Warsito, Indhika Fauzhan; Fiedler, Patrique; Komosar, Milana; Haueisen, Jens

Novel replaceable EEG electrode system

Original published in:	Current directions in biomedical engineering. - Berlin : De Gruyter. - 8 (2022), 2, p. 249-252.
Original published:	2022-09-02
ISSN:	2364-5504
DOI:	10.1515/cdbme-2022-1064
[*Visited:*	2022-10-12]

Indhika Fauzhan Warsito*, Patrique Fiedler, Milana Komosar, and Jens Haueisen

Novel replaceable EEG electrode system

https://doi.org/10.1515/cdbme-2022-1064

Abstract: Due to the direct contact between electrode and scalp, dry EEG electrodes are exposed to increased mechanical wear compared to conventional gel-based electrodes. However, state-of-the-art commercial cap systems commonly use permanently fixated electrodes which can lead to downtime of the EEG cap during professional repair and replacement as well as reduced overall lifetime. An easily replaceable EEG electrode would furthermore improve hygiene, especially for newborn and infant applications. We propose a novel replaceable electrode system, consisting of an electrode holder, a snap top, a contact ring fixated inside the electrode holder, and a replaceable electrode. The production process consists of 3D printing, silicone molding, resin casting, and electroless plating. The replaceable electrode system is integrated into a multichannel EEG cap system. A verification study is conducted with 30 volunteers. The operators experienced that the new electrode holder eases adjustment of the electrode to have proper contact with the scalp. During the study, defective electrodes can be replaced without a soldering process. Furthermore, all electrodes stayed in the holder and did not fall off the cap for the whole session. In conclusion, the novel replaceable electrode system is suitable for EEG measurements.

Keywords: Electroencephalography, dry electrode, infant, newborn, neonatal intensive care unit, neurophysiological monitoring

***Corresponding author:**
Indhika Fauzhan Warsito: Institute of Biomedical Engineering and Informatics, Faculty of Computer Science and Automation, Technische Universität Ilmenau, Ilmenau, Germany, e-mail: indhika-fauzhan.warsito@tu-ilmenau.de.
Patrique Fiedler, Milana Komosar, Jens Haueisen: Institute of Biomedical Engineering and Informatics, Faculty of Computer Science and Automation, Technische Universität Ilmenau, Ilmenau, Germany.

1 Introduction

Dry electrodes are increasingly used for rapid EEG with reduced preparation effort compared to conventional wet electrodes [1]–[5]. Due to the direct contact between electrode and scalp, dry electrodes are exposed to increased mechanical wear compared to conventional gel-based electrodes. However, state-of-the-art cap systems commonly use permanently fixated electrodes [2], [3], [6]–[8]. As a result, individual electrodes cannot be replaced by the user. This can lead to downtime of the EEG cap during professional repair and electrode replacement as well as a reduced overall lifetime of the cap. A replaceable EEG electrode would improve maintenance, overall cap lifetime, and hygiene, especially for newborn and infant applications [9]. Combining replaceable electrodes of specific shape and height can allow adaptation to the individual hair type and hair density, thus improving overall signal quality, channel reliability, and comfort [8], [10].

State of the art commercial replaceable dry EEG electrodes such as g.SAHARA (g.tec medical engineering GmbH, Austria), flex sensors (Cognionics Inc., USA), and Drytrode (Neuroelectrics, Spain) implement a snap-on mechanism. The actiCAP Xpress Twist (Brain Products GmbH, Germany) implements a screw mechanism using solid polymeric holders.

We propose a novel replaceable electrode system comprising components fixated permanently in the cap fabric, and an easily replaceable dry electrode with a screw mechanism. Our main requirements are high patient comfort [11], high mechanical stability, and fixation of the electrodes prior to cap application. We describe the design and function of each component of the system and perform a study on 30 volunteers, to verify (a) stable and reliable electrical contact between the fixated and replaceable components, (b) mechanical stability and durability of the electrode fixation, (c) usability and overall function in a multichannel cap during a multi-volunteer study.

2 Methods

2.1 Design

The replaceable electrode system comprises an overall number of five components (Figure 2): snap top, cap (fabric) layer, electrode holder, contact ring, and (replaceable) dry electrode. All components have been designed and iteratively optimized using CAD.

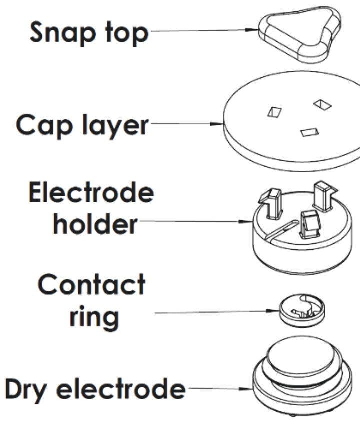

Figure 2 Exploded view of the replaceable EEG electrode system showing the five components in the order of integration into textile cap systems.

The snap top is used to permanently fixate the electrode holder within the fabric cap layer using a three cantilever hook design. The three hooks of the electrode holder pass through the cap textile layer and click into the snap top. The design was optimized to ensure stability and reduce rotation and tilting tendencies of the overall construction [10].

A contact ring is permanently fixated inside the electrode holder and a signal wire is soldered to the backside of the contact ring. The contact ring acts as an interface between the dry electrode and the signal cable. The main criterion for the contact ring design is to maximize the contact area with the electrode to reduce the interfacial electrode-contact ring impedance.

The replaceable electrode is inserted into the electrode holder, with its backplane establishing a mechanical and electrical contact with the contact ring. A helical thread mechanism is implemented for this purpose which is then integrated into the electrode holder (Figure 1) and the dry electrode. The thread mechanism between the dry electrode and the electrode holder was optimized to allow easy electrode replacement while ensuring (a) the electrode stays in place during cap application and measurement, and (b) a stable mechanical and thus electrical contact between electrode and contact ring is established.

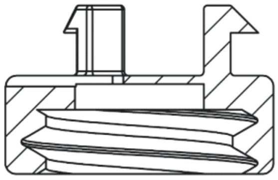

Figure 1 Section view of the electrode holder, with helical thread for replacable electrodes, and three cantilever hooks for permanent fixation in textiles in combination with the snap top.

2.2 Component production

Dedicated materials and production processes have been selected for optimal functional characteristics and feasible costs of production. While the snap top is produced by additive manufacturing using an Objet30 Prime with VeroWhite material (Stratasys Ltd., USA).

The production process of the contact ring and the electrode holder consists of 1) additive manufacturing of the master model, 2) silicone molding, 3) resin casting, and 4) electroless plating. First, the master model is printed using Anycubic Photon with Anycubic white UV resin material (Shenzen Anycubic Technology Co., Ltd., China). Then, based on the printed master model, a silicone mold is produced using Zhermack ZA 4 LT Rosso (Zhermack SpA, Italy) in a vacuum chamber to reduce defects. Sika UR419 resin (Sika AG, Switzerland) is cast to produce the electrode holder (Shore hardness A98), while Sika UPX 8400-1 (Sika AG, Switzerland) is used to produce the contact ring substrate (Shore hardness A95) and the electrode substrate (Shore hardness A60 and A85).

Finally, electrically conductive coating on the contact ring and the electrode is applied with Ag/AgCl material which is the gold standard for EEG electrodes [12]–[14]. The contact ring and the electrode are coated with an electroless plating method as described in [3]. The intended shore A hardness of the final electrode including the coating was ensured [15].

2.3 Electrode layout optimization

The replaceable electrode system is then integrated into a 64 channel EEG cap with an equidistant electrode arrangement (Figure 4).

Before performing EEG measurements for the functional verification, the optimal electrode layout in the cap was determined. Common dry electrode headsets and caps use the same pin length of electrodes for all positions. Using the replaceable electrode function, we performed a pilot study on 2 volunteers to select optimal pin length for different head regions, balancing comfort, applicability (short preparation times), and electrode-skin impedance. The electrode-skin impedance was determined using the integrated functions of a commercial referential 64-channel EEG amplifier (eego EE-225, ANT Neuro b.v., Netherlands) after optimal placement of the cap on the volunteer's head.

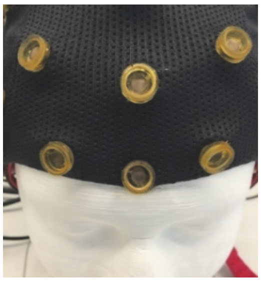

Figure 4: Textile cap with the novel replacable electrode system. The cap is shown turned inside-out prior to adding dry electrodes to the electrode holders. Frontal view of the cap placed on a phantom head.

2.4 Functional verification

A functional verification study was conducted with 30 volunteers (age: 25±4 years). The total measurement time, including sitting and lying positions, was 1 hour and 40 minutes. The objective was to compare the novel replaceable EEG electrode system and a state-of-the-art commercial cap with a non-replaceable EEG electrode system (waveguard™ touch, ANT Neuro b.v.).

In the study, our focus was on ensuring i) mechanical fixation and durability, assessed by means of fallen-out electrodes during the study, ii) cleanability and disinfectability, assessed by visual inspection after respective usage and cleaning/disinfection cycles, and iii) reliable electrical contact between electrode and skin, assessed by measurement of the electrode-connector resistance.

3 Results and discussion

3.1 Electrode layout optimization

The electrode-skin impedance (mean over both volunteers) for the pilot study is shown in Figure 3.

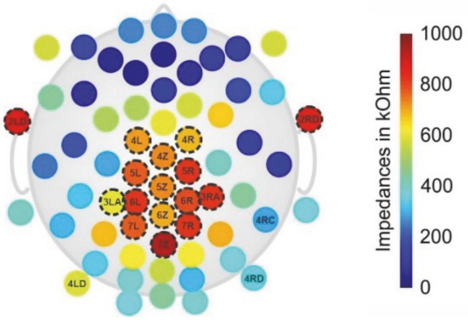

Figure 3: Electrode-skin impedance at different head regions. Mean over both volunteers participating in the pilot study. Dashed lines indicate electrode positions subsequently equipped with electrodes comprising extra long pins.

For the locations with impedances >600 kOhm (indicated in Figure 3 by dashed lines) the electrodes may be replaced with ones comprising longer pin lengths, while all other positions are equipped with electrodes of homogeneous pin length. The replacement of electrodes was perceived as easy and straightforward by all operators.

3.2 Functional verification

During the verification study, no electrode fell out from the electrode holder. Therefore, the electrode holder successfully held the electrode in place and the mechanical fixation mechanism proves durable for repetitive EEG measurement.

Visual inspection following cleaning and disinfection after each of the 30 applications revealed no foreign object or contamination visible between the electrodes and their respective holder. Thus, the fixation mechanism prevents foreign objects or dirt from entering and hindering contact between the dry electrode and the contact ring.

After 30 applications, the electrode-connector resistance was measured on every channel. From 64 channels, 2 channels showed broken solder connections, while all other channels showed low resistance connections. The cause of the two broken solder connections is likely caused by a non-optimal solder joint between the cable and the contact ring after the production of this prototype.

The operators experienced that the new electrode holder eases adjustment of the electrode to have proper contact with the scalp. During the placement of the caps, dry electrodes sometimes tilt and thus might need manual correction ensuring they are placed perpendicular to the scalp. Three operators consistently reported that the novel replaceable EEG electrode system is easier to recognize when tilted as well as easier to grip and adjust compared with the commercial non-replaceable electrode system. During the study, electrodes can be replaced if needed for either replacing defective electrodes or adjusting the electrode pin length. Replacement is straightforward without a soldering process.

4 Conclusion

We developed and optimized a novel replaceable EEG electrode system and have successfully verified its function within a study on 30 volunteers. The novel system allows the electrode to be replaced and adjusted to individual head shapes and hair types. Furthermore, easy electrode replacement can shorten downtime and increase the overall lifetime of the EEG cap. Following multiple applications within a study on 30 volunteers, the replaceable electrode system proved easy to use in a 64-channel cap, provides reliable mechanical fixation, low resistance electrical contact, and compatibility with cleaning and disinfection procedures. In conclusion, the novel replaceable electrode system is suitable for repetitive multichannel dry EEG measurements.

Author Statement

Research funding: This research was supported in part by the European Union within Horizon 2020, Marie Sklodowska-Curie Actions H2020-MSCA-ITN-2018 (grant ID 813483), and in part by the Free State of Thuringia (2018 IZN 004), co-financed by the European Union under the European Regional Development Fund (ERDF). Conflict of interest: The authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee. Acknowledgments: We thank Mrs. Ina Schramm for her technical assistance.

References

[1] M. A. Lopez-Gordo, D. Sanchez Morillo, and F. Pelayo Valle, "Dry EEG electrodes," *Sensors (Switzerland)*, vol. 14, no. 7, pp. 12847–12870, 2014, doi: 10.3390/s140712847.

[2] P. Fiedler, S. Griebel, P. Pedrosa, C. Fonseca, F. Vaz, L. Zentner, F. Zanow, and J. Haueisen, "Multichannel EEG with novel Ti/TiN dry electrodes," *Sensors Actuators, A Phys.*, vol. 221, pp. 139–147, 2015, doi: 10.1016/j.sna.2014.10.010.

[3] P. Fiedler, P. Pedrosa, S. Griebel, C. Fonseca, F. Vaz, E. Supriyanto, F. Zanow, and J. Haueisen, "Novel Multipin Electrode Cap System for Dry Electroencephalography," *Brain Topogr.*, vol. 28, no. 5, pp. 647–656, 2015, doi: 10.1007/s10548-015-0435-5.

[4] G. Di Flumeri, P. Aricò, G. Borghini, N. Sciaraffa, A. Di Florio, and F. Babiloni, "The dry revolution: Evaluation of three different eeg dry electrode types in terms of signal spectral features, mental states classification and usability," *Sensors (Switzerland)*, vol. 19, no. 6, pp. 1–21, 2019, doi: 10.3390/s19061365.

[5] I. Fridman, M. Cordeiro, K. Rais-Bahrami, and N. J. McDonald, "Evaluation of Dry Sensors for Neonatal EEG recordings," *J. Cinical Neurophysiol.*, vol. 33, pp. 149–155, 2016, doi: 10.1016/j.physbeh.2017.03.040.

[6] P. Fiedler *et al.*, "Modular multipin electrodes for comfortable dry EEG," *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS*, vol. 2016-Octob, pp. 5705–5708, 2016, doi: 10.1109/EMBC.2016.7592022.

[7] B. Vasconcelos, P. Fiedler, R. Machts, J. Haueisen, and C. Fonseca, "The Arch Electrode: A Novel Dry Electrode Concept for Improved Wearing Comfort," *Front. Neurosci.*, vol. 15, no. October, pp. 1–14, 2021, doi: 10.3389/fnins.2021.748100.

[8] P. Fiedler, C. Fonseca, E. Supriyanto, F. Zanow, and J. Haueisen, "A high-density 256-channel cap for dry electroencephalography," *Hum. Brain Mapp.*, vol. 43, no. 4, pp. 1295–1308, 2022, doi: 10.1002/hbm.25721.

[9] R. O. Lloyd, R. M. Goulding, P. M. Filan, and G. B. Boylan, "Overcoming the practical challenges of electroencephalography for very preterm infants in the neonatal intensive care unit," *Acta Paediatr. Int. J. Paediatr.*, vol. 104, no. 2, pp. 152–157, 2015, doi: 10.1111/apa.12869.

[10] P. Fiedler *et al.*, "Modular multipin electrodes for comfortable dry EEG," *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS*, vol. 2016-Octob, pp. 5705–5708, 2016, doi: 10.1109/EMBC.2016.7592022.

[11] J. Haueisen, P. Fiedler, A. Bernhardt, R. Gonçalves, and C. Fonseca, "Novel dry electrode EEG headbands for home use: Comparing performance and comfort," *Curr. Dir. Biomed. Eng.*, vol. 6, no. 3, pp. 0–3, 2020, doi: 10.1515/cdbme-2020-3036.

[12] P. Fiedler, J. Haueisen, D. Jannek, S. Griebel, L. Zentner, F. Vaz, and C. Fonseca, "Comparison of three types of dry electrodes for electroencephalography," *Acta IMEKO*, vol. 3, no. 3, pp. 33–37, 2014, doi: 10.21014/acta_imeko.v3i3.94.

[13] P. Pedrosa, P. Fiedler, C. Lopes, E. Alves, N. P. Barradas, J. Haueisen, A. V. Machado, C. Fonseca, and F. Vaz, "Ag:TiN-Coated Polyurethane for Dry Biopotential Electrodes: From Polymer Plasma Interface Activation to the First EEG Measurements," *Plasma Process. Polym.*, vol. 13, no. 3, pp. 341–354, 2016, doi: 10.1002/ppap.201500063.

[14] P. Tallgren, S. Vanhatalo, K. Kaila, and J. Voipio, "Evaluation of commercially available electrodes and gels for recording of slow EEG potentials," *Clin. Neurophysiol.*, vol. 116, no. 4, pp. 799–806, 2005, doi: 10.1016/j.clinph.2004.10.001.

[15] I. F. Warsito, R. Machts, S. Griebel, P. Fiedler, and J. Haueisen, "Influence of silver / silver chloride electroless plating on the Shore hardness of polyurethane substrates for dry EEG electrodes," *Curr. Dir. Biomed. Eng.*, vol. 7, no. 2, pp. 9–12, 2021.