doi.org/10.3389/fnhum.2018.00014

Lee, J. C., & Tan, D. S. (2008). Using a low-cost electroencephalograph for task classification in HCI research. *UIST 2006: Proceedings of the 19th Annual ACM Symposium on User Interface Software and Technology*, 81–90. https://doi.org/10.1145/1166253.1166268

Lotte, F., Larrue, F., & Mühl, C. (2013). Flaws in current human training protocols for spontaneous Brain-Computer interfaces: Lessons learned from instructional design. *Frontiers in Human Neuroscience*, *7*(SEP), 1–11. https://doi.org/10.3389/fnhum.2013.00568

Lu, R. R., Zheng, M. X., Li, J., Gao, T. H., Hua, X. Y., Liu, G., Huang, S. H., Xu, J. G., & Wu, Y. (2020). Motor imagery based brain-computer interface control of continuous passive motion for wrist extension recovery in chronic stroke patients. *Neuroscience Letters*, *718*(December 2019), 1–8. https://doi.org/10.1016/j.neulet.2019.134727

Lugo, Z. R., Pokorny, C., Pellas, F., Noirhomme, Q., Laureys, S., Müller-Putz, G., & Kübler, A. (2020). Mental imagery for brain-computer interface control and communication in non-responsive individuals. *Annals of Physical and Rehabilitation Medicine*, *63*(1), 21–27. https://doi.org/10.1016/j.rehab.2019.02.005

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variable Analysis. *Cognitive Psychology*, *41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Moran, A., & O'Shea, H. (2020). Motor Imagery Practice and Cognitive Processes. *Frontiers in Psychology*, *11*(March), 1–5. https://doi.org/10.3389/fpsyg.2020.00394

Neumann, N., & Kübler, A. (2003). Training locked-in patients: A challenge for the use of brain-computer interfaces. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *11*(2), 169–172. https://doi.org/10.1109/TNSRE.2003.814431

Özgören, M., Başar-Eroğlu, C., & Başar, E. (2005). Beta oscillations in face recognition. *International Journal of Psychophysiology*, *55*(1), 51–59. https://doi.org/10.1016/j.ijpsycho.2004.06.005

Rahman, M. M., & Fattah, S. A. (2017). Mental Task Classification Scheme Utilizing Correlation Coefficient Extracted from Interchannel Intrinsic Mode Function. *BioMed Research International*, *2017*, Article ID 3720589. https://doi.org/10.1155/2017/3720589

Roberts, S. J., & Penny, W. D. (2000). Real-time brain-computer interfacing: A preliminary study using Bayesian learning. *Medical and Biological Engineering and Computing*, *38*(1), 56–61. https://doi.org/10.1007/BF02344689

Roc, A., Pillette, L., Mladenovic, J., Benaroch, C., N'Kaoua, B., Jeunet, C., & Lotte, F. (2021). A review of user training methods in brain computer interfaces based on mental tasks. *Journal of Neural Engineering*, *18*(1), 011002. https://doi.org/10.1088/1741-2552/abca17

Tan, D., & Nijholt, A. (2010). Brain-Computer Interfaces and Human-Computer Interaction. In D. Tan & A. Nijholt (Eds.), *Brain-Computer Interfaces* (pp. 3–19). Springer-Verlag London Limited 2010. https://doi.org/10.1007/978-1-84996-272-8_1

Taylor, M. J., Arsalidou, M., Bayless, S. J., Morris, D., Evans, J. W., & Barbeau, E. J. (2009). Neural correlates of personally familiar faces: Parents, partner and own faces. *Human Brain Mapping*, *30*(7), 2008–2020. https://doi.org/10.1002/hbm.20646

Togha, M. M., Salehi, M. R., & Abiri, E. (2019). Improving the performance of the motor imagery-based brain-computer interfaces using local activities estimation. *Biomedical Signal Processing and Control*, *50*, 52–61. https://doi.org/10.1016/j.bspc.2019.01.008

Tversky, B. (1991). Spatial mental models. *Psychology of Learning and Motivation - Advances in Research and Theory*, *27*(C), 109–145. https://doi.org/10.1016/S0079-7421(08)60122-X

Wolpaw, J. R., Birbaumer, N., McFarland, D. J., Pfurtscheller, G., & Vaughan, T. M. (2002). Brain Computer Interfaces for communication and control. *Clinical Neurophysiology*, *112*, 767–791. https://doi.org/10.1016/s1388-2457(02)00057-3