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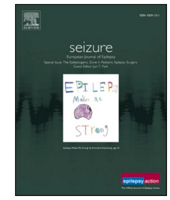

Automated spike and seizure detection: Are we ready for implementation?

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ABSTRACT

Objective: Automated detection of spikes and seizures has been a subject of research for several decades now. There have been important advances, yet automated detection in EMU (Epilepsy Monitoring Unit) settings has not been accepted as standard practice. We intend to implement this software at our EMU and so carried out a qualitative study to identify factors that hinder ('barriers') and facilitate ('enablers') implementation.
Method: Twenty-two semi-structured interviews were conducted with 14 technicians and neurologists involved in recording and reporting EEGs and eight neurologists who receive EEG reports in the outpatient department. The study was reported according to the Consolidated Criteria for Reporting Qualitative Studies (COREQ).
Results: We identified 14 barriers and 14 enablers for future implementation. Most barriers were reported by technicians. The most prominent barrier was lack of trust in the software, especially regarding seizure detection and false positive results. Additionally, technicians feared losing their EEG review skills or their jobs. Most commonly reported enablers included potential efficiency in the EEG workflow, the opportunity for quantification of EEG findings and the willingness to try the software.
Conclusions: This study provides insight into the perspectives of users and offers recommendations for implementing automated spike and seizure detection in EMUs.

1. Introduction

Machine learning has increasingly been used and been the subject of research in health care with the aim of improving efficiency [1]. Fields of interest in epilepsy include analysis of imaging and clinical data, epilepsy source localization, prediction of medical and surgical outcomes, and automated EEG-based detection [2]. The latter has been the scope of research for several decades [3,4,5], with some remarkable achievements [6,7]. The research focused on development and testing of new detection algorithms; validation studies of various commercially available software packages were published, often with promising results [8–13]. Despite these publications and advances automated EEG-based detection in EMU (Epilepsy Monitoring Unit) settings has not been accepted as standard practice.

Implementing changes in health care practice is often challenging. Successful implementation largely depends on acceptance by professionals; that is, the extent to which they believe that a given innovation is agreeable or satisfactory, and a willingness to try an innovation [14].

In the current qualitative study we surveyed thoughts, attitudes, experiences and needs of both producers and recipients of EEG reports regarding automated EEG-based detection, using semi-structured interviews. We aimed to identify factors that hinder ('barriers') and facilitate ('enablers') future implementation. This information may help guide successful implementation of such software.

2. Method

We conducted semi-structured interviews using a phenomenological approach. Method and results were reported according to the Consolidated Criteria for Reporting Qualitative Studies (COREQ) [15].

2.1. Current EEG (review) process

The study was performed in Stichting Epilepsie Instellingen Nederland (SEIN), a tertiary referral center with two clinical locations (Heemstede and Zwolle) and an outpatient clinic network. Each location has an Epilepsy Monitoring Unit (EMU) where we perform prolonged EEG recordings [16].

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Abbreviations

EMU Epilepsy Monitoring Unit

2.2. Participants

We applied consecutive sampling for the selection of participants: all technicians, neurologists and physician assistants working at both clinical neurophysiology departments and all neurologists at the outpatient clinics received an email invitation to participate in the study. Potential participants were invited for interview by email. Prior to the invitation, they attended a presentation about the use of automated detection for reviewing prolonged EEGs, including previous research on automated detection [9,10,11] and our proposed method of using automated detection in combination with sampled review [17], see Fig. 1.

Nineteen of 36 clinical neurophysiology staff members and twelve of 29 outpatient clinic neurologists who we contacted were willing to participate in an interview. Based on the reached data saturation, we included nine technicians (participants TC1 to TC9), five medical staff members, consisting of neurologists and physician assistants (participants MC1 to MC5), and eight outpatient clinic neurologists (participants MO1 to MO8). No participant dropped out. Seventeen of the 22 participants were familiar with the interviewer, and all participants knew that the researcher was involved in research on automated EEG detection.

2.3. Data collection

Semi-structured interviews were conducted by ER, a female physician assistant and research fellow working at the department of clinical neurophysiology. ER was trained to perform semi-structured interviews. The training included discussion of content and practicalities regarding qualitative interviewing, as well as practice interviews including reflection and feedback afterwards.

The preliminary interview questions underwent pilot testing with two non-participating colleagues prior to the commencement of the study. Feedback was solicited from the participants at the end of the pilot interviews and subsequently integrated into the final interview protocol. The same set of questions was used for all participants, and all participants were interviewed once. Topics regarded experience with, knowledge of, and trust in automated EEG-based detection. In addition, technicians and neurologists at the clinical neurophysiology departments were interviewed about their current EEG review method, as well as willingness to work with automated EEG-based detection and requirements necessary for that. Most such questions were open ended. Only the interviewer and the participant were present during the interview, which took place within the institution or online.

Interviews were semi-structured with open-ended questions to facilitate participant led, free-flowing conversation. Participants could raise new subjects. Interviews lasted between 14 and 42 min. After each interview, the interviewer asked whether the participant was satisfied with all the answers or wanted to add anything.

We continued to invite participants until data saturation was reached; that is, no new information was gathered and no new themes or subjects had emerged in the last three interviews. The range of work experience of the participants was 3 to 46 years (median 12 years).

2.4. Data analysis

Interviews were audio recorded and transcribed in full. No field notes were made. Participants did not receive interview transcripts. Software package NVivo was used to analyze interview transcripts (QSR International Pty Ltd. Version 12, 2020). ER coded the interviews using an inductive thematic analysis [18]. All coded interview transcripts were reviewed for a second time and were discussed within the research team until consensus was reached on all themes. Quotes were selected to illustrate the final themes.

2.5. Ethical approval

This study was approved by the institutional review board of SEIN. All participants gave their written informed consent prior to the interview.

3. Results

3.1. Clinical neurophysiology: technicians, physician assistants and neurologist

We identified 13 barriers and 13 enablers, see Table 1.

3.1.1. Current review process

Technicians were satisfied with the quality of the current review process, which they felt ensured that no important information was missed: *"I don't think that we miss important information"* (TC1). The medical staff agreed: *"I have the impression that EEGs are read very carefully"* (MC1). Some technicians mentioned the labor intensiveness of the review process: *"It is a lot of work. We record quite a few hours of EEG"* (TC2). Neurologists and physician assistants also stated that reviewing EEGs took a technician a long time: *"It is a time-consuming process, especially for technicians …They are really working on it for many hours"*

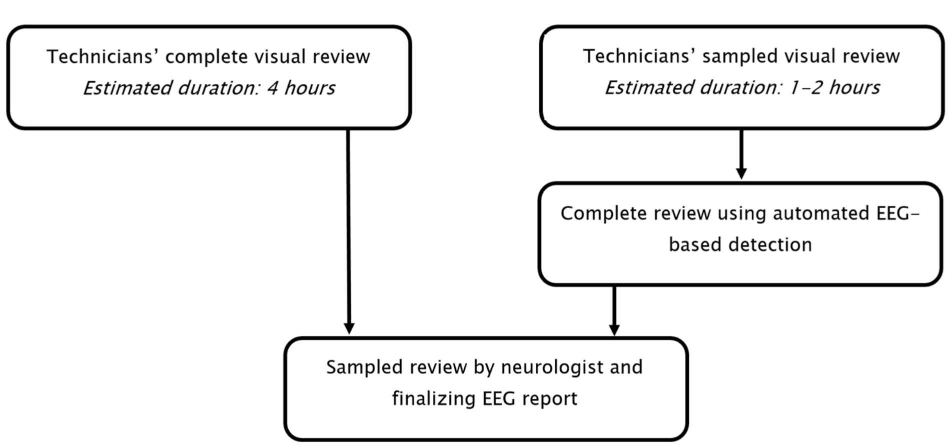

Fig. 1. Current EEG workflow (left) and possible future EEG workflow (right).

Table 1
Enablers and barriers regarding use of automated detection software.

Barriers	Technicians	Neurologists and PAs clin neurophys	Neurologists outpatient department
Satisfaction with quality of the current review process	X	X	X
Colleagues' unwillingness to try	X		
Technicians need a lot of training and guidance		X	
Teaching EEG review to new students is suboptimal	X		
Fear losing ability to review long periods of EEG	X		
Previous experience with automated seizure detection was disappointing	X		
Can only be used as supplement, not as (partial) replacement	X		
Only works in EEGs with normal background	X		
Too many false positives	X		
Software sometimes malfunctions	X	X	
Software doesn't perform as well as human experts do	X		
Fear of missing (subtle) seizures or other important information	X	X	X
Fear of missing non-specific EEG abnormalities			X
Fear of losing job	X		
Enablers	**Technicians**	**Neurologists and PAs clin neurophys**	**Neurologists outpatient department**
Current EEG reviewing process is time-consuming	X	X	
Need for more efficient workflow	X	X	X
Software can potentially make workflow more efficient	X	X	X
Possibility of growing future trust in the software	X		
Positive attitude among most participants	X	X	
The need to adopt machine learning in modern diagnostics	X	X	X
Presentations and discussions about the subject increase willingness to use the software	X		
Trust in neurologists and PAs of Clin Neurophys to use the software only when it performs properly			X
Willingness to try themselves	X	X	X
Opportunity for technicians to learn new skills		X	
Trend analyses have added value	X	X	
Helpful in identifying subtle EEG changes over time	X		
Can quantify (interictal and ictal) events	X	X	X
Prefer review by automated EEG-based detection when it means the workflow is faster			X

X = subject was mentioned by at least one participant, clinical neurophys = clinical neurophysiology department, PAs = physician assistants.

(MC4).

3.1.2. Necessity

The need for a more efficient workflow was recognized by most technicians and all medical staff: *"Somehow it has to be made more efficient and faster"* (MC1); *"Health care is only getting more expensive"* (MC4). Respondents felt automated EEG-based detection could play a role in this: *"You don't suddenly have more EEG technicians. So you have to make an efficiency move in a different way"* (MC4).

Technicians, physician assistants and neurologists thought automated detection could help quantify epileptiform discharges: *"If you receive a score which says this abnormality occurs 600 times, that quantifies it more than an estimation by words"* (TC6); *"An algorithm can quantify the spikes for us… this will save the technician time"* (MC3). Additionally, automated detection could help detect gradual changes over time; *"you don't always immediately see the EEG is gradually slowing in, for instance, presurgical patients."* (TC4).

3.1.3. Previous experience

Most participants reported no prior use of automated EEG detection. However, some previously worked with trend analyses, automated seizure detection or automated spike detection software. Users were positive regarding trend analyses: *"It is useful to be able to see it objectively"* (TC3), but negative toward automated seizure detection: *"I found the results disappointing"* (TC2). Previous experience with spike detection had two aspects: users were satisfied with the interface: *"very nice averages of spikes"* (TC6), but more skeptical about the rate of false positive results: *"especially with muscle artifacts"* (TC6).

3.1.4. Willingness

Most technicians felt that future use of automated EEG-based detection was unavoidable: *"We can't get around it anymore, so we have to deal with it"* (TC3); *"So much data is quantified, we can't stay behind with the EEG"* (TC4). All technicians stated they were willing to try using automated EEG-based detection. Some participants proposed initially using the detection software as an additional review method, along with complete visual review: *"by doing it simultaneously for a while. Just to experience the software"* (TC5); *"I think we need to do both at first. That is the investment we need to make to find out if it is working or not"* (TC4). Some technicians compared the change to using automated EEG-based detection for review with the transition from analog to digital EEG: *"In the beginning the digital EEG was also like 'oh, help', and now you're so used to that"* (TC4).

Some technicians thought some colleagues would be hesitant to use the software: "I would want to start today, but I think maybe some technicians will need more time to get used to this and gain some confidence" (TC1).

All neurologists and physician assistants stated willingness to try the software: "Medicine continues to develop and this is a form of development" (MC2).

3.1.5. Trust in performance

Most technicians did not trust the software to perform as well as they did. However, most stated that trust could grow with experience with the software: "*I think that trust in these machines has to grow, trust that it performs well. I think that it will take a long time before you can say: 'we will let the machine review the last couple of hours'*" (TC2); "*we need to gain trust in the system*" (TC4).

Some technicians said that not all seizures would be detected without visual review of the EEG: "*We know patients do not always report their seizures adequately, and also that nurses can miss seizures, so…*"(TC7). They felt that the software could not take over this part of EEG review. Regarding spike detection, technicians were mostly worried about false positives: "*I think that it will take a lot of time. You can get confused or insecure about software detection, because the software detects a spike*" (TC2). Some technicians thought automated EEG-based detection could only work in EEGs with normal background activity: "*Detection is a lot simpler when you have a normal background pattern with low amplitude because spikes then distinguish themselves from background really clearly*" (TC5).

Most medical staff stated trust in the software. Others said they did not know yet, because they had not used it before: "*I don't have an exact image of how sensitive automated detection is*" (MC2).

3.1.6. Fears

One medical staff member noticed much distrust regarding implementation, in particular from technicians: "*they also saw a danger to their own job. If everything is going to be automated, where would that leave them?*" (MC4). Some technicians also mentioned a fear of losing their job: "*At the beginning, I indeed was skeptical, I thought I might lose my job. But when I heard more and we talked about it some more with colleagues, you begin to think this might be useful after all*" (TC3); "*The idea that you are kind of unnecessary, well, that is a difficult step*" (TC2).

Some technicians feared that teaching EEG review to trainee technicians would be less than optimal when using automated EEG-based detection, or that they themselves might lose the ability to review long periods of EEG, when only reviewing shorter parts of the EEG. They stated the need to see the raw EEG to keep or to gain experience: "*You must continue reviewing longer periods of EEG, you can't learn if something is abnormal or not based on half an EEG page*" (TC3).

In addition, technicians feared loss of quality: "*fear of missing something that you might have detected yourself*" (TC2).

3.1.7. User needs

Technicians stated that they do not need much time to start working with the software, just proper instructions and clear guidelines: "*Which part do I need to review visually? … And what do we do with the information we get from the software?*" (TC4). Some of the medical staff felt in contrast that: "*They [the technicians] need a lot of training and guidance in doing so*" (MC4).

3.1.8. Future use of the software

Almost all participants said that automated EEG-based detection could at least have an assisting role. Some were surprised that this kind of detection software was not already used in clinical practice: "*It already surprised me when I started working as a technician. And if we continue to review EEGs only visually for the next ten years. Well.. that sounds really old-fashioned*" (TC2); "*We need to enter the 21st century*" (MC4).

Some technicians thought automated EEG detection would never take over the review workload: "*I can't imagine that visual review by a technician will ever disappear.*" (TC5). Others thought this might happen in the future, but not in the near future: "*I have been doing this for 5 years now, and for all these 5 years, the review process stayed the same. So I won't be surprised if we are still doing the same thing in 5 years' time*" (TC6); "*It is going to be a long time before you can really say: 'well, let's have the last few hours checked by a machine instead of a human expert'*" (TC2).

Most medical staff thought the visual review could in part be replaced by automated EEG-based detection: "*I think we can have some of the work done by the computer rather than just by manpower*" (MC3), which would make the review process more efficient. Additionally, they saw an opportunity for the technician's job to evolve: "*Then technicians will get some task shifting. Getting some different work instead of, well, scrutinizing those EEGs, which is also a waste of their qualifications*" (MC5).

Both technicians and medical staff agreed that automated detection must be reviewed by human experts: "*You want to know if the detections are true and not for instance horizontal movements*" (TC6). You also need a back-up in case of software malfunction: "*I can imagine that such a program sometimes malfunctions*" (MC1).

3.2. Outpatient clinic neurologists

We identified 3 barriers and 7 enablers, see Table 1.

3.2.1. Quality current EEG process (recording, review and report)

All participants were satisfied with the quality of the current EEG review and report: "*The current EEG report is fine*" (MO2). They felt that clinical neurophysiology staff were doing a good job: "*they work meticulously and they know exactly what to look for*" (MO6); "*I always get an answer to my referral question*" (MO5). Some neurologists would like to see epileptiform abnormalities quantified: "*I like it myself if there is a kind of quantification of abnormalities, and if you have a previous EEG you can compare*" (MO3). Others said they found this information less relevant.

3.2.2. Necessity

The need for more efficiency was recognized by all participants, pointing to increasing EEG data and decreasing availability of personnel: "*I can see that reviewing EEGs takes a lot of time. And given the aging population … we can't expect that this amount of work can be done by humans alone*" (MO1). Respondents also felt that waiting times were too long: "*my only complaint are the long waiting times*" (MO5). Most neurologists supported review with automated detection if this meant shorter waiting times: "*If it helps speed things along I would rather have the software review the EEG*" (MO2).

3.2.3. Trust in performance

Some neurologists were hesitant to trust the automated software to review EEGs, and doubted it provided the same quality as human reviewers: "*If there is a chance that you miss something relevant. You don't want to miss that*" (MO4); "*I wonder, subtle ictal EEG changes, does the software detect that? I have my doubts*" (MO6); "*Does it also detect slow activity?*" (MO4).

Others were fully confident that automated EEG-based detection software would only be implemented when it worked properly: "*I trust the opinion of the clinical neurophysiology neurologists*" (MO3); "*We [outpatient clinic neurologists] know that it is carefully looked after*" (MO1).

3.2.4. Future use of the software

All outpatient clinic neurologists thought automated detection software would be used within the next 5 years: "*I think that will be the next step*" (MO2); "*That would be great, that we indeed are confident*" (MO6); "*I think that much more will be automated in the future*" (MO1). One respondent thought it would only be used on a small scale: "*I think it will be used for specific purposes*" (MO4). Respondents mentioned that a control system must be built in, to ensure no important information would be missed: "*Provided it is properly checked. I think you should check that randomly*" (M07); "*As long as there is a human check*" (M08). Finally, most neurologists stated they did not want to have a say in deciding whether or not automated EEG-based software would be implemented, but wanted to be informed: "*It would be great if we were kept informed*" (M08).

4. Discussion

Nearly all participants expressed a need for a more efficient workflow and believed that automated EEG-based detection could play a role in this. They stressed that this kind of detection software could adapt EEG review to growing healthcare costs and personnel shortage. Furthermore, the EEG report producers group felt trends analyses have additional value, and that they are were willing to try the software.

We also noted significant challenges. The most prominent barrier was trust in the software, especially regarding automated seizure detection. Both producers and recipients of EEG reports feared the software would miss seizures or other important information. Most additional barriers were reported by technicians. Most believed that automated EEG-based detection could only be used as a supplement, mainly useful to quantify EEG spike detections, and not as (partial) replacement. Additionally, they fear a large quantity of false positives. Some technicians feared they would lose their ability to review long periods of EEG or that they might lose their jobs. A few participants doubted whether all technicians would be willing to try the software.

4.1. Limitations

This study was conducted with employees of two different EMUs from the same tertiary epilepsy center. The results may not be applicable elsewhere. However, our findings may serve as a baseline to consider challenges when implementing automated EEG-based detection software.

We chose to inform participants about automated detection software before the interviews. This approach may have introduced a bias, but ensured participants were well-informed. Additionally, there might be a selection bias in that respondents volunteered to participate, leaving open the possibility that nonrespondents felt differently.

The interviewer was familiar with the work and knew the respondents, which may have affected responses in an unknown direction.

4.2. Practice recommendations

Qualitative methods are a valuable tool in implementation research because they help to answer complex questions such as how and why efforts to implement best practices may succeed or fail [19]. We evaluated potential factors influencing the future implementation of automated EEG-based software.

Based on the results, we suggest the following recommendations regarding implementation. We learned that trust in the software needs to be gained, especially regarding the ability to detect seizures. Merely reading papers stating that automated EEG-based detection can be used safely does not inspire sufficient trust. Users need to acquire first-hand experience regarding the performance of automated EEG-based detection and must therefore be given time to do so. We propose reviewing EEGs both visually and with automated detection software. Furthermore, we suggest applying the software selectively, as we previously showed that the software did not detect all seizure types adequately, nor was it equally useful for all groups of patients. For example, reliability was limited in pediatric EEGs and short tonic seizures [10]. Hence, EEGs in these categories are better reviewed by the conventional methods, implying the need for triage.

Some technicians mentioned a fear of losing their ability to review long periods of EEG or even losing their job. We recommend that untrue fears be addressed as such. This can be achieved by providing sufficient information. We previously proposed a method where we use sampled visual review combined with automated EEG-based detection in a selection of EEGs [17]. With such a hybrid approach, technicians would still review EEGS, just to a lesser extent and for shorter periods. Furthermore, technicians need to be given the opportunity to learn new skills. This can be, for example, extracting more information from the EEG using trend analysis or improving the skill of reviewing difficult pediatric EEGs. Finally, outpatient clinic neurologists must also be kept informed regarding changes in the EEG review workflow using (educational) meetings.

Both information providing and training can be achieved by frequent educational meetings and feedback [20,21]. Outcome improves with, for example, shorter meetings, better attendance, shorter follow-up or interactive teaching methods [21].

The advantage of automated spike and seizure detection is improved efficiency. It would be useful to measure savings in time and money, after implementation, as would users' thoughts, attitudes, experiences and needs. Furthermore, the output of these detection software packages can also be used for other purposes, for instance averaging interictal epileptiform discharges for source localization and determining seizure onset zones [22,23]. Additionally, it would be informative to share experience with other EMUs.

5. Conclusions

This research gives an insight into (future) users' perspectives. Thereby we provide practice recommendations regarding implementation.

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Declaration of competing interest

None of the authors has any conflict of interest to disclose.

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