Mini-Symposia Title:

BCIs for lower extremity rehabilitation, language decoding, elucidation of early dementia onset, and control of a robotic hand-orthosis for patients.

Mini-Symposia Organizer Name & Affiliation:

Alexander Lechner, g.tec medical engineering GmbH

Mini-Symposia Speaker Name & Affiliation 1:

Dean Krusienski, Department of Biomedical Engineering, Virginia Commonwealth University

Mini-Symposia Speaker Name & Affiliation 2:

Tomasz M. Rutkowski, RIKEN AIP, Japan

Mini-Symposia Speaker Name & Affiliation 3:

Javier M. Antelis, Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, Monterrey, Mexico

Mini-Symposia Speaker Name & Affiliation 4:

S Mini-Symposia Speaker Name & Affiliation 5:

Mini-Symposia Speaker Name & Affiliation 6:

Theme:

- ○ 01. Biomedical Signal Processing
- ○ 02. Biomedical Imaging and Image Processing
- ○ 03. Micro/ Nano-bioengineering; Cellular/ Tissue Engineering &
- ○ 04. Computational Systems & Synthetic Biology; Multiscale modeling
- ○ 05. Cardiovascular and Respiratory Systems Engineering
- ○ 06. Neural and Rehabilitation Engineering
- ○ 07. Biomedical Sensors and Wearable Systems
- ○ 08. Biorobotics and Biomechanics
- ○ 09. Therapeutic & Diagnostic Systems and Technologies
- ○ 10. Biomedical & Health Informatics
- ○ 11. Biomedical Engineering Education and Society
- ◉ 12. Translational Engineering for Healthcare Innovation and

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Mini-Symposia Synopsis— Max 2000 Characters

with Functional Electrical Stimulation for the motor rehabilitation of the lower extremity.

Recent studies have demonstrated the possibility of decoding various speech representations such as phonemes, words, and phrases directly from intracranial recordings of brain activity. With the aim of progressing toward a transparent speech neuroprosthetic, the present work presents approaches for directly synthesizing speech using intracranial brain activity from speech-production areas.

Dementia, especially the age-related memory decline, is one of the most significant global challenges in the 21st century's mental well-being and social welfare. The presented methodology showcases the possible social benefits of artificial intelligence (AI) applications for the elderly and establishes a step forward to develop AI techniques for applying simple wearable devices. We present a behavioral and brainwave (EEG or fNIRS) data collection concept for subsequent AI-based employment together with a range of machine learning encouraging results of early dementia onset elucidation.

Brain-machine interfaces are used as communication and control channels for people with neurological disorders such as amyotrophic lateral sclerosis (ALS). This work presents the design, implementation, and evaluation of a P300-based brain-machine interface (BMI) coupled with a robotic hand-orthosis aiming to assist ALS patients to freely open and close their fingers and hands.

Brain-Computer Interface System for Lower Extremity Rehabilitation of Chronic Stroke Patients

Marc Sebastián Romagosa, Woosang Cho, Rupert Ortner, Alexander Lechner, Christoph Guger

Abstract — **Brain-computer interfaces are used as a treatment for the motor rehabilitation in stroke survivors. The motor impairment that affects walking is one of the most frequent limitations, which causes a high functional deficit in the patient's autonomy. The objective of this work is to analyze the effectiveness of the BCI technology combined with Functional Electrical Stimulation for the motor rehabilitation of the lower extremity. Ten stroke patients in chronic stage were recruited for this study, and all of them performed 25 sessions of BCI training for the lower extremity. The results show a statistically significant improvement in the gait speed, stability and range of motion of the ankle. These outcomes show the feasibility of this BCI approach for chronic stroke patients, and further support the growing consensus that these types of tools might develop into a new paradigm for rehabilitation tool for stroke patients.**

I. INTRODUCTION

Neurorehabilitation based on Brain-Computer Interfaces (BCIs) show important rehabilitation effects for patients after stroke. Previous studies have shown improvements for patients that are in a chronic stage and/or have severe hemiparesis and are particularly challenging for conventional rehabilitation techniques.

II. METHODS

For this publication ten stroke patients in chronic phase with hemiparesis in the lower extremity were recruited. All of them participated in 25 BCI sessions about 3 times a week. The BCI system was based on the Motor Imagery (MI) of the paretic ankle dorsiflexion and healthy wrist dorsiflexion with Functional Electrical Stimulation (FES) and avatar feedback. Assessments were conducted to assess the changes in motor improvement before, after and during the rehabilitation training. Our primary measures used for the assessment were 10-meters walking test (10MWT), Range of Motion (ROM) of the ankle dorsiflexion and Timed Up and Go (TUG).

III. RESULTS

Results show a significant increase in the gait speed in the primary measure 10MWT fast velocity of 0.16 m/s (SD = 0.14). This improvement is above of the minimally clinically important difference (MCID). The speed in the TUG was also significantly increased by 0.06 m/s, P = 0.002. One patient was not able to perform TUG assessment before the rehabilitation training but was able to perform it after the BCI treatment with time 92.2 seconds. The passive ROM assessment increased 8.61° (SD = 6.54), P = 0.002, and active ROM increased 8.50° (SD = 7.23) after rehabilitation training, P =.008.

IV. DISCUSSION & CONCLUSION

These outcomes show the feasibility of this BCI approach for chronic stroke patients, and further support the growing consensus that these types of tools might develop into a new paradigm for rehabilitation tool for stroke patients. However, the results are from only ten chronic stroke patients so the authors believe that this approach should be further validated in broader randomized controlled studies involving more patients.

MI and FES-based non-invasive BCIs are showing improvement for the gait rehabilitation of the patients in the chronic stage after stroke. This could have in impact on the rehabilitation techniques used for these patients, especially when they are severely impaired, and their mobility is limited.

CG, AL, WC are with g.tec medical engineering GmbH, Austria; MSR, RO are with g.tec medical engineering Spain SL, Spain. Corresponding author: Christoph Guger, guger@gtec.at

Speech Synthesis using Intracranial Signals

Dean J. Krusienski, Department of Biomedical Engineering, Virginia Commonwealth University

Abstract— **Recent studies have demonstrated the possibility of decoding various speech representations such as phonemes, words, and phrases directly from intracranial recordings of brain activity. With the aim of progressing toward a transparent speech neuroprosthetic, the present work presents approaches for directly synthesizing speech using intracranial brain activity from speech-production areas.**

I. INTRODUCTION

Intracranial brain recordings including electrocorticography (ECoG) and stereotactic electroencephalography (sEEG) can provide insights about networks for speech production, while simultaneously providing localized information for decoding nuanced aspects of the underlying speech processes. Thus, such intracranial recordings are instrumental for investigating the detailed spatiotemporal dynamics of speech. In pursuit of the ultimate objective of developing a natural speech neuroprosthetic for the severely disabled, the present work investigates approaches for the synthesis of speech directly from brain activity.

II. METHODS

Intracranial data were collected from subjects undergoing clinical monitoring for epilepsy. The subjects performed a battery of speech tasks including modal speech based on word and sentence prompts. The high gamma-band power (70-170 Hz) was extracted from the intracranial signals corresponding to speech-production areas.

For offline synthesis based on modal speech, the gamma-band features are used to train a densely-connected 3D convolutional neural network (CNN) to estimate the audio spectrogram of the corresponding speech [1]. The resulting spectrograms are synthesized into audible speech using a Wavenet vocoder. An alternate approach, referred to as *Unit Selection* [2], computes the cosine similarity between incoming gamma-band features to a bank of gamma-band training data with associated acoustic speech units. The corresponding speech unit that maximizes the similarity is selected and the resulting sequence of speech units are combined to produce a continuous acoustic waveform.

To achieve real-time speech synthesis, speech spectrograms are predicted from gamma-band features using a pre-trained linear model and synthesized using the Griffin-Lin algorithm [3].

*Research supported by NSF (1902395/2011595) and BMBF (01GQ1602) as part of the NSF/NIH/ BMBF Collaborative Research in Computational Neuroscience Program. This work is in collaboration with C. Herff, M. Angrick, T.Schultz and other team members from [1, 2, 3].

III. RESULTS

Figure 1 shows an example spectrogram generated by the unit selection approach [2]. The CNN [1] achieves similar spectrogram reconstruction results. For the unit selection approach, a 4-option forced intelligibility test with 55 human listeners resulting in an average accuracy was 66.1%, which was above the chance level for all listeners. Additionally, real-time, closed-loop feedback of whispered and imaged speech was successfully demonstrated in a single participant, with utterance timings comparable to the vocalized speech reference.

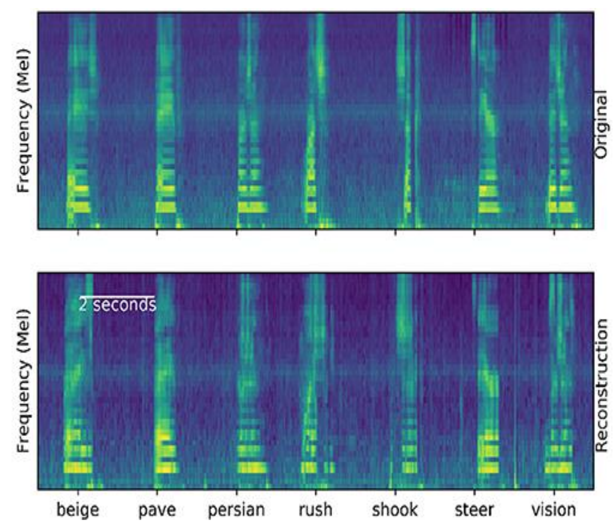

Figure 1. Examples of actual (top) and generated (bottom) audio spectrograms of seven words spoken by a selected participant.

IV. DISCUSSION & CONCLUSION

These results demonstrate that it is possible to synthesize speech directly using intracranial brain activity both offline and in real-time. The synthesized speech has consistently accurate utterance timings and a degree of intelligibility, demonstrating notable progress toward a practical speech neuroprosthetic.

REFERENCES

[1] Angrick, M., Herff, C., Mugler, E., Tate, M. C., Slutzky, M. W., Krusienski, D. J., Schultz, T. (2019). Speech synthesis from ECoG using densely connected 3d convolutional neural networks. J. Neural Eng. 16:036019.

[2] Herff, C., Diener, L., Angrick, M., Mugler, E., Tate, M. C., Goldrick, M. A., Krusienski, D. J., Slutzky, M. W., Schultz, T. (2019). Generating Natural, Intelligible Speech from Brain Activity in Motor, Premotor, and Inferior Frontal Cortices. Frontiers in neuroscience, 13, 1267.

[3] Angrick M., Ottenhoff M., Diener L., Ivucic D., Ivucic G., Goulis S., Saal J., Colon A.J., Wagner L., Krusienski D.J., Kubben P.L., Schultz T., Herff C. (2020). Real-time Synthesis of Imagined Speech Processes from Minimally Invasive Recordings of Neural Activity. bioRxiv.

D.J. Krusienski is with the Department of Biomedical Engineering, Virginia Commonwealth University, Richmond, VA 23219 USA, e-mail: djkrusienski@vcu.edu.

Passive BCI Paradigm to Elucidate Early Dementia Onset

Tomasz M. Rutkowski
RIKEN AIP, Japan

Abstract— **Dementia, especially the age-related memory decline, is one of the most significant global challenges in the 21st century's mental well-being and social welfare. The presented methodology showcases the possible social benefits of artificial intelligence (AI) applications for the elderly and establishes a step forward to develop AI techniques for applying simple wearable devices. We present a behavioral and brainwave (EEG or fNIRS) data collection concept for subsequent AI-based employment together with a range of machine learning encouraging results of early dementia onset elucidation.**

I. INTRODUCTION

Worldwide, the increased longevity and mainly for elderly adults above 65, dementia numbers, and costs are rising. The Cabinet Office in Japan announces annual reports on an aging society to address the difficulty. We present a practical health-theme machine learning (ML) application concerning the 'AI for social good' domain with our previously developed EEG and behavioral biomarkers for dementia [1,2,3,4,5], and our initial neuroimaging techniques results utilizing combined EEG and fNIRS modalities. We evaluate methods concerning the problem of a potential elderly adult dementia onset prediction in aging societies.

II. METHODS AND RESULTS

Experiments we performed with human subjects agreed with the guidelines and approval of the RIKEN Ethical Committee for Experiments with Human Subjects in the Center for Advanced Intelligence Project (AIP). All participants gave informed written consent, and they received monetary gratification for their participation in the study. Each subject experiment consisted of 72 video presentation trials (5 ~ 7 seconds each) with 24 different emotion categories [1,2,5]. Three different videos portrayed every emotion, with actors differing in age, gender, and skin color. The order of the videos was randomized before the experiment but was the same for every participant. During the data recording experiments, valence and arousal responses and the reaction times were also recorded by the stimulus presentation application developed in a visual programming environment MAX by Cycling '74, USA. We recorded EEG and fNIRS brainwaves using g.Nautilus fNIRS wearable headset by g.tec medical instruments GmBH, Austria.

III. DISCUSSION & CONCLUSION

We presented the current project resulted in encouraging results with a sample of older adults confirming a possibility of AI-based prediction of early dementia onset biomarkers using EEG- and fNIRS-derived biomarkers in the spatial- and implicit-working-memory task.

We also expect that future AI methods for fully interactive stimuli in closed-loop user behavior and brainwave monitoring shall lead to even more impactful results possible to implement in wearable devices for daily use for patients at home.

REFERENCES

1. Rutkowski TM, Abe MS, Koculak M, Otake-Matsuura M. Cognitive Assessment Estimation from Behavioral Responses in Emotional Faces Evaluation Task - AI Regression Approach for Dementia Onset Prediction in Aging Societies. In: NeurIPS Joint Workshop on AI for Social Good - Track 1 - Producing Good Outcomes. Vancouver, Canada; 2019. p. 1-4.
2. Rutkowski TM, Koculak M, Abe MS, Otake-Matsuura M. Brain Correlates of Task–Load and Dementia Elucidation with Tensor Machine Learning Using Oddball BCI Paradigm. In: ICASSP 2019 - 2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP); 2019. p. 8578–8582. [arXiv copy]
3. Rutkowski TM, Zhao Q, Abe MS, Otake-Matsuura M. Passive BCI for Task-load and Dementia Biomarker Elucidation. In: 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). IEEE Engineering in Medicine and Biology Society. Berlin, Germany: IEEE Press; 2019. p. ThC01.1.
4. Rutkowski TM, Zhao Q, Abe MS, Otake M. AI Neurotechnology for Aging Societies – Task-load and Dementia EEG Digital Biomarker Development Using Information Geometry Machine Learning Methods. In: AI for Social Good Workshop at the Neural Information Processing Systems (NeurIPS = formerly NIPS) 2018. Montreal, Canada; 2018. p. 1-4.
5. Rutkowski TM, Abe MS, Koculak M, Otake-Matsuura M. Classifying Mild Cognitive Impairment from Behavioral Responses in Emotional Arousal and Valence Evaluation Task - AI Approach for Early Dementia Biomarker in Aging Societies -. In: 42nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). IEEE Engineering in Medicine and Biology Society. Montreal, Canada: IEEE Press; 2020. p. 5537-5543.

This work is credited to Christian Herff, Miguel Angrick, Tanja Schultz, and the team members from [1, 2].

P300-based Brain-Machine Interface coupled with a Robotic Hand-Orthosis for Amyotrophic Lateral Sclerosis Patients

Javier M. Antelis[1], Jonathan Delijorge[1], Omar Mendoza-Montoya[1], Jose L. Gordillo[1], Ricardo Caraza[2], Hector R. Martinez[2]

[1] Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, Monterrey, Mexico, [2] Tecnologico de Monterrey, Escuela de Medicina y Ciencias de la Salud, Monterrey, Mexico

Abstract — **Brain-machine interfaces are used as communication and control channels for people with neurological disorders such as amyotrophic lateral sclerosis (ALS). This work presents the design, implementation, and evaluation of a P300-based brain-machine interface (BMI) coupled with a robotic hand-orthosis aiming to assist ALS patients to freely open and close their fingers and hands. In operation, the user can select one of six targets representing the flexion-extension of one finger or of the five fingers simultaneously. The BMI was evaluated with eighteen healthy subjects (HS) and eight ALS patients. Around half of the participants achieved 100% of online accuracy while the global average online accuracy was 89.83%.**

I. INTRODUCTION

BMIs may significantly improve the lives of patients who suffer neuromuscular disorders such as ALS. However, researchers and engineers must solve many technical and practical problems before bringing this technology into everyday life with end users. This work presents the development and evaluation of a P300-based BMI coupled with a robotic hand-orthosis device aiming to assist people with ALS to perform movements of individual fingers of one hand, or more complex tasks that involve a sequence of actions of one or more fingers. Eighteen healthy participants and eight ALS patients conducted an experiment in which they tested the proposed BMI selecting a sequence of actions that the robotic hand-orthosis executed. Training data was used to evaluate offline the performance of the classification model implemented in the BMI to discriminate between target and non-target epochs. Online data was used to calculate the classification accuracy and the selection times of the BMI.

II. METHODS

The hardware components of the interface are: (i) An 8 electrodes EEG recording system (g.GAMMASYS and a g.USBamp amplifier, g.tec medical engineering GmbH, Austria); (ii) A Hand of Hope robotic arm. The users can wear the robotic device on any hand; (iii) A monitor that displays the graphical user interface (GUI) of the BMI; (iv) A computer that processes the EEG signals, synchronizes the stimulus presentation, and sends the control commands to the hand-orthosis. The software elements, including the GUI, and the pipeline to process and decode the EEG activity.

We conducted experiments with eighteen healthy participants (10 females and eight males, aged between 19 and 63 years old, mean age 32.7) and eight ALS patients (three females and five males, aged between 49 and 72 years old, mean age 59.6). ALS participants were selected from the patients attending the TecSalud ALS Multidisciplinary Clinic considering the disease duration and disability level as inclusion criteria. Experiments were carried out in a dedicated medical room at Zambrano-Hellion Medical Center. An experimental session started with the subject preparation and system setup. Then, the participant trained the BMI and tested the interface freely where the user selected freely any option of the interface and notified if the system detected the desired action correctly (the purpose was to obtain information about the detection times and demonstrate the users that the BMI is effectively responding to their intentions). Finally, the experiment concluded with the online tests where subjects were indicated to focus attention on the specified target option until the BMI recognized a P300 response for one of the flashing elements and activates the orthosis accordingly.

III. RESULTS

The online evaluation showed that around 46% of the participants achieved an accuracy of 100% in the online operation of the BMI. The mean online accuracy was 89.83%, and only three participants obtained accuracies below 75%. Hence, the implemented BMI decodes the user's intentions effectively in most cases, and users could manipulate the hand-orthosis without much hassle in more complex tasks. The average detection time observed in our experiments was 8.54 s, whereas the ITR was 18.13 bit/min.

IV. DISCUSSION & CONCLUSION

We presented a P300-based BMI coupled with a robotic hand-orthosis for ALS patients. With this system users can manipulate each finger of a hand or perform a sequence of movements of one or more fingers. The system can provide a range of options for different needs. The BMI is able to adapt to the individual characteristics of the users (e.g., spasticity, rigidity, level of hand motor impairment), however, for this initial evaluation, we wanted to test the general performance of the interface at the most individual level (single finger movements) and with the most complex. Both HS and ALS participants were able to control the hand-orthosis with the interface. Only three subjects obtained online accuracies below 75%, and 46% of the study subjects completed all the test runs without errors.

REFERENCES

[1] Delijorge et al. (2020) Evaluation of a P300-Based Brain-Machine Interface for a Robotic Hand-Orthosis Control. Front. Neurosci. DOI: 10.3389/fnins.2020.589659

[2] Martínez et al. (2020). A multidisciplinary clinic for amyotrophic lateral sclerosis patients in northeast México. Rev. Mex. Neuroci. 21, 66–70. DOI: 10.24875/RMN.19000144