Providing Physical Autonomy to Disabled People through Telemonitoring and Home Support

Felip Miralles, Eloisa Vargiu, Stefan Dauwalder, Eloi Casals, and José Alejandro Cordero

Abstract The long term rehabilitation goal for individuals with a severe disability, such as acquired brain injury, is resettlement back in the community away after a discharge. Thus, solutions and systems that provide physical autonomy must be investigated and designed. In this paper, we present a solution that relies on telemonitoring and home support and that use context-aware techniques to be personalized and adaptable to users' needs. The system is part of the BackHome project and is currently running at end-users facilities in Belfast and Würzburg. Here, we present and discuss preliminary experiments performed in Barcelona with healthy users.

1 Introduction

Acquired Brain Injury (ABI) as well as further traumatic injury or disease limit the individuals capacity for participation and inclusion in society and may cause the so-called "locked-in syndrome"[1]. Assistive technologies are particularly important to enable individual engagement and promote independence providing benefits to both the person experiencing the disability [8] [9] and their carer. In fact, the long term rehabilitation goal for individuals with an ABI is resettlement back in the community away from institutional care. The ideal scenario is that the person will return to her/his previous home and life roles.

The adoption of a Brain-Computer Interface (BCI) within assistive technologies extends the potential and contribution that such systems can make through the trajectory of a disability [12] [11]. BCI aims to assist and augment function by de-

Barcelona Digital Technology Center, e-mail: {fmiralles, evargiu, sdauwalder, ecasals, jacordero}@bdigital.org

[1] http://www.cbsnews.com/news/harnessing-the-power-of-the-brain/

veloping interfaces, based on the detection of brain signals, ultimately providing communication and control to people with severe disabilities [5] [1] [19].

In this paper, we present a user-centered solution aimed at providing a suitable infrastructure for supporting physical autonomy of disabled people. In particular, we provide physical support to BCI users through the adoption of suitable sensors and actuators as well as communication services. The system rely on context awareness to provide adaptive capabilities. The combined action of these adaptive capabilities and a set of predefined rules allows the system to be proactive, anticipating user requests. This characteristic is aimed at greatly optimizing user experience when interacting with the system.

The proposed system is part of BackHome[2], an EU project concerning physical and social autonomy of people with disabilities, by using mainly BCI and integrating other assistive technologies as well [3].

The rest of the paper is organized as follows, in Section 2, the platform defined and implemented in BackHome is presented. Section 3 illustrates our proposal to provide physical autonomy to disabled people. Section 4 briefly presents how personalization and adaptation have been provided by relying to context awareness. In Section 5, we describe the current implementation and our first experimental results. Section 6 ends the paper with a discussion on the main results and summarizing future research directions.

2 The Overall System

The overall system, implemented under the umbrella of the BackHome project, relies on two stations: (i) the user station and (ii) the therapist station. The former is the main component which the user interacts with. It contains the modules responsible for the user interface, the execution of cognitive rehabilitation tasks, the control of the smart home and the other services, and the intelligence of the system, including the algorithm to assess the quality of life [17]. The latter[3] is responsible for the communication between the therapist and the user, as well as on handling cognitive rehabilitation tasks and quality-of-life assessment.

The overall system provides to the user several services and applications [10]:

- *Smart Home*, to allow the user controlling home devices (e.g., a light, a TV, a radio), as well as to interact with the XBMC multimedia player.
- *Cognitive Stimulation*, to allow users to improve their cognitive capabilities by performing cognitive rehabilitation tasks assigned by a therapist [16] or by using their creative skills through Brain Painting[14].
- *Web Access* that enables participation and inclusion by offering users the possibility to engage in social interaction through the Web, such as Web browsing, emailing and twittering.

[2] http://www.backhome-fp7.eu/

[3] https://station.backhome-fp7.eu:8443/BackHome

3 Providing Phyisical Autonomy

In order to support the BackHome end-users with physical autonomy, we provide telemonitoring by a sensor-based system and home support by smart home devices. In particular, among the most common types of assistance, we take into account the enhancement in the capabilities of controlling some devices and appliances, as well as to learn how to proactively perform actions.

Adaptation, personalization, alarm triggering, and control over environment are handled with a rule-based approach [2] that relies on a suitable language [7].

3.1 Telemonitoring

To monitor users at home, we develop a sensor-based system able to monitor the evolution of the user's daily life activity [18]. The implemented system is able to monitor indoor activities by relying on a set of home automation sensors and outdoor activities by relying on Moves[4].

As for indoor activities, we use presence sensors (i.e., Everspring SP103), to identify the room where the user is located (one sensor for each monitored room) as well as temperature, luminosity, humidity of the corresponding room; a door sensor (i.e., Vision ZD 2012), to detect when the user enters or exits the premises; electrical power meters and switches, to control leisure activities (e.g., television and pc); and pressure sensors (i.e., bed and seat sensors) to measure the time spent in bed (wheelchair). Figure 1 shows an example of a home with the proposed sensor-based system.

From a technological point of view, we use wireless z-wave sensors that send the retrieved data to a central unit (based on Raspberry pi) located at user's home. That central unit collects all the retrieved data and sends them to the cloud where they will be processed, mined, and analyzed. Besides real sensors, the system also comprises "virtual devices". Virtual devices are software elements that mash together information from two or more sensors in order to make some inference and provide new information. For instance, sleep hours may be inferred by a virtual device that meshes the information from the bed sensors together with that from the presence sensor located in the bedroom. Let us consider the case in which the user is in bed reading. In that case, the luminosity level measured by the presence sensor assesses that the user is not sleeping, yet, even if the bed sensor is activated. In so doing, the system is able to perform more actions and to be more adaptable to the context and the user's habits. Furthermore, the mesh of information coming from different sensors can provide useful information to the therapist (e.g., the number of sleeping- or inactivity-hours). In other words, the aim of a virtual device is to provide useful information to track the activities and habits of the user, to send them back to the

[4] http://www.moves-app.com/

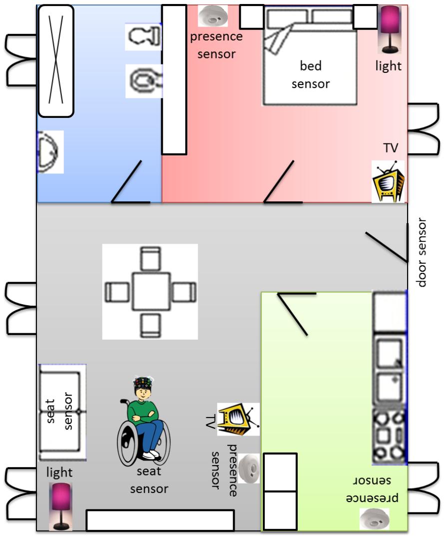

Fig. 1 An example of a home with the sensor-based system installed.

therapist through the therapist station, and to adapt the user station, with particular reference to its user interface, accordingly.

As for outdoor activities, we are currently using the user's smartphone as a sensor by relying on Moves, an app for smartphones able to recognize physical activities (such as walking, running, and cycling) and movements by transportation. Moves is also able to store information about the location in which the user is, as well as the corresponding performed route(s). Moves provides an API through which is possible to access all the collected data.

3.2 Home Support

Smart home devices, which give control over the built environment and free standing electrical goods, are installed in the user's home so that the user is able to control them through the BCI.

They offer a complete description of the context of the user constantly supporting other subsystems and modules in their work. We rely on a modular, flexible and scalar approach to add new devices independently of the protocol just introducing new drivers to the system. By now, we integrated three different appliances: light, TV, and IP Camera. We use a remote power switch to turn on/off a light. The module is controlled by a remote control, an Arduino Fio controlled by an USB connection and connected to a 433 MHz transmitter. TV is controlled by the DreamBox series feature TV tuners for DVB-T/C/S, which includes a hard disk based DVR via EPG, network connectivity, and an adaptable OSD with support for skinning. Finally, the system is able to control a D-Link DCS-5020L camera, which has Pan and Tilt function like the previous camera. It also adds some new features like sound and motion detection, night vision and it can also expand the Wi-Fi network.

The end user controls the Smart Home system via a P300 control interface. With the proposed BCI, all applications can be operated via control matrices that were first proposed in [6] for a spelling system. As control signals the BCI uses event-related potentials (ERPs) that can be extracted from the EEG. Of these ERPs the P300 is often the most prominent [15]. During stimulation, rows and columns of the matrix are highlighted in random order. To operate the system, users are asked to attend to the symbol (e.g., a letter or a command) in the matrix that they want to select and silently count whenever it is highlighted. The rows and columns including the target symbol elicit the ERP response. Thus, the system can identify the target symbol as the symbol at the intersection of the row and column that elicited the P300 response and execute the desired action. The BCI components together allow the user to control the User Station with services and actuators and receive feedback from sensors and services. In particular, to control Smart Home devices, the P300 control interface shows the distribution and availability of all smart home devices (see Figure 2). Let us note that some actuators can be as simple as a switch (i.e., the light control) and they can be included directly in the interface indicating only the action that can be performed (e.g., in the case of the light, "ON" or "OFF"). On the contrary, complex actuators allows more actions that are showed in the interface.

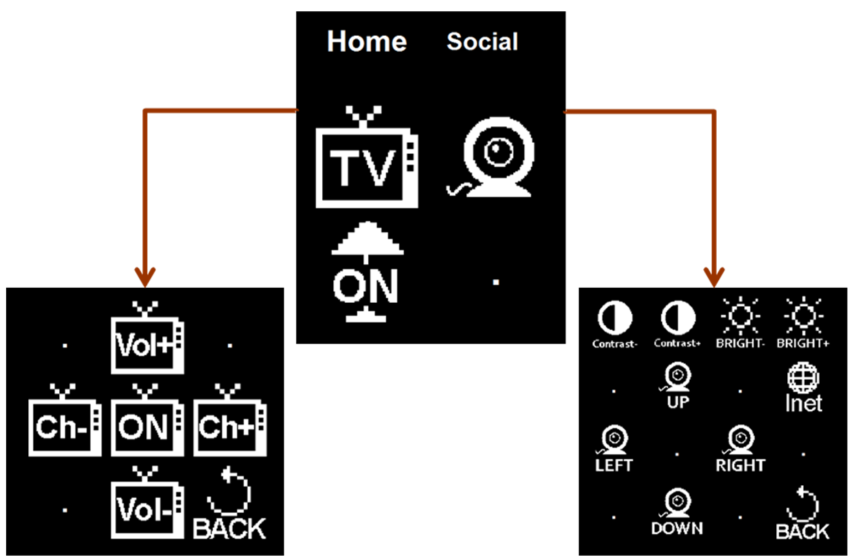

Fig. 2 P300 interface. In the middle, the main menu. On the sides, the navigation menus for the TV (on the left) and the IP camera (on the right), respectively.

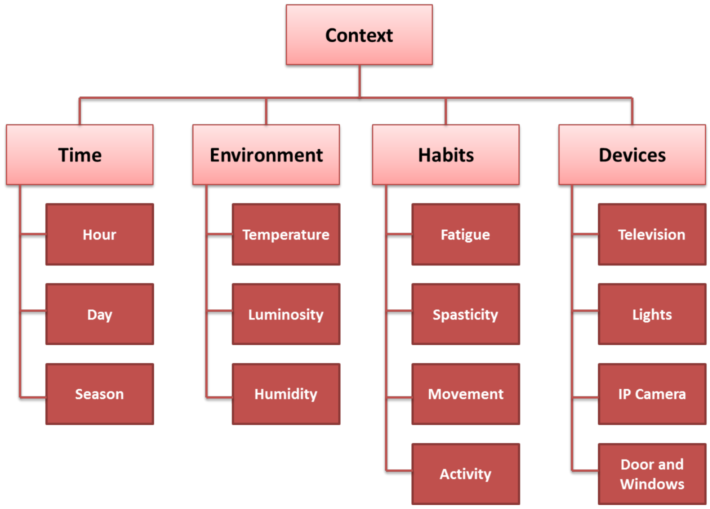

Fig. 3 Context definition in BackHome.

4 Providing Personalization and Adaptation

The overall system provides personalization and adaptation. In particular, starting from the information of the context, triggers and rules may be defined. A knowledge representation of the context which needs to be captured, and stored, from the different data/information sources and adopted devices, has been devised. The outcome of the context formalization is depicted in Figure 3, in which the different context component are presented. This definition incorporates different categories taken into account when evaluating the context:

- Time: representing the current moment taking place.
- Environment: referring to direct information of the context depending on environmental measures.
- Habits: providing information about physiological measurements and normal activities.
- Device: representing the status of the devices controlled by the system.

To perform personalization and adaptation we rely on machine learning techniques able to infer the behavioral patterns of the system, to learn user's habits and to adapt according to user's preferences [2].

5 Preliminary Experiments and Results

To test the telemonitoring and home support system, we created an experimental protocol that was first conducted by healthy participants, before testing with poten-

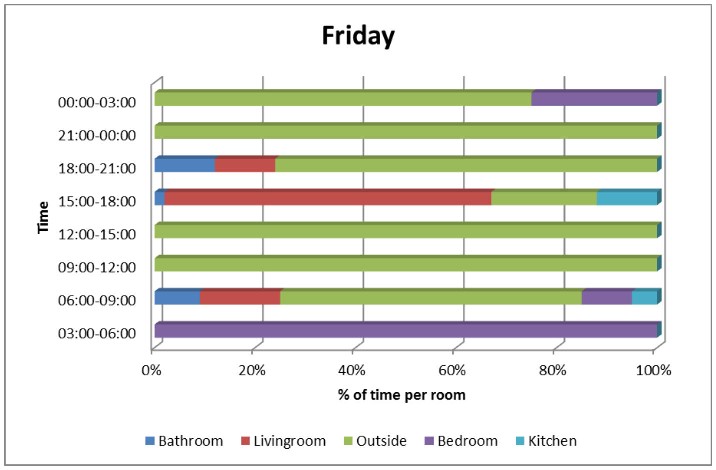

Fig. 4 User's habits: part-time workday.

tial end users. The experimental protocol required participants to perform normal activities at home (telemonitoring) and BCI tasks to interact with home appliances (home support). The context-aware rule approach is then used to provide user interface adaptation and alarm triggering.

5.1 Telemonitoring

The system is currently running in a healthy user's home in Barcelona. The corresponding user is a 40-year-old woman who lives alone. This installation is currently available and data continuously collected. According to the home plan, the following sensors have been installed: 1 door sensor; 3 presence sensors (1 living room, 1 bedroom, 1 kitchen); 3 switch and power meters (1 PC, 1 Nintendo WII, 1 kettle); and 1 bed sensor. Moreover, the user has installed in her iPhone the Moves app.

Collected data have been used to recognize habits as well as to assess the movement ability of the given user [13].

To recognize user's habits, we performed a preliminary experiment considering indoor habits and relying on presence sensors (one for each monitored room) and the main door sensor (to know when the user enters or leaves the premises). We collected data from one month (November '13 – December '13) and we considered time slot of 3 hours. Our preliminary results show that we can note three different habits depending on the kind of the day: workday, part-time workday and weekend. Results show that it is possible to note changes in the habits of the user depending on the day of the week. In particular, it could be noted the hours in which the user is at home and the room(s) in which passes the majority of the time. Figure 4 shows an example of recognized habits for a part-time workday (i.e., Friday).

To assess movement ability, we considered a window of three months (February ’14 – April ’14) and made comparisons of results for three classifiers: decision tree, k-nn with k=1, and k-nn with k=3. During all the period, the user answered to the question “Today, how was your ability to move about?”, daily at 7 PM. Answers have been then used to label the item of the dataset to train and test the classifiers built to verify the feasibility of the proposed QoL approach. Given a category, we consider as true positive (true negative), any entry evaluated as positive (negative) by the classifier that corresponds to an entry labeled by the user as belonging (not belonging) to that class. Seemly, we consider as false positive (false negative), any entry evaluated as positive (negative) by the classifier that corresponds to an entry labeled by the user as not belonging (belonging) to that class. Results have been then calculated in terms of precision, recall, and F_1 measure.

Let us stress the fact that in this preliminary experimental phase, we are considering data coming from a healthy-user. Thus, while analyzing data, the following issues must be considered: tests have been performed with only one user; the user is healthy; and a window of less than 4 months of data has been considered. As a consequence, results can be used and analyzed only as a proof of concept of the feasibility of the approach.

The best results have been obtained using the decision tree. In fact, in that case, on average we calculated a precision of 0.64, a recall of 0.69 and a F_1 of 0.66. It is worth noting that, as expected (the user is healthy and not have difficulty in movements), the best results are given in recognizing “Normal” mobility. In fact, in this case we obtained a precision of 0.80, a recall of 0.89 and an F_1 measure of 0.84.

5.2 Home Support

We tested the home support system in Barcelona with 10 healthy volunteers from 25 to 47 years old (32.6 on average), 4 females. All participants had normal or corrected to normal vision and reported that they had no history of neurological or psychological disorders.

The following protocol was performed once for each user:

- select from the main matrix the “Smart Home” command (see Figure 2);
- select the “ON” command to turn on the light and, subsequently, the “OFF” command to turn it off:
- select the icon corresponding to the camera in the “Smart Home” command (see Figure 2) in the main menu;
- move it the camera “UP”, “DOWN”, and “LEFT” (see Figure 2).

Following our user-centered design approach we asked the participants to fill out three questionnaires, specifically eQuest 2.0 [4] , a visual analogue scale (VAS) questionnaire for user satisfaction and a custom usability questionnaire. The aim of the questionnaires was to collect subjective feedback from the users regarding general satisfaction, the overall usability of the system and the overall feeling regarding the technology, the interface, the software, the hardware as well as the BCI cap.

Table 1 Results of smart home control device. TTF means time to finish, Total Selections are all activation, FP the false positive, i.e. wrongful activation, and FN are the false negative, i.e. wrongfully missed activation.

ID	Age	Sex	TTF	Total select.	FP	FN	Acc. (%)
1	40	F	3.7	11	0	4	63.6
2	29	M	5.5	18	4	4	55.5
3	32	M	4.4	12	2	2	66.6
4	34	F	3.8	15	1	6	53.3
5	47	F	2.6	7	0	1	85.7
6	32	F	10.9	29	4	19	20.6
7	27	M	–	–	–	–	–
8	33	M	4.8	15	2	6	46.6
9	25	M	2.4	8	1	4	87.5
10	27	M	1.9	9	1	1	77.7
Avg.	32.6		4.5	13.8	1.7	4.8	61.9
SD	6.7		2.7	6.8	1.5	5.8	21.0

Table 1 shows the results of the performed experiments[5]. As for the overall results, on average, we obtained an accuracy of 62.0% (SD 19.8). For the needed time, on average, users spent almost 4.5 minutes to make all the required selections.

User satisfaction regarding the system was positive. In fact, on average, users expressed a 7.6 of overall satisfaction in a scale from 0 to 10 (VAS questionnaire). The main result regarding the QUEST questionnaire is that the overall satisfaction is, on average, 3.3 in a scale from 1 to 5. The elements “aesthetic design” and “ease of use” received the lowest scores. The features voted to be most important were “Ease of use” (number 5), “Robustness” (number 9), and “Speed” (number 10).

Through the usability questionnaire, users have also been asked to comment on positive and negative aspects of the approach. The majority of them suggested to improve the user interface (the BCI matrix) and to add more feedback, especially in case when there was no selection. Moreover, the use of gel is considered one of the most negative aspects. As for positive aspects, users appreciated the opportunity to interact with a PC through the BCI and, in particular, liked to control home devices.

Following the outcome of the healthy users evaluation cycle, the home support system is currently under experimentation with BackHome end-users at the laboratories of Cedar Foundation[6] and at the University of Würzburg.

[5] The system needed to be retrained for 3 users; moreover, User 7 was not able to finish the experiments, so the corresponding accuracy has not been calculated.

[6] http://www.cedar-foundation.org/

5.3 Context Awareness

Some proactive context-trigger actions have been designed and developed. Context-trigger actions are clear examples of the proactive nature of the system: whenever a rule condition is met the corresponding action is triggered. In particular, rules can be automatically generated depending on the context. Thus, we used the information collected by the telemonitoring system about the activity of the user and her habits in conjunction with information coming from the home control system. For instance, let us consider that the user every night at 9.00 PM watches the TV when she is staying at home. Studying her habits, the system learns this context and assumes that at around 9.00 PM the user may turn ON the TV. Hence, the system automatically generates a rule that displays a TV shortcut in the BCI matrix (i.e., the user interface, as shown in Figure 5).

Fig. 5 Interface interaction to turn the TV on when the corresponding shortcut is suggested by the system.

Moreover, the therapist can define some rules in order to be alerted in case some anomalies are detected. For instance, let us consider the case the therapist is interested in tracking the sleeping pattern. In fact, since BackHome real end-users have a very strong disability, they may feel depressed. Thus, detecting how much time the user is sleeping can help the therapist detect a depression at an early stage of the disease. To this end, the therapist may set a rule to raise an alarm if the user spends more than ten hours at bed in a day. The system controls the sleep pattern of user to detects abnormal situations. In so doing, if the user has been at bed for more than ten hours and the user station detects it, an alert is raised to the therapist who receives a message at the dashboard of the system showing the alert that has been triggered and the user who is involved. After receiving the alert, the therapist contacts with user's caregiver in order to know the reason of this situation.

6 Conclusions and Future Directions

We presented a user-centered solution to support physical autonomy of disabled people. Physical support is provided to BCI users through the adoption of sensors and actuators as well as communication services. Context-aware techniques has been used to provide adaptive capabilities. Preliminary experiments have been conducted by healthy participants. The experimental protocol required participants to perform normal activities at home (telemonitoring) and BCI tasks to interact with home appliances (home support).

At time of writing we are finalizing the integration of all the functionality in the overall BackHome platform and install the corresponding system at real end-users' homes in Belfast. The installation is expected on November 2014. Then, we will start experiments with BackHome end-users and results will be used to modify/tune the overall system according to the adopted user-centered approach.

Acknowledgements

The research leading to these results has received funding from the European Community's, Seventh Framework Programme FP7/2007-2013, BackHome project grant agreement n. 288566.

References

1. Allison, B., Millan, J.d.R., Nijholt, A., Dunne, S., Leeb, R., Whitmer, D., Poel, M., Neuper, C.: Future directions in brain/neuronal computer interaction (future bnci) (2010)
2. Casals, E., Cordero, J.A., Dauwalder, S., Fernández, J.M., Solà, M., Vargiu, E., Miralles, F.: Ambient intelligence by atml: Rules in backhome. In: Emerging ideas on Information Filtering and Retrieval. DART 2013: Revised and Invited Papers; C. Lai, A. Giuliani and G. Semeraro (eds.) (2014)
3. Daly, J., Armstrong, E., Miralles, F., Vargiu, E., Müller-Putz, G., Hintermller, C., Guger, C., Kuebler, A., Martin, S.: Backhome: Brain-neural-computer interfaces on track to home. In: RAatE 2012 - Recent Advances in Assistive Technology & Engineering (2012)
4. Demers, L., Wessels, R., Weiss-Lambrou, R., Ska, B., De-Witte, L.: An international content validation of the quebec user evaluation of satisfaction with assistive technology (quest). OTI **6**(3), 159–175 (1999)
5. Edlinger, G., Holzner, C., Guger, C.: A hybrid brain-computer interface for smart home control. In: Proceedings of the 14th international conference on Human-computer interaction: interaction techniques and environments - Volume Part II, HCII'11, pp. 417–425. Springer-Verlag, Berlin, Heidelberg (2011)
6. Farwell, L.A., Donchin, E.: Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials. Electroencephalography and clinical Neurophysiology **70**(6), 510–523 (1988)
7. Fernández, J.M., Torrellas, S., Dauwalder, S., Solà, M., Vargui, E., Miralles, F.: Ambient-intelligence trigger markup language: A new approach to ambient intelligence rule definition.

In: 13th Conference of the Italian Association for Artificial Intelligence (AI*IA 2013). CEUR Workshop Proceedings, Vol. 1109 (2013)

8. Guger, C., Sellers, E., Holzner, C., Krausz, G., Carabalona, R., Gramatica, F., Edlinger, G.: How many people are able to control a p300-based-brain-computer interface (bci)? Neuroscience Letters **462**, 94–98 (2009)
9. Holzner, C., Schaffelhofer, S., Guger, C., Groenegress, C., Edlinger, G., Slater, M.: Using a p300 brain-computer interface for smart home control. In: World Congress 2009 (2009)
10. Käthner, I., Daly, J., Halder, S., Räderscheidt, J., Armstrong, E., Dauwalder, S., Hintermüller, C., Espinosa, A., Vargiu, E., Pinegger, A., Faller, J., Wriessnegger, S., Miralles, F., Lowish, H., Markey, D., Müller-Putz, G., Martin, S., Kübler, A.: A p300 bci for e-inclusion, cognitive rehabilitation and smart home control. In: G. R. Mller-Putz, G. Bauernfeind, C. Brunner, D. Steyrl, S. Wriessnegger, R. Scherer (Eds.), Proceedings of the 6th International Brain-Computer Interface Conference, pp. 60–63 (2014)
11. Mason, S.G., Bashashati, A., Fatourechi, M., Navarro, K.F., Birch, G.E.: A Comprehensive Survey of Brain Interface Technology Designs. Annals of Biomedical Engineering **35**, 137–169 (2007)
12. Millán, J., Rupp, R., Müller-Putz, G., Murray-Smith, R., Giugliemma, C., Tangermann, M., Vidaurre, C., Cincotti, F., Kübler, A., Leeb, R., Neuper, C., Müller, K., Mattia, D.: Combining brain-computer interfaces and assistive technologies: State-of-the-art and challenges. Frontiers in Neuroscience **4** (2010)
13. Miralles, F., Vargiu, E., Casals, E., Cordero, J., Dauwalder, S.: Today, how was your ability to move about? In: 3rd International Workshop on Artificial Intelligence and Assistive Medicine, ECAI 2014 (2014)
14. Münssinger, J., Halder, S., Kleih, S., Furdea, A., Raco, V., Hösle, A., Kübler, A.: Brain painting: First evaluation of a new braincomputer interface application with als-patients and healthy volunteers. Front Neurosci **4:182. doi: 10.3389/fnins.2010.00182** (2010)
15. Polich, J.: Updating p300: an integrative theory of p3a and p3b. Clinical neurophysiology **118**(10), 2128–2148 (2007)
16. Vargiu, E., Dauwalder, S., Daly, J., Armstrong, E., Martin, S., Miralles, F.: Cognitive rehabilitation through bnci: Serious games in backhome. In: G. R. Mller-Putz, G. Bauernfeind, C. Brunner, D. Steyrl, S. Wriessnegger, R. Scherer (Eds.), Proceedings of the 6th International Brain-Computer Interface Conference, pp. 36–39 (2014)
17. Vargiu, E., Fernández, J.M., Miralles, F.: Context-aware based quality of life telemonitoring. In: Distributed Systems and Applications of Information Filtering and Retrieval. DART 2012: Revised and Invited Papers. C. Lai, A. Giuliani and G. Semeraro (eds.) (2014)
18. Vargiu, E., Fernández, J.M., Torrellas, S., Dauwalder, S., Solà, M., Miralles, F.: A sensor-based telemonitoring and home support system to improve quality of life through bnci. In: 12th European AAATE Conference (2013)
19. Wolpaw, J.R., Birbaumer, N., McFarland, D.J., Pfurtscheller, G., Vaughan, T.M.: Brain–computer interfaces for communication and control. Clinical neurophysiology **113**(6), 767–791 (2002)