TECHNICAL PAPER

Biological surface electromyographic switch and necklace-type button switch control as an augmentative and alternative communication input device: a feasibility study

DongGeon Lee[1] · SeungJun Lee[2] · Kuem Ju Lee[3] · GyuChang Lee[4]

Abstract

Augmentative and alternative communication (AAC) is an approach used to supplement, improve, and support the communication of those with speech or language impairments. We developed an AAC device for diverse approaches, using an electromyographic (EMG) switch and a necklace-type button switch. The EMG switch comprised an EMG signal processor and a switch interface processor. EMG signals were processed using an electrode through the stages of signal acquisition, amplification, filtering, rectification, and smoothing. In the switch interface processor, the microprocessor determined the switch as ON or OFF in response to an input EMG signal and then converted the EMG signal into a keyboard signal, which was transmitted to a smart device via Bluetooth communication. A similar transmission process was used for the necklace-type button switch, and switch signals were input and processed with general-purpose input/output. The first and second feasibility tests for the EMG switch and button switch were conducted in a total of three test sessions. The result of the feasibility test indicated that the major inconvenience and desired improvement associated with the EMG switch were the intricacy of the AAC device settings. The major inconveniences and desired improvements for the necklace-type button switch involved device shifting, volume and weight, and inconvenience in fixing the switch in various directions. Thus, based on the first and second feasibility tests, we developed an additional device. Finally, the EMG switch and necklace-type button switch developed to remedy the inconveniencies had high feasibility.

Keywords Augmentative and alternative communication · Communication aids · Surface electromyography · Mechanical button switch

Introduction

Augmentative and alternative communication (AAC) is an approach used to supplement, improve, and support the communication process of those with an impaired ability

to speak, or to replace communication in total [1]. Those who have lost the ability to communicate due to a disease or disorder can communicate in various ways using high-tech AAC systems [2]. Users of AAC systems have a wide variety of characteristics, depending on the type of disease and/or the severity of the disorder; hence, systems that can provide suitable support to a range of users are required [3]. Users can communicate using AAC devices such as mechanical switches, as well as head movements [4], eye movements [5], or brain signals [6] through surface electromyography (EMG), depending on the degree of impaired motor function.

Among these, the mechanical switches, including button switches, head switches, and sip-and-puff devices, are popular AAC devices for many disabled persons. The mechanical switch system has advantages: it is relatively inexpensive compared to other AAC devices, it is easy to repair, and it allows the direct selection of a desired word, letter, or

✉ GyuChang Lee
  leegc76@kyungnam.ac.kr

1   Department of Physical Therapy, Graduate School of Kyungnam University, Changwon, Republic of Korea

2   J.MARPLE Inc., R&D Team, Seoul, Republic of Korea

3   Department of Rehabilitation & Assistive Technology, Korea National Rehabilitation Research Institute, Seoul, Republic of Korea

4   Department of Physical Therapy, Kyungnam University, 7 Kyungnamdaehak-ro, Masanhappo-gu, Changwon, Gyeongsangnam-do 51767, Republic of Korea

picture. Despite the advantages of direct selection, it has the limitation that the physical function must activate the exact selective movement for each exact choice [7, 8]. Moreover, in cases of upper spinal cord injury, control of the sterno-cleidomastoid muscle is lost. This muscle is essential for control of head position, and thus the system could not be used with head movement [2]. Therefore, recently, several AAC devices have been developed that track eye or head movement. Many tracking systems, however, are camera-based and need to have complete control over illumination, stable head positions, and eye movements for long period of time [2]. In addition, unlike other AAC devices, users must be positioned in front of a camera or a computer screen for communication. This raises the problem of limiting the user's environment. Further, the user must remain exactly on a desired word, letter, or picture for a time set for selection in the tracking system [9]. Such a time-consuming method may enhance accuracy but reduces the number of possible selections per minute [9]. Moreover, AAC devices that can be used irrespective of the degree of motor impairment include electroencephalography (EEG), a brain signal conditioning device. However, although EEG enables communication, it has a low reliability because it is very slow and less accurate [10].

Among existing AAC devices, surface EMG can be used with only small muscular action, even by those with severely impaired motor function. Surface EMG has the advantage that it can detect the size of a signal more accurately than AAC devices using EEG [11]. In addition, Cler et al. stated that utilizing surface EMG could be a more reasonable alternative or aid than other AAC devices. It is said that signals can be acquired even from scarred skin if there is any muscle control that can activate EMG signals, without any gross movement [2]. stated that utilizing surface EMG could be a more reasonable alternative or aid than other AAC devices. It is said that signals can be acquired even from scarred skin if there is any muscle control that can activate EMG signals, without any gross movement [12]. Such a proposal could be a far better AAC device for an individual who does not have enough muscular strength to control a mechanical interface or generate limb or head movements that could be recognized by a camera-based device [2]. However, Cler et al. reported that users who have difficulty in communication due to impaired motor function would need two or more innovative augmentative systems for communication. The Cler et al. [2] reported that users who have difficulty in communication due to impaired motor function would need two or more innovative augmentative systems for communication. The usability and process speed of augmentative systems should not be confined to a single device, and two compatible technologies are required in the protocol for communication. Thus, two compatible devices need to be developed at the same time, and as many options as possible

should be introduced for those who have problems with motor control [2]. They reported that the two systems should have applicability even with very small movement, be stable, and provide comfort when inputting the voice output, etc. In addition, it is suggested that it should be possible to use AAC devices irrespective of tablet size and OS (Android, iPhone OS), and that AAC devices should be as lightweight and small in volume as possible so that they can be used in a variety of ways, depending on users' motor functions [2]. In addition, it is suggested that it should be possible to use AAC devices irrespective of tablet size and OS (Android, iPhone OS), and that AAC devices should be as lightweight and small in volume as possible so that they can be used in a variety of ways, depending on users' motor functions [13].

Therefore, in the present study, we developed a surface EMG switch and a necklace-type button switch that minimizes volume and weight and can be used with minimal muscle strength and small motions. In addition, feasibility tests were conducted with adults and children with disabilities to collect the diverse opinions of disabled persons on volume, weight, and connection simplicity, which were reflected in the development process.

Methods

Development of AAC device

Mechanical system

EMG switch The EMG switch was developed such that it might be attached and used as an electrode (Fig. 1). The attached device of the EMG switch is small; however, an internal battery had the disadvantages of reduced battery life and heavy weight. The main users of the EMG switch are physically disabled persons, who may use moving aids such as a wheelchair or spend significant time in bed. Therefore, the device was developed such that it used an external battery to extend the time of usage and reduce the weight of the device.

Necklace-type button switch A wearable necklace-type button switch was developed to allow easier use for disabled persons with difficulty moving their hands, who currently use a switch secured to a wheelchair (Fig. 2). The battery and charging circuit were included in the development, but battery consumption was small because a keyboard signal was generated only when there was input into the switch.

Controls and algorithms

The circuit portions of both the EMG switch and button switch comprised the microprocessor unit, power unit, and
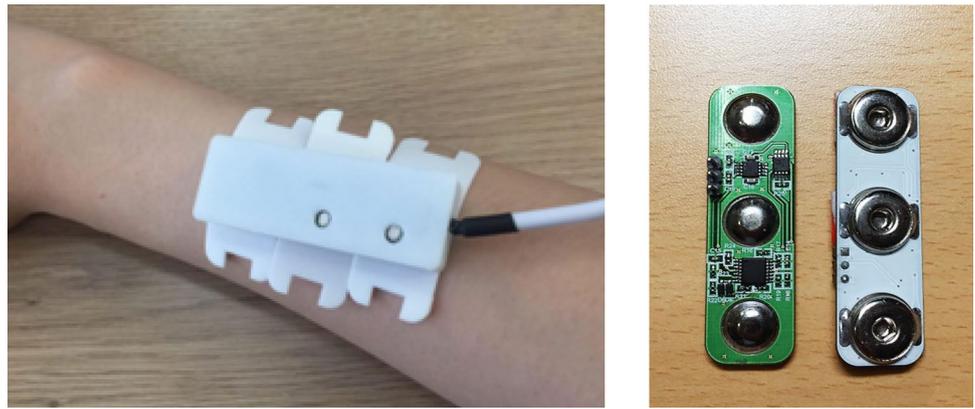
Fig. 1 EMG switch

Fig. 2 Necklace-type button switch

Bluetooth unit. The universal protocol of Bluetooth Human Interface Device (HID) was used because the device is required to connect to a Bluetooth keyboard. The button switch included a battery and a charger, whereas the EMG switch included the analog filter unit and Bluetooth Low Energy (BLE), which can communicate with an application (app) that sets the threshold.

Circuit configuration and signal processing algorithm of the EMG switch The circuit configuration of the EMG switch is shown in Fig. 3. An electromyography signal is an electrical signal generated along the muscle fibers according to the movement of the body. It is predominantly 10 mV or below, and the frequency range is below 500 Hz.

EMG signals are collected via an electrode and then signal processing is required due to friction between the electrode and skin, or ambient noise entering through the electrode. Since the EMG signal is a weak electrical signal, it must be amplified by hundreds of amplifiers and input to the microcontroller unit (MCU) to be processed. An 8-bit microprocessor (Atmega328P) was used, which is driven by 8 MHz clock speed and 3.3 V operating voltage. Therefore, the signal was amplified 100 times through the differential amplifier circuit of the analog filter. To obtain a positive amplitude value for the EMG signal of the sinewave waveform, the rectified EMG value was amplified by 1.5 times through the non-inverting amplifier circuit and the analog circuit, which was able to obtain an EMG signal of 0–5 V through the envelope circuit. The EMG signal is input to the MCU's 10-bit analog–digital converter (ADC) through the analog filter (Fig. 4).

Because the muscle contraction to operate the switch has a bandwidth of several Hz, it was treated with a Digital Low Pass Filter (LPF) of 10 Hz. The filter-processed EMG signal (x_k) was compared to the threshold value, and when it was greater than 0, it was regarded as "ON" and when it was less than 0, it was determined as "OFF". Operation of the switch is determined according to the following formula:

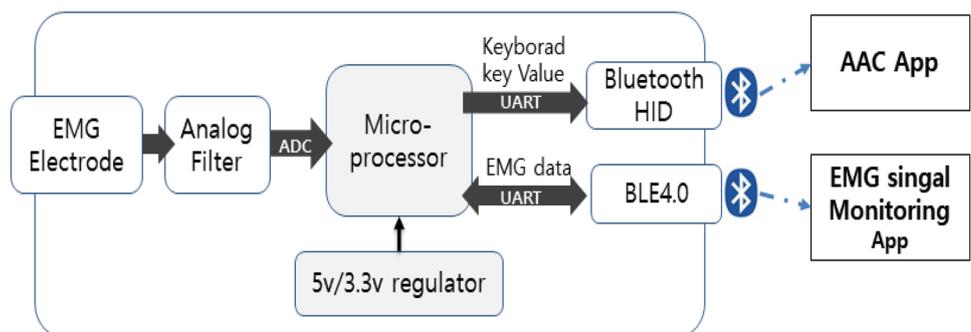**Fig. 3** Circuit configuration of EMG switch
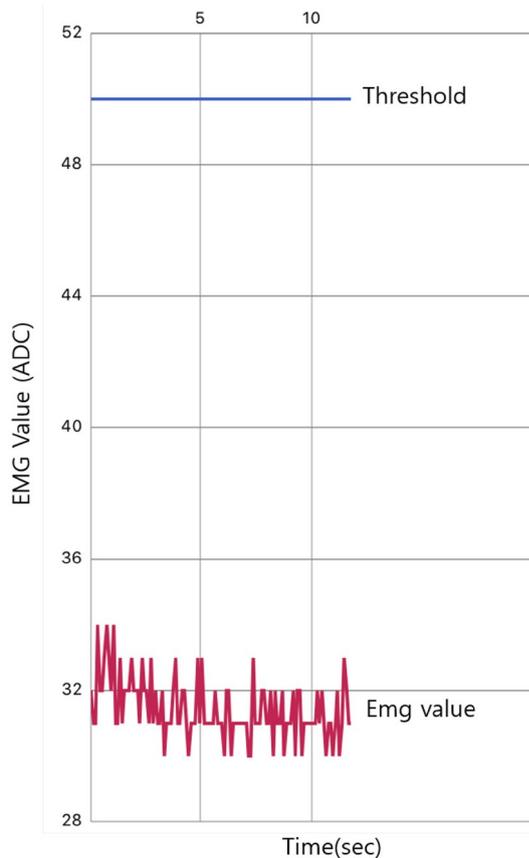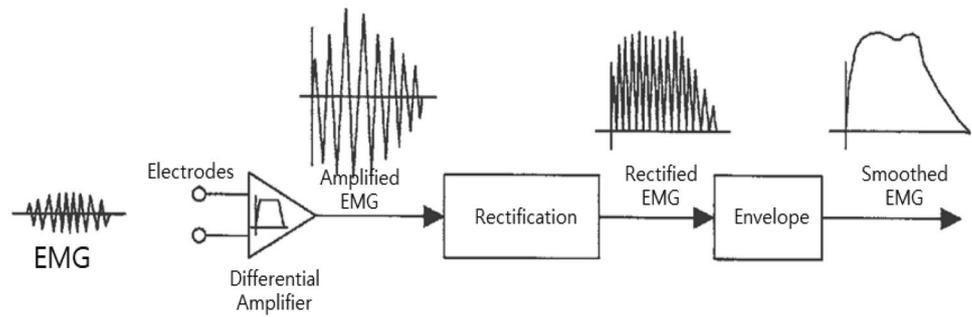
Fig. 4 Algorithms of EMG signal processing

Fig. 5 The range of the EMG value output

Fig. 6 The user can set the threshold value, which is the reference of the switch operation, while monitoring the EMG value

Switch value = EMG value (x_k) − threshold

The range of the EMG output varies depending on the position of the attached muscle and the degree of contraction. The EMG output value (0–1024) from the ADC was confirmed to be 0–50 as the baseline value without muscle contraction (Fig. 5). The EMG output value was 32 ($\pm$ 3) without muscle contraction and a minimum of 80 during muscle contraction. The threshold value was set as 50 to operate the switch using muscle contraction. If a user has a tremor or wants to operate the switch using gross movement,
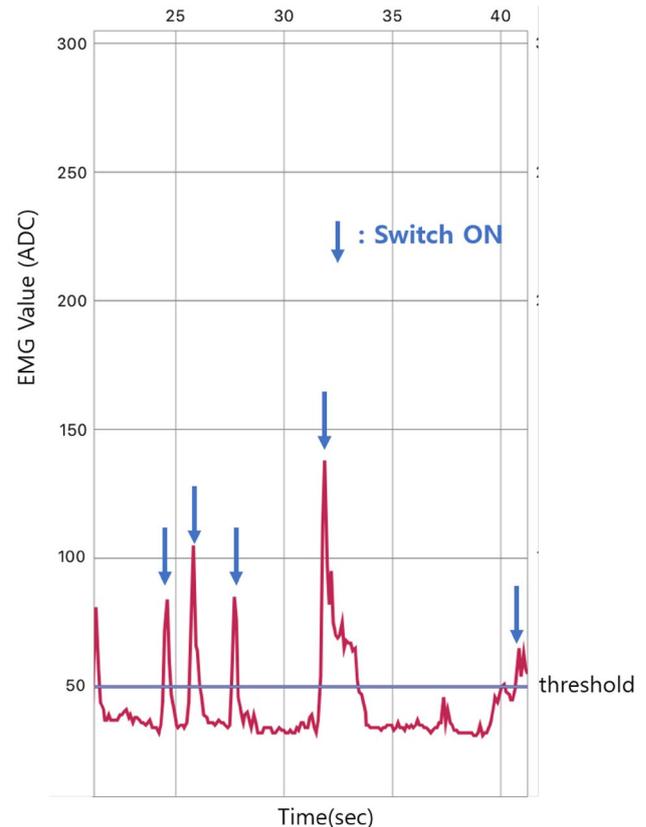
the threshold can be set to a greater value. Therefore, the user can set the threshold value, which is the reference of the switch operation, while monitoring the EMG value outputted through the app (Fig. 6).

When the switch is on, upon pressing the enter key, a signal is sent through the Bluetooth HID. When it is off, the value is transmitted when the enter key is released. In addition, the EMG value is monitored through the application, and the filtered EMG and the set threshold values are transmitted through BLE 4.0 so that the threshold value can be set. Additionally, when a new threshold value is

transmitted through the app, the threshold value is stored in the Electrically Erasable Programmable Read-Only Memory (EEPROM) of the MCU. Threshold value can be changed through the software, which was named MINTO EMG (Figs. 7, 8).

A signal collected by the EMG electrode is input into the microprocessor via the analog filter and ADC, and an EMG value was obtained. The analog filter was simplified into amplification, filtering, rectification, and smoothing, since it was intended to discriminate whether the EMG

value exceeded the threshold value. When this occurred, it indicated muscle contraction, thereby obtaining ON/OFF as output rather than collecting an exact EMG raw data value. When the EMG value exceeded the threshold, the ON state was detected, and the keyboard output was transmitted to the smart device (AAC app) via Bluetooth HID. Muscle contraction varied with the position of the device attachment to the muscle and the object in use, and thus, an EMG signal-monitoring app was developed to allow the threshold value to be altered. One keyboard key output could be used for one EMG switch, and it was arranged such that two EMG switches were attached to the movable muscle and could be registered with the 'easy-to-use' manner of a smart device. In addition, it was arranged that when using only one switch, the auto scanning function could be accessed and used.
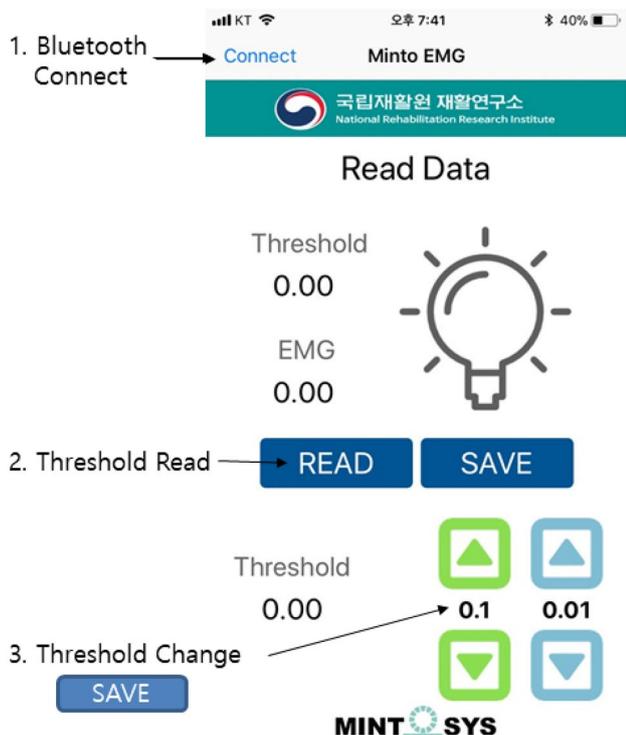
Circuit configuration and signal processing algorithm of the necklace-type button switch The circuit configuration of the necklace-type button switch is shown in Fig. 9.

Input was accepted from two button switches; when a switch was pressed, the microprocessor generated a relevant keyboard value for the switch, and the keyboard value was sent to a smart device (AAC app) via Bluetooth HID.

The buttons were equivalent to the space and enter keys on the Bluetooth keyboard. The space key was set as "easy-to-use move" on the smart device, so that the user was able
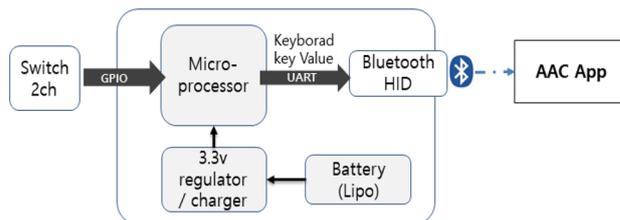

Fig. 7 Bio-signal transmission/reception software application (iOS version 1.0)

Fig. 9 Circuit configuration of necklace-type button switch

Fig. 8 Bio-signal transmission/reception software application (Android version 1.0)

to toggle through a list by one space when the switch was pressed. The enter key was set as "easy-to-use" on the smart device, so that the button selected the current option when pressed. Thus, all the functions of a smart device could be used with the two buttons.

Development of bio-signal transmission/reception software application A bio-signal transmission/reception software application was developed so that EMG signals might be used directly by a smart device (Android and iPhone OS).

iPhone OS (iOS) and Android apps received the EMG value (xk) through the Generic Attribute Profile Protocol (GAPP) of BLE 4.0. The communication port was opened to receive the EMG value through the bluetooth device scan, connect device, and connection setup (BLE Manager, Transaction Builder, Receiver creation) to connect the Generic Attribute Profile (GATT). The input EMG value was displayed numerically and graphically. If it exceeded the threshold value, the light on the screen changed to check whether the switch was operating. The threshold value could also be changed by pressing the threshold button and then setting the new threshold value by pressing the save button.

Using the MINTO EMG ver. 1.0 (Mintosys Inc., Seoul, Republic of Korea), an application used to check raw data of an EMG signal and set the threshold, was developed. MINTO EMG is available via iOS Apple Store and Google Play Using the Bluetooth Connect button, connection was ensured between the EMG switch and raw EMG signals and the threshold value, and the switch ON/OFF state could be checked. After checking the monitored EMG value, the threshold value of the EMG switch was changed and saved in EEPROM. The software app was developed so that it could be used with iOS and Android (Figs. 7, 8).

Performance features of the AAC device

EMG switch The EMG switch, which was developed so that the input could be generated from only minimum muscle activity and volume (58 mm in length, 20 mm in area, and 10 mm in thickness), can be used on any region to which it can be attached to the residual muscles that can activate EMG signals. After its attachment to the muscle, it can be used with the simple control of the threshold value at a bio-signal transmission/reception software application. The threshold value can be directly controlled with the threshold bar, while monitoring an EMG signal value, which appears as a number to the user, whose basic threshold can be raised or lowered (Fig. 10).

Necklace-type button switch The necklace-type button-switch-device portion was attached to several joints so that the input could be generated with minimum movement of the head alone. Head movements in various directions,
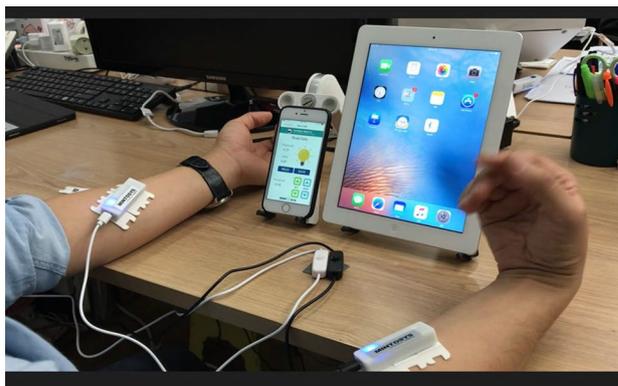

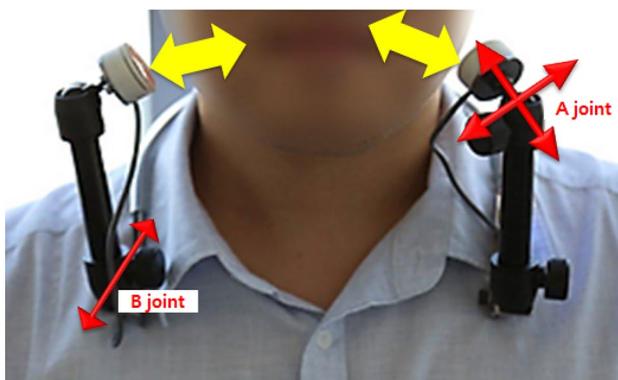**Fig. 10** Smart device control using EMG switch

Fig. 11 Mechanism that can be changed in various directions using necklace-type button switch

such as flexion, extension, lateral bending, and rotation and irregularities on the surface of the face can impose limitations on the use of the button switch. Therefore, the two button switches were not fixed, but were configured in such a way that the user could move and fix the joints in various directions to suit a range in which repeated movements were possible (Fig. 11). Such features of the device portion will allow the user to move the head comfortably and to make adjustments according to the directions of the residual muscles and the face contact area.

AAC program

The AAC program (My AAC, Android and iOS Ver. 1.08, NCSOFT Cultural Foundation, Seoul, Korea) used in the study is an AAC program supporting Korean people, which is supplied and distributed free of charge to support communication for people who have difficulty in communication by Nonprofit Public Foundation NC Cultural Foundation of NCSOFT, a Korean software company (Download homepage address: https://www.myaac.co.kr/web/software/

apps#myaac/). On November 15, 2015, this program was released by NCSOFT Cultural Foundation free of charge through Google Play. On October 26, 2017, an update was made to Ver. 2.0, which is the current version at the time of writing. The application is available to the Korean public free of charge.

'My AAC' is for first-time users or those with very severe or multiple disabilities. It is designed to support basic communications with minimal choice (choice between two things) such as "Yes" or "No," and "Like" or "Dislike." In addition, the following functions can also be used: (1) speak with a communication board, a function that allows the user to make an expression with a recommended communication board or a customized communication board they have previously prepared; (2) retrieve from and save in the Cloud, a function to retrieve or save a communication board prepared on a PC or mobile device and saved in the Cloud; (3) choose and say, a function that allows the user to make a basic expression with a choice between two things, such as positive or negative; (4) look and say, a function to support iterative learning in which the user looks at pictures and speaks utilizing basic special education curricula; (5) listen and say, a function to support iterative learning in which the user listens to a sound and guesses or says the name of an object; and (6) make up a story, a function to produce and deliver a story with a time flow, so that the user can express what they are interested in or what they want to say.

We developed an AAC device through this study but did not develop a program (software) linked to the AAC device. Thus, we used 'My AAC,' a free Korean version of the AAC program that has previously been developed and is readily available, linking it to the AAC device we developed.

Feasibility studies

Participants and methods

The feasibility test of an AAC (EMG and button switches) was conducted in three sessions, with seven adult hemiplegic stroke survivors and eight quadriplegic children or adolescents with cerebral palsy, hospitalized at a rehabilitation center or an outpatient pediatric center. The participants were recruited in response to a public notice displayed in the centers. The participants were screened in accordance with the following criteria: (1) adult hemiplegic stroke survivors (age ≥ 20) or children or adolescents with cerebral palsy (age < 20); (2) those with speech or language disorders, but no structural problems of articulation; (3) participants who could follow directions provided by the researcher or Mini Mental Status Examination score (MMSE) ≥ 24. Of the 20 volunteers who expressed interest in the feasibility test, 15 volunteers eventually participated. We excluded three

volunteers who could not recognize the picture and writing, and two volunteers who could not follow the instructions.

The feasibility test was conducted with the 15 subjects using the developed AAC device with the necklace-type button switch and the EMG switch. The program used for communication was named "My AAC." The subjects were fully familiarized with the device before the feasibility test. They used the developed AAC device and were asked to answer questions about satisfaction with the usability of the developed AAC devices using a 5-point Likert scale. The feasibility test items were largely categorized into the setting, usability, and storage of the AAC device, and the subjects were asked to answer 12 questions with sub-categories (Table 1). Moreover, additional interviews were conducted with the subjects to investigate their opinions about inconveniences identified by the feasibility test. The results were then reflected in the further development of the AAC device.

The first feasibility test was conducted at the developmental stage, while the second and third feasibility tests were conducted after improving the first product and the final development, respectively. In the first feasibility test, two adult hemiplegic stroke survivors and three quadriplegic children or adolescents with cerebral palsy participated. The second feasibility test was conducted in the same way as the first feasibility test, using the improved AAC device based on the results of the first feasibility test. The participants included two adult hemiplegic stroke survivors and three quadriplegic children or adolescents with cerebral palsy. The third feasibility test was conducted in the same way as the previous two feasibility tests, using the AAC device improved based on the results of the second feasibility test. The participants included three adult hemiplegic stroke survivors and two quadriplegic children or adolescents with cerebral palsy. A total of three feasibility tests were conducted, and the AAC device continuously improved according to the results of each feasibility test.

Results

The general information regarding the subjects from the feasibility tests was as follows (Table 2).

The subjects' Likert-scale answers to each question were as follows (Table 3).

First feasibility test

Regarding the satisfaction with the use of the AAC device, the mean Likert-scale score for the necklace-type button switch was found to be 3 points. Both subjects 1 and 2, who were adult hemiplegic stroke survivors, answered that they could not press the necklace-type button switch accurately because the movements of their heads on the

Table 1 Contents of feasibility test

Category	Items	Likert scale
Setting of AAC device		
1	Is it possible for the user to set the hardware of AAC device?	
2	Is it convenient for the user to set the hardware of AAC device?	
3	Is it possible for the user to set the software of AAC device?	
4	Is it convenient for the user to set the software of AAC device?	
Use of AAC device		
5	Is it possible for the user to select a desired letter, word, or picture with the AAC device?	
6	Is it convenient for the user to select a desired letter, word, or picture with the AAC device?	
7	Is it possible for the user to output a desired letter, word, or picture with the AAC device?	
8	Is the time taken until the user selects and outputs a desired letter, word, or picture with the AAC device suitable?	
9	In case of using the AAC device, are the volume and weight of the device suitable?	
Storage of AAC device		
10	Is it possible for the user to unset the AAC device?	
11	Is it convenient for the user to unset the AAC device?	
12	Are the carriage and storage of the AAC device suitable?	

Table 2 General characteristics of subjects

Variables	First feasibility test					Second feasibility test					Third feasibility test				
	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S 10	S 11	S 12	S 13	S 14	S 15
Age (year)	76	78	14	8	11	68	73	8	14	15	76	53	70	17	10
Gender (M/F)	F	F	M	F	M	M	F	F	F	M	F	F	F	M	M
Etiology (H/I/CP)	H	I	CP	CP	CP	H	I	CP	CP	CP	I	H	I	CP	CP
Paralysis location (R/L/Q)	R	R	Q	Q	Q	L	L	Q	Q	Q	R	L	R	Q	Q
Disease duration (year)	5	1	14	8	11	3	4	8	14	15	5	7	5	17	10

S, subject; M, male; F, female; H, hemorrhage; I, infarction; CP, cerebral palsy; R, right; L, left; Q, quadriplegia

Table 3 Results of feasibility test

	First feasibility test			Second feasibility test			Third feasibility test	
	Necklace-type button switch	EMG switch		Necklace-type button switch	EMG switch		Necklace-type button switch	EMG switch
Subject 1	3 (1–3)	2 (1–3)	Subject 6	3 (2–4)	3 (1–4)	Subject 11	5 (1–5)	5 (1–5)
Subject 2	3 (1–4)	2 (1–5)	Subject 7	3 (3–3)	5 (1–5)	Subject 12	5 (4–5)	5 (4–5)
Subject 3	4 (1–5)	2 (1–5)	Subject 8	4 (2–5)	3 (1–5)	Subject 13	5 (3–5)	5 (3–5)
Subject 4	4 (1–5)	2 (1–4)	Subject 9	5 (4–5)	3 (1–5)	Subject 14	4 (3–5)	5 (3–5)
Subject 5	5 (1–5)	3 (1–4)	Subject 10	5 (3–5)	3 (1–5)	Subject 15	3 (2–5)	3 (2–5)
Total median	3 (1–5)	2 (1–5)	Total median	4 (2–5)	3 (1–5)	Total median	4 (1–5)	5 (1–5)

Values are presented as median (range)

less affected side was different to that on the more affected side. Both subjects 1 and 2 evaluated the switch at a score of 3 points. At the same time, subjects 3 and 4 (quadriplegic cerebral palsy children in adolescence) answered that the device was bulky and heavy to wear continuously, and that it was difficult to operate because it was not exactly fastened to the body. Both subjects 3 and 4 evaluated the switch with 4 points. Subject 5 (quadriplegic child or adolescent with cerebral palsy) evaluated the switch with a score of 5 points because the switch was smaller in volume and lighter than the existing button switch, although it had room for improvement.

The Likert-scale score for the EMG switch was 2 points on average. Subjects 1 and 2 (hemiplegic stroke survivors) pointed out that it took too long to connect to the communication app and the communication device and they did not know how much movement they should make, as it was not possible to know the exact extent of the EMG signal while measuring it. Conversely, subjects 3, 4, and 5 (quadriplegic children or adolescents with cerebral palsy) answered that they felt the device was inconvenient because in order to use it, they had to maintain high muscle tone, so they could not find the reference point for the threshold. Additionally they reported that it was necessary to check the EMG signal visually, even for a single movement because it was difficult to make isolated movements. Therefore, subjects 3, 4, and 5 evaluated the device with scores of 2, 2, and 3 points, respectively. However, they made favorable comments about its small volume and lightness. Moreover, they shared the opinion that it was too difficult for them to connect the EMG switch to a computer, and then to a smart device again.

Second feasibility test

Regarding satisfaction with the use of the AAC device, the Likert-scale score for the necklace-type button switch was found to be 4 points on average. Subjects 6 and 7, who were adult hemiplegic stroke survivors, answered that they had difficulty in repeated button touches for a desired direction for head movements (less affected side), and that they hoped for an adjustment to fit the face surface. Both subjects 6 and 7 evaluated the switch with a score of 3 points. Subjects 8, 9, and 10 (quadriplegic children or adolescents with cerebral palsy) said that while operating the necklace-type button switch repeatedly, the switch lost its original position and continued to move, which was inconvenient. However, they answered that the reduced volume and weight were positive. Subjects 8, 9, and 10 (quadriplegic children or adolescent with cerebral palsy) evaluated the switch at 4, 5, and 5 points, respectively.

The Likert-scale score for the EMG switch was 3 points on average. Subjects 6 and 7, who were hemiplegic stroke survivors, answered that signals were not picked up well from muscle activation on the more affected side. Therefore, they said that an improvement to signals acquisition was necessary. Subjects 6 and 7 evaluated the switch at 3 points and 5 points, respectively. Subject 7 appreciated the switch highly with a score of 5 points, because it was able to measure the muscle signals on the more affected side, albeit inaccurately. Subjects 8, 9, and 10 said that the function of the device as a switch was insufficient for small movements because they had difficulty in making detailed adjustments to the threshold, although they attached the device to the desired regions and made movements to activate EMG

signals. Subjects 8, 9, and 10 evaluated the switch with a score of 3 points.

Third feasibility test

Regarding the satisfaction with the use of the AAC device, the Likert-scale score for the button switch was 4 points on an average. Subjects 11, 12, and 13, adult hemiplegic stroke survivors, reported that the difficulty in desired repeated button touches was remedied by the improvement of the device. Specifically, they found it more suitable for the face and for movements on the more affected side. However, they answered that when using the device for a long time, the attachment of the fixture correcting the movement of the device portion had a tendency to weaken problematically. Subjects 11, 12, and 13 gave a score of 5 points. In the same way as subjects 11, 12, and 13, subjects 14 and 15 also evaluated the adjustment as a positive change; however, they answered that additional improvement in weight would be necessary for it to be used by children for a long time. Subjects 14 and 15 evaluated the switch with 4 and 3 points, respectively.

The Likert-scale score for the EMG switch was 5 points on average. Subjects 11, 12, and 13 strongly appreciated the fine adjustability of the threshold after acquiring EMG signals, even with small movements on the more affected side. In addition, they gave very positive responses to the change from the existing process, where the device had to be connected to a computer to adjust the threshold and then re-connected to a smart device in a process through which all the settings and direct use of the app could be accessed through a smart device. Subjects 11, 12, and 13 evaluated the switch with a score of 5 points. Similar to subjects 11, 12, and 13, subjects 14 and 15 (quadriplegic children or adolescents with cerebral palsy) also evaluated the adjustment as a positive change; however, they answered that the process of connecting to the Bluetooth communication device would need to be simplified for children with no knowledge of smart devices. Subjects 14 and 15 evaluated the switch with scores of 5 and 3 points, respectively.

For the necklace-type button switch, satisfaction with the use of the developed AAC device was 3 points in the first feasibility test, 4 points in the second feasibility test, and 4 points in the third feasibility test. For the EMG switch, the satisfaction was 2 points in the first feasibility test, 3 points in the second feasibility test, and 5 points in the third feasibility test. Although the necklace-type button switch had greater user satisfaction in the first and second feasibility tests than the EMG switch, the EMG switch had higher scores in the third feasibility test. Required major improvements of the necklace-type button switch included reduction in volume and weight, fixation, and the adjustment of button position according to movements of the face or the more

affected side. As a result of improving the above-mentioned issues, the score for the feasibility test increased by one point from 3 points in the first test to 4 points in the third test. For the EMG switch, the desired improvements were related to minimizing the volume, simplifying connection protocols, and adjustment methods after EMG signal measurement and visual checking. As a result of addressing the above-mentioned issues, the score for the feasibility test increased from 2 points in the first test to 5 points in the third test.

Discussion

In modern society where the ability to communicate with others is essential, new and diverse strategic approaches are required to allow persons with limitations in communication due to disability to share equal communication methods [14]. Among the major causes leading to disorders of language or the ability to speak are neurological disorders resulting from degenerative diseases such as cerebral palsy (CP) and amyotrophic lateral sclerosis (ALS), traumatic brain injury (TBI), stroke, and physical dysfunctions. Moreover, it has been reported that approximately 0.2–0.6% of the world population [15] and approximately 1.4% of population of the US need AAC systems because of serious communication problems [16]. Therefore, guidance on communication is essential for individuals with disabilities to improve their quality of life and allow independent living in society and engaging in social interaction with non-disabled persons, and the AAC approach has recently been emphasized worldwide for this purpose [14].

McNaughton and Light [17] stated that an iPad and other mobile technologies could become effective tools to improve communication for disabled persons. Explaining this, they cited that the social perception and acceptance of AAC devices should be facilitated by universally-employed tools, thereby, contributing to the social integration of disabled persons, and that these technologies could be used in a variety of ways for speaking, writing, information gathering, social relationship promotion, and so on, thereby easily satisfying the diverse communication desires of disabled persons [17]. In developing AAC devices, it is necessary to reflect the various characteristics of users (e.g. age, gender, time of evolution, lesion location, premorbid cognitive status, setting) [18]. When all variables are properly considered, the enhanced communication through these devices may provide even modest improvements in the severe emotional reactions these vulnerable patients' and contribute to healthcare decisions, thereby having a major impact on well-being [19]. In this study, we developed an AAC device by fully reflecting the opinions of users in the development process and attempted to use it as a communication device for people with disabilities.

Hodge et al. reported their opinions on the existing AAC devices for children and adult users. They write that most of the existing AAC devices needed to be secured to a wheelchair for successful communication. However, it was reported that having their usage limited to a wheelchair caused frustration to users whose physical movements were slow or inefficient while secured to a wheelchair [20]. reported their opinions on the existing AAC devices for children and adult users. They write that most of the existing AAC devices needed to be secured to a wheelchair for successful communication. However, it was reported that having their usage limited to a wheelchair caused frustration to users whose physical movements were slow or inefficient while secured to a wheelchair [20]. To improve this problem, this study developed a necklace-type button switch, which was intended to allow use everywhere, breaking away from the existing method of fastening such devices to a wheelchair arm. However, in the first feasibility test, satisfaction with its usability barely reached 3 points on the Likert scale. However, the fact that it was usable regardless of location was relatively well received compared to fastening the device to a wheelchair. Hemiplegic stroke survivors said that they could not press the button switch precisely due to differences in head movements on the less affected side and more affected side during the use of the necklace-type button switch. Moreover, it was reported that the device was too bulky and heavy for quadriplegic children with cerebral palsy to wear continuously, and that it was difficult to operate because it was not secured to the body precisely. Regarding the EMG switch, satisfaction with its usability was 2 points in the first feasibility test. Although its light weight and small volume were highly appreciated, most of the users pointed out that the method of using the EMG switch was too difficult. In particular, the complicated procedure to use the device was presented as a problem for parents as well as for children with cerebral palsy. McNaughton et al. also noted that insufficient knowledge of new technology has negative effects on the use of the device from the standpoint of both parents and users. In addition, they commented that these devices need to be as simple as possible, noting that learning to use the devices can be a great challenge. McNaughton et al. [21]. also noted that insufficient knowledge of new technology has negative effects on the use of the device from the standpoint of both parents and users. In addition, they commented that these devices need to be as simple as possible, noting that learning to use the devices can be a great challenge.

For the EMG switch developed in this study, the threshold value for then EMG signal was set by connecting the device to a computer before connecting to a smart device, and then connection was made again to the smart device where an AAC app was installed. It seemed that the process of connecting the device to a computer again to reset the threshold of an EMG signal was seen as complicated.

Moreover, it was reported that there were also many limitations in checking variations between the EMG signal in the resting state and an EMG signal during movement, which made it more difficult to set the threshold value of the EMG signal to select the movement. The main problem reported in the first feasibility test was that the device lacked portability, a simple procedure for use, and a convenient method of operation to choose a desired function. Kong et al. reported that satisfaction with AAC devices used currently or in the past is 54%, and that steps to achieve higher satisfaction included: implementing simple methods for operating and selecting a desired function, and better portability obtained through volume and weight reduction [14]. reported that satisfaction with AAC devices used currently or in the past is 54%, and that steps to achieve higher satisfaction included: implementing simple methods for operating and selecting a desired function, and better portability obtained through volume and weight reduction [14]. Therefore, measures to address the above-mentioned issues were reflected in the further development and improvement of the AAC device prior to the second feasibility test.

In the second feasibility test, satisfaction with the usability of the necklace-type button switch was 4 points on average. The satisfaction increased one point from that in the first feasibility test, and investigation showed that the reason was the reduction of the device's volume and weight. However, hemiplegic stroke survivors reported that on their less affected side, they had difficulty in repeated button touches for a desired direction due to the reduction of its weight and volume. In addition, it was proposed that adjustments should be made to improve the attachment to the face, since it was inconvenient when the button switch moved continuously from its original position during repeated operation. An external battery was used to reduce the weight of the device and the button switch was miniaturized to reduce the volume. However, this seemed to reduce the fixation of the button switch. Satisfaction with the improved EMG switch in the second feasibility test was found to be 3 points on average, one point higher than in the first feasibility test. The easily recognizable visualized (graph or number) method for setting the threshold of an EMG signal seemed to have positive effects. It was reported that the process of connecting to a smart device after connecting to a computer and setting the threshold was still complicated, and it was also difficult to make detailed adjustments to the threshold unit, even though EMG signals were activated by attaching the device to desired regions. A previous study, in which 60% of the subjects, mostly disabled persons, suffered from difficulty in hand functions as well as problems of language disorder, suggested that the configuration of an operation interface and the connectivity to an external input device should be as simple and convenient as possible [14]. However, in the second feasibility test we found major inconveniences to include a lack of fixation in the configuration of the operation interface in the case of the button switch as well as the need to connect to an external input device in the case of the EMG switch. Therefore, before the third feasibility test, methods for addressing these issues were reflected in the improvement of the AAC device.

In the third feasibility test, satisfaction with the usability of the necklace-type button switch was 4 points on average. The result was the same as that of the second feasibility test, but hemiplegic stroke survivors reported that the difficulty in desired repeated button touches was remedied by the improvement of the device portion so that it might be suitable for the facial topography and detecting movements on the more affected side. Moreover, it was noted that the movement of the whole necklace-type button switch could be fully improved by applying non-slip pad materials to the surface of the necklace. However, it was proposed that quadriplegic children with cerebral palsy would need further reduction in the weight and volume of the device. Although connection to an external battery was employed in the second feasibility test to reduce weight, the button switch developed for the third feasibility test employed an embedded battery. Consequently, while the simplification of battery connecting lines, thanks to the embedded battery, received high scores, the increase in the weight of the battery for the sufficient time of usage was found to be an appreciable burden to children with cerebral palsy. Cooper et al. [22] stated that insufficient battery capacity could be a significant burden to the users of AAC devices. However, the increased battery weight required to increase battery use time would make it necessary to develop an external battery that could be selected by users. From the third feasibility test, satisfaction with the usability of the EMG switch was found to be 5 points on average. This 5-point score, one point higher than that of the second feasibility test, is the degree of satisfaction closest to a perfect score. The EMG switch used in the first and second feasibility tests received high satisfaction scores, mostly due to its small volume and light weight; however, the process of setting the threshold and the criterion for selection and movement were found to be inconvenient. In contrast, in the third feasibility test, the EMG switch was accompanied by an app that could be used on smart devices (Android and iPhone OS). This meant that Bluetooth connection was made directly to a smart device, without the need to connect to a computer; EMG signals were measured, and the threshold value (the criterion for a signal), could be set by means of the developed bio-signal transmission/reception software app. The developed app allowed the threshold value to be set very precisely and made it easy to visually identify the degree by which the EMG signal value exceeded the set threshold value. In addition, an external battery was used to minimize volume and maximize use time. As a result, very high satisfaction was

obtained in the third feasibility test. Despite the very high satisfaction, some users suggested that the program should be integrated with AAC systems currently popularized, i.e. it would be preferable if a bio-signal transmission/reception software app capable of setting EMG signals were also to be incorporated into one communication program.

This study developed a necklace-type button switch and an EMG switch for augmented and alternative communication based on a total of three sessions of feasibility testing. In the process of development, the necklace-type button switch, which used the mechanical inputting system, was found to have the advantages that it was rarely non-functional, like the existing button switches, it was cheap, and it could be easily repaired. Despite the advantages of the mechanical switch, however, it required a certain level of physical functional ability for the movement necessary for exact choice [5, 7, 8]. To supplement this, the EMG switch may be usefully employed for those who have more limited physical functional levels. However, existing commercialized EMG switch products are expensive and family members have great difficulty in understanding the technical aspects of the devices [23]. In contrast, in the development of this type of switch, this study used a communication app on existing smart devices and developed an EMG signal-setting app; thereby making it possible to supply the low-cost EMG signal device at an affordable price. Therefore, users could use the necklace-type button switch and the EMG switch alternately according to their requirements. In addition, the devices were also minimized in volume. In the study of Cler et al. [2], the authors suggested that EMG devices should be minimized in volume and light for convenience, and in addition, should be compatible with other devices in software and interface. In this respect, the necklace-type button switch and the EMG switch from the present study may be useful in clinical settings.

The feasibility tests of this study investigated satisfaction with usability, convenience, and stability, but did not compare the developed product with the existing AAC devices with respect to message-generating hours. In addition, by using the Likert test as the measure of feasibility, the satisfaction of the patients with the device was confirmed. However, the preferences for some questions could not be investigated by this test. Finally, one of the limitations of this study was its small sample size. We conclude that for the popularization of the necklace-type button switch and the EMG switch developed, it is necessary to compare them with currently available products in the studies conducted in the future.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Ethics approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the Kyungnam University Institutional Review Board and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Lewis RB (1993) Special education technology: classroom applications. Brooks/Cole Publishing Company, Pacific Grove
2. Cler MJ, Nieto-Castañón A, Guenther FH, Fager SK, Stepp CE (2016) Surface electromyographic control of a novel phonemic interface for speech synthesis. Augment Altern Commun 32:120–130
3. Beukelman D, Mirenda P (2005) Augmentative and alternative communication: supporting children and adults with complex communication needs. Paul H. Brookes, Baltimore
4. Williams MR, Kirsch RF (2008) Evaluation of head orientation and neck muscle EMG signals as command inputs to a human–computer interface for individuals with high tetraplegia. IEEE Trans Neural Syst Rehabil Eng 16:485–494
5. Higginbotham DJ, Shane H, Russell S, Caves K (2007) Access to AAC: present, past, and future. Augment Altern Commun 23:243–257
6. Orhan U, Hild KE, Erdogmus D, Roark B, Oken B, Fried-Oken M (2012) RSVP keyboard: an EEG based typing interface. In: Proc IEEE Int conf Acoust speech signal Process, pp 645–648
7. Beukelman DR, Mirenda P (2013) Augmentative & alternative communication: supporting children & adults with complex communication needs, 4th edn. Paul H. Brookes Pub, Baltimore
8. Fager S, Bardach L, Russell S, Higginbotham J (2012) Access to augmentative and alternative communication: new technologies and clinical decision-making. J Pediatr Rehabil Med 5:53
9. Majaranta P, MacKenzie IS, Aula A, Räihä KJ (2006) Effects of feedback and dwell time on eye typing speed and accuracy. Univers Access in Inform Soc 5:199–208
10. Tonet O, Marinelli M, Citi L et al (2008) Defining brain–machine interface applications by matching interface performance with device requirements. J Neurosci Methods 167:91–104
11. Stepp CE (2012) Surface electromyography for speech and swallowing systems: measurement, analysis, and interpretation. J Speech Lang Hear Res 55:1232–1246
12. Saxena S, Nikolic S, Popovic D (1995) An EMG-controlled grasping system for tetraplegics. J Rehabil Res Dev 32:17
13. Mobasheri MH, King D, Judge S et al (2016) Communication aid requirements of intensive care unit patients with transient speech loss. Augment Altern Commun 32:261–271
14. Kong JY, Kim KY, Nam SH, An NY (2017) Survey on the use of Korean-type augmentative and alternative communication (AAC) for person with brain lesions. AAC Res Pract 5:25–50

15. Cook A, Hussesy S (2002) Assistive technology: preincilples and practive, 2nd edn. Mosby, St. Louis

16. Beukelman D, Mirenda P (2012) Augmentative and alternative communication, 4th edn. Paul H. Brookes Publishing Co, Baltimore

17. McNaughton D, Light J (2013) The iPad and mobile technology revolution: benefits and challenges for individuals who require augmentative and alternative communication. Augment Altern Commun 29:107–116

18. Russo MJ, Prodan V, Meda NN et al (2017) High-technology augmentative communication for adults with post-stroke aphasia: a systematic review. Expert Rev Med Devices 14(5):355–370

19. Ten Hoorn S, Elbers PW, Girbes AR, Tuinman PR (2016) Communicating with conscious and mechanically ventilated critically ill patients: a systematic review. Crit Care 20(1):333

20. Hodge S (2007) Why is the potential of augmentative and alternative communication not being realized? Exploring the experiences of people who use communication aids. Disabil Soc 22:457–471

21. McNaughton D, Rackensperger T, Benedek-Wood E, Krezman C, Williams MB, Light J (2008) A child needs to be given a chance to succeed": parents of individuals who use AAC describe the benefits and challenges of learning AAC technologies. Augment Altern Commun 24:43–55

22. Cooper L, Balandin S, Trembath D (2009) The loneliness experiences of young adults with cerebral palsy who use alternative and augmentative communication. Augment Altern Commun 25:154–164

23. Bailey RL, Parette HP, Stoner JB, Angell ME, Carroll K (2006) Family members' perceptions of augmentative and alternative communication device use. Lang Speech Hear Serv Sch 37:50–60