Smartphone use as an efficient tool to improve anomia in primary progressive aphasia

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Abstract

Cognitive interventions are helpful in the non-pharmacological management of Primary progressive aphasia (PPA) and other neurodegenerative disorders of cognition, by helping patients to compensate for their cognitive deficits and improve their functional independence. In this study, we examined the effectiveness of cognitive rehabilitation based on the use of mobile device technology in PPA. The aim of this research study was to determine if BL, a patient with semantic variant PPA (svPPA) and severe anomia, was able to learn using specific smartphone functions and an application to reduce her word finding difficulties. She was trained during the intervention sessions on a list of target pictures to measure changes in picture naming performance. Errorless learning was applied during learning. BL quickly learned to use smartphone functions and the application over the course of the intervention. She significantly improved her anomia for trained pictures, and to a lesser extent for untrained semantically related pictures. Picture naming performance was maintained six months after the intervention, and she continued to use her smartphone regularly to communicate with family members and friends. This study confirms that smartphone use can be learned in PPA, which can help reduce the symptoms of anomia and improve communication skills.

Key words: primary progressive aphasia, smartphone use, mobile technology, errorless learning, cognitive intervention

Word count: 7530

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Introduction

Primary progressive aphasia (PPA) is a neurodegenerative disease characterized by gradual and predominant difficulties in the expression and comprehension of language [1, 2]. PPA has been classified into three subtypes: the semantic variant (svPPA), the logopenic variant (lvPPA) and the non-fluent/agrammatic variant (nfvPPA) [2]. At the neuropathological level, the svPPA and the nfvPPA are part of the frontotemporal lobar degeneration (FTLD) spectrum [2, 3], while the logopenic variant is associated with a higher probability of Alzheimer's disease (AD) [1]. The onset of PPA usually occurs before the age of 65 [4, 5], which is relatively early compared to the onset of sporadic AD.

Anomia is a cardinal symptom of PPA [6]. Anomia, or word finding difficulties, reflect the inability to recall the names of objects, people, or places during conversations. This experience occurs several times a week in the general population and increases with age [7]. It is one of the most common and irritating cognitive problems in older people and this difficulty is exacerbated in major neurocognitive disorders such as PPA and AD. It can occur during conversation but also while performing specific language tests such as picture naming, picture description, and verbal fluency tests. Anomia can result in various types of errors such as omissions (non-responses), circumlocutions (e.g., whisk: "This object is used to mix ingredients"), semantic paraphasias (whisk: "fork") and phonological paraphasias (whisk: "whisp"). Anomia can be a very frustrating experience and can have a significant impact on the social lives of people living with dementia, for instance by leading to withdrawal in social leisure activities [8].

Semantic variant PPA (svPPA), also known as semantic dementia [9, 10], is characterized by a slow and progressive loss of semantic memory, which reflects our knowledge and comprehension of the outside world. This semantic loss can have important consequences on independence in everyday life, for example by causing problems in recognizing food and preparing meals [11, 12]. Despite fluent language, svPPA patients experience difficulties in single word comprehension and their speech production is marked by word-finding difficulties. Anomia, a consistent feature of svPPA, is primarily associated with the underlying degraded semantic representations of concepts, although it can also reflect a post-semantic impairment, or difficulties in retrieving the phonological representations of words [13]. Due to the conceptual nature of the breakdown, there are also non-verbal semantic deficits in svPPA [14], which may be expressed across different sensory modalities. For example, a patient may not recognize an object such as *clarinet* via its name, its visual representation, its haptic representation, or by the sound it produces. Anomia is also a core feature of lvPPA but results mainly from phonological working memory deficits [15] and deficits in retrieving the phonological representations of words than from a semantic impairment. Anomia can also be found in nfvPPA, although the primary feature here is often agrammatism. Behavioral changes may also occur early in PPA, but are not the main cause of functional impairment [2].

Non-pharmacological interventions are a promising approach in the management of dementia, making it possible to support and improve cognition, functional independence, and well-being of affected individuals. Since anomia is the key clinical feature of svPPA, several studies have worked on cognitive rehabilitation of anomia in svPPA, by proposing language interventions that consisted in relearning words through various strategies such as repetition [16-20]. Post-intervention improvements in word naming were found in svPPA, but there often was little or no generalization to untrained vocabulary. For instance, 4 SD patients with varying degrees of severity who underwent a word training program improved their naming of trained items following repetitive practice of a word-picture pairing task, but no changes were observed for untrained items [19]. Some intervention studies, however, reported generalization to untrained words and even to conversations in svPPA as well as in lvPPA [21-26]. A recent review providing recommendations for treatment in PPA suggested that anomia therapy may be useful in patients with different levels of anomia severity as long as some level of spoken language remains preserved. According to this review, most studies have shown good adherence of patients to practice, and benefits lasted up to 6 months and sometimes longer [27] (for a systematic review of anomia therapy in PPA see also [28]).

Procedural memory can also be optimized in the context of cognitive intervention in PPA, as it seems to remain preserved in this disease [29], as in normal aging [30] and AD [31, 32]. Procedural memory refers to an implicit memory system that processes procedures underlying cognitive and motor skills [33]. The execution of various daily routine such as dressing, driving, cycling, working on a computer, or using a smartphone greatly relies on procedural memory. Interventions aimed at increasing reliance on procedural memory in svPPA have been used to routinize an activity [12] or enhance relearning of object use [34].

Several cognitive rehabilitation studies have shown that focusing on intact memory systems such as procedural memory, by means of specific techniques such as errorless learning (EL), may help (re)learn information in PPA [12, 29]. EL consists in step-by-step learning where the patient is not given the opportunity to make errors via given cues, as opposed to trial-and-error learning where the patient is more likely to reproduce the same errors over and over [35-37]. In addition, EL can increase motivation and reduce the frustration resulting from mistakes and an approach focused on deficits**.** EL learning has successfully been used in svPPA. For instance, a cognitive intervention relying on procedural learning promoted the relearning of cooking skills using a computerized application in a patient with svPPA [24]. EL was also successfully used to optimize learning of different functions on a smartphone [29, 38], and to train words on a computer [16] in svPPA. Similarly, although declarative memory impairment is the hallmark of AD, procedural memory is also preserved in AD, at least in the early stages of the disease [32]. EL has also been successfully used to relearn verbal material in AD such as face-name associations [40] and object names [41, 42], and to learn procedural skills such as golf putting [31].

Interventions relying on new technologies [12, 24, 29, 38] and based on EL thus seem to have a strong potential in supporting people with PPA, by promoting greater functional independence and improving communication skills. Successful EL learning of smartphone functions and applications has been reported in single case studies. However, there are mixed results on whether this type of learning can improve anomia and whether learning can transfer to untrained words [24, 29]. Therefore, more studies are needed to determine if word-finding difficulties in svPPA can be improved through alternative strategies using smartphone technology. In the current single case study, the research objective was to determine if a svPPA patient with anomia was able, based on the learning principles of EL: (i) to learn to use smartphone functions and an application, (ii) to relearn the names of trained pictures that she could not name at baseline to support her word-finding difficulties, (iii) and to determine if relearning the names of trained pictures also improved naming of semantically-related untrained pictures.

Case description

BL, a French-speaking 66-year-old woman, was a retired high school teacher (CEGEP), who received a diagnosis of semantic variant primary progressive aphasia (svPPA) by her physician slightly less than a year before she started the intervention. BL showed progressive difficulties in her comprehension of language and concepts, which had slowly worsened over the past two and a half years.

Her spontaneous speech was fluent and well-articulated, without agrammatism, but she presented occasional word-finding difficulties (anomia) that occurred in her spontaneous speech. She reported that these word-finding difficulties were a handicap for her in daily life, and resulted in stress, frustration, and anxiety. For instance, she would sometimes try to find the correct word for hours at a time (e.g., “stamp”, after putting a stamp on an envelope) and that she would not be able to fall asleep for hours at night because she could not remember the name. BL was referred by her geriatrician and was offered to participate in the present research study on anomia, which she eagerly accepted. Apart from her severe anomia and semantic impairment, BL was independent in any activities of daily life and had normal spatial and temporal orientation. For instance, she drove on her own to familiar and new places, she managed the couple’s finances, and travelled to other countries with her husband on a regular basis. She regularly went to the gym with her husband to exercise.

BL did not present with behavioural changes since the onset of her disease, nor at the time of the intervention, such as confirmed by her husband. Her behaviour was always appropriate, she was aware of her difficulties and did not present with anosognosia, and she could express her difficulties and provide specific examples of problematic situations in her daily life. Throughout the length of the study, she was always motivated to participate and interested to learn, and she usually travelled to the hospital research center in Montreal (Canada) on her own and did not miss any sessions. She received a great deal of support from her husband who accompanied her at the beginning of the intervention and helped her to practise at home. BL had no notable medical history and did not take any medication. Magnetic Resonance Imaging (MRI) of the brain was not available, as BL had a hip prosthesis which was MRI-incompatible. However, a Positron Emission Tomography (PET) scan performed one year before showed hypometabolism in the temporal lobes.

Neuropsychological performance

Results of the neuropsychological assessment prior to the intervention (at baseline) are presented in Table 1. On general cognitive screening tests, BL's performance was within the normal range on the MMSE [43] but was abnormal on the MoCA [44]. She was largely impaired on the DTLA, a brief language screening test [45]. In the language and semantic domain, BL showed normal performance on tests of oral comprehension and repetition but was impaired on tests assessing picture naming and semantic knowledge. Her performance on tests of attention, visual memory, and visuoperceptual and visuospatial processing was normal. Her performance on a test of verbal learning was impaired for the immediate recall of words but not for delayed recall and recognition. This performance on a verbal learning test is not surprising and must be interpreted with caution, however, since the meaning of the words that need to be learned can be compromised by the underlying semantic impairment. In summary, BL showed a circumscribed semantic disorder and anomia, in the relative absence of deficits in other cognitive domains. Her profound semantic impairment contrasted with her normal day-to-day episodic memory and normal spatial and temporal orientation, which is quite typical in svPPA. In everyday life situations, she was able to perfectly recall what she had done in recent days, weeks, and months. She could perfectly talk about her summer holidays and explain where she had been and what she had visited, the content of which was confirmed by her husband. For example, she did not remember what a "sheep" was, but when her husband asked her if they had seen this animal on a recent trip, she remembered she had seen some sheep in the countryside during her summer trip to England a few months before. Her only remaining knowledge of the concept "sheep" was thus purely episodic. A summary of baseline performance on neuropsychological tests is presented in Table 1. BL's drawings of a daisy (1A) and a chicken (1B) reflecting degraded conceptual knowledge is presented in Figure 1A and 1B.

[Insert Table 1 about here]

[Insert Figure 1A and 1B about here]

Questionnaires

Finally, BL was also asked to fill out questionnaires before and after the intervention about her perceived well-being [46], her perceived proficiency with mobile devices such as assessed with the MDPQ [47], and her perceived ease with technology such as assessed with the WP3 common measures questionnaire. Her husband was also asked to fill out the Communication effectiveness index (CETI) [48], the WP3 caregiver common measures questionnaire, and the Caregiver burden inventory [49].

Design of the intervention

The design of the anomia intervention is an ABA design, where A refers to pre-intervention and post-intervention measurement and B refers to the intervention aiming at improving anomia and, more secondarily, communication with family and friends through learning smartphone technology. Picture-naming measurements (outcome) were taken before, during and after the intervention. During each session, BL was asked to name lists of trained pictures (target pictures) and untrained pictures (semantically related and semantically unrelated pictures).

The cognitive intervention program took place over 15 sessions: During the first meeting, the general aims of the research project were explained to BL and her husband, and she gave informed consent to participate. During the following 3 *measurement* sessions (A) (sessions 1-3): (i) BL's knowledge of smartphone functions and of the application was assessed, (ii) she carried out the neuropsychological tests, and (iii) she completed lexical-semantic measures. The *intervention* phase was then divided in two different parts: (1) learning general smartphone functions and applications (sessions 4-5), (2) learning an application and relearning the names of objects that could not be named prior to the intervention (sessions 6-8). The intervention phase was then followed by three post-intervention sessions starting one week after the intervention (*measurement* sessions, sessions 9-11), and three follow-up sessions (6 months after the intervention, sessions 12-14) to measure the long-term retention of learning. Pre-intervention, intervention and post-intervention sessions took place once a week, spanning over 3 months, while the 3 follow-up sessions took place 6 months after the end of the intervention. The smartphone remained available to BL once the intervention was completed.

At the beginning of the program, BL was provided with an Android smartphone with a mobile internet connection for the duration of the intervention and was offered to keep the smartphone at the end of the intervention (which she accepted). The research project was approved by the Research Ethics Board of the IUGM, and BL provided written informed consent prior to the study. A schematic description of the cognitive intervention is presented in Figure 2.

[Insert Figure 2 about here]

Measurements (A)

Smartphone functions. BL had never owned a smartphone before, so it was assumed she had no prior knowledge of smartphone use. Prior to the intervention, measures of BL's ability to use different smartphone functions were taken during three baseline sessions to formally assess her prior knowledge (or absence of knowledge) of these functions. During each of the baseline sessions, BL was asked if she could use 26 different smartphone functions, 10 of which were later trained during the intervention and 16 of which were not trained. The list of trained and untrained functions was determined prior to the start of the intervention. Smartphone functions included different functions, some basic and other more complex, such as turning the smartphone on and off, connecting to Wi-Fi, taking a picture, calling a contact, sending a text message, checking the weather forecast via a weather app, writing a memo, etc. (see Table 2 for the full list of 26 functions and applications). For instance, she was asked, "Do you know how to call someone in your contacts?" or "Do you know how to take a picture?". If she knew how to use a function at the baseline, she was asked to show proper use of this function on the smartphone. If she didn't understand a word or an expression, it would be formulated differently and explained. Scores were computed for each session prior to the intervention, during the intervention and post intervention, based on her ability to complete the different steps required for the proper manipulation of each function.

Smartphone application. In the current study, we used the Taptapsee ™ application powered by CloudSight Inc. ™ image recognition technology. Taptapsee is a mobile camera application that is designed for blind and visually impaired users. This assistive technology application uses the device's camera to take a picture or a video of any two- or three-dimensional object at any angle and identifies it within seconds. Pictures or videos can also be selected from a camera roll on the smartphone or device. In the current study, we used this application with BL, a svPPA patient with severe anomia, to determine if she could learn using it and if it could help her recall the forgotten names of objects. She had no prior knowledge of the application. As for smartphone functions, however, this was formally assessed during the three baseline sessions prior to intervention. After the intervention, her ability to use the application was tested during the 3 post-intervention measurement sessions and during 3 maintenance sessions 6 months post-intervention, based on her ability to complete the different steps required for the proper use of the application.

Lexical-semantic measures. During each of the 3 baseline assessments, BL was asked to name 120 high-quality coloured photographs presented individually in paper format and free of any background. These pictures included common everyday objects (e.g., kitchen utensils, tools, furniture, musical instruments, fruits, vegetables, and animals). BL was asked to name each picture (maximum 20 seconds). If she was unable to provide an answer or if the answer was incorrect, she was asked, “Do you know what it is?”. She was also asked questions that assessed her general knowledge about the concept. For example, for a turtle, she would be asked, “Do you know where it lives?”; for a comb, she would be asked, “Do you know what it is used for?”. These semantic questions allowed determining if BL had some knowledge of the pictures she could not name or named incorrectly, as opposed to not knowing what the picture was. One point was awarded for each correct naming response. Pictures typically had only one name, but in specific instances when a picture had a possible alternative name (e.g., *patate* and *pomme de terre* for *potato*), the alternative response was accepted as a correct answer. One point was awarded for a correct semantic response, and 0.5 point for a partial response. One point was awarded when she could provide rather specific information about a picture such as an object, animal, etc. Half a point was given for responses indicating partial knowledge. Semantic scoring was lenient and briefly assessed however as this was not the primary focus of the study.

Results from the baseline measurements indicate that BL was able to correctly name 50/120 pictures. A picture was properly considered to be properly identified if it was named correctly in at least 2 of the 3 baseline sessions. From this initial list, 60 pictures were then selected for the intervention based on BL’s naming performance (i.e., pictures she could not name): 20 target stimuli (T) to be trained during the intervention, 20 stimuli semantically related (SR) to the targets (taxonomic relationships) but that would not be trained, and 20 stimuli semantically unrelated (SU) to the targets that would not be trained. The SR and SU conditions served as within-subject control conditions. The stimuli from the 3 lists were matched and did not differ significantly in terms of mean lexical frequency (T=8,1; SR=5,9; SU=6,1; F=0.64, p=0.53), number of letters (T=7,4; SR=8,0; SU=7,6; F=0.37, p=0.69), number of phonemes (T=5,5; SR=5,6; SU=5,5; F=0.02, p=0.99), and number of syllables (T=2,2; SR=2,3; SU=2,1; F=0.15, p=0.86). In addition, the target stimuli were selected to be as ecological as possible. Many of the target items were items that she and her husband believed were more likely of being encountered or used in situations of daily life or that were more personally relevant. During and after the intervention (post-intervention and follow-up sessions), only these 60 pictures were asked to be named. The order of presentation of the pictures differed across sessions, as well as the order of the lists (T, SR, SU). The order was randomized for test items. Pictures were not presented within semantic category groups. At baseline sessions, the mean number of words she could not name and for which she seemingly had no underlying knowledge was 4.0, 5.3 and 8.3 for T, SR and SU stimuli, respectively, while the mean number of words she could not name but for which she had partial or seemingly preserved knowledge was 7.3, 6.5 and 5.7 for T, SR and SU stimuli respectively.

Intervention (B)

Five intervention sessions were planned. Each intervention session lasted about one hour. The first 2 sessions involved learning the basic smartphone functions and the next 3 sessions involved learning the smartphone application that allowed to identify objects. The 20 Target stimuli were trained with this application. From the 26 smartphone functions, 10 were trained during the first 2 sessions and 16 were not trained. The intervention consisted of practising the functions with the experimenter's help.

The application was learned and practised during the 3 subsequent sessions. Regarding the trained smartphone functions and the app, the correct use of each function or application was broken down into several different steps that had to be performed in a specific order.

For instance, to use the application, identifying an object in the environment with the smartphone required the following steps:

1) on the Home screen, tap the app icon to open it,

2) position the phone at a certain distance from the object to be identified,

3) press the screen and check that the object appears in the background,

4) wait for the verbal label to appear at the bottom of the screen,

5) to quit the application, double-click on the Home button. A menu with all the apps appears. Close the app.

In addition, identifying an object from a photograph in a folder required the following steps:

1) on the home screen, tap the app icon to open it,

2) select Library, which gives access to the photos,

3) select the photo of the object to be identified,

4) wait for the verbal label to appear at the bottom of the screen,

5) to quit the application, double-click on the Home button. A menu with all your apps appears. Close the app.

The smartphone functions and the application were learned using the errorless learning (EL) principles. As a first step, the purpose and use of each function and the application are verbally described by the experimenter (SJ). Then, a scenario is presented explaining in what types of situations you would use the function. The experimenter then shows each step of the function, until complete use of the function is achieved (verbal and motor guidance). The patient is then verbally guided through each step in an errorless learning fashion. The patient is instructed not to guess and to avoid making errors as much as possible. If an error occurs, it is immediately corrected by the experimenter and the steps are repeated until successful. Once all steps are completed successfully, the patient is asked to repeat them in the same order. If an error is made, the error is corrected, and the patient then starts again from this step. The patient is then asked to complete the entire sequence until it is successfully completed at least 2-3 times. Once learning was achieved, BL was asked to practise the application during each of the 3 intervention sessions with the 20 target stimuli to foster their relearning. She could practise the application at home between each session with the 20 target stimuli. BL was instructed to train only with the target stimuli at home, but she was not forbidden to look up the names or the meaning of words from the other lists. She was encouraged to find words in everyday situations when she expressed word-finding difficulties.

Statistical analysis

A combination of visual and statistical analyses was used [50]. Performance relative to the smartphone functions, the application, as well as picture naming and semantic performance was analyzed using visual analyses of graphed data across the different phases of the study [51]. Data were presented for each phase, as expressed by BL's mean percentage of correct responses in each session. This allowed visual observation of tendencies and progression between baseline, intervention, post-intervention, and follow-up (maintenance) measures. Fig. 3 shows the progression of performance in smartphone function use, while Fig. 4 and 5 show the progression in picture naming and semantic knowledge. Statistical analyses were performed using the Tau-U statistic. Tau-U is a nonparametric method for measuring data non-overlap between phases. Tau-U is ideal for small datasets and single-case intervention studies. Essentially, the Tau-U statistic reflects the percentage of data that improves over time between two phases (e.g., a Tau-U of 1 means that 100% of the data improved between the two selected phases) [24]. Analyses were performed using the online calculator at http://singlecaseresearch.org/calculators/tau-u. A strength of this web application is that it can analyze data for several phase contrasts from a single design independently [52]. The level of significance was set at $p = .05$.

Results

Results of BL's performance on the use of 26 smartphone functions are presented in Figure 3, which shows BL's mean percentage of correctly completed functions during each session. BL's accuracy in terms of correct smartphone function use (pooled performance of 10 trained and 16 untrained functions) is presented in Figure 3.

[Insert Figure 3 about here]

BL showed significant improvements in her use of target functions, such as indicated by the difference in target function use between pre- and post-intervention sessions (Tau=1; $p<0.05$). She also showed long-term retention of target function use (at the 6 months follow-up, Tau=1; $p<0.05$). Although BL had not owned a smartphone before the beginning of the intervention, Fig.3 shows that BL had good knowledge of several trained functions at baseline, which is likely because she used her husband's smartphone occasionally to perform specific tasks before participating in the intervention (such as taking a picture, checking the weather forecast or sending a text message). BL also showed improved use of untrained smartphone functions post-intervention (Tau=1; $p<0.05$). The difference between pre-intervention and follow-up measures was also significant (Tau=1; $p<0.05$), despite a slight decline in untrained functions between post-intervention and follow-up measures (Tau=-1, $p<0.05$). The general improvement for untrained functions probably reflects the fact that she learned several functions with the help of her husband at home over the course of the intervention. Fig.3 shows that she correctly used 60% of untrained smartphone functions vs. 100% of target functions at the follow-up. Overall, these results demonstrate that there were long lasting beneficial effects in BL's ability to efficiently use her smartphone. The list of the 26 smartphone functions and their use before and after the intervention is presented in Table 2.

[Insert Table 2 about here]

Regarding the application, BL was quickly able to learn how to use it. She could use the application (without any mistake) after a single session of training, but she continued training with the app over the next 2 intervention sessions. BL's correct use of the application was 0% prior to intervention and 100% post-intervention and at the follow-up. This was reflected by a significant difference in performance between pre-intervention and post-intervention measures (Tau=1; $p<0.05$), and by improved performance between pre-intervention and follow-up measures (Tau=1; $p<0.05$).

Relearning names. Using the application, BL practiced relearning the names of 20 target pictures. Results are presented in Figure 4. BL showed a significant improvement in relearning the names of target stimuli (T). There was a significant difference in naming target pictures between pre- and post-intervention measures (Tau=1; $p<0.05$). There also was a significant difference between pre-intervention and follow-up measures for target pictures (Tau=1; $p<0.05$), indicating that her ability to correctly name these pictures was maintained 6 months after the intervention. As can be seen in Fig. 4, BL's naming accuracy for trained (target) pictures improved from 7% at baseline to 95% at the follow-up. In addition, although relearning was clearly not as important as for target pictures, BL nonetheless showed a significant improvement in naming SR pictures post-intervention (Tau=1; $p<0.05$), but this effect was not sustained at follow-up (Tau=0.89, $p=0.08$). In contrast, BL did not improve her naming of SU pictures from baseline to post-intervention and from baseline to follow-up (Tau=0.89, p=0.08).

During picture naming, BL made omissions ("don't know" or no response), semantic paraphasias (e.g., *kangaroo* > *bear*), circumlocutions (e.g., *funnel* > "to put liquids in a container"), and a few phonological paraphasias (e.g., *tabouret* > *tribulet*). For instance, she was unable to name the picture of a stapler, but when asked to provide more details, she answered, "to gather the sheets" and imitated the movement, indicating that she had some knowledge of the object. In contrast, for the picture of a can opener, she answered it was a tool. When asked what it was used for, she answered that she didn't know what this object was. As is common in svPPA, BL's semantic deficits were consistent across sessions, for example she could not name and did not know what a can opener was across the 3 baseline sessions. Interestingly, at post-intervention and at the follow-up, she could name almost all the items correctly (95% of targets at 6-month follow-up) and was at this stage able to provide semantic features for pictures she could not name before the intervention (e.g., "to open can lids" for a can opener). BL's picture naming performance across sessions is presented in Figure 4.

[Insert Figure 4 about here]

Semantic knowledge of pictures. BL's knowledge of the 60 pictures (T, SR, SU) was assessed at each session before, during, and after the intervention. The semantic features of pictures, however, were not trained during the intervention. Semantic knowledge of target, semantically related and unrelated pictures across sessions is presented in Figure 5.

[Insert Figure 5 about here]

Regarding semantic knowledge of target pictures, results show that the difference between pre- and post-intervention measures was significant (Tau=1; p<0.05), as well as the difference between pre- and follow-up measures (Tau=1; p<0.05). BL's semantic knowledge of SR pictures did not significantly improve between pre- and post-intervention measures (Tau=-0.11; p=0.83) but improved between pre-intervention and follow-up measures (Tau=1; p<0.05), and between post-intervention and follow-up measures (Tau=1, p<0.05). Finally, her knowledge of SU pictures improved neither between pre- and post-intervention (Tau=0.33, p=0.51) nor between pre-intervention and follow-up (Tau=0.11, p=0.83).

Questionnaires. Scores on the questionnaires before and after the intervention are presented in **Table 3**. BL reported greater self-reported well-being and greater mobile device proficiency after the intervention, while her husband found that her communication effectiveness and technology proficiency had improved post-intervention. While there were some numerical differences in pre and post self-report, these differences were not statistically measured to confirm reliable change.

[Insert Table 3 about here]

Discussion

In the current study, BL, a 66-year-old woman with svPPA who had severe anomia and semantic impairment, learned to use a smartphone to improve her anomia and enhance her communication skills. BL learned i) to use specific smartphone functions and an application to retrieve the names of objects, and ii) to use this application to learn to name a list of target pictures she was unable to name prior to the intervention. Overall, results showed that BL was quickly able to learn to use a smartphone, including the specific functions and application that were trained. Importantly, she improved her naming skills for the trained pictures, and to a slight extent for the semantically related pictures. These learning effects were sustained 6 months after the end of the intervention. Results from questionnaires also suggest that BL showed greater self-perceived mobile device proficiency and greater general well-being after the intervention. Even though BL had not owned a smartphone before, six months after the end of the intervention she used her smartphone on a regular basis to communicate with her friends and family members. For instance, she called her contacts regularly and was able to add new contacts, she could take pictures and videos and send text messages with pictures, which, as she pointed out, helped her connect more regularly with her grandchildren. She had also stopped using her landline. She reported that by relying on her smartphone she sought help from her husband much less often (e.g., to question the name or meaning of something), thereby increasing her functional independence and relieving caregiver burden. She also reported applying the learned strategies to real-life situations. BL reported being overall very satisfied with the intervention and "being more in tune with society".

The fact that BL was quickly and effortlessly able to learn to use smartphone functions and an application to improve her word-finding abilities corroborates recent studies that involved learning new technologies in PPA [12, 24, 29, 38, 53]. For instance, Bier et al. [29] reported that MH, a 55-year-old man with svPPA, was successfully able to learn smartphone functions and the use of a visual dictionary application when learning relied on preserved implicit procedural memory processes. In a more recent study, a svPPA patient was able to learn smartphone functions 5 years after his initial diagnosis and expanded his use of an application he had learned 4 years earlier [38]. Similarly, svPPA patient EC was successfully able to relearn cooking recipes, an activity she enjoyed and which allowed her to maintain social contacts with her friends, using a computer application that she learned [12]. Cooking as a socially meaningful and ecological activity was therefore reintroduced in her life. In line with these studies, the present results support the potential of mobile technologies as useful assistive technology for cognition, allowing svPPA patients to compensate their difficulties in everyday life situations, improve their naming impairment, and more generally improve their communication abilities [38], thereby promoting functional independence. However, such studies are still few in number, and more studies are needed to investigate and confirm the potential benefits of mobile technologies in supporting PPA.

In the current study, as in other intervention studies on svPPA [12, 16, 29, 38, 54], learning relied on errorless learning (EL) principles. In cognitive intervention programs, the use of EL was initially applied to support learning in amnesic patients of different aetiologies with severe anterograde amnesia [55]. An underlying assumption is that patients with anterograde amnesia tend to reproduce the same errors because they have impaired explicit memory processes and have difficulty monitoring their responses. Errors are thus reinforced and global learning is affected [35]. Thus, learning different types of information can be achieved by bypassing impaired explicit memory processes and relying on intact implicit memory processes. Another study also found that independent activities of daily living were better relearned in AD when using errorless vs. errorful learning (EF) [56]. In svPPA, despite the profound semantic impairment, episodic memory remains relatively unaffected, and procedural memory is also spared [29]. Nonetheless, svPPA patients may be more likely to reproduce errors in an error-prone context due to their underlying semantic impairment [54, 57]. As proposed by Jokel and Anderson [54], PPA patients may benefit from EL because it circumvents the use of impaired semantic memory in learning or relearning verbal information. In fact, EL has been successfully applied in the relearning of words and concepts in svPPA [54]. Indeed, this method can increase motivation and reduce frustration, while EF learning emphasizes errors and deficits. Savage et al. [19] also showed that EL can be successfully applied at different stages of severity to svPPA. Since implicit memory is reported to be resistant to aging [58] and to cortical dementias such as svPPA and AD [59-61], it is possible that BL's retention of smartphone use 6 months after the intervention may be due to more long-lasting effects of EL.

In summary, results of this study corroborate previous evidence that EL may be effective in the relearning of both verbal material and new technologies in svPPA [16, 54]. Moreover, other studies have shown that EL is effective not only in svPPA, but also in the speech and language therapy of non-fluent PPA and logopenic PPA patients [62, 63]. To better understand the types of EL that are the best predictors of success, future studies should provide detailed information about the type of EL procedure and compare it to a standard EF procedure. It is also possible that the EL of new information that involves a motor component (such as using smartphone) may be particularly effective compared to EL of purely cognitive or linguistic material. It has also been proposed that motor and sensorimotor representations may foster (re)learning of concepts [29].

Results of the current study differ from previous studies in some respects. Firstly, some previous studies did not find that relearning words and semantic features of words improved using smartphone applications. For instance, svPPA patient MH was not able to improve his picture naming or retrieval of semantic attributes using a visual dictionary, although he was perfectly able to learn smartphone functions and learning how to use the visual dictionary [29]. Therefore, procedural learning of smartphone use and functions worked well in MH, but there was no improvement in relearning verbal labels and their semantic features. The different neuropsychological profiles of impairment of BL and MH may account in part for this difference, i.e., more severe impairment in MH than BL, affecting to greater extent semantics, but also working memory, episodic memory and language in MH. Thus, the differences may be related in part to severity of disease. The difference may also lie in the nature of the intervention. In BL, the intervention was specifically designed to retrieve and practice the names of pictures using an application, while in MH it was more semantically oriented and consisted in searching in different semantic categories and subcategories as well as visual features of concepts. Savage et al. [26] suggested that pairing the picture of an object with a word form may be a critical element of training and simple enough to significantly improve naming.

In a recent study [24], 2 svPPA patients and 3 lvPPA patients carried out a self-administered therapy using a smart tablet (based on semantic feature analysis), which led to a significant improvement for the trained words after the intervention. Generalization to untrained items was observed in 2/5 patients (one svPPA and one lvPPA), while a significant reduction of anomia during post-intervention conversation was found in 4/5 patients (2 svPPA and 2 lvPPA). The effects were maintained in 4/5 patients 2 months post-treatment.

In the current study, BL improved her naming performance for target pictures from 7% at baseline to 95% six months after the intervention. Several factors may have contributed to this naming improvement. Firstly, as discussed above, the fact that EL was combined with the repetition of names may have enhanced naming performance, possibly by promoting greater automation of verbal responses. Secondly, the fact that most of the trained items were partially meaningful may also be a contributing factor. In some studies the effectiveness of learning varied according to the level of comprehension of the words trained [16, 64], while other studies specifically trained words with partially preserved meaning rather than words for which the meaning is completely lost to maximize the outcome of the intervention [19]. Thirdly, the fact that the intervention took place over several weeks may have resulted in more practice, and hence allowed greater reinforcement of the material learned [19, 65, 66]. As mentioned above, the nature of the task used, pairing the picture of an object with a word form, may also have contributed to the naming improvement [19]. Additionally, it must be pointed out that BL was highly motivated to relearn, she practised at home, and received much help and support from her husband. These motivational factors are critical and are one of the foundations for a successful intervention, as may be the involvement of a caregiver [67]. In addition to the application that she learned during the intervention and trained with, BL also reported using at home picture folders on her smartphone which included the pictures of the trained stimuli, but also those of other meaningful stimuli, such as various objects, tools, food, animals, etc. She also used search engines to look up the definition of a word when she was unsure about its meaning, as well as different pictures of a word. For example, she had lost the meaning of the word “heron”, so she looked up 20 different pictures of a heron until she believed she had formed an accurate visual representation of a heron (e.g., it is a large, grey bird with a long beak which stands on its long feet). These strategies she used on a regular basis at home (and at follow-up) may have helped boost her naming performance of the trained items. This may also explain why she also improved, to a lesser extent, her ability to name untrained items. Future work should examine the utility of such strategies and additional home practice in combination with using more direct picture-word associations.

Overall, results of this study indicate that BL successfully integrated learning during the intervention phase, and that she used it at home along with other strategies, in ecologically valid situations of daily life. Finally, BL did not present with behavioural difficulties or changes in personality, nor did she present with apparent difficulties in executive functions, which may have contributed to the positive outcome of the study [27]. She still managed the couple’s finances and household chores, pursued her hobbies, and continued to travel abroad on a regular basis with her husband. This profile of neuropsychological impairment, with a relatively circumscribed semantic breakdown and the absence of behavioral changes and dysexecutive function, may also have contributed to the overall success of the intervention.

In addition to improving her naming of target pictures, BL also improved her ability to provide correct semantic features for these pictures, even though there was no formal training of the semantic features during the intervention sessions. This result may be explained by the fact that she probably looked up the meaning of trained words (and some untrained words) at home and relearned this information during and after the intervention. Semantic knowledge of pictures, however, was not assessed in depth in the current study. In conclusion, we believe that the observed transfer effects to untrained semantically related pictures both at the naming and semantic level do not appear to indicate a generalization effect resulting from diffusion within the lexical-semantic system, but rather suggests that additional learning of the names and semantic features of trained and untrained items may have occurred at home independently from the intervention. As pointed out previously, learning in svPPA is to a great extent context dependent and is supported by episodic memory, making it difficult to generalize [24, 54]. Finally, results on questionnaires also seemed to suggest that the cognitive rehabilitation of BL using a smartphone improved her general well-being and self-perceived proficiency with technology and mobile devices, both from her own perspective and from her husband's perspective.

There are some limitations to the current study. Firstly, a pragmatic aspect of the intervention was that BL practiced at home and we were not able to control this factor. It would be important in future studies to carefully monitor the level of practice at home. Secondly, BL's communication skills were assessed informally through self-report and via the communication effectiveness index reported by her caregiver. A more formal assessment of communication skills should perhaps be considered in future studies. Thirdly, there are obvious inherent limitations to single case-studies in terms of generalization. Smartphone-based cognitive interventions should be assessed when possible in larger groups and with other forms of PPA where anomia is important, such as in logopenic PPA, as has been done in some recent studies [24, 63]. Since the semantic impairment in lvPPA is less present and anomia results more from the retrieval of phonological word forms, lvPPA patients may respond even better. Smartphone-based cognitive interventions should be assessed in logopenic PPA where anomia is prominent. More studies are needed to determine the long-term benefits of technology-based cognitive interventions. As the behavioural deficits set in with time, along with the dysexecutive deficits and the more global cognitive decline, patients may become less proactive and motivated and may not maintain the learning strategies. It is still unclear in the current literature to what extent the cognitive, psychological, motivational, and social characteristics of patients, as well as the inherent changes in time related to the neurodegenerative disease process, determine the outcome of cognitive interventions. Nevertheless, one study reported maintenance of treatment gains for lexical retrieval treatment in eighteen PPA patients at follow-up assessments up to a year [22], while another study reported that post-intervention improvements in naming performance in a group of SD patients could be sustained with revision (booster) sessions [68]. Similarly, it is conceivable that booster sessions may support the long-term maintenance of smartphone use in PPA.

In conclusion, this study showed that BL, a 66-year-old woman with svPPA who had not previously owned a smartphone, successfully learned to use, through the errorless learning principles, many key functions and an application to improve her anomia. She was able to significantly improve her naming skills and these benefits were maintained over time. Mobile technologies may be promising and useful for patients with language and cognitive deficits, allowing them to compensate for their difficulties in situations of everyday life, in a non-stigmatising way, and to communicate more efficiently and maintain social contacts.

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Table 1. Summary of baseline performance on neuropsychological tests.

	BL
General	
Mini-Mental State Examination (MMSE) (30)	27
Montreal Cognitive Assessment (MoCA) (30)	**23***
Language screening test (DTLA) (100)	**69***
Language and semantics	
Boston Naming Test (BNT) total (30)	**13***
Boston Naming Test (BNT) spontaneous (30)	**10***
MT-86 Comprehension (38)	36
MT-86 Repetition (33)	33
Verbal fluency (120 seconds)	
Category fluency (number of words - animals)	**11***
Letter fluency (number of words - letter P)	14
Test of Famous Faces	
Naming (10)	**1***
Semantics (20)	**10***
Test of famous person knowledge (POP10) (10)	**4***
Pyramids and Palm Trees Test (PPTT) (52)	**41***
Memory	
RAVLT	
Immediate recall total (75)	**33***
Delayed recall (15)	8
Recognition (15)	14
Rey-Osterrieth Figure - Immediate recall (36)	
Immediate recall (36)	9,5
Delayed recall (36)	7,5
Executive functioning and attention	
Stroop-Victoria Test	
Color	17 sec (0 errors)
Word	19 sec (0 err)
Interference	27 sec (0 err)
Trail Making Test	
Part A	44 sec (0 err)
Part B	83 sec (0 err)
d2 Test of Attention	
TN-E	372
CP	151
FR	9
Visual and spatial perception	
Rey-Osterrieth Figure - Copy (36)	31,5
Judgment of line orientation (30)	27

scores in bold and with an * indicates impaired scores
maximum score for each test is indicated in brackets

Table 2. List of the 26 smartphone functions and their use before and after the intervention.

Trained functions	Before the intervention	After the intervention
1. Turning the phone on/off	X	X
2. Locking/unlocking the phone	X	X
3. Connecting to Wi-Fi	0	X
4. Using the home button to go to the home screen	X	X
5. Taking a picture	X	X
6. Taking a video	0	X
7. Navigating between pictures	X	X
8. Looking at a picture or watching a video	X	X
9. Zooming in on a picture	X	X
10. Calling someone	X	X
Untrained functions		
11. Looking up the meaning of a word on the internet	X	X
12. Putting the smartphone in airplane mode	0	X
13. Checking the weather forecast	X	X
14. Adding a location in the weather forecast application	0	X
15. Typing a note in the Memo app	0	X
16. Creating an appointment in the calendar	0	X
17. Programming an alarm/modifying an existing alarm	0	X
18. Controlling the volume	0	X
19. Putting the phone in ring mode or in silent mode	0	X
20. Dragging apps around	0	0
21. Closing all running apps	0	X
22. Using the stopwatch	0	0
23. Using a maps application	0	X
24. Adding contacts to favourites	0	X
25. Sending a text message	X	X
26. Using the calculator	0	X

X indicates she knows how to use the function and 0 indicates she cannot use the function

Table 3. Scores on the questionnaires before and after the intervention.

Questionnaire	pre-intervention	post-intervention
BL		
General well being (score > 72 indicates positive well being)	79	86
WP3 User technology evaluation common measures (score range=0-50, lower score indicates greater perceived mastery of the technology)	24	22
Mobile device proficiency questionnaire (score range=0-32, higher score indicates greater proficiency)	14	23,5
Caregiver (husband)		
WP3 User technology evaluation (of BL) (score range=0-50, lower score indicates greater perceived mastery of the technology)	44	30
Communication effectiveness index (of BL) (100 point maximum, higher score indicates communication skills more similar to premorbid functioning)	61	77
Caregiver burden inventory (0-20=no burden to mild burden, 21-40=mild to moderate burden, 41-60 moderate buden, 61-80 severe burden)	35	28