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Universal EEG Cap with Carbon Fiber-Based Conductive Silicone Sponge Electrodes and Fabric-Printed Electrode-Connecting Wires

Abstract

An improved electroencephalogram (EEG) cap. In one embodiment, the EEG cap comprises a head covering comprising auxetic fabric, wherein the auxetic fabric allows the head covering to fit on and conform to a head, wherein the head is any shape and size; one or more electrodes disposed on an internal surface of the head covering, wherein each of the one or more electrodes comprise a conductive sponge comprising a two-part silicone foam, a silicone thinning fluid, and carbon fiber, and a sponge seat comprising a silicone or thermoplastic elastomer material, wherein the conductive sponge is disposed within the sponge seat; and one or more wires printedly embedded in the head covering that connect the one or more electrodes to external electronics.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a non-provisional application that claims the benefit of U.S. Application Ser. No. 63/345,088 filed May 24, 2022, the disclosure of which is incorporated by reference herein in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT
[0002] Not applicable.
BACKGROUND OF THE INVENTION
Field of the Invention
[0003] The present invention relates to the field of electroencephalography and electroencephalograms (EEGs). More particularly, the present invention relates to an improved, universally fitting EEG cap comprising carbon fiber-based conductive silicone sponge electrodes and fabric-printed electrode-connecting wires.
BACKGROUND OF THE INVENTION
[0004] Electroencephalography is a non-invasive method of measuring a brain's electrical activity via an EEG that may be widely used in epilepsy diagnosis, studying neurological disorders, neuroscientific studies, and brain-machine interfaces. Typically, an EEG utilizes various equipment such as electrodes, connecting wires, amplifiers, a computer control module, and a display device to offer high temporal resolution during testing, however such equipment may often be limited to low spatial resolution during testing due to low-electrode counts. To mitigate this shortcoming, high-density EEG (HD-EEG) systems have been developed which incorporate the use of several hundred electrodes. While these HD-EEG systems have potential to become low-cost imaging technology that improves spatial resolution, their developments may have some challenges.
[0005] For instance, to correctly localize an epileptic seizure, there may be a need to measure EEG signals before and at the onset of a seizure, requiring extended-time HD-EEG recordings. As such, HD-EEG equipment setup time, setup ease, type, and longevity may be highly important considerations. Currently, HD-EEG equipment may utilize EEG caps that incorporate electrodes and connecting wires to thereby improve setup time and ease. However, such EEG caps may require manufacturing in various sizes to accommodate users of variously sized heads, and further may utilize electrodes known in the art that have various shortcomings. For example, current EEG caps may utilize wet electrodes, that while capable of providing a high Signal-to-Noise Ratio (SNR), may be cumbersome to setup. Alternatively, current EEG caps may utilize dry electrodes, that while less cumbersome to setup, may provide a poor SNR.
[0006] Consequently, there is a need for an improved, universally fitting EEG cap that incorporates high performing electrodes and electrode-connecting wires. More particularly, there is a need for an improved, universally fitting EEG cap comprising carbon fiber-based conductive silicone sponge electrodes and fabric-printed electrode-connecting wires.
BRIEF SUMMARY OF SOME OF THE PREFERRED EMBODIMENTS
[0007] These and other needs in the art are addressed in one embodiment by an

electroencephalogram (EEG) cap, comprising a head covering comprising auxetic fabric, wherein the auxetic fabric allows the head covering to fit on and conform to a head, wherein the head is any shape and size; one or more electrodes disposed on an internal surface of the head covering, wherein each of the one or more electrodes comprise a conductive sponge comprising a two-part silicone foam, a silicone thinning fluid, and carbon fiber, and a sponge seat comprising a silicone or thermoplastic elastomer material, wherein the conductive sponge is disposed within the sponge seat; and one or more wires printedly embedded in the head covering that connect the one or more electrodes to external electronics.

[0008] The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter that form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and the specific embodiments disclosed may be readily utilized as a basis for modifying or designing other embodiments for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent embodiments do not depart from the spirit and scope of the invention as set forth in the appended claims.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] For a detailed description of the preferred embodiments of the invention, reference will now be made to the accompanying drawings in which:

[0010] FIG. **1** illustrates a mapping of electrodes for an EEG cap according to embodiments of the present invention;

[0011] FIG. **2** illustrates an electrode according to embodiments of the present invention;

[0012] FIG. **3** illustrates an electrode according to embodiments of the present invention;

[0013] FIG. **4** illustrates a perspective view of an electrode according to embodiments of the present invention;

[0014] FIG. **5** illustrates an embodiment of the electrode according to embodiments of the invention;

[0015] FIG. **6** illustrates an embodiment of the electrode of FIG. **5** of cross section A-A;

[0016] FIG. **7** illustrates an embodiment of section B of the electrode embodiment of FIG. **6**;

[0017] FIG. **8** illustrates an embodiment of one or more electrode-connecting wires according to embodiments of the present invention;

[0018] FIG. **9** illustrates an embodiment of one or more electrode-connecting wires according to embodiments of the present invention; and

[0019] FIG. **10** illustrates a computer board according to embodiments of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0020] In embodiments as shown in FIG. **1**, the present invention relates to an improved, universally fitting EEG cap **200** for use with new or existing EEG systems that non-invasively measure a brain's electrical activity via electrodes, connecting wires, amplifiers, a computer control module, and a display device. In embodiments, the improved, universally fitting EEG cap **200** may comprise a head covering **100**, one or more electrodes **20**, and one or more electrode-connecting wires **400**.

[0021] In embodiments as shown in FIG. **1**, EEG cap **200** includes head covering **100**. Head covering **100** may be at least one layer of an elastic fabric manufactured and configured in such a way as to fit over and conform to a user's head. In embodiments, the elastic fabric may comprise an auxetic material that when stretched, stressed, loaded, or placed under a tension force, becomes thicker and stronger, contrary to other elastic fabrics. Any suitable auxetic material may be used.

By nature of this auxetic material, the head covering of the EEG cap **200** may be capable of fitting over and conforming to the heads of various users, regardless of head shape or size, and may do so without compromising on strength, durability, and comfort. In further embodiments, the elastic fabric may comprise the auxetic material and one or more additional fabric materials such as, without limitation, cotton, nylon, or combinations thereof. In such embodiments, the auxetic material or auxetic fibers may be woven into the fibers of the one or more additional fabric materials to create a special fabric blend for the head covering. An auxetic material utilized by the present invention may be described in U.S. Pat. No. 8,916,262 and U.S. Pat. No. 9,962,313, the disclosures of which are incorporated by reference herein in their entirety. In some embodiments as shown in FIG. **1**, head covering **100** may comprise two fabric layers, inner layer **45** and outer layer **40**. The first or inner layer **45** (i.e., the layer closest to the user's head) may be any suitable fabric for disposition against the user's head. In some embodiments, inner layer **45** is an active cooling fabric that aids in keeping the user cool during operation. Without limitation, embodiments of inner layer **45** comprise cotton, linen, nylon, polyester, rayon, silk, wool, or any combinations thereof. In some embodiments, inner layer **45** comprises cotton, linen, nylon, polyester, rayon, silk, wool, auxetic materials, or any combinations thereof. The second or outer layer **40**, (i.e., the layer furthest from the user's head) may be a fabric of auxetic fibers. In embodiments, outer layer **40** includes auxetic fibers weaved into other fibers. Any suitable other fibers may be used such as cotton, nylon, or combinations thereof. In further embodiments, the head covering **100** may further comprise a fastening mechanism **210** to aid in securing the head covering **100** to a user's head. In an embodiment, outer layer **40** provides compression to the top of electrodes **20** which presses downward providing a sufficient contact with the scalp of the user. In embodiments, at least one or all of electrodes **20** are disposed between outer layer **40** and inner layer **45**. In an embodiment, electrodes **20** protrude through inner layer **45** providing contact with the scalp of the user. In embodiments as shown, electrodes **20** protrude through holes **290** in inner layer **45**. Holes **290** may be provided by any suitable method such as by die cut of holes **290** in inner layer **45**. In embodiments, fastening mechanism **210** may include any suitable mechanism for securing head covering **100** to a user's head. In embodiments, fastening mechanism **210** is a strap, buckle, or combination thereof. The fastening strap or buckle may be any fastening strap or buckle known to one of ordinary skill in the art that may be attached to head covering **100** in a configuration that allows the fastening strap or buckle to be secured to the user such as under the user's chin.

[0022] The one or more electrodes **20** may be disposed on an inner surface of the head covering **100** whereby the one or more electrodes **20** may be in contact with the user's head during operation. In embodiments as shown in FIG. **1**, electrodes **20** are disposed on inner layer **45**. Head covering **100** may include any suitable number of electrodes **20**. In embodiments, the one or more electrodes **20** may be placed at or mapped to any suitable location on the head covering **100**. In one particular embodiment, the electrodes **20** may be placed on the head covering **100** according to EEG montage **500** shown in FIG. **1**, which graphically illustrates a particular mapping of electrodes for the EEG cap **200**. In such embodiments, EEG cap **200** has, in relation to placement on a user's head, front of cap **250**, right of cap **260**, back of cap **270**, and left of cap **280**. In such EEG montage **500**, embodiments include EEG montage **500** comprising FpZ electrode **20**, GND electrode **20**, FZ electrode **20**, F4 electrode **20**, C4 electrode **20**, Cz electrode **20**, REF electrode **20**, Pz electrode **20**, F3 electrode **20**, and C3 electrode **20**. FpZ electrode **20** and GND electrode **20** may have any suitable center to center measurement **1**, such as between about 25 mm and about 40 mm, alternatively at about 32 mm. GND electrode **20** and FZ electrode **20** may have any suitable center to center measurement **2**, such as between about 25 mm and about 45 mm, alternatively at about 36 mm. FZ electrode **20** and F4 electrode **20** may have any suitable center to center measurement **3**, such as between about 40 mm and about 60 mm, alternatively at about 47 mm. F4 electrode **20** and C4 electrode **20** may have any suitable center to center measurement **4**, such as between about 50 mm and about 70 mm, alternatively at about 61 mm. FZ electrode **20** and Cz electrode **20** may have any suitable center to center measurement **5**, such as between about 55 mm and about 80 mm, alternatively at about 67 mm. FZ electrode **20** and F3 electrode **20** may have any suitable center to center measurement **6**, such as between about 40 mm and about 55 mm, alternatively at about 47 mm. F3 electrode **20** and C3 electrode **20** may have any suitable center to center measurement **7**, such as between about 50 mm and about 70 mm, alternatively at about 61 mm. CZ electrode **20** and REF electrode **20** may have any suitable center to center measurement **8**, such as between about 30 mm and about 40 mm, alternatively at about 35 mm. REF electrode **20** and Pz electrode **20** may have any suitable center to center measurement **9**, such as between about 30 mm and about 40 mm, alternatively at about 35 mm. In embodiments of such EEG montage **500**, F3 electrode **20** is disposed on left of cap **280** opposing F4 electrode **20** disposed on right of cap **260**, C3 electrode **20** is on left of cap **280** opposing C4 electrode **20** disposed on right of cap **260**. Further in embodiments of EEG montage **500**, FpZ electrode **20** is disposed on front of cap **250** opposing Pz electrode **20** disposed on back of cap **270**, GND electrode **20** is disposed on front of cap **250** opposing REF electrode **20** disposed on back of cap **270**, with GND electrode **20** disposed between FpZ electrode **20** and FZ electrode **20** and with REF electrode **20** disposed between Cz electrode **20** and Pz electrode **20**. Additionally in embodiments, FZ electrode **20** is disposed between F3 electrode **20** and F4 electrode **20**, and Cz electrode **20** is disposed between C3 electrode **20** and C4 electrode **20**. In embodiments, a tail of at least one of the electrodes **20** exits head covering **100** at back of cap **270**. It is to be understood that EEG cap **200** may include any other suitable EEG montage and is not limited to EEG montage **500**.

[0023] Regardless of placement, each of the one or more electrodes **20** may comprise a conductive sponge **22** and a sponge seat **24**, as illustrated in FIG. **2**. Conductive sponge **22** may comprise any suitable conductive sponge material. In embodiments, conductive sponge **22** includes a two-part silicone foam, a silicone thinning fluid, carbon fiber, or any combinations thereof. In embodiments, part A of the two-part silicone foam may be present in an amount between about 0.01 g and about 10.0 g, or alternatively between about 1.0 g and about 7.5 g, or further alternatively between about 2.0 g and about 5.0 g. In an embodiment, part A is a silicone foam. Part B of the two-part silicone foam may be present in an amount between about 0.01 g and about 10.0 g, or alternatively between about 0.1 g and about 5.0 g, or further alternatively between about 1.0 g and about 3.0 g. In an embodiment, part B is a curing agent. The silicone thinning fluid may be present in an amount between about 0.01 g and about 5.0 g, or alternatively between about 0.1 g and about 1.0 g. The carbon fiber may be present in amount between about 0.01 g and about 5.0 g, or alternatively between about 0.1 g and about 1.0 g. A conductive sponge utilized by the present invention may be described in International Application Publication No. WO 2020/010219 A9, the disclosure of which is incorporated by reference herein in its entirety.

[0024] This configuration of conductive sponge **22** may facilitate the conductivity of the one or more electrodes **20**. During operation, each conductive sponge **22** may be dry or alternatively saturated with water, saline, or the like. For instance, conductive sponge **22** may be wetted with a 0.9% saline solution and inserted into sponge seat **24**. In embodiments, an electrode **20** with a dry conductive sponge **22** may achieve an impedance comparable to that of a standard dry electrode known to one of ordinary skill in the art. However, an electrode **20** with a wet conductive sponge **20** may achieve an impedance of about 2 kΩ at 1 KHz, which may be lower than a standard wet gold cup electrode with electrode gel and a standard disposable hydrogel electrode.

[0025] Sponge seat **24** may be for housing conductive sponge **22**. Sponge seat **24** may have any suitable configuration for use with EEG cap **200**. In embodiments as shown in FIG. **2**, sponge seat **24** may have sponge holder **27** of a substantially cylindrical configuration comprising an internal bore **25**. Sponge seat **24** may also have flange **32**. Flange **32** may have any suitable configuration. In embodiments, flange **32** has a substantially flat underside. Flange **32** may also have securing means **26**. Securing means **26** may be disposed in any configuration suitable for facilitating securing of sponge seat **24**. In embodiments, securing means **26** may be radially distributed about flange **32** in an off-set configuration as illustrated. As shown in FIGS. **6** and **7**, securing means **36** comprise sewing loops **39**. Sewing loops **39** are suitable for securing electrode **20** to fabric such as head covering **100**.

[0026] In embodiments, sponge seat **24** may comprise any suitable material such as, without limitation, silicone, a thermoplastic elastomer (TPE) material, or any combinations thereof. These materials may be conductive as well as increase comfort for the user during operation. In embodiments, the dimensions of sponge seat **24** may be any suitable dimensions, with internal bore **25** corresponding with the dimensions of conductive sponge **22**, such that conductive sponge **22** may be securely disposed or seated within the internal bore **25** of sponge seat **24** by any suitable means. FIGS. **2**, **3**, **4**, **5**, **6** and **7** illustrate a particular embodiment of sponge seat **24**. Sponge **22** is disposed in internal bore **25**. Raised edges **28** are disposed on walls **29** of internal bore **25**. Raised edges **28** are disposed radially about internal bore **25**. Without limitation, raised edges **28** facilitate securing of conductive sponge **22** in internal bore **25**.

[0027] In embodiments as shown, one or more electrodes **20**, comprising conductive sponge **22** and sponge seat **24**, may be attached to the head covering **100** by any suitable means, whereby the auxetic characteristics of the head covering fabric **100** facilitating attachment. In some embodiments, and particularly those in which the head covering **100** comprises two fabric layers (i.e., outer layer **40** and inner layer **45**), one or more electrodes **20** may be disposed within die cutouts made on the inner layer **45** of the head covering **100**. This may allow one or more electrodes **20** to be secured between the inner layer **45** and outer layer **40** of the head covering **100** as well as protrude through the inner layer **45** to make contact with the user's head during operation. In such embodiments, the outer layer **40** of the head covering **100** may provide compression to the top of each of the one or more electrodes **20**. By this compression, the head covering **100** may ensure that each of the one or more electrodes **20** have adequate contact with the user's head as well as elicit an automated function of pressing each the of one or more electrodes **20** into place.

[0028] As shown in FIGS. **8** and **9**, EEG cap **200** may include one or more electrode-connecting wires **400** embedded in head covering **100** which are capable of connecting one or more electrodes **20** to any EEG electronics. In embodiments, the one or more electrode-connecting wires **400** may be conductive wires **405** printed on a thin substrate **410** that may be heat transferred to textiles such as the fabric of head covering **100** via any suitable means such as via equipment known to one of ordinary skill in the art in the garment decorating industry. In embodiments, thin substrate **410** is attached to head covering **100**. In some embodiments, thin substrate **410** is attached to inner layer **45**. The ink used to print the one or more electrode-connecting wires **400** onto the thin substrate **410**, as well as the thin substrate **410** itself, may have the ability to stretch and flex with the fabric of head covering **100** once effectively applied. In some embodiments, and particularly those in which head covering **100** comprises two fabric layers (i.e., outer layer **40** and inner layer **45**), the one or more electrode-connecting wires **400** may be disposed between inner layer **45** and outer layer **40**. In embodiments, thin substrate **410** is attached to head covering **100**. In some embodiments, thin substrate **410** is attached to inner layer **45**. FIGS. **8** and **9** illustrate one embodiment of the one or more electrode-connecting wires **400**. In this particular embodiment, the one or more electrode-connecting wires **400** may be split into two circuits corresponding to various electrodes **20**, however the one or more electrode-connecting wires **400** may be split into any number of circuits, or alternatively comprise only one circuit.

[0029] In embodiments, the one or more electrode-connecting wires **400** may be connected to any EEG electronics used to monitor and/or record activity measured by the one or more electrodes **20**. EEG electronics may comprise, without limitation a computer board **600** that will process any measured EEG data. In embodiments, the computer board may comprise an A/D convertor, EEG software, BLE transmitters, and an accelerometer. Further, the EEG software used to process said EEG data may be an open-source product. In some embodiments, the computer board may

comprise Bluetooth capabilities that allow for wireless connection to an external device, such as a cell phone, smart phone, computer, or the like. FIG. **5** illustrates one embodiment of computer board **600**.
[0030] Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations may be made herein without departing from the spirit and scope of the invention as defined by the appended claims.

Claims

1. An electroencephalogram (EEG) cap, comprising: a head covering comprising auxetic material, wherein the auxetic material allows the head covering to be disposed upon and conform to a head, and wherein the head covering comprises an inner layer and an outer layer; one or more electrodes, wherein the one or more electrodes are disposed on the inner layer, wherein each of the one or more electrodes comprise: a conductive sponge comprising a two-part silicone foam, a silicone thinning fluid, carbon fiber, or any combinations thereof; and a sponge seat comprising a silicone or thermoplastic elastomer material, wherein the conductive sponge is disposed within the sponge seat; and one or more electrode-connecting wires printedly embedded in the head covering that connect the one or more electrodes to external electronics.
2. The electroencephalogram (EEG) cap of claim 1, wherein the one or more electrodes protrude through the inner layer.
3. The electroencephalogram (EEG) cap of claim 1, further comprising a fastening mechanism for securing the head covering to the head.
4. The electroencephalogram (EEG) cap of claim 1, wherein the compression to a top of the one or more electrodes. outer layer comprises
5. The electroencephalogram (EEG) cap of claim 1, further comprising an EEG cap montage consisting of FpZ, GND, FZ, F3, F4, Cz, C3, C4, REF, and Pz.
6. The electroencephalogram (EEG) cap of claim 1, wherein each electrode comprises a conductive sponge and a sponge seat.
7. The electroencephalogram (EEG) cap of claim 6, wherein the sponge comprises a two-part silicone foam, a silicone thinning fluid, a carbon fiber, or any combinations thereof.
8. The electroencephalogram (EEG) cap of claim 7, wherein the two-part silicone foam comprises a part A, wherein the part A is present in an amount between about 0.01 g and about 10.0 g.
9. The electroencephalogram (EEG) cap of claim 8, wherein the part A comprises a silicone foam.
10. The electroencephalogram (EEG) cap of claim 7, wherein the two-part silicone foam comprises a part B, wherein the part B is present in an amount between about 0.01 g and about 10.0 g.
11. The electroencephalogram (EEG) cap of claim 10, wherein the part B comprises a curing agent.
12. The electroencephalogram (EEG) cap of claim 7, wherein the silicone thinning fluid is present in an amount between about 0.01 g and about 5.0 g.
13. The electroencephalogram (EEG) cap of claim 7, wherein the carbon fiber is present in an amount between about 0.01 g and about 5.0 g.
14. The electroencephalogram (EEG) cap of claim 6, wherein the sponge is disposed in the sponge seat.
15. The electroencephalogram (EEG) cap of claim 14, wherein the sponge seat comprises a sponge holder of a substantially cylindrical configuration comprising an internal bore, wherein the sponge is disposed in the internal bore.
16. The electroencephalogram (EEG) cap of claim 15, wherein the internal bore comprises raised edges disposed on a wall of the internal bore, wherein the raised edges are disposed radially about the internal bore.
17. The electroencephalogram (EEG) cap of claim 6, wherein the sponge seat comprises a flange.
18. The electroencephalogram (EEG) cap of claim 17, wherein the flange comprises securing

means.
19. The electroencephalogram (EEG) cap of claim 6, wherein the sponge seat comprises silicone, a thermoplastic elastomer, or any combinations thereof.
20. The electroencephalogram (EEG) cap of claim 1, wherein the electrode-connecting wires are split into two circuits corresponding to particular electrodes.