PROYECTOS CERO – ENVEJECIMIENTO FUNDACIÓN GENERAL CSIC

Brain Computer Interface for cognitive training and domotic assistance against the effects of ageing

Results from the whole project

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Contents

1. Introduction

The present project proposed BCI tools for promoting active ageing. More specifically, we developed a first BCI tool for cognitive training against the effects of ageing and a second BCI tool for domotic assistance at home. Firstly, this report presents a brief description of both developed tools and the main results. Secondly, the protocol and results from the joint analysis of both the training and the assistive BCI-based applications are shown. Thus, the influence of cognitive training on the management of the assistive application is assessed. Finally, the degree of accomplishment of the objectives of the project is evaluated.

2. Development of a BCI-based tool for cognitive training of elderly people

2.1. BCI tool for cognitive training

A BCI tool for cognitive training was developed by means of a motor imagery (MI)-based BCI. The proposed tool allows users to perform neurofeedback training (NFT) and cognitive training tasks. More specifically, five different NFT tasks and one cognitive training (CT) task were implemented. They are summarized below.

- NFT Task 1

This task contains two targets. The first type of trial of this task shows a closed door during the pre-feedback phase. The user has to imagine repeatedly right hand movements to open the door during the feedback phase. The task also shows a message with the required kind of movement: “right”. If the application detects that the user is imaging the required movement, then it shows an image of the open door during the post-feedback phase.

The second type of trial shows a closed window during the pre-feedback phase. The user has to imagine repeatedly left hand movements to open the window during the feedback phase. The task also shows a message with the required kind of movement: “left”.

If the application detects that the user is imaging the required movement, then it shows an image of the open window during the post-feedback phase. Both types of trials are shown in Figures 1 and 2.

- NFT Task 2

This task contains six different scenarios with 3 possible targets. During the pre-feedback phase a house, a wardrobe or a fridge is shown on the right or the left side of the screen. During the feedback phase, a silhouette of a man, a pair of trousers or a fish appears on the centre of the screen. During this phase, the user has to imagine repeatedly right or left hand movements in order to move the corresponding cursor towards the side of the screen where the target is shown. The task also shows a message with the required kind of movement: “right” or “left”.

If the cursor reaches the target, then the application shows the house, the wardrobe or the fridge with the door open during the post-feedback phase. Several snapshots of NFT Task 2 are shown in Figures 3 and 4.

- NFT Task 3

This task contains four different scenarios. During the pre-feedback phase a wardrobe and a fridge are shown one on each side of the screen. In the feedback phase, a cursor (a pair of trousers, a shirt, a fish or a steak) appears on the centre of the screen. During this phase, the user has to imagine repeatedly right or left hand movements in order to move the cursor

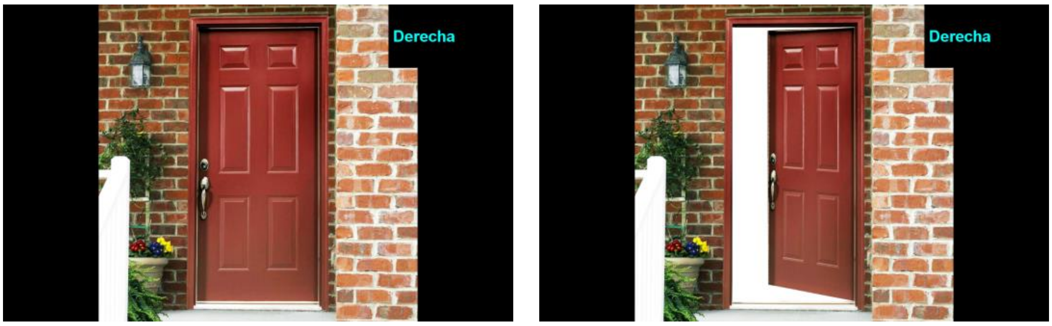


Figure 1. Snapshots of NFT Task 1 – Type of trial: RIGHT (‘Derecha’)

Figure 2. Snapshots of NFT Task 1 – Type of trial: LEFT (‘Izquierda’)

towards the right target (the wardrobe for clothes and the fridge for food).

If the pair of trousers or the shirt moves into the wardrobe, then the application shows the open wardrobe during the post-feedback phase. If the fish or the steak moves into the fridge, then the application shows the open fridge. Figures 5 and 6 show snapshots of different trials during NFT task 3.

- NFT Task 4

In this task a cursor represented by a man walking through a road is shown. The user has to move the walking man to the left or the right in order to avoid the incoming obstacles. Each trial represents an incoming obstacle (a tractor,

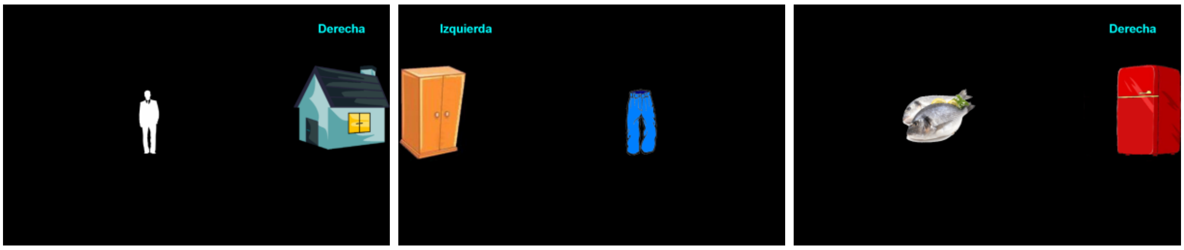


Figure 3. Snapshots of NFT Task 2 – Different types of cursors and targets

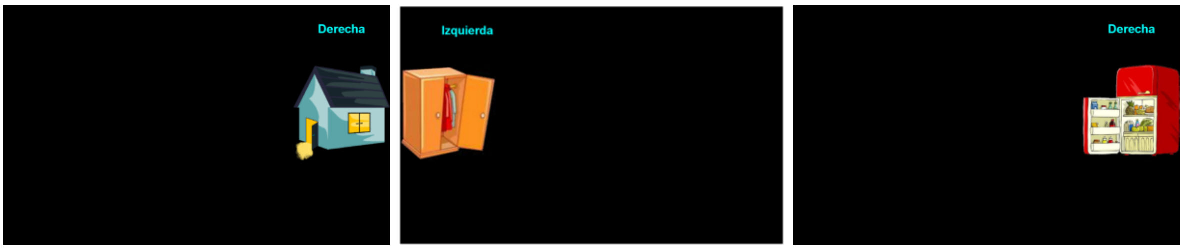


Figure 4. Snapshots of NFT Task 2 – Different scenes after the cursor reached the target

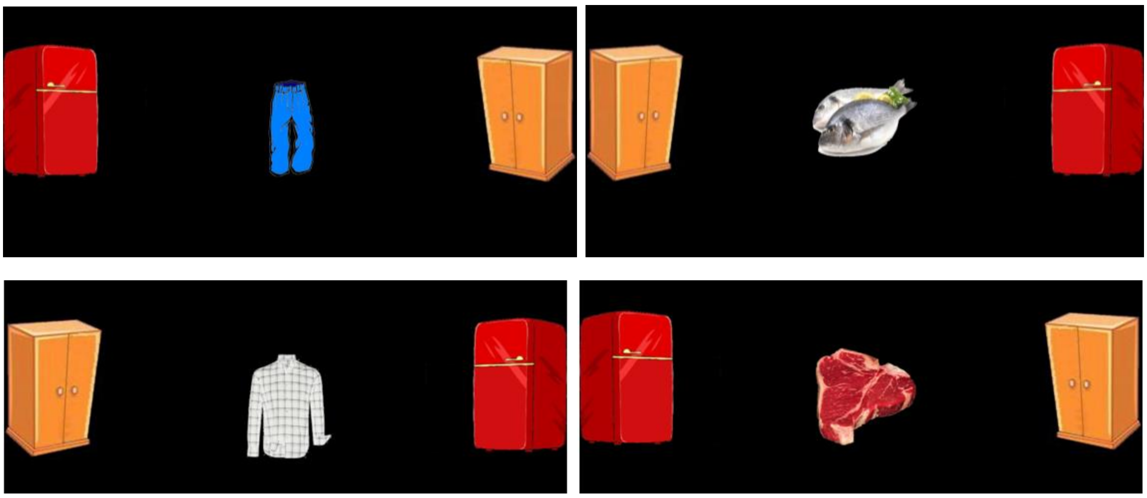


Figure 5. Snapshots of NFT Task 3 – Different types of cursors and target positions

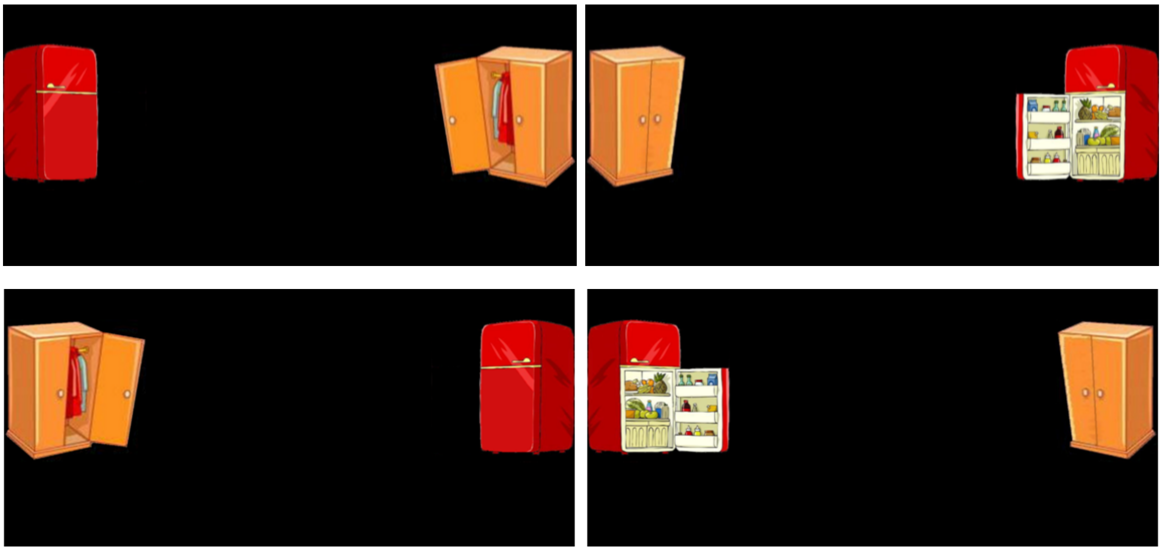


Figure 6. Snapshots of NFT Task 3 – Different scenes after the cursor reached the right target

a pig, a cow and a rock). The obstacle appears at the beginning of the feedback phase.

There are two difficulty levels. In the “easy” level, the application shows a message with the movement that the user must imagine in order to avoid the current obstacle (left or right). In addition, in this level the obstacles move slowly. In the “difficult level”, the application does not show the required movement and the obstacles move faster. Figure 7 presents screenshots of the “easy” level of this task.

If the user manages to avoid the obstacle, then the application shows a “well done” message during the post-feedback phase in both difficulty levels. If the user didn’t manage to avoid the obstacle, then the application shows an encouraging message. Moreover, the application shows the number of obstacles correctly overtaken in green and the number of obstacles failed in red.

- NFT Task 5

This task contains two different targets: left or right, and it presents three different levels. In the first level, the task shows a figure on the left side of the screen and another different figure on the right side of the screen during the pre-feedback phase. The two different figures are the same colour. Then, the two figures disappear and the task shows again two figures: one of the two figures showed previously and a different one. During the feedback phase, a red cursor appears on the centre of the screen. The user has to imagine repeatedly right or left hand movements in order to move the cursor towards

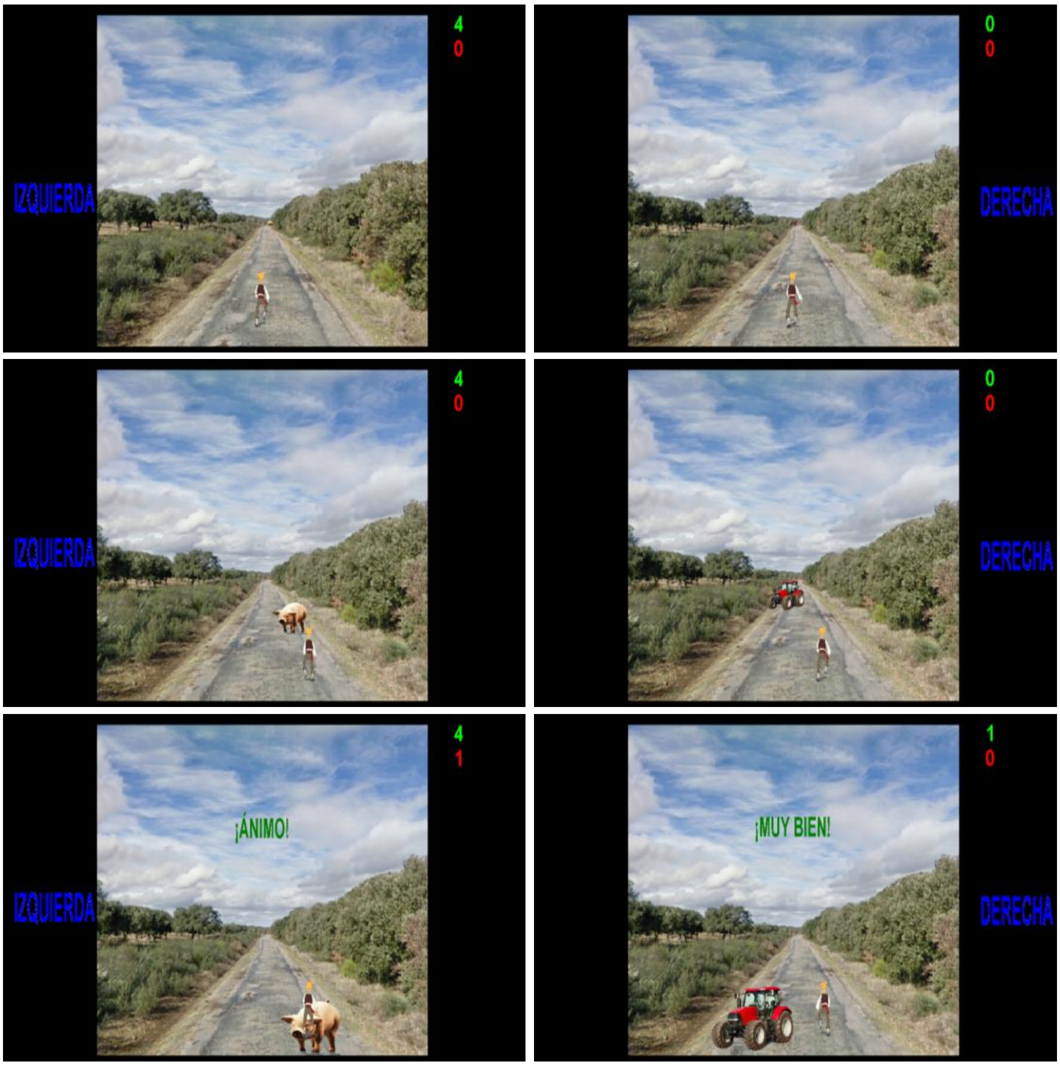


Figure 7. Snapshots of NFT Task 4 (Easy level) – Different types of obstacles

the figure that appeared during the pre-feedback phase. Snapshots of level 1 are shown in Figure 8.

In the second level the figures are presented to the user showing different colours, as can be seen in Figure 9.

In the third level, the task shows just one face during the pre-feedback phase. Then, the task shows two different faces: the previous one and another different one. The user has to imagine repeatedly right or left hand movements in order to move the cursor towards the face that appeared during the pre-feedback phase. Some snapshots for this level are shown in Figure 10.

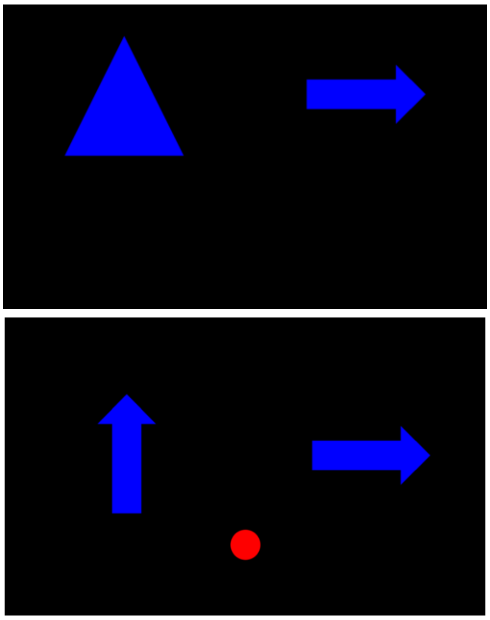


Figure 8. Snapshots of NFT Task 5 – Level 1 (Two figures, same colour)

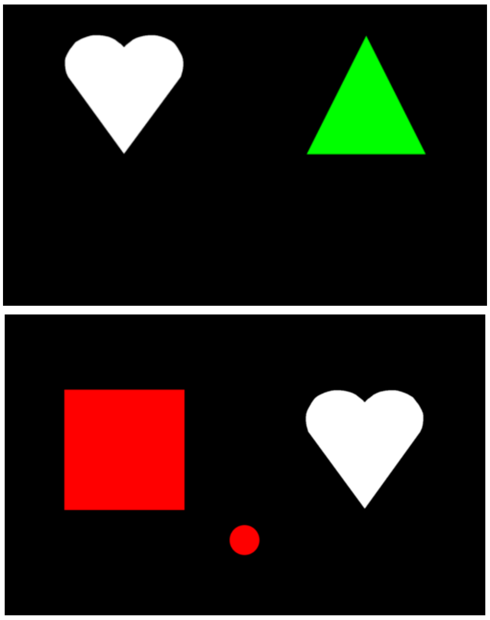


Figure 9. Snapshots of NFT Task 5 – Level 2 (Two figures, different colours)

- Cognitive training task

This task concerns cognitive training of working memory (CTWM) and users have to memorize figures. There are five different levels. In the first level, the task shows a white figure on the left side of the screen and another white figure on the right side of the screen during the pre-feedback phase. These two figures are called stimulus. Then, the figures disappear and the task shows a figure (called response): one of the two figures showed before or another different one. The user has to press the spacebar if the response

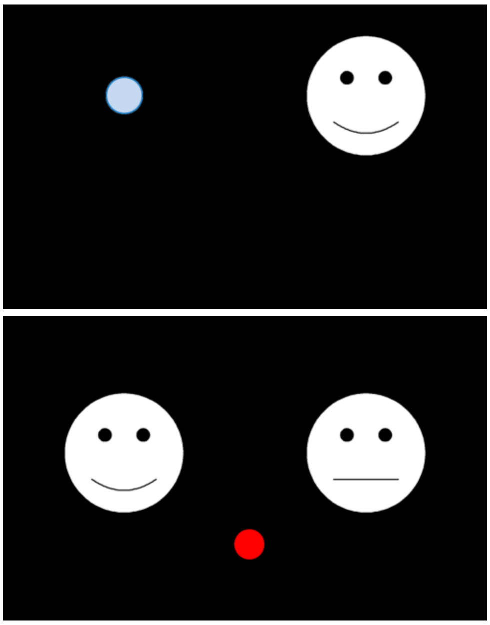


Figure 10. Snapshots of NFT Task 5 – Level 3 (Faces)

figure is different or another key if it has already been showed in the last stimulus. If the user responds correctly, the figure disappears and the next trial begins. Otherwise, the task shows the correct answer in red (“Sí” or “No”). Figure 11 shows several snapshots for level 1 of CT task.

In the second level, two different figures with different colours are shown. The third level presents three different figures with different colours. In the fourth level, two different figures with different colours and one face are shown. And, finally, in the fifth level, three different faces with different expressions or colours are presented. Figures 12 to 15 show snapshots for level 2 to level 5 of CT tasks.

At the beginning of each level, users performed some training trials. In this kind of trials, the task shows the stimulus and the response altogether. In these trials, users do not need to memorize the stimulus.

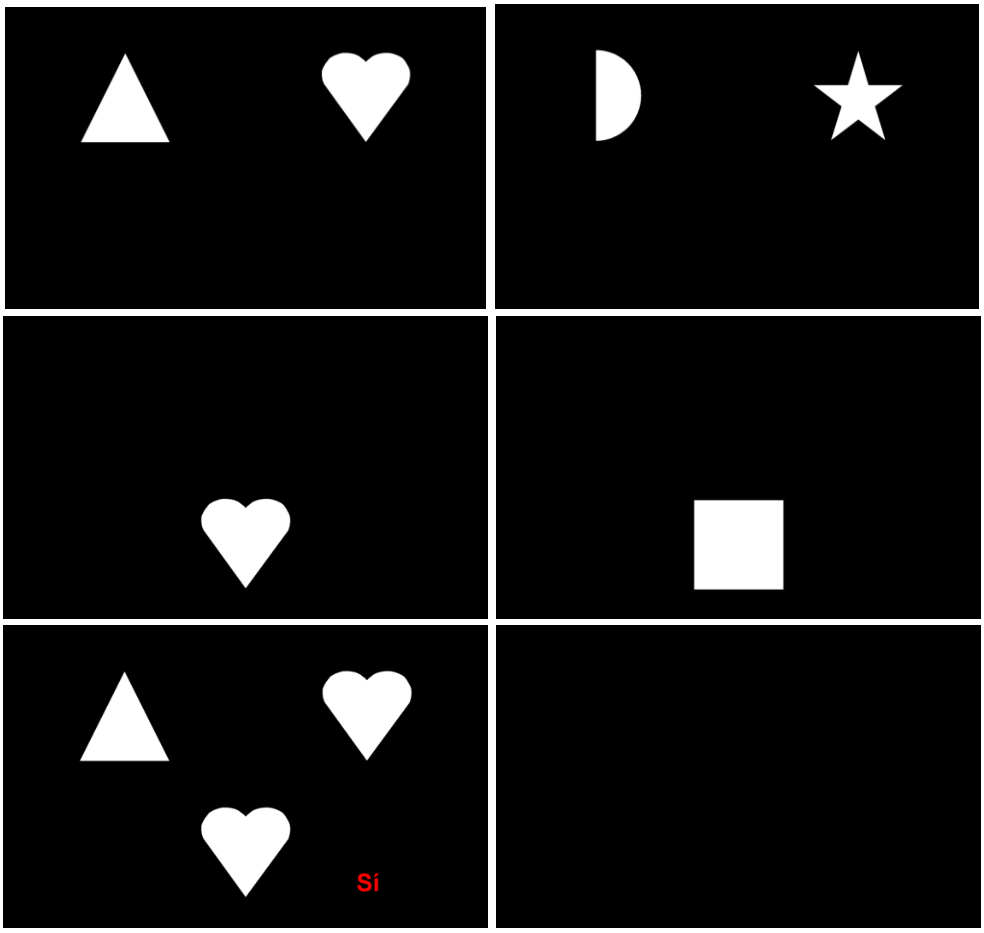


Figure 11. Snapshots of CT task – Level 1 (Two figures, white colour)

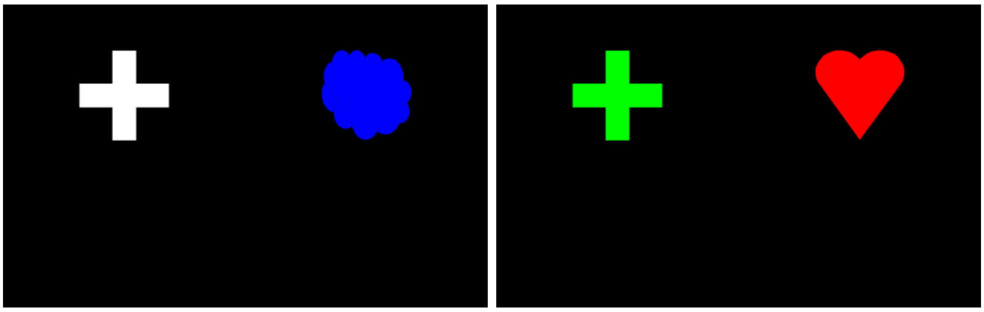


Figure 12. Snapshots of CT task – Level 2 (Two figures, different colours)

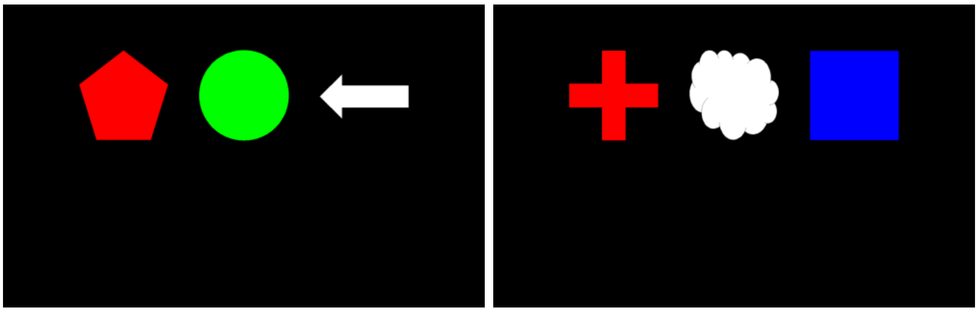


Figure 13. Snapshots of CT task – Level 3 (Three figures, different colours)

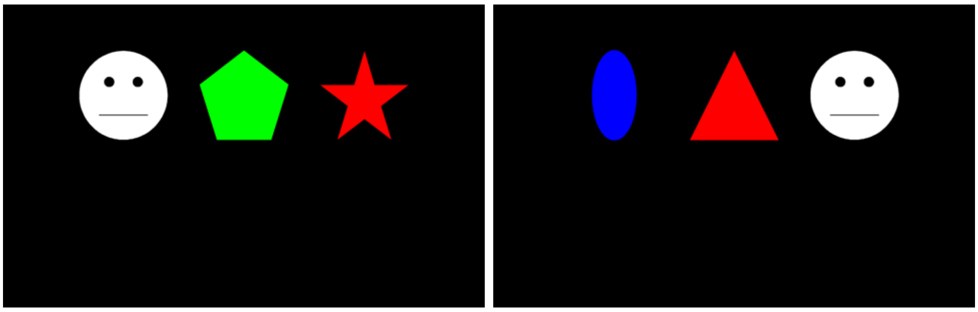


Figure 14. Snapshots of CT task – Level 4 (Two figures and one face, different colours)

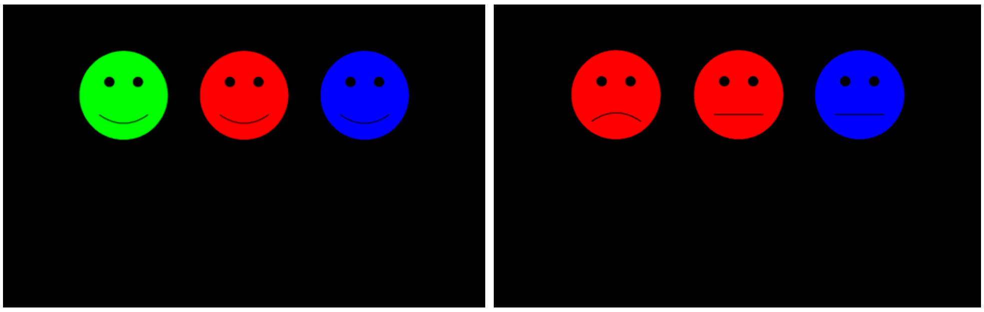


Figure 15. Snapshots of CT task – Level 5 (Three faces, different colours)

2.2. Assessment of the NFT-BCI tool

Sixty three people, recruited by the National Reference Centre on Disability and Dependence (CRE-DyD) from San Andrés del Rabanedo (León, Spain), participated in the assessment of the NFT-BCI tool. All participants were older than 60 years, healthy and without any neuropsychological disorder. They all were BCI-naive (without any BCI previous experience). Thirty one (13 male, 18 female, mean age = 62.26, range = 63 - 81) received neurofeedback training (experimental group), while remaining thirty two (9 male, 23 female, mean age = 68.03, range = 61 - 80) did not (control group). Non-significant differences were observed in the mean age or gender ($p > 0.05$, Mann–Whitney U-test) of both groups.

Firstly, subjects from both groups (experimental and control groups) performed the Luria Adult Neuropsychological Diagnosis (AND) test. The Luria test includes nine sub-tests distributed in five different areas: visuospatial (visual perception and spatial orientation), oral language (receptive speech and expressive speech), memory (immediate memory and logical memory), intelligence (thematic draws and conceptual activity) and attention (attentional control). Thus, an initial assessment of cognitive functions of all participants was carried out. Secondly, participants from the experimental group performed 10 training sessions: 5 neurofeedback training (NFT) sessions alternated with 5 working memory tasks (WMT) sessions. Each NFT session lasted approximately 60 min, while each WMT session lasted about 20 min. Each subject performed one NFT session and one WMT session every week during 5 weeks. Next, the protocol is described:

S1: 150 trials NFT task 1 (75 type A + 75 type B). Random order.

45 trials NFT task 2 (15 of each scenario). Random order.

S2: 60 trials cognitive training task (40 type 1 + 20 type 2).

S3: 60 trials NFT task 1 (30 type A + 30 type B). Random order.

90 trials NFT task 2 (30 of each scenario). Random order.

60 trials NFT task 3 (15 of each cursor). Random order.

S4: 60 trials cognitive training task (20 type 1 + 40 type 2).

S5: 90 trials NFT task 2 (30 of each scenario). Random order.

48 trials NFT task 3 (12 of each cursor). Random order.

2 trials NFT task 4, easy level.

S6: 60 trials cognitive training task (20 type 2 + 40 type 3).

S7: 45 trials NFT task 2 (15 of each scenario). Random order.

32 trials NFT task 3 (5 of each cursor). Random order.

2 trials NFT task 4, easy level.

1 trial NFT task 4, difficult level (or easy, if previous task was unsuccessful)

30 trials NFT task 5 (10 of each type). Random order.

S8: 60 trials cognitive training task (40 type 3 + 20 type 4).

S9: 45 trials NFT task 2 (15 of each scenario). Random order.

3 trial NFT task 4, difficult level.

75 trials NFT task 5 (25 of each type). Random order.

S10: 60 trials cognitive training task (40 type 4).

Finally, subjects from both groups (experimental and control groups) performed again the Luria AND test in order to carry out a final assessment of their cognitive functions.

On the other hand, Luria scores were analysed in order to explore the effects of the proposed training programme. Firstly, the nonparametric Mann–Whitney U–test was used to assess the statistical differences (p-value < 0.05) in the scores of each neuropsychological function between both groups.

Secondly, in order to assess the statistical differences between the scores of pre and post-tests, the nonparametric Wilcoxon signed–rank test ($p<0.05$) was applied. The results are shown in Table 1. A graphical summary for both groups is shown in Figure 16.

Analysis of pre-scores show that both groups (experimental and control groups) presented the same distribution for each neuropsychological function. Thus, there was no significant differences between experimental and control groups before starting the CT programme. Regarding the post-tests, we found significant differences between both groups for several functions: visual perception, expressive speech, immediate memory, thematic drawings and conceptual activity. Scores for tests of these functions were significantly increased for the experimental group after carrying out the CT programme. For this reason, significant differences between pre and post-scores in the experimental group were also found in all the measured cognitive functions except for the attentional control one.

Neuropsychological area	Cognitive Function	E vs. C Pre	E vs. C Post	E Post–Pre	C Post–Pre	E vs. C Post–Pre
Visuospatial	Visual perception	0.346	**<0.05**	**<0.05**	**<0.05**	**<0.05**
	Spatial orientation	0.830	0.471	**<0.05**	**<0.05**	0.129
Oral language	Receptive speech	0.632	0.122	**<0.05**	0.104	**<0.05**
	Expressive speech	0.242	**<0.05**	**<0.05**	0.077	**<0.05**
Memory	Immediate memory	0.187	**<0.05**	**<0.05**	0.364	**<0.05**
	Logical memory	0.745	0.254	**<0.05**	**<0.05**	0.061
Intelligence	Thematic drawings	0.216	**<0.05**	**<0.05**	0.364	**<0.05**
	Conceptual activity	0.056	**<0.05**	**<0.05**	**<0.05**	0.0173
Attention	Attentional control	0.363	0.166	0.137	0.138	0.986

Table 1. Statistics associated to the Mann-Whitney U-test and to the Wilcoxon signed-rank test for the scores of the Luria AND tests for each specific neuropsychological function. Significant values (*p*-value < 0.05) are highlighted in bold.

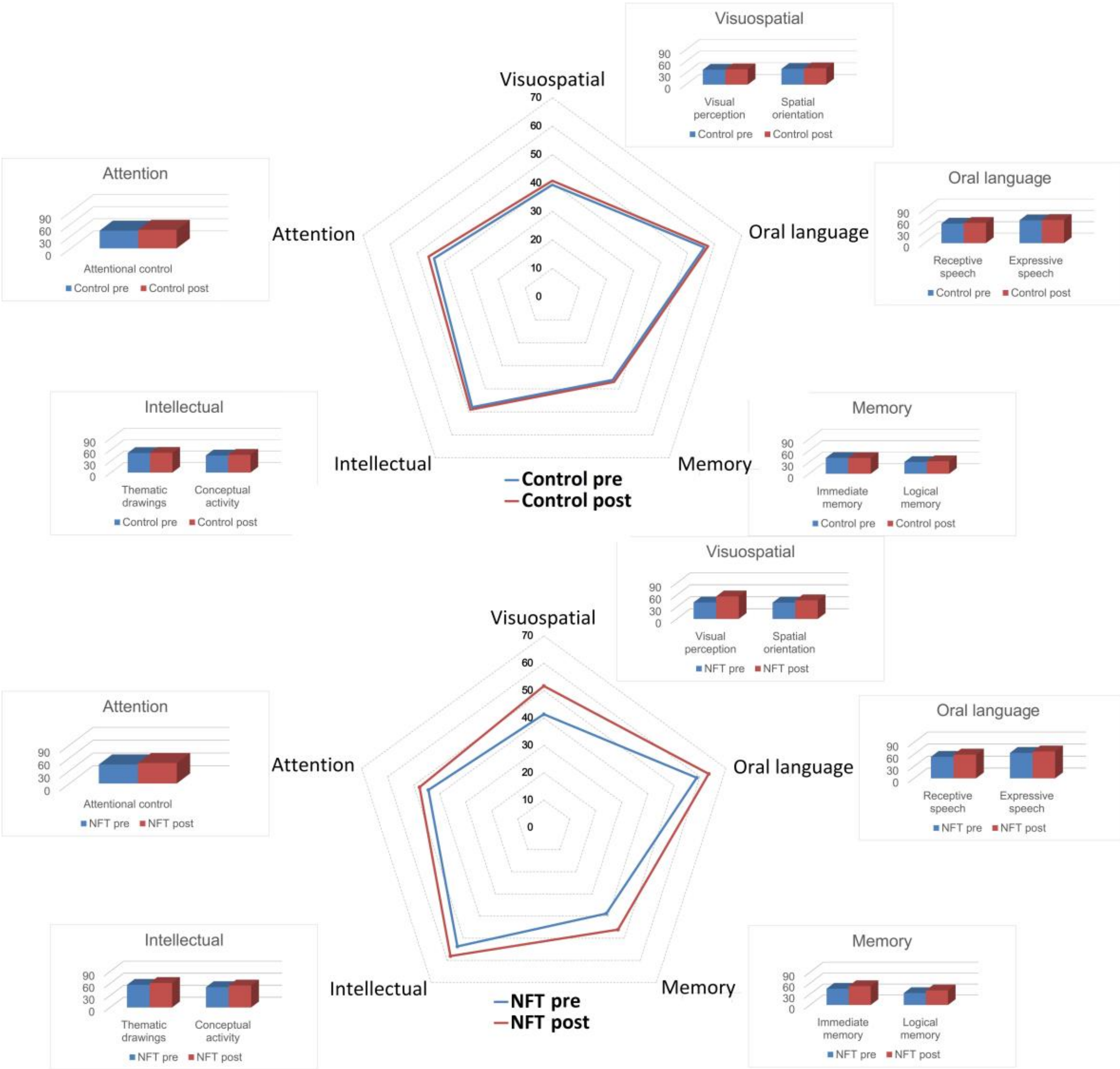


Figure 16. Test scores for control (top) and experimental NFT (bottom) groups. Bar diagrams show all cognitive features of each neuropsychological area. NFT group shows an evident generalized increase in the post-scores, i.e. after performing the proposed BCI training programme.

Regarding to the variations between the results of pre and post-tests, there were four significant differences for the control group: visual perception, spatial orientation, logical memory and conceptual activities. This could be due to the bias when a neuropsychological test is performed more than once, since the subjects may experience learning from the fact of repeating the same tests. The results suggest that there were real enhancements for experimental subjects in most of the cognitive functions. In addition, these results are coherent with the differences found in the post- tests between both groups.

Finally, several significant differences for five functions were observed regarding the variations between the experimental and control group: visual perception, receptive speech, expressive speech, immediate memory and thematic drawings. Since these tests compare the score improvements for both groups, the bias due to learning is corrected by this measure. Differences found indicate that the increases between the pre and post-scores in the experimental group for these functions are significantly higher than the increases found in the control group. Hence, our results suggest that the proposed CT programme could be an useful tool to improve cognitive abilities in general and specific functions in particular, such as visual perception, expressive speech, immediate memory and thematic drawings.

3. Development of a BCI-based tool for assistance of severely impaired people at home

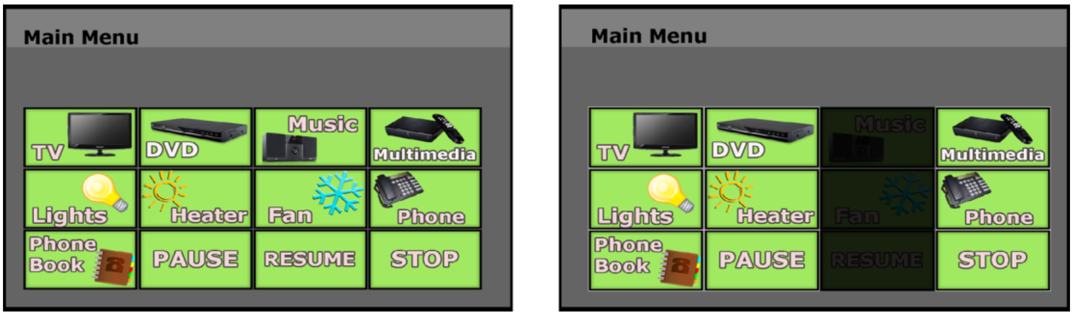
3.1. BCI tool for assistance of severely impaired people at home

A BCI tool for assisting dependent elderly people at home was developed by means of a P300-based BCI. The proposed tool allows users to manage 8 electronic devices usually present at home. Thus, the main comfort, communication and entertainment needs are fulfilled. Their main features are described below.

P300 evoked potentials are positive deflections in the electroencephalogram (EEG) time-locked to auditory or visual stimuli. Infrequent or particularly significant auditory, visual or somatosensory stimuli, when interspersed with frequent or routine stimuli, typically evoke in the EEG over parietal cortex a positive peak at about 300 ms. A BCI application that presents items in a matrix with random row/column stimuli allows to identify the specific cell that evoked the P300 responses. Hence, it is possible to identify the user's desired item.

At the beginning, the assistive BCI tool presents a main menu by means of a 3x4 matrix depicting different devices and the pause, resume and stop commands. The main menu is presented in Figure 17a. For performing a single item selection, several sequences of dimming stimuli are shown (see Figure 17b). For each sequence, all rows and columns are dimmed once. Thus, rows and columns are dimmed in a random sequence in such a manner that all rows and columns were intensified before any was repeated. Hence, each character dims twice in a complete sequence. The user can select one option menu by focusing on the desired item and mentally counting how many times the row or column containing the desired choice dims. Once the desired item (corresponding to the row and column with the highest evoked responses) is identified, the application access to the menu of the selected device. A new menu with a new matrix, showing specific commands for this device, is shown.

Similarly to the main menu, users can select different commands. The application sends the commands to the specific devices by means of an infrared (IR) emitter device (RedRat Ltd., Cambridge, UK). Therefore, users can navigate through different menus and control common electronic devices present at their environment. Figures 18-26 shows screenshots of all application "views" (Main menu and control submenus) of the assistive BCI tool.



(a) (b)

Figure 17. Snapshot of the assistive tool: (a) Main menu: it shows a 3x4 matrix consisted of images depicting all available devices: TV, DVD player, Hi-Fi system, multimedia drive, lights, heater, fan, and phone. (b) Main menu while the third column is dimmed.

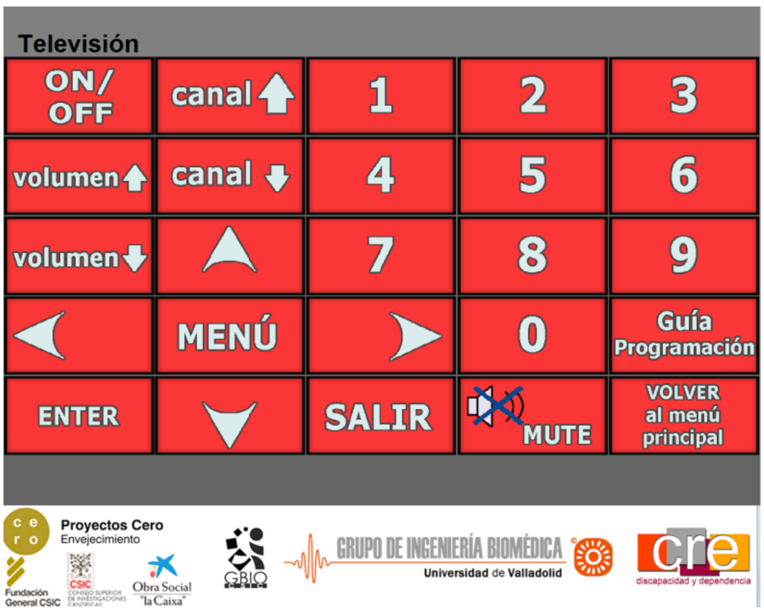


Figure 18. Snapshot of the TV submenu. The user can manage different functions commonly present in a TV remote control as well as go back to the Main menu.

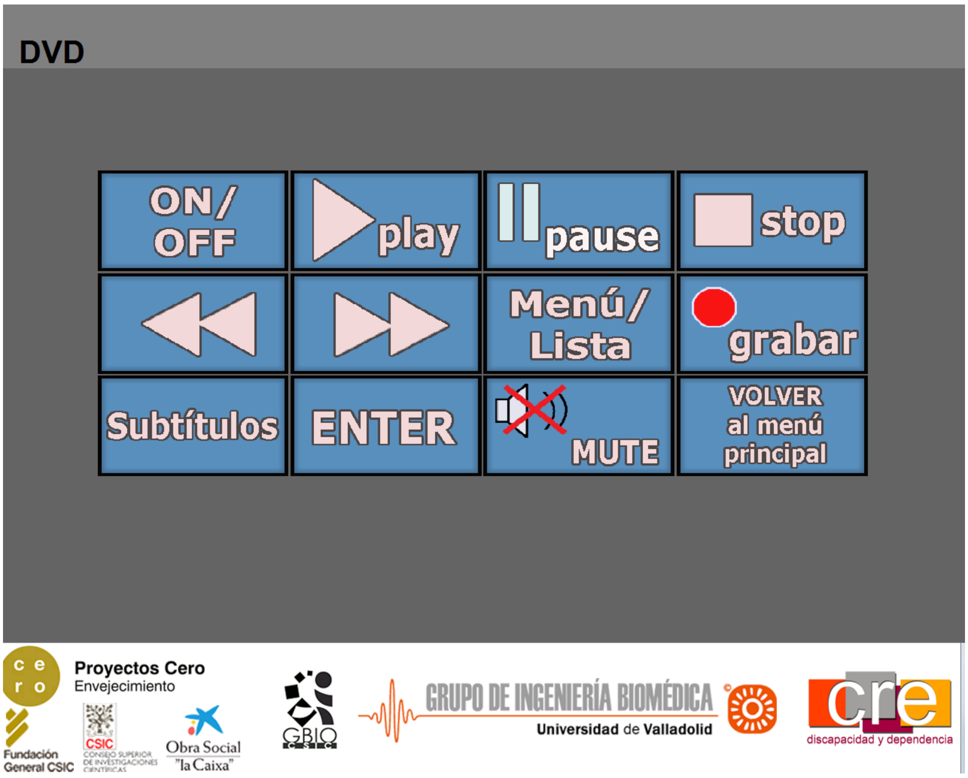


Figure 19. Snapshot of the DVD submenu. The user can manage different functions commonly present in a DVD remote control as well as go back to the Main menu.

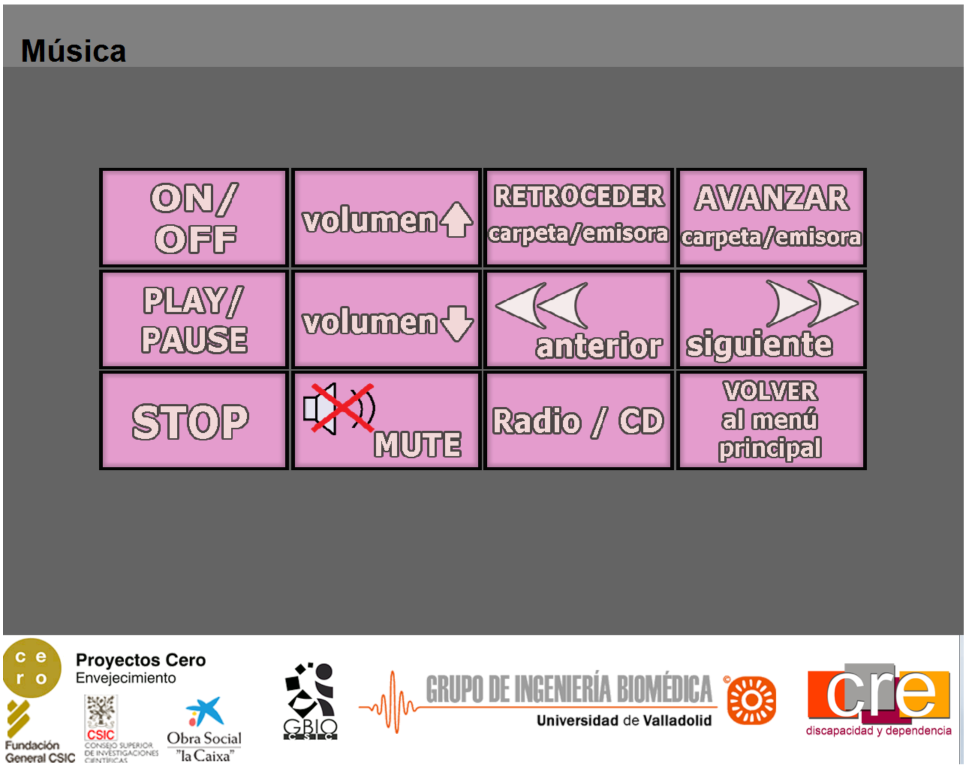


Figure 20. Snapshot of the Hi-Fi system submenu. The user can manage different functions commonly present in a Hi-Fi remote control as well as go back to the Main menu.

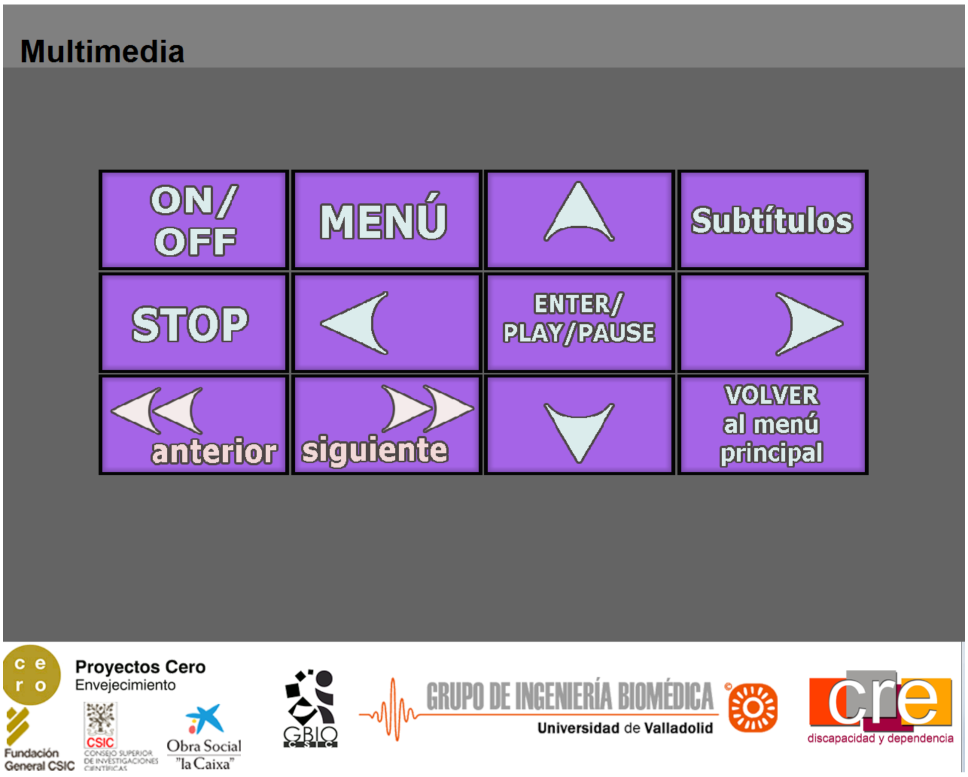


Figure 21. Snapshot of the Multimedia hard drive submenu. The user can manage different functions commonly present in a Multimedia remote control as well as go back to the Main menu.

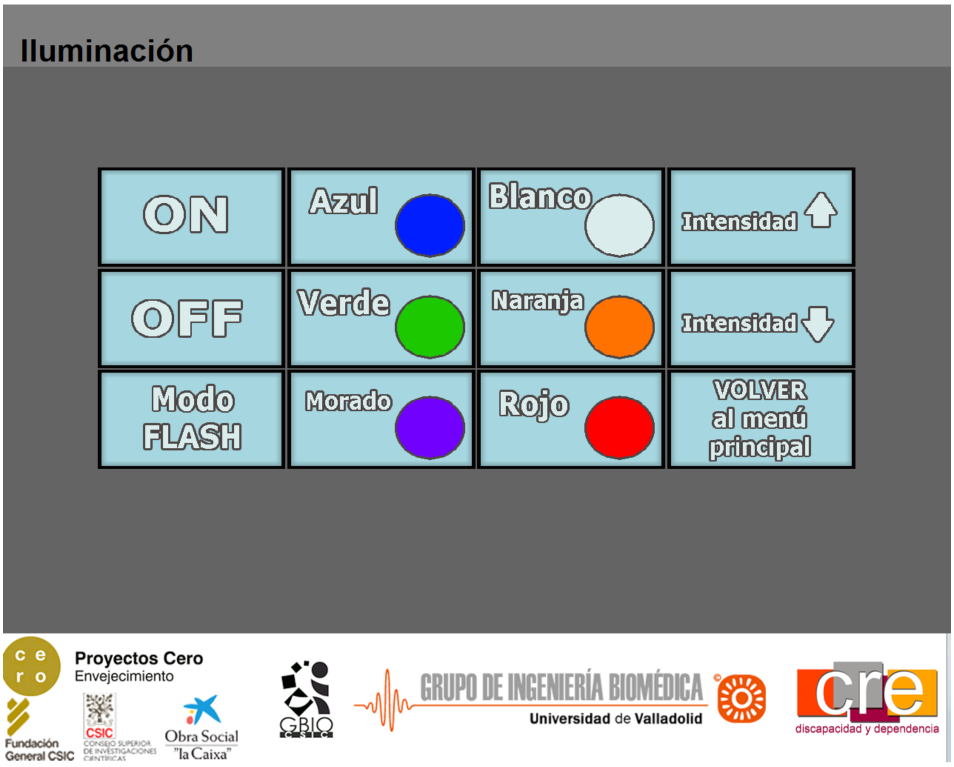


Figure 22. Snapshot of the Lights submenu. The user can mange different functions linked with intensity and colour of a LED light with remote control as well as go back to the Main menu.

Figure 23. Snapshot of the Heater submenu. The user can manage different functions commonly present in a Heater remote control as well as go back to the Main menu.

Figure 24. Snapshot of the Fan submenu. The user can manage different functions commonly present in a Fan remote control as well as go back to the Main menu.

Figure 25. Snapshot of the Telephone submenu. The user can manage different functions commonly present in a Telephone as well as go back to the Main menu.

Figure 26. Snapshot of the Phonebook submenu. The user can manage different functions commonly present in phonebook as well as go back to the Main menu.

3.2. Assessment of the assistive BCI tool

Thirty people, recruited through the National Reference Centre on Disability and Dependence (CRE-DyD) from San Andrés del Rabanedo (León, Spain), participated in the assessment of the P300-based tool. All subjects (19 males, 11 females; mean age = 48,70 ± 10,57 years, range = 26 – 68) performed three sessions (a first one for calibration and two evaluation sessions) and one neuropsychological evaluation by means of the Luria test. They were potential BCI end-users since they presented motor disabilities. Moreover, they all were BCI-naive (without any BCI previous experience).

Subject	Calibration Ac (%)	Evaluation1 Ac (%)	Evaluation2 Ac (%)	Max ITR (bit/min) with pauses	Max ITR (bit/min) without pauses
U01	100,00	96,55	95,65	14,10	24,20
U02	100,00	100,00	91,04	17,85	43,42
U03	100,00	97,06	74,51	5,37	7,30
U04	100,00	95,00	96,00	20,06	48,80
U05*	35,71	55,56 /46,15	-	2,19	2,82
U06*	68,86	46,51 / 64,71	-	2,60	3,35
U07*	78,57	46,67 / 77,78	-	3,22	4,14
U08	91,67	100,00	92,86	13,20	22,65
U09	96,67	100,00	90,48	12,48	21,43
U10	82,35	75,76	84,38	6,84	9,29
U11**	38,89 / 80,00	63,33	-	3,33	4,29
U12	87,50	100,00	84,62	15,37	37,39
U13***	27,78 / 33,33 / 37,50	-	-	-	-
U14	95,83	100,00	78,46	9,39	16,12
U15*	67,86	60,00 / 65,00	-	3,25	4,18
U16	100,00	95,24	71,83	6,14	9,07
U17	100,00	100,00	93,55	9,03	12,56
U18	90,91	89,39	96,72	16,03	29,80
U19	86,36	95,00	68,52	4,31	5,74
U20	100,00	93,55	82,61	6,99	9,72
U21	86,36	96,77	93,55	9,03	12,56
U22	100,00	96,83	94,20	15,08	28,05
U23	95,45	80,65	96,67	12,10	18,60
U24	100,00	100,00	96,72	20,42	49,67
U25	100,00	95,24	100,00	25,91	81,58
U26*	66,67	38,16 / 36,84	-	-	-
U27	100,00	82,54	94,55	11,50	17,68
U28	90,91	88,24	87,69	8,43	12,05
U29	100,00	96,77	97,14	23,91	75,29
U30	77,27	96,77	89,06	8,13	11,31

*: During the third session these participants repeated Evaluation1 tasks, due to accuracy lower than 70% during the previous Evaluation1 session.
**: During the second session this participant repeated Calibration tasks, due to accuracy lower than 70% during the Calibration session. During the third session, this participant performed Evaluation1 tasks.
***: During the second and third sessions this participant repeated Calibration tasks , due to accuracy lower than 70% during the previous Calibration sessions.

Table 2: Results of accuracy and ITR for each experimental session and participant.

An assessment of the results of the proposed BCI tool used by users of CRE-DyD was performed. Table 2 shows the measures of accuracy and information transfer rate (ITR) achieved by each user during each experimental session. In summary, our results showed that twenty three out of the thirty participants were able to properly manage the proposed tool with accuracy higher than 80%. Nineteen out of them even achieved accuracy above 95%. Moreover, the users' performance was analysed in order to explore its relation to the Luria AND scores achieved for each participant. Statistical differences were not found between the accuracy or information transfer rate reached by the patients and the Luria score for specific cognitive functions. Therefore, our results show that P300-based BCIs could be really proper to assist severely impaired people at their own home.

4. Joint analysis of both developed BCI tools

4.1. Population under study

Ten people, recruited through the National Reference Centre on Disability and Dependence (NRC-D&D) located in San Andrés del Rabanedo (León, Spain), participated in the joint analysis of both BCI tools. On one hand, the experimental group consisted of five people (2 males, 3 females, mean age = 76.2 ± 4.1 years) who received several cognitive training BCI-based sessions before performing tasks with the BCI assistive tool. On the other hand, the control group consisted of five people (2 males, 3 females, mean age = 64.2 ± 3.8 years) who did not received cognitive training before performing tasks with the BCI assistive tool.

All participants were older than 60 years, healthy and without any neuropsychological disorder. All of them were BCI-naïve, i.e.: they did not have any BCI previous experience. The study was approved by the local ethics committee. All subjects gave their informed consent for participation in the study.

4.2. Protocol of the experiment

Firstly, each participant from the experimental group performed 5 cognitive training BCI-based sessions of approximately 1h. More specifically, they performed one session per week during 5 weeks. The specific procedure of the training sessions was the same as the procedure performed to assess the neurofeedback training (NFT) tool designed at the first part of the present project. The training programme for this former study is presented below.

Secondly, participants from both groups performed three sessions with the proposed assistive P300-based BCI tool. During these sessions, users interacted with the application managing each electronic device and performing different control tasks. The assistive BCI application is based on a main menu where it is possible to select the device that the user wants to manage. Once the desired device is selected, a new menu with specific control commands for that device appears. From each menu, the user can also go back to the main menu. Hence, users can control different options of eight devices: TV, DVD player, Hi-Fi system, multimedia hard drive, lights, heater, fan and phone. When a user selects the desired action and the computer identifies it, the command is sent to the corresponding device by means of an infrared (IR) emitter device (RedRat Ltd., Cambridge, UK).

During the assistive tool assessment, the electroencephalogram (EEG) was recorded from 8 active electrodes (Fz, Cz, P3, Pz, P4, PO7, PO8 and Oz) placed in an elastic cap according to international 10–20 system. Signals were amplified by a g.USBamp amplifier (Guger Technologies OG, Schiedlberg, Austria). Subsequently, signals were bandpass filtered (0.1–60 Hz) and notch-filtered at 50 Hz in order to remove the power line interference. Finally, signals were digitally stored at a sampling rate of 256 Hz. EEG signals were processed in real-time using the BCI2000 general-purpose system.

All participants performed three sessions with the P300-based BCI tool. The procedure and objectives of each session are detailed below.

- Calibration session

The Calibration session was comprised of 10 runs of approximately 4 min each. Data was collected in copy-spelling mode. In this initial session, only one matrix was presented to the user: the 5 x 5 TV menu matrix. In each run, the user was asked to focus on a specific item from a proposed series of 5-6 items. 15 sequences of stimuli were presented for each single item selection. Runs were separated by intervals of 60 s. This session approximately lasted one hour. During the Calibration session, feedback was not provided to participants. Step Wise Linear Discriminant Analysis (SWLDA) was applied to data from the 5 first runs of the Calibration session to determine the classifier weights for each user. This classifier was used during the subsequent 5 runs of the Calibration session.

- Evaluation 1 session

Evaluation1 started with 12 items of copy-spelling using the TV menu matrix in order to ensure proper performance. Subsequently, participants were ready to interact with the proposed assistive BCI tool and all available menus. Evaluation1 session comprised at least 7 evaluation runs. In each run, participants were asked to select items across different menus in order to complete a proposed series of at least 6 items, e.g.: “access the TV menu”, “switch to channel 8”, “turn up the volume”, “return to the main menu”, “access the DVD menu”, “record the actual channel”. For each single item selection, 15 sequences of stimuli were presented during Evaluation1. For each subject, the classifier built during the previous Calibration session was applied during the running of Evaluation1 and Evaluation2, unless during the initial copy-spelling items of Evaluation1 an improper performance was detected. In this specific case, a new classifier was created using these initial copy-spelling runs.

- Evaluation 2 session

Evaluation2 session was similar to Evaluation1. Participants started with 12 items of copy-spelling facing the TV menu matrix in order to ensure proper performance. Then, subjects were asked to select items across different menus in order to complete previously proposed tasks. During Evaluation2, the number of sequences of stimuli was reduced for each user in order to decrease the selection time. The less the number of sequences needed to suitably detect the P300 peak, the faster the users can navigate through all devices and control commands. The lowest number of sequences assigned was 2, corresponding to the participant with the highest offline performance (C-3). This methodology allows us to measure the maximum information transfer rate (ITR) achieved per subject.

4.3. Results

The results achieved by all participants during the assistive BCI tool's assessment are summarized in Tables 3 and 4. Table 3 shows the results for each participant from the control group (they did not receive previous NFT sessions), whereas Table 4 shows the results for participants from the experimental group (they received previous NFT sessions). Online accuracy, measured as the percentage of hits divided by the total number of proposed items, is shown for Calibration, Evaluation1 and Evaluation2 sessions. Furthermore, the maximum ITR (bit/min) during the Evaluation2 session for each subject is also provided. The ITR is a measure of the operating speed of the application related to the time required to execute a single command (variable for each user). Hence, the users who reached higher ITR completed the control sequence commands faster than the users who presented lower ITR values. Since a large pause (5 seconds) was set in order to let the participants enough time to note the current result and to focus on the next item, ITR values were calculated with and without taking into account the pause between selections. Thus, it is possible to compare our ITR values with other studies.

Seven users (C-1, C-3, C-4, C-5, E-2, E-3 and E-5) reached 100% online accuracy during the initial Calibration session. The remaining participants also achieved high accuracies, above 90%. The classifier derived in this session was then used to perform Evaluation1 and Evaluation2 sessions.

Regarding Evaluation1 session, four participants (C-2, C-4, C-5 and E-3) achieved 100% online accuracy. The remaining participants reached higher accuracy values too, above 82%. During Evaluation2 session, the accuracy ranged from 76% to 98%. Accuracy results are lower than in Evaluation1 session since they used less number of dimming sequences for selecting each

User	Calibration ACC (%)	Evaluation1 ACC (%)	Evaluation2 ACC (%)	Maximum ITR (bit/min)	
				With pause	Without pause
C-1	100,00	93,33	90,74	13,91	25,87
C-2	90,91	100,00	87,18	10,54	17,01
C-3	100,00	97,67	98,00	24,44	76,96
C-4	100,00	100,00	96,00	20,06	48,80
C-5	100,00	100,00	87,23	8,97	13,25
Mean	**98,18**	**98,20**	**91,83**	**15,58**	**36,38**

Table 3. Results of online accuracy (ACC) per session and maximum Selection Rate and ITR during Evaluation2 session for each participant from the control group.

User	Calibration ACC (%)	Evaluation1 ACC (%)	Evaluation2 ACC (%)	Maximum ITR (bit/min)	
				With pause	Without pause
E-1	95,45	95,56	76,47	6,92	10,23
E-2	100,00	95,56	91,11	12,67	21,74
E-3	100,00	100,00	82,61	11,50	21,39
E-4	90,91	82,93	85,71	7,52	10,46
E-5	100,00	82,93	82,93	9,54	15,39
Mean	**97,27**	**91,39**	**83,77**	**9,63**	**15,84**

Table 4. Results of online accuracy (ACC) per session and maximum Selection Rate and ITR during Evaluation2 session for each participant from the experimental group.

item. Therefore, they made each selection faster but with slightly lower accuracy.

Finally, ITR values ranged between 6,92 and 24,44 bit/min. If we do not take into account the pause between selections, ITR ranged from 10,23 to 76,96 bit/min. The users who needed less number of dimming sequences made faster selections and achieved the highest ITR values.

4.4. Discussion

The aim of this study was to perform a joint assessment of both BCI tools developed in the global BCI-Ageing project. Specifically, the usefulnesss of previous cognitive training using the BCI-based NFT tool was assessed by means of the performance achieved when managing the assistive BCI tool.

Regarding the global results, the mean accuracies and ITR values achieved by the subjects from both groups were similar. Accuracies and ITR results per subject and averaged accuracies per group are shown in Figures 27 and 28, respectively. The control group achieved slightly higher accuracies than the experimental one. More specifically, the decrease in averaged accuracies between Calibration and Eval1 sessions was lower in the control group than in the experimental one. Nevertheless, the decrease in mean accuracies between Eval1 and Eval2 sessions was very similar in both groups. In fact, no significant differences (p>0.05) between the experimental and the control group in any metrics (ACC and ITR) were found. Hence, the NFT training program performed by the experimental group does not enhance or increase the ability to control P300 evoked potential based-BCIs. These results agree with the basis of P300-based BCIs. As exogenous BCIs, they do not depend on the users' ability of controlling their own brain activity.

The assistive BCI tool developed in the BCI-Ageing project was assessed by real end-users, people with severe disabilities. The results achieved by that population were quite different than the results reached by the group of elderly people. The performance of the impaired people was usually lower. More

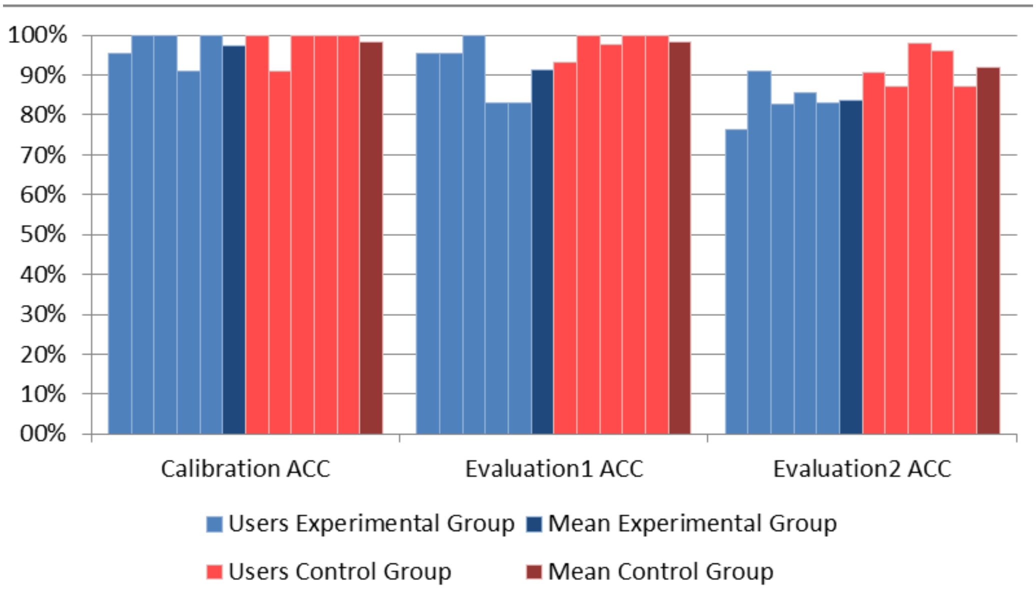


Figure 27. Accuracies reached per subject and averaged accuracies per group during the three experimental sessions performed with the assistive BCI tool.

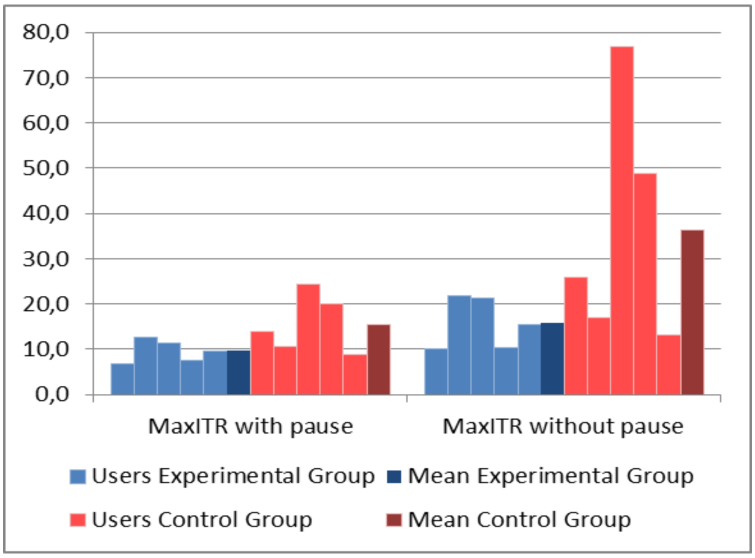


Figure 28. ITR values reached per subject and averaged ITR values per group during the three experimental sessions performed with the assistive BCI tool.

specifically, when users presented poor attentional control abilities, the accuracy decreased. On the contrary, elderly population who assessed jointly both BCI applications did not present any cognitive disorder.