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Tablet-based EloQ software for presenting tasks during brain function mapping

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ABSTRACT

Functional mapping of cortex and white matter tracts is important in surgery for epilepsy and supratentorial tumors. One of the limitations for speech mapping is difficult standardization, selection and presentation of stimuli during cortical stimulation.

Objective. To develop a user-friendly tablet application for creation of customized stimulus packages specific to speech cortex and white matter tracts for their presentation during mapping.

Results. The EloQ application contains predefined task packages for mapping of non-motor cortical functions of dominant hemisphere. It is supplemented with system for their automatic selection depending on intended mapping area. EloQ offers various image display and audio settings allowing it to be used not only in the operating theater but also in long-term invasive electroencephalography (EEG) monitoring ward. The application is freely available, and physician survey using a 5-point Likert scale showed overall satisfaction with EloQ.

Conclusion. Free EloQ tablet application simplifies and standardizes non-motor cortical mapping expanding the possibilities of neurosurgical treatment of gliomas and drug-resistant epilepsy.

Keywords: *speech cortex mapping, functional cortex mapping, intraoperative neurophysiological monitoring, EloQ.*

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Abbreviations

FCM — functional cortical mapping
DCS — direct cortical stimulation
DRE — drug-resistant epilepsy

Introduction

In neurosurgery for supratentorial tumors and DRE, localization of cortical functions and association tracts is not only an object of fundamental research but also a crucial applied task. FCM implies intraoperative electrical stimulation [1]. This technique occurred in the 1930s, underwent significant changes and remained the gold standard for FCM. Indeed, DCS does not require complex equipment, and it is highly reproducible in all patient groups [2]. FCM with DCS is possible intraoperatively and in patients with implanted intracranial electrodes before neurosurgical treatment of DRE [3].

DCS-based FCM implies depolarization of cortical neuronal membranes spreading around and inward from electrode due to charge diffusion. This leads to functional changes of neurons with clinical symptoms corresponding to their specialization [4].

Unlike motor cortex mapping [5], mapping of speech and other higher cortical functions is a more complex task. It requires not only constant contact with the patient but also selection of tasks (stimuli) specific to appropriate functional cortical area. Preliminary selection of tasks that the patient can perform during stimulation is a necessary stage [6]. Before invention of portable electronic devices, task sets were presented to the patient on ordinary sheets of paper [7]. Tablet computers and smartphones have made it possible to display tasks on their screens. In most cases, free pre-installed software tools, such as PowerPoint (Microsoft Office Corporation) and PDF (Portable Document Format) files, are used for this purpose [8, 9]. Veljanoski D. et al. [9] performed international survey of 37 groups conducting speech and other cognitive function tests. Only 3% of respondents used specialized stimulus presentation apps. Our analysis revealed no available automated stimulus presentation apps.

Material and methods

We developed and tested the "EloQ" tablet application for stimulus presentation. It can be used on any tablet computer or smartphone running the Android operating system.

This application is based on Flutter framework (architecture design rules that initially define a "skeleton" that can be expanded and modified according to specified requirements) and Dart programming language. It allows code to be compiled for iOS and Android devices. A significant advantage of this framework is flexibility of text widgets. For example, this enabled instant translation of graphical interface text from Russian to English with the click of a button. The application uses local SQLite database whose tables store patient data, as well as information about completed testing sets. This information is visually presented in the patient's file and can be accessed at any time. The application does not require the Internet and does not transmit information to third parties.

Results

The "EloQ" application ("Eloquent Cortex") simplifies creation of a customized stimulus set and standardizes presentation during FCM. The application interface is currently available in two languages: Russian and English. "EloQ" is free and can be downloaded from Google Play via a search query or obtained from the repository (www.eloqbrainmapping.com). Release on the App Store is planned for the near future.

Tasks/stimulus packages. EloQ comes preloaded with stimulus material for mapping of cortical representations and association fibers involved in speech, memory and recognition processes according to modern data on their distribution [10]. Some tasks (images of objects and actions) were presented by Dragoy O.V. et al. and validated for Russian language [11, 12]. Other tasks were developed with participation of professional neuropsychologists experienced in work within operating theater. Available literature data were also used. Patients have various levels of education and social experience, and we provide several difficulty levels for some tasks. Future updates of application will expand the range of tasks and include more complex tests as they will be developed. Stimulus packages may also be used to test white matter pathways involved in speech function **(Table 1)**.

Since the application is designed for neurologists, neurosurgeons and neurophysiologists, it offers simplified automated task selection based on cerebral region of interest. After entering the patient ID fields, the program will automatically suggest a set of predefined tasks for appropriate "Hemisphere-Cortex-Gyrus" columns with option to add other packages. If necessary, any stimulus material prepared in appropriate format can be additionally included in testing package. To map the tracts involved in speech, stimulus packages should be added manually.

To simplify task selection, the EloQ application contains a "Help" section outlining the application's operating sequence, as well as tables and diagrams for selecting tasks for mapping cortical representations and subcortical structures. Examples and data presented by E. de Witte et al. [13] are used.

Stages of cortical mapping using EloQ app. FCM consists of three stages:

1) "assessment" — baseline assessment of the patient's ability to perform tasks from stimulus package and their selection for mapping;
2) "mapping" — DCS-guided testing with perioperative presentation of images;
3) "re-assessment" — re-assessment of the number of correct tasks to compare these results with preoperative status.

Thus, EloQ allows any loaded task package to be played back in two modes ("assessment" and "mapping"), and then comparisons are made by re-analysis in "re-assessment" mode.

"Assessment" stage. For non-motor functions, the "baseline" is individual tasks that the patient can name or perform preoperatively. "Assessment" mode implies selection of stimuli that will be used to test the patient during FCM. When selecting tasks, one should consider the patient's recognition speed and initial word pronunciation. For this purpose, the EloQ settings include a configurable image display timer in "assessment" phase (default value 3 seconds). Selecting the "Image shading" option after time has elapsed allows the tester to immediately assess the patient's perception and task completion time, as well as to make mapping more individual. After selection in "assessment" mode, the EloQ user sees a complete set of thumbnail images presented to the patient with excluded stimuli outlined in red and accepted stimuli in green. Manual correction is possible, if necessary. This creates a "baseline" for mapping non-motor functions and subsequent comparison of results **(Fig. 1a)**. After com-

Table 1. **Preset stimulus packages for FCM of dominant hemisphere**

Stimulus	Number of images in a package	Difficulty levels	Mapped cortical area/tract
Naming objects	50	1	Posterior superior temporal gyrus Middle, inferior temporal gyrus Temporoparieto-occipital area Supplementary motor area Inferior frontal gyrus Supramarginal gyrus Insular lobe Occipital lobe Frontal longitudinal tract (Aslant) Inferior fronto-occipital fasciculus
Naming actions	50	1	Inferior frontal gyrus Posterior parts of the middle frontal gyrus Supplementary motor area Frontal longitudinal tract (Aslant)
Automated speech (e.g. counting 1—10, seasons, etc.)	18	1	Inferior frontal gyrus Supplementary motor area Arcuate tract (ventrally) Frontal longitudinal tract (Aslant)
Mathematical calculations	40—40—40	3	Angular gyrus
Reading sentences	34—9	2	Supramarginal gyrus Angular gyrus
Reading words consisting of 2 or 3 syllables	34—44—50	3	Middle temporal gyrus Precentral gyrus Arcuate tract (ventrally)
Completing sentences	11—20—20—20	4	Supramarginal gyrus

pleting the "assessment" phase, the task name is highlighted in orange. Immediately after selecting stimuli in "assessment" mode, the EloQ app displays the absolute numbers and percentage of selected stimuli, and one can make quick decision regarding feasibility of awake surgery **(Fig. 1b)**.

"Mapping" stage is a clinical analysis of the patient's functions during DCS.

Sound signals. The EloQ settings provide options for intraoperative and extraoperative DCS. For intraoperative mode, the application emits a high-pitched beep to synchronize DCS with stimulus presentation. After that, surgeon should apply the stimulating probe to appropriate cortical area. After a configurable delay (3 seconds by default), a low-pitched beep indicates the need to stop DCS. This second beep can be disabled if necessary **(Fig. 2a)**.

False stimulation. One of the methods for DCS-based FCM is presentation of images without electrical current ("false stimulation") **(Fig. 2b)**. This approach confirms causal relationship between symptoms and stimulation of certain cortical area. Alternating task with and without electrical stimulation reduces the risk of false-positive responses [14]. This feature is available in the EloQ app (the ability to skip sound signal after certain number of stimuli).

Additional settings. The app also features some additional settings for individualization of feedback system based on specialist's experience and patient's functional status: pause between stimulus, time between sound signal and stimulus presentation, stimulation time. By default, pause is 2 seconds, and sound signal occurs 500 ms before stimulus presentation **(Fig. 2a)**. Available prolongation of time between sound signal and stimulus presentation individualizes the time necessary for surgeon to recognize the sound and apply the probe to the cortex. This allows to begin stimulation when the patient begins to perceive the stimulus and pronounce the word.

Repetition and order of stimulus presentation. Another feature of "EloQ" distinguishing this app from basic image display programs on a tablet computer is available presentation of selected images in a random order. Randomization of stimulus presentation, i.e., shuffle, can also be activated in settings **(Fig. 2a)**. This prevents "memorizing" stimulus sequence and makes naming conscious rather automated process.

End of presentation. At the mapping stage, EloQ automatically repeats stimulus package after presentation of the entire selected stimulus package. It is also possible to stop and restart or pause the program by simply tapping the screen.

Re-assessment stage. In clinical practice, there is a need for repeated testing of functional status after surgery. For this purpose, EloQ features "re-assessment" mode launched by tapping "Repeat" in the patient drop-down menu. A copy of the patient's record is created with additional name. At the "re-assessment" stage, the "baseline" selected at the first stage is considered 100%, and the result is presented as a percentage of correct and incorrect answers.



Fig. 1. **EloQ app screen in "Assessment" mode.**
a — selected images of objects in "assessment" mode with option for manual correction. Stimulus image not included in individual mapping task package is outlined in red; b — percentage of correctly completed tasks after "assessment" stage. Completed tasks are marked in orange, and results are presented in absolute values and percentages. White font indicates a task not used.

Ease of use. The app is currently used in 4 neurosurgical hospitals in Moscow and St. Petersburg for tumors near functional cortical areas and DRE. Full-time neurologists of neurosurgical departments or neuropsychologists perform selection and speech assessment. We asked users (n=7) to rate the app's usability. Responses were scored on a 5-point Likert scale **(Table 2)**.

Discussion

Maximum possible resection of abnormal tissue within functional cortical zones is a crucial goal in surgery for supratentorial tumors and DRE. However, there is still no consensus on speech mapping. Different neurosurgical centers vary not only in protocols for awake neurosurgery, but also in procedures for selecting patients for speech testing, tasks for this testing and even specialization of staff [15].

Electronic devices for presenting speech or other tasks significantly simplifies and allows for standardization of non-motor function mapping. Image presentation methods proposed by some authors most often rely on standard tablet applications for displaying PDF files or PowerPoint presentations [9]. The disadvantage of this approach is time-consuming preparation of individual stimulus set requiring special experience and separate personal computer for subsequent downloading of results to a tablet. Synchronizing stimulation with image display is also difficult for surgeons without extensive experience in mapping. In some countries, the problem is compounded by no specialists, such as neuropsychologists, in neurosurgical departments [16].

The NeuroMapper platform (The Medical College of Wisconsin Inc., USA) is the most common among modern systems for presenting stimuli and paradigms. Its architecture incorporates two Apple iPad tablets running the iPadOS operating system. The system not only simultaneously presents stimuli but also provides audio and video recording of responses [17]. Although the application is open source, NeuroMapper requires permission from the developers, and its interface is available only in English. Such platforms are in demand for researches and development of new stimulation paradigms. However, a simpler application requiring a single tablet or mobile phone running the more versatile Android operating system is sufficient for neurosurgical departments. The advantages of the EloQ application are free distribution and bi-



Fig. 2. **The possibilities of intraoperative use of "EloQ".**
a — settings for "mapping" and "assessment" stages; b — scheme of intraoperative presentation of "false stimuli" (without sound signal) alternately with "active" stimuli and feedback for neurosurgeon.

Table 2. **User ratings of the app**

Question	Score, Me (Q_1; Q_3)
How easy is it to install the EloQ program on a device for testing?	5 (4; 5)
How convenient is it to enter patient's data into the app?	5 (5; 5)
How easy is it to select tasks for mapping different brain lobes?	4.5 (4; 5)
How complete is the package of pre-installed tasks in the program?	4 (4; 5)
How convenient is it to assess patient's basic functional status?	5 (4; 5)
How convenient is it to use the program during stimulation mapping?	5 (4; 5)
How convenient is it to retrieve testing results of previous patients?	4 (3; 4.25)
Rate overall usability of the EloQ program	5 (4; 5)

lingual support. In the future, we plan to add multilingual support and presentation of auditory stimuli. The application is compatible with device for stimulation-free invasive FCM based on electrocorticography and can be used as a remote control for the system [18].

Our survey revealed overall satisfaction among physicians with application design and task selection process.

Conclusion

The EloQ application is the first open-source stimulus presentation application for mapping of non-motor cortical functions and white matter tracts requiring only a single tablet or phone running the Android operating system. Its unique feature is not only available customization of display settings but also easy selection of specific tasks. Survey of doctors confirmed high user-friendliness of interface and comprehensiveness of preset tasks. This suggests that the app can be used by various specialists.

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COMMENT

The authors developed "EloQ" software for Android tablets for presentation of tasks before, during and after surgery. The main features of this program: 1) automatic selection of individualized tests according to patient's capabilities; 2) automatic selection of individualized tests according to tumor location and their automatic presentation. The tests themselves are not new, but selected adequately to appropriate brain area. Audible cues are also provided for surgeon to allow for comparison of stimulus presentation and electrical stimulation. The program is well-developed. It has already been implemented in 4 hospitals in Moscow and St. Petersburg with only positive feedback from specialists. A significant advantage of this program is available storage of patient data and task results on the same device and their extraction as needed. A significant advantage is free distribution of the program and no sharing of clinical information with third parties over the Internet. The program can undoubtedly be used in awake surgery with patient testing. It would be interesting to hear from the authors in the future: why was sentence completion test chosen for stimulation of supramarginal gyrus?

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