

An Assistive Technology Program for Enabling Five Minimally Conscious Adolescents to Engage in Communication, Occupation, and Leisure Opportunities

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ABSTRACT

Background: Post-coma patients emerging from a minimally conscious state may have extensive motor disabilities and pose serious challenges to medical centers and home settings.

Objectives: To promote academic performance and communication skills of post-coma individuals with traumatic brain injuries emerging from a minimally conscious state through an Assistive Technology setup. To evaluate its effects on the participants' positive participation. To generalize the learning process. To assess the intervention's clinical and social validity.

Method: Study I included five adolescents exposed to an Assistive Technology setup enabling them with the targeted adaptive behaviors. Study II involved fifty external raters in a social validation assessment.

Results: Data evidenced an improved performance of all the participants during the intervention, assessed through a non-concurrent multiple baseline design across participants.

Conclusion: An Assistive Technology setup may be helpful to enhance performance and positive participation of adolescents with traumatic brain injuries emerging from a minimally conscious state.

Introduction

Persons with post-coma outcomes may constitute significant challenges for daily settings. Either in medical centers or home contexts they may require specific therapeutic and pharmacological attention with specialistic treatments [1-2]. Additionally, patients with traumatic brain injuries (TBI) and neurological disorders can require individualized rehabilitative programs capable of (a) promoting self-determination and independence, (b) emphasizing an active role and constructive engagement, (c) enhancing positive participation and improving their quality of life, and (d) reducing caregivers and families' burden [3-5]. Thus, individuals emerging from a minimally conscious state may progressively acquire awareness of their clinical conditions (e.g., extensive motor disabilities and lack of speech added to communication failures) and may need individualized programs [6-7]. Depending upon their behavioral repertoire and their level of consciousness (i.e., communication abilities), they may be supported with different functional and/or occupational future directions. For instance, social interaction and request and choice of preferred stimuli could be relevantly compromised among post-coma children and adolescents due to their general conditions [8]. Next to music therapy, stimulation therapy, brain computer interfaces, and transcranial deep stimulation, assistive technology-based interventions (AT) may be planned [9-10].

AT setups broadly include any technological solution more or less sophisticated useful to fill the gap between behavioral responses and environmental requests among persons diagnosed with neurodevelopmental disorders and multiple disabilities [11-12]. That is, a favorable occupation may be fostered. Microswitches, a basic form of AT easily activable by minimal responses, may be helpful to encourage beneficial daily coping in individuals with a post-coma condition [13]. Both assessment and recovery purposes may be pursued through learning setups (i.e., causal association between behavioral and environmental consequences) mediated by technological options [14-15]. For example, Lancioni et al. [16] evaluated sign of responsiveness in two adults diagnosed in a vegetative state through an AT-based setup consisting of an electronic regulated optic sensor fixed on an

eyeglasses' frame wore by both participants during the sessions, and a control system unit connected to pleasant stimuli. The adapted behavioral response was an eye blinking. An ABABCB experimental sequence was implemented, with A representing baselines, B the contingent intervention phases, and C the control non-contingent intervention phases. Because both participants demonstrated a higher performance (i.e., microswitch's activations) during B phases with respect to A phases, a clear sign of awareness by both participants, a more favorable diagnosis (i.e., minimally conscious state) could be made. Lancioni et al. [17] assessed a program to promote constructive engagement, request and choice by a young man in a minimally conscious state with extensive motor disabilities. An AT setup was adopted. The primary goal was the acquisition of a thumb response to independently access to visual stimulation. The subsequent objective was his acquisition of a dual vocal response (i.e., shorter or longer vocal utterances) to call her mother or sister who presented him with different stimuli. Data demonstrated that the participant was capable of a purposeful choice between both vocal utterances and thumb response.

Although a wide literature on the use of AT setups for patients with post-coma is available [18-25], few studies targeted pediatric population and TBI [26-27]. Stasolla and De Pace [26] exposed two post-coma children with TBI who were diagnosed as emerged from a minimally conscious state and presented extensive motor impairments to an AT-based program (i.e., microswitch combined with a computerized hierarchical system and adapted software) enhancing request and choice of preferred stimuli. Both participants increased their performance during intervention phases. Sixty students involved in a social validation assessment (i.e., a standard procedure used to corroborate clinical validity) confirmed the effectiveness and the suitability of the adopted intervention. Stasolla et al. [27] extended the use of an AT-based setup to ensure three new post-coma children with TBI emerging from a minimally conscious state with leisure and communication opportunities combined to literacy access. Intervals with positive participation as a sign of constructive engagement and favorable occupation were additionally recorded. Forty-eight students were recruited as social raters. Data demonstrated that the participants' adaptive responding significantly increased during

intervention phases as well as indices of positive participation. Social raters favorably endorsed the use of the technology. However, further extension was warranted with regard to (a) participants involved, (b) technological options and/or solutions, (c) follow-up phases, and (d) social validation assessment.

In light of the above, the current two studies were conducted to provide a suitable extension of the aforementioned outcomes. Specifically, study I included five new post-coma adolescents emerging from a minimally conscious state, TBI and extensive motor disabilities combined to communication impairments. They were exposed to an AT-based setup enabling them with (a) academic performance, (b) leisure and communication opportunities, and (c) literacy access. Indices of positive participation as an outcome measure of their constructive engagement and functional occupation were recorded. A 6-month follow-up implemented at participants' home was carried out. Study II involved fifty external raters, equally divided in 5 groups (i.e., neurologists, parents, physiotherapists, psychologists, and speech therapists), with a 10-years of either a personal or a professional experience in the field of the neurodevelopmental disorders, in a social validation procedure [28].

STUDY I

Method

Participants and Settings

Because they met the eligibility criteria, namely (a) a history of coma, (b) traumatic brain injuries, (c) a diagnosis of emergence from a minimally conscious state, and (d) an age included between 13 and 18 years, the participants (Alexis, Christine, Eloise, Frank, and George) were enrolled. They were aged of 15, 14, 16, 17, and 18 years and had been involved in a road accident 2, 3, 2, 4, and 3 years prior the beginning of the study, respectively. All the participants reported extensive TBI. Alexis

coma lasted 10 days. Her coma condition turned into a vegetative state and evolved in a minimally conscious state. Her computerized tomography (CT) revealed a right parieto-occipital damage with an extended hematoma, which was evacuated after decompressive craniotomy. Her electroencephalogram activity (EEG) showed low diffuse voltage of the theta rhythm. Alexis evidenced visual atrophy, left hemiplegia, limited body control (i.e., minimal head and trunk movements) and lack of speech although she was capable of “YES” and “NO” responses through smiling or abstaining from it appropriately. Alexis was fitted with a gastronomy tube for nutrition. Her total score on the Coma Recovery Scale-Revised (JFK-CRS-R) [29] was 16 with partial scores of 3, 3, 4, 2, 2, and 2 on auditory, visual, motor, oromotor/verbal, communication, and arousal subscales respectively.

Christine coma lasted 2 weeks. She first emerged in a vegetative state and subsequently improved in a minimally conscious state. Her CT evidenced a lesion in the thalamus (i.e., posterior region) and in the nucleus pallidus. Furthermore, a ventricular enlargement and a cortical atrophy through functional magnetic resonance (fMRI). The EEG activity outlined a medium diffuse voltage with delta rhythm. Auditory assessment carried out through event-related brain potentials demonstrated a P300 wave of reduced amplitude contingently to the presentation of familiar voices. She presented spastic tetraplegia, lack of speech, minimal head and trunk control. Christine was provided with a urinary catheter. She was capable of “Yes” and “NO” responses correctly produced through a prolonged eye blinking versus a double blinking. Her total score on the JFK-CRS-R was 15 with partial scores of 2 on arousal, auditory, oromotor/verbal, and communication subscales, 3 on visual and 4 on motor subscales respectively.

Eloise coma lasted 3 weeks. Her CT emphasized a wide left temporo-parietal injury. She emerged in a clinical condition that was assessed as vegetative state associated with extensive motor disabilities (i.e., spastic tetraplegia with minimal motor behavior). Additionally, she presented lack of speech. She was fitted with a gastronomy tube for nutrition and was unable of sphincteric control. After approximately one year, she was capable to be fed through her mouth. At the beginning of the

study her nutrition was regular. She was equipped with a wheelchair although she spent a considerable amount of time (i.e., 18 h per day) in her bed. She progressively acquired gaze orientation and had “YES” and “NO” responses through few head appropriate movements. Furthermore, Eloise smiled contingently to the presentation of positive stimulation. Her total score on JFK-CRS-R was 17 with 2 on arousal, oromotor/verbal, and communication subscales, 3 on auditory subscale, 4 on visual and motor subscales.

Frank coma lasted 15 days. His CT outlined a large corpus callosum reduction with a midline shift. EEG activity documented slow delta and theta rhythms. He first evolved in a vegetative state and improved in a minimally conscious state. Frank evidenced minimal trunk and head control, with left hemiplegia. Lack of speech and incapacity of sphincteric control were additionally observed. He was fitted with a gastronomy tube for nutrition. He was capable of “YES” and “NO” appropriate responses through eye blinking and smiling. His total score on JFK-CRS-R was 18 with 2 on arousal, oromotor/verbal, and communication subscales, 3, 4, and 5 on auditory, visual, and motor subscales respectively.

George coma lasted 4 weeks. His condition first evolved in a vegetative state then turned in a more favorable minimally conscious state. His CT indicated a thalamic injury and cerebellar atrophy. EEG activity was characterized by diffuse slow recordings in the delta range. His minimal behavior included trunk rigidity, low head control, few movements of the right hand. He was fitted with both gastronomy tube and urinary catheter. He presented lack of speech and epilepsy partially controlled through medication. George showed appropriate “YES” and “NO” responses to familiar objects and voices through prolonged eye blinking and smiling. His total score on JFK-CRS-R was 16 with partial scores of 2 on arousal, communication, and oromotor/verbal subscales, 3 on auditory and visual subscales, and 4 on motor subscale.

All the participants were rated at the sixth level of the Rancho Cognitive Functioning Scale (i.e., confused and appropriate behavior) by their neurologist [30]. Additionally, they were all capable

of small hand closures as reported by both families and caregivers and suggested by the initial informal observations. The aforementioned scale is a validated clinical tool used to evaluate how individuals with an acquired brain injury are recovering. Thus, once the patient “wakes-up” following a cerebral injury he/she goes through different recovery levels of the scale. Each level summarizes a general (i.e., behavioral, motor, and cognitive) pattern of recovery. Overall, ten levels are included from the lowest up to the highest level of recovery. The study was conducted in the rehabilitative medical center where the participants were hospitalized along the baselines and intervention phases, and in the participants’ homes during the follow-up/generalization phase (see experimental conditions below).

Selection of Stimuli

An informal 30-min interview with both families and caregivers was conducted prior to a formal preference screening according to Craford and Schuster [31]. Seven 10-min sessions were collected for each participant. The positive stimulation to be used during the intervention and follow-up/generalization phases was selected with a formal 8-10 s presentation of each environmental screened event with a rest interval of 15 s. Thus, academic activities, leisure, and personal preferred items (e.g., highly motivating academic activities, frequent personal needs, beverages, videos, and songs) were retained and screened through both informal and formal strategies. Overall, 50 presentations of each selected item were carried out for each participant. Alerting, orientation, and smiling were adopted as selection criteria, with a minimum of 80% of preference for each event. Additionally, the participants were directly involved in such selection through their “YES” and “NO” responses above detailed. Finally, five non-preferred stimuli (i.e., distorted sounds) were considered and randomly interspersed during both intervention and generalization phases to record the participants’ unintentional choices (see Technology and Response sub-section below). None of the distorted stimuli produced a positive response by any participant. The parents (i.e., legal

representatives) of the participants considered the rehabilitative program highly promising and signed an informed consent for their inclusion accordingly. The study was approved by a local ethical and scientific committee and conducted according to the Helsinki Declaration and its later amendments.

Technology and Response

The technology included a laptop with a 15.6 inches monitor and equipped with a Clicker 5 software package (Crick House, Moulton Park, Northampton, UK), a two-membrane pressure sensor embedded in a small box-like suitable structure and placed in the right hand for all the participants, except for Eloise who used the left hand, and an interface connecting the sensor (i.e., microswitch) to the computer and to the software package. The outer membrane (i.e., facing to the fingers) consisted of a touch-sensitive layer activable by simple contact of the fingers. The inner membrane was activated if the participants applied a pressure of 15 g [26-27]. The selected adaptive response which seemed to be the most plausible for all the participants was either a finger contact with the outer membrane or a 15 g pressure with the inner membrane.

The first page of the computer screen provided the participants with three pictures which were automatically scanned each 2 s through a colored encirclement. The pictures represented a child who was reading (i.e., academic option), a child who was asking for his father (i.e., communication option), a child who was writing (i.e., literacy option). For instance, by selecting the communication option (i.e., by activating the microswitch once such option was encircled by the colored light) the software opened a second page with three new items (i.e., snacks, beverages, and leisure). By selecting leisure category (i.e., a new adaptive response was requested once the category was encircled) the software opened a third page with three items (i.e., preferred song, preferred video, and preferred familiar voices/images). By selecting the song (i.e., contingently to its encirclement selection) a new page was opened with a dichotomous question such as: “Do you really want to listen to the song?”. A “YES” and “NO” choices green and red colored respectively were automatically

scanned. By selecting “YES” the participant would be provided with 10 s of the requested song. By selecting “NO” the system would come back to the homepage, ready for a new selection. A double cue (i.e., verbal and visual) was provided for each option. Specifically, an auditory and customized instruction (e.g., Eloise would play), combined with a yellow encirclement for each scanned option was provided for each participant. A similar hierarchical 4 step-response was designed for the academic activities accordingly. The academic activities included highly preferred academic tasks between those selected by the aforementioned screening (e.g., listen a story or watch a short video). Each academic activity lasted 10 s. Such process was planned to minimize the unintentional choices combined with the distorted sounds randomly interspersed. The tangible items (e.g., snacks and beverages) were provided by a research assistant along 10 s. The environmental consequences were customized for each participant.

Conversely, by selecting the literacy category, the participants were provided with a keyboard emulator. The participants could write short messages to the available persons with a word processor available above the keyboard emulator on the monitor, free of any limitation. That is, the system automatically scanned the rows of the keyboard emulator each 2 s. Once a row was selected through a microswitch activation, each letter of the selected row was automatically scanned each 2 s. The participants were requested to produce a new microswitch activation to write the desired letter contingently on its encirclement. Once the letter was written on the word page, the system was available for a new row/letter selection. To ensure the process' s completion, a research assistant asked the participant “Did you really conclude your writing”? A “YES or NO” response was expected by the participant as confirmation [32-33]. The rationale to use a unique brief reinforcement delivery, except for the literacy, was justified by provide the participants highly rewarding events and motivate the use of the system for a new request.

Sessions and Data Collection

Sessions lasted 10 min and were video recorded. Typically, 3 sessions were collected 3 days per week for each participant. That is, 9 sessions per week were conducted for each participant. Overall, 280 sessions were collected for the 5 five participants. The study lasted approximately 8 months, with 6-month follow-up/generalization phase (see experimental conditions) included.

Data collection concerned (a) microswitch activations, (b) choice sequences correctly completed (with the 4-step process above described), and (c) intervals of indices with positive participation (i.e., alerting, gaze oriented to the monitor, smiling for at least 5 s, as operant definitions). Indices of positive participation, representing an outcome measure of constructive engagement and favorable occupation, were collected according to a 15 s partial interval recording system with 10 s of observation and 5 s of dichotomous recording of absence/presence of the index in the previous 10 s interval [34-35].

Interobservers agreement (IOA)

An IOA index (i.e., reliability percentage) was extracted by dividing the number of the agreements by the number of the agreements added to the number of the disagreements and multiplying it by 100. Thus, two research assistants who were totally blind to the objectives and the procedures of the study, coded simultaneously and independently all the video-recorded sessions. Mean percentages of agreement were 99% (range 98-100) for both microswitch activations and corrected responses and 97% (range 95-100) for indices of positive participation.

Procedural Integrity

The aforementioned blind research assistants monitored the study step by step. Thus, both coded the sessions independently according to a provided checklist (i.e., selection of stimuli, data recording, prompts and stimulation delivery). Consequently, a systematic and simultaneous comparison between

both was performed. Finally, they assessed the follow-up/generalization phase and the social validation procedure (i.e., see Study II). They assessed each step by a YES or NO dichotomic check. An interrater agreement was finally calculated similarly to the IOA index above reported. A 100% of corrected procedural implementation was empirically documented.

Experimental Conditions

The study was carried out according to a non-concurrent multiple baseline design across participants [36]. Thus, a different length of the baseline phase occurred for each participant. Specifically, 2, 4, 6, 8, and 10 sessions during the baseline were collected for Alexis, Christine, Eloise, Frank, and George, respectively. Accordingly, 52, 54, 56, 58, and 60 sessions were overall collected for Alexis, Christine, Eloise, Frank, and George, along the study.

Baseline

During the baseline, which occurred along one day for Alexis, two days for Christine, three days for Eloise, four days for Frank, and five days for George, the technology was available and active. The participants were requested to perform their request through a traditional mouse. The rationale to use a mouse was justified by providing the participants with a standard and traditional device they daily used before the road accident. Whenever they correctly performed and completed the choice sequence, the requested environmental consequence was delivered. Physical and verbal prompts were provided every 30 s of non-independent responding.

Intervention

During the intervention, the participants were equipped with the adapted microswitch instead of the mouse. The reader may refer to a visual representation provided by Lancioni et al. [64]. The technology was available and active. They were requested to perform their request and choice process through the double membrane microswitch above described. Thirty sessions were collected for each participant along one month. Physical and verbal prompts were provided every 30 s of non-independent responding.

Follow-up/Generalization

A six-month follow-up occurred. Conditions were identical to the intervention phase, except for the setting. Thus, the follow-up took place at participants' home where the participants came back after the hospitalization. Twenty sessions were collected for each participant over three weeks. Between the end of the intervention and the follow-up the participants freely and sporadically used the system, as informally reported by both parents and caregivers.

Results

Data were summarized in Table 1, 2, 3, plotted in Figure 1, and deposited in a public repository (DOI; 10.6084/m9.figshare.12792344). Because few prompts for all the participants involved were necessary at the beginning of the study, they were not reported in the included tables. The reader may find those data in the dataset available in the public repository above indicated. A detailed differentiation among the options available for each participant can additionally be found in the same dataset.

INSERT TABLES 1, 2, AND 3 HERE

INSERT FIGURE 1 APPROX HERE

Both descriptive data and graphical inspection revealed an increased independent responding and positive participation along the intervention and follow-up phases for all the participants involved. A series of comparisons using the Tau-U index proposed by Parker et al. [61] were conducted between (a) the baseline and the intervention, (b) the baseline and the follow-up, and (c) the intervention and the follow-up phases, for each participant and for each variable (independent responses and positive participation). Overall, 30 comparisons were performed, namely three comparisons for two variables for five participants. Tau-U effect sizes varied between 0.82 and 0.98 (Median = 0.91) for the comparisons between baseline and intervention or follow-up phases for all the participants and for independent responding. They varied between 0.20 and 0.54 (Median = 0.32) for the comparisons between intervention and follow-up phases for all the participants and for independent responding. They varied between 0.96 and 0.99 (Median = 0.98) for the comparisons between baseline and intervention or follow-up phases for all the participants and for positive participation. They varied between 0.18 and 0.56 (Median = 0.26) for the comparisons between intervention and follow-up phases for all the participants and for positive participation. It should be noticed that a completed choice included four microswitch activations. A 10 s of positive reinforcement was contingently delivered, except for the literacy process (see above).

Study II

Participants

Fifty external raters, equally divided in 5 groups (i.e., neurologists, parents, physiotherapists, psychologists, and speech therapists) were recruited in a social validation procedure. They had at least 10 years of personal or professional experience. Their mean ages per group were 50.7, 51.3, 45.4, 47.3, and 45.0 and their age standard deviations were 3.5, 2.4, 3.5, 2.2, and 3.0, for neurologists,

parents, physiotherapists, psychologists, and speech therapists, respectively. They represented a convenience sample of professionals interested in the field of consciousness disorders. They were eligible because added to their either personal or professional experience above indicated, they supervised or participated in at least one AT-based program for children and young adults with consciousness disorders. The pool from which the raters were recruited included (a) parents of children with neurological disorders, (b) neurologists, (c) psychologists, (d) physiotherapists, (e) speech therapists, (f) practitioners, and (g) caregivers. The participants were completely blind to the research goals. Both parents and caregivers of the participants enrolled in Study I were preliminarily excluded to avoid biased evaluations.

Procedure

They were told that they were requested to watch a 6 min-video including an adolescent with neurological and consciousness disorders exposed to an AT-based intervention, in 3 different experimental conditions. They were divided in small groups of 5 raters. Each participant was randomly assigned to 2 groups (i.e., ten raters). Raters watched one of the participants included in Study I in a randomized sequence of 3 experimental conditions, (a) baseline, (b) intervention, (c) follow-up/generalization. Each video represented a 2-min standard session of the aforementioned conditions. Each experimental condition was detailed and explained by a research assistant as reported in the experimental conditions sub-heading of Study I. Raters were invited to fill a 7-item questionnaire (see Table 4), which was validated by Stasolla et al. [37], and each item was rated on a 5-point Likert-like scale, which varied from totally disagree (=1) to totally agree (=5).

INSERT TABLE 4 HERE

Statistical Analysis

Statistical analysis was performed with R software. A general linear model was employed to test the null hypothesis that there were no differences across conditions (i.e., baseline, intervention, and follow-up phases) and across the groups of raters (i.e., professions: neurologists, parents, physiotherapists, psychologists, and speech therapists) for the five adolescents involved in Study I, along the seven items of the questionnaire. The general linear model was chosen in order to control for each independent and dependent variable included in the analysis. Follow-up analyses were conducted, as appropriate, to test for significant main effects on univariate measures. A p -value $< .05$ was determined to be significant for interpreting multivariate results, and a p -value $< .0071$ was determined to be significant for interpreting univariate results, as effect of a Bonferroni correction, i.e., the initial alpha level (.05) was divided for the number of dependent variables (7). The present analysis was conducted in order to formally endorse the use of the AT by expert external raters.

Results

Data were deposited in a public repository (DOI: 10.6084/m9.figshare.12793778) and summarized in Table 5, which reports mean scores and standard deviations on the seven questionnaire items for the five groups of raters and for the three conditions. Results of the general linear model showed that the main multivariate effects of condition (Wilks' Lambda = 0.024, $F(2,135) = 101.23$, $p < 0.001$), and groups of raters (Wilks' Lambda = 0.321, $F(4,135) = 6.18$, $p < 0.001$) were significant. Indeed, all groups of raters gave significantly higher scores for the intervention and follow-up compared to the baseline (with $p < .001$) for all the items, and no significant differences were found between intervention and follow-up. There were also significant differences between groups of raters (at least with $p < .05$). Also the first-order interaction effect (Wilks' Lambda = 0.362, $F(8,135) = 2.60$, $p < 0.001$) was significant. Parents and psychologists generally gave higher scores for intervention and follow-up phases with respect to the other three groups. Regarding univariate effects for comfort dimension, the score differences between baseline and intervention sessions and between baseline

and follow-up sessions were significantly higher (at least with $p < 0.05$) for parents and psychologists with respect to speech therapists. Regarding univariate effects for beneficial outcomes dimension, the score differences between baseline and intervention sessions and between baseline and follow-up sessions were significantly higher (at least with $p < 0.05$) for parents and psychologists with respect to neurologists. Concerning univariate effects for self-determination dimension, the score differences between baseline and intervention sessions and between baseline and follow-up sessions were significantly higher (at least with $p < 0.05$) for parents and psychologists with respect to the other three groups. Regarding univariate effects for participation dimension, the score differences between baseline and intervention sessions and between baseline and follow-up sessions were significantly higher (at least with $p < 0.05$) for parents and psychologists with respect to neurologists and speech therapists. About medical and home contexts, no univariate first-order interaction effects emerged. Concerning univariate effects for agreement dimension, the score differences between baseline and intervention sessions and between baseline and follow-up sessions were significantly higher (at least with $p < 0.05$) for parents and psychologists with respect to neurologists.

INSERT TABLE 5 HERE

General Discussion

Data emphasized that the proposed AT-based setup successfully improved the participants' general conditions. The rehabilitative program was effective and suitable to promote self-determination, constructive engagement and an active role of the participants involved. Thus, through the use of the adopted technological solution five post-coma adolescents with TBI and neurological disorders who were emerging from a minimally conscious state could independently access to either academic performance or personal needs. Furthermore, the system ensured them with literacy opportunity. Communication skills were fostered accordingly. Intervals of indices with positive participation additionally increased. The use of AT options for post-coma individuals and consciousness disorders

was positively extended. All the participants maintained and generalized the learning process once the use of the technology was transferred in their homes (Study I). Their consistent trends could be explained by their incapacity to profitably achieve the request and choice process during the baseline due to the extensive motor impairments. Conversely, during the intervention phase, once equipped with a suitable microswitch they were ensured with a favorable participation to the proposed opportunities. The customized and highly rewarding items could additionally corroborate that interpretation. Social raters favorably scored the use of the AT-based intervention (Study II). The results were widely supported by previous findings [38-42] and suggested the following considerations.

First, a customized technological equipment could be very helpful for individuals with neurological disorders emerging from a minimally conscious state who presented extensive motor disabilities and lack of speech to autonomously access to communicate their personal needs to parents and caregivers or to actively participate and consequently to enhance adequately academic performance. Otherwise, they were free of writing whenever they desired to the available persons. One can argue that the AT-based setup profitably enabled the adolescents enrolled in Study I with self-determination and independence towards environmental events [43-45].

Second, it may be considered a great educational and rehabilitative resource. In fact, it may be viewed as a considerable gain and a remarkable achievement for individuals with extensive motor disabilities and minimal behavior. Instead of a traditional mouse, the participants were equipped with a suitable device which enabled their independent activities. The availability of such device constituted a relevant difference between a fairly passivity with a risk of deprivation and social interaction opportunities [46-48].

Third, the participants' social image, desirability, and status were improved, with beneficial outcomes on their quality of life. Similarly, one may argue that their independent capacities to actively choose and request desired items produced a relevant reduction of caregivers' burden and their social

acceptance of the participants involved. Accordingly, a strong form of well-being was established. Data additionally evidenced that the request and choice process for all the participants was purposeful [49-50].

Fourth, indices of positive participation increased as well. That is, the participants were favorably occupied and constructively engaged. Higher levels of alertness, vigilance, gaze orientation, and smiling were empirically documented during the intervention, if compared to the baseline for all the participants. Their awareness during the request and choice process was evidenced and the participants enjoyed the sessions while dealing with the achievement of the proposed tasks, as sign of an improved general condition [51-52].

Fifth, the participants consolidated the learning process and generalized it once transferred at home. Even with a 6-month suspension, they were able to independently access to positive stimulation, to request and choice among the different options. Consolidation and Generalization processes were successfully achieved accordingly [53-54].

Sixth, social raters favorably scored the use of the technology, irrespective of the participants observed, of the experimental sequence to which they were exposed, and of the group they were included in. All the raters endorsed intervention and follow-up phases if compared to the baseline. No differences emerged between intervention and follow-up. Some differences between the five groups emerged in the magnitude of the difference score between baseline and intervention and follow-up sessions for all the dimensions except medical and home contexts. Indeed, parents and psychologists tended to maximize the difference score with respect to neurologists and speech therapists. This result could reflect different degrees of specific competence as well as of involvement in daily practices for each group, but all of them substantially agreed in considering the AT program effective, affordable and suitable for the five participants. Thus, one may argue that both social and clinical intervention's validity were formally consolidated [55-56].

Limitations

Despite the encouraging and promising findings above discussed, the present investigation presented some limitations. First, it was used a single-subject experimental design with five participants. Caution was undoubtedly mandatory while interpreting the results. Additionally, it was used a non-concurrent multiple baseline design across participants with a different baseline length between participants. A multiple probe design for both ethical and methodological issues would be probably preferable. Second, a systematic comparison with different research methods would be warranted. For example, one may envisage the use of event-evoked potentials (i.e., P300 and mismatch negativity) [57]. Otherwise, one could resort on transcranial deep stimulation and/or brain computer interface [58-59]. That comparison may be viewed as a relevant significance for both assessment and recovery purposes [62]. Third, communication opportunities with distant partners were not embedded [60]. Fourth, a participant's preference check assessment was lacking. Fifth, we assessed a unique reinforcement duration (i.e., 10 s) except for the literacy. It would be preferable to differentiate according to the environmental consequences delivered.

Future Directions

In light of the above, new research within this framework should include the following topics. An extension to new participants with post-coma outcomes should be examined. A further extension of the AT setup with new technological solutions (e.g., smartphones and/or tablets) should be assessed. A systematic comparison between AT-based approach and other integrative research method (e.g., physiotherapy, stimulation therapy, transcranial deep stimulation, and brain computer interface) should be included. New behavioral responses (e.g., small head movements) should be targeted. A long-term follow-up (e.g., one year) could finally be evaluated. Additionally, we might differentiate whether the consistent trends between the participants may be explained by the use of a suitable AT-device or the accessibility to the pleasant stimuli, although we feel that both are responsible for that

consistency. Finally, we could assess the use of virtual reality setups and wearable home-based technology to promote cognitive functions, as recently proposed by Bernini et al. [65] and Stasolla et al. [66] in individuals with acquired brain injuries and neurodegenerative diseases. That options are specifically recommended in the Covid-19 pandemic era to overcome quarantine and social distancing preventive measures.

Compliance with Ethical Standards

Declaration of conflicts of interest

The authors declared no conflicts of interest with respect to the research, authorship, and/or publication of the article. The authors alone are responsible for the content and the writing of the article.

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Informed Consent

Informed consent was obtained for all the recruited participants by their legal representatives (i.e., their parents).

Ethical Approval

All performed procedures of the study have been carried out in accordance with Helsinki Declaration (1964) and its later amendments or comparable ethical standards.

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Table 1. Mean frequencies and ranges of activations

Participants	Baseline	Intervention	Follow-up
Alexis	7 (6-8)	78.7 (65-86)	76.9 (70-80)
Christine	5.2 (4-7)	71.2 (50-80)	71.9 (70-75)
Eloise	3.5 (2-6)	60.6 (48-70)	62.5 (60-65)
Frank	2.7 (1-5)	71.1 (52-85)	68.3 (65-70)
George	2.3 (1-4)	63.2 (41-76)	69.4 (61-75)

Table 2. Mean frequencies and ranges of independent responses

Participants	Baseline	Intervention	Follow-up
Alexis	0 (0-0)	14.2 (10-16)	14.2 (12-16)
Christine	0 (0-0)	13.1 (10-15)	13.6 (13-14)
Eloise	0 (0-0)	11.3 (8-13)	11.2 (10-13)
Frank	0 (0-0)	13.1 (10-16)	11.6 (11-13)
George	0 (0-0)	11.6 (7-15)	12.7 (11-14)

Table 3. Mean frequencies and ranges of positive participation

Participants	Baseline	Intervention	Follow-up
Alexis	5 (5-5)	28.7 (16-34)	28.8 (24-32)
Christine	6.6 (4-8)	30.3 (22-36)	29.6 (24-32)
Eloise	5 (4-7)	30 (26-36)	29.3 (26-32)
Frank	3.5 (2-5)	31.3 (18-38)	28.3 (24-30)
George	2.6 (1-4)	32 (22-36)	28.7 (26-32)

Table 4. Social Validation Questionnaire

Do you think the participant is comfortable with this condition?

Do you think this condition promotes self-determination?

Do you think this condition has beneficial/rehabilitative outcomes?

Do you think this condition enhances positive participation?

Do you think this condition is suitable for home contexts?

Do you think this condition is suitable for medical/rehabilitative contexts?

Do you support (agree with) this condition?

Table 5. Mean scores and standard deviations on the seven questionnaire items for the five groups of raters and for the three conditions; post hoc analyses and p-values for univariate main effects of condition for each group of raters and for each item.

[illegible]

		AT and Post-Coma						
Speech therapist	Baseline (B)	1.50 ± 0.53	2.00 ± 0.00	1.40 ± 0.52	1.30 ± 0.48	2.50 ± 0.53	1.50 ± 0.53	1.80 ± 0.42
	Intervention (I)	3.40 ± 0.52	4.00 ± 0.47	4.10 ± 0.32	4.10 ± 0.32	4.30 ± 0.48	4.30 ± 0.48	4.30 ± 0.48
	Follow-up (F)	3.40 ± 0.52	4.10 ± 0.32	4.20 ± 0.42	4.10 ± 0.32	4.50 ± 0.53	4.30 ± 0.48	4.30 ± 0.48
		B < I = F	B < I = F	B < I = F	B < I = F	B < I = F	B < I = F	B < I = F
		p<.001	p<.001	p<.001	p<.001	p<.001	p<.001	p<.001

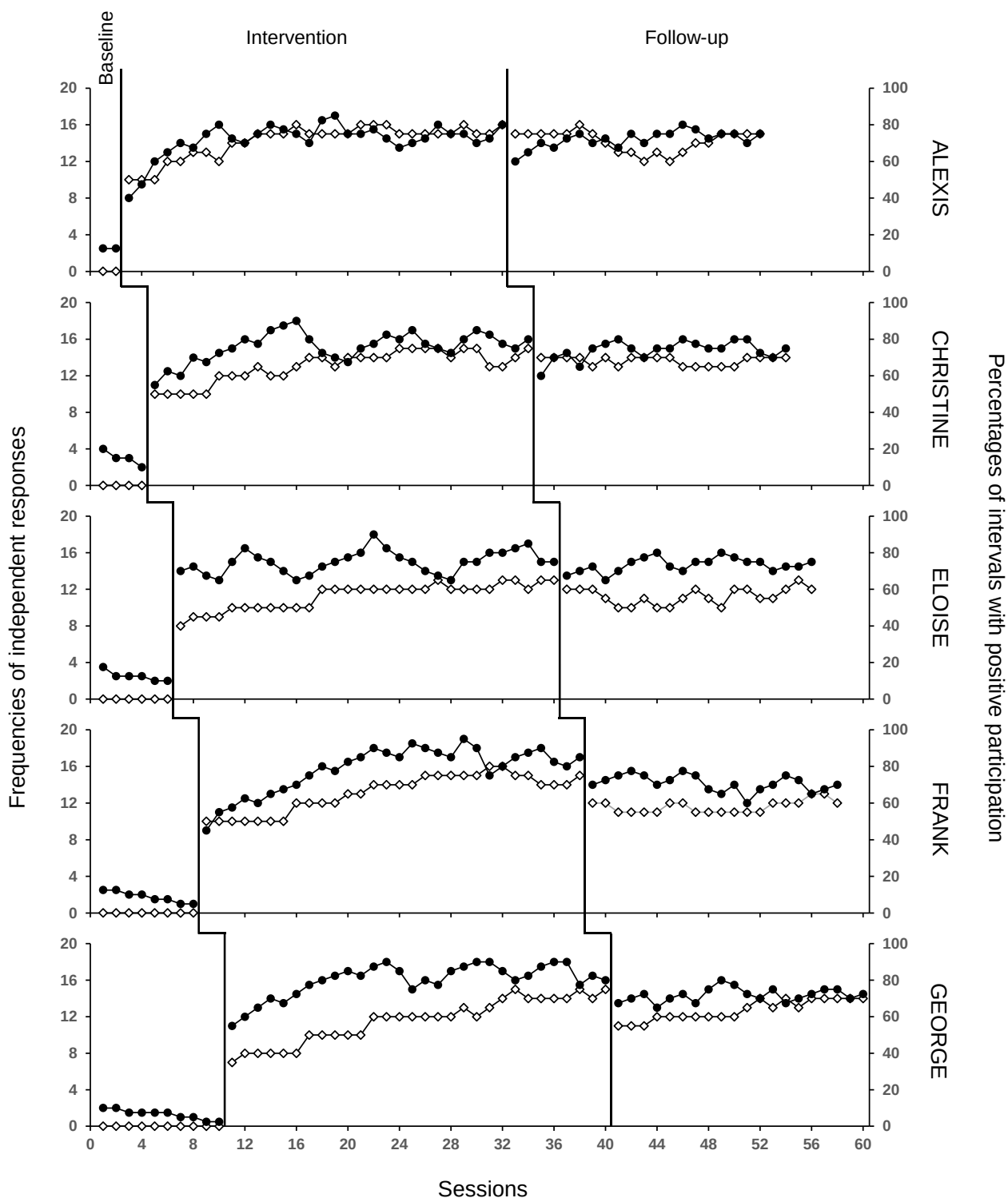


Figure 1. The graph summarizes the data for the five participants. The white diamonds indicate the frequencies of independent responses over the sessions for the baseline, intervention, and follow-up phases. The black dots refer to the percentages of intervals with positive participation over the sessions for the baseline, intervention, and follow-up phases.