EEG Recording Caps and Related Products

Step-by-Step Instructions to Rework Emotiv, Build a Mobile Cap, and Join Both Together
V.26.07.2013

The paper *Debener et al. (2012): How about taking a low-cost, small, and wireless EEG for a walk?, Psychophysiology 49, 1449-1453* describes how the Emotiv-Headset can be combined with an EEG cap to achieve good signal quality by high-quality electrodes, precise electrode localization, and short, non-moving cables. This combination is not available as a finished product but needs to be built from the single components. This file describes step-by-step the necessary steps to realize the hardware.

Overview

From Emotiv you'll buy the Emotiv Headset, a receiver, and the necessary software. The headset consists of electrodes, amplifier, and a wireless sender (Fig.1).

The wireless transmission is received by the USB stick plugged into a notebook or similar device, which also runs the acquiring-, storage-, and processing-software.

Fig 1: Unaltered Emotiv

After reworking the Emotiv with the parts from Easycap the headset is separated into A) cap with electrodes (Fig.2), and B) amplifier & sender (Fig.3). Thus you can decide separately, how many caps you want to build and how many Emotivs you want to rework.
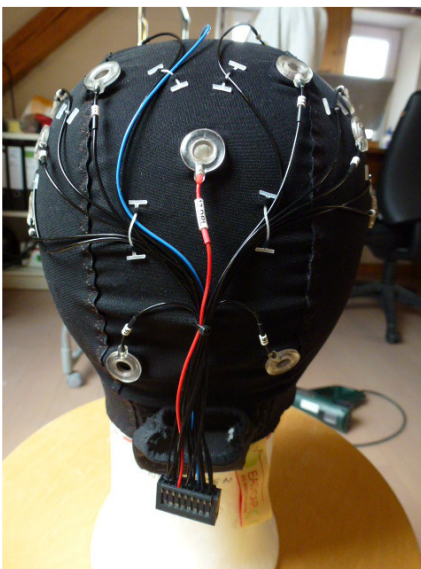

Fig. 2: Cap with electrodes, terminated into connector

Fig.3A: All Emotiv hardware built into a box with cap-connector …

Fig. 3B: … to Velcro-attach to the back of the cap.

1. Parts to Rework an Emotiv: These you'll need once PER EMOTIV

- From Emotiv: Research Edition EEG SDK
- From Easycap:
  - EMOC BOX
  - EMOC TORNISTER

1.1 Which Emotiv package is necessary? How to prove correct delivery?

The Emotiv Website www.emotiv.com offers several packages. It is necessary to buy a package whose software gives access to the raw EEG, e.g. the Research Edition EEG SDK @ USD 750.00 at http://www.emotiv.com/store/dev.php .

To purchase one needs to register and log in. Keep the Login-data well, they are needed again later. It is recommended to register under the actual users name, not as an institution or purchasing officer.

During the purchase process ordering data are issued by Emotiv, namely a Order Number and Serial Key. While the headset itself is delivered by parcel service, these data are necessary to download the software and to install it.

You have purchased the correct package if after installing the software there is a program called "Testbench.exe".

1.2 Easycap Parts

The catalogue-number EMOC BOX includes a fully machined housing to admit all Emotiv hardware, all mounting materials (screws, bolts, nuts), and the connector where the electrodes are plugged in.

To attach this box to the cap the EMOC TORNISTER, a bag from stretchy material with a Velcro-patch is recommended.

2. Parts to build an EEG Cap. These you'll need once PER CAP

List of Easycap Catalogue Numbers
- 1 CSCHS-#: Cap size #, modified for use as Emotiv-Cap with openings for electrodes and Velcro-patch
- 16 B18-LUR-150-TR: 14 electrodes for EEG-channels plus 2 spare
- 2 B18-LUB-150-BL: 1 electrode for CMS-channel, 1 spare
- 2 B18-LUS-150-SW: 1 electrode for DRL-channel, 1 spare
- 1 LABELSATZ EMOC: full double set of shrinking tube labels for each electrode
- 1 16POL-BUCHSE: 16Ch-female connector to terminate all electrodes and connect to hardware
- 1 SCC: Start-Set consumables

2.1 Comments

The above list of Easycap articles constitutes a sort of recommended standard package. With these components you have everything to work along this step-by-step-instructions. Of critical parts we gave spare ones.

Please note, that the articles listed and this step-by-step-instructions do not restrict your layout. You can realize almost any electrode layout based on 10%-electrode positions including drop-down electrodes for polygraphy or nose reference. You can even realize caps with variable layouts. All this is explained in chapter 4 below.

Still, the above list is no must. You can change quantities, skip unwanted items, or add others from the full Easycap catalogue.

Please find below the necessary product knowledge for each article which you might need to order exactly the right thing.

- Cap: The cap is made of black high-elasticity fabric, which accomodates to many head sizes and shapes. The cap sizes are given in centimeter head circumference. Although the caps are made in steps of 2 cm circumference it is enough to have caps in 4-cm-steps:
  - Adult caps: 54, 56, 58, 60, 62, 64 (average male: 58, average female: 54)
  - Children caps: 50 (5 years), 52 (7 years), 54 (11 years)
  - Infant caps: 36 (newborn), 38, 40 (3 months), 42, 44 (7 month), 46, 48 (3 years)
  - Pre-Term babies caps: 32, 34

  The cap cut is termed "SubInion-Cut". It encompasses the head so widely, that it does rarely slip. The cap is fixed with an integrated chin belt, it needs no chest-belt.
  The cap is prepared with openings at all 74 electrode positions defined by the 10%-System (Figure 4). Openings not needed for electrodes can be used to braid in the electrode wires.
  Further, the cap comes with a patch of Velcro at the Inion-area to attach the hardware box there.
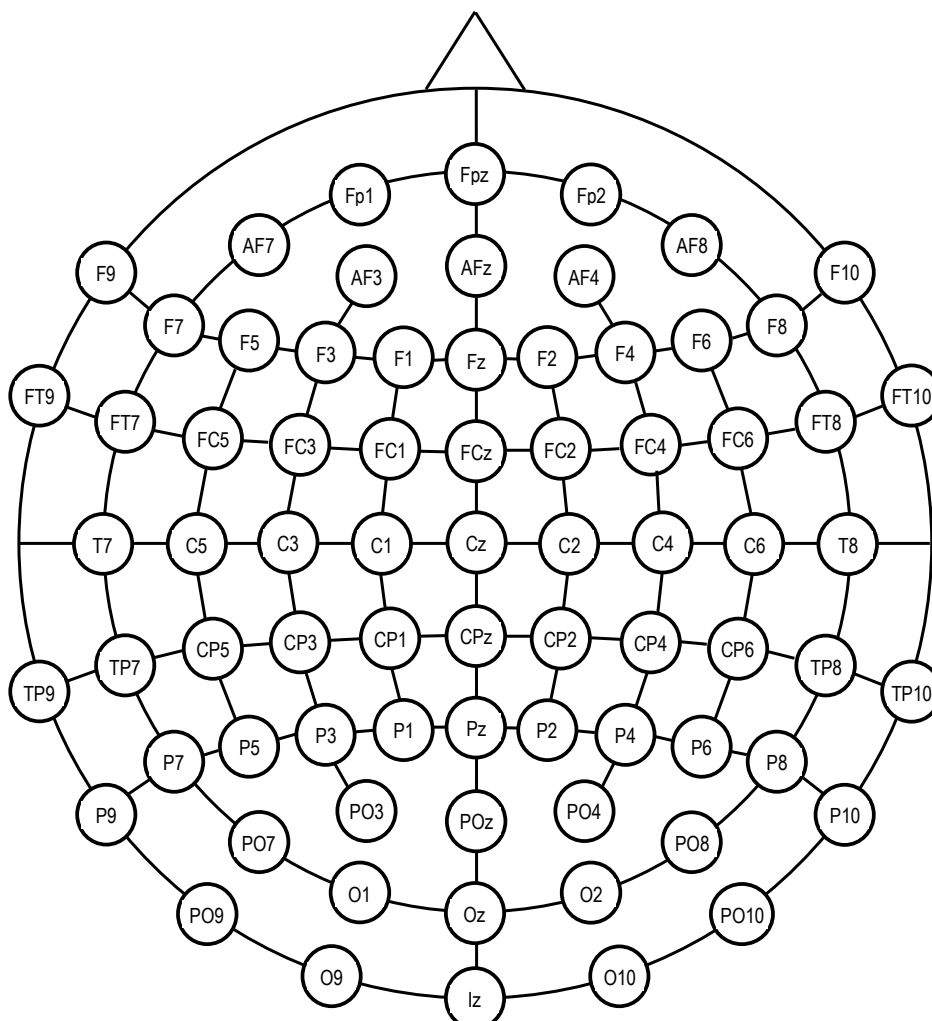

Fig. 4: 10%-System (Montage No. 1)

- Electrodes: 14 red electrodes, 1 blue, 1 black, are needed, the others are spare ones. Technically all electrodes are equal, the colours are only for identifying purposes. The electrodes come with 150 cm cable length and will be shortened during reworking according to your needs.

- Electrode labels are only for comfort. If you can identify the channel-number in everyday practice otherwise, they can be skipped.

- The catalogue-numbers 16-POL-BUCHSE (Female 16Ch-connector including crimping sockets) and EMOC BOX (machined housing, mounting materials, male 16Ch-connector) are essential and cannot be skipped.

- Start-Set Consumables: The start-set includes a cap-mounting-manual and contains small quantities of all consumables mentioned in that manual. It allows you to start using the cap right out of the box. Later, it might be more convenient to obtain the consumables locally.

Orders can be sent to Easycap by email, fax, letter, telephone. Please make sure the order shows invoice- and delivery-address, and anything required on your side, e.g. an official order number. Payment can be done as prepayment by Credit Card (Visa, Master, Amex) or 30 days net by wire transfer.

Digression

The EEG-signal passes through several stations, like connectors, the hardware's PCB, the Emotiv software, maybe further processing software. It was not possible to give each channel the same name at each step. Thus please find here a complete assignment table how each channel is labelled at each step. You don't need to read it now, but remember it's here, so you can always look up the different identifiers.

Table 1: Assignment-Table of all channel-labels used in the remainder of this text.

Electrode Number	Pin Number of 16Ch-Socket (at end of electrodes)	Pin Number of 16Ch-Connector (in box)	Emotiv PCB	Displayed in Emotiv Software as	Free Column for self-editing
1	1	1	1	O1	
2	2	2	2	P7	
3	3	3	3	T7	
4	4	4	4	F7	
CMS	5 CMS	5 CMS	5 CMS	CMS	
5	6	6	6	AF3	
6	7	7	7	FC5	
7	8	8	8	F3	
			9 not used		
			10 not used		
8	9	9	11	O2	
9	10	10	12	P8	
10	11	11	13	T8	
DRL	12 DRL	12 DRL	14 DRL	DRL	
11	13	13	15	F8	
12	14	14	16	AF4	
13	15	15	17	FC6	
14	16	16	18	F4	

3. How to disassemble and rework the Emotiv Headset

Note: While dissassembling the Emotiv Headset you will get in touch with the circuit boards carrying sensitive electronic parts. As a step of precaution, either put on an anti-static wrist strap or periodically touch your hand to a large non-electric metal object, such as a sink faucet. This will dissipate any built up static electricity which can potentially fry the circuit board. If you do not have an anti-static wrist strap, you only need to discharge static electricity every hour.

Necessary tools:

- tweezer
- fine slot screwdriver
- fine cross-tip screwdriver
- fine wire cutter
- Fine solder iron and solder wire
  for electronics (not depicted)
- Adjustable hot-air gun with narrow nozzle
- Crimping tool

Fig. 5: Some of the needed tools.

1. Unpack the Emotiv Set and store all items.
   On the inside of the headset's bail there is a
   type label covering the whole inside. Remove
   this label completely with the help of the tweezer.
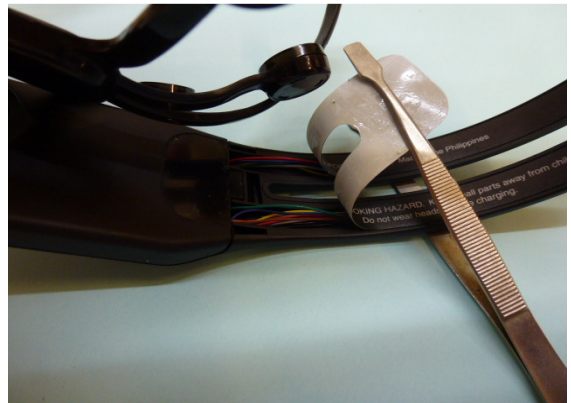

Fig. 6: Remove the type label

2. Remove the left and right cover panels with the slot screwdriver. Underneath you'll find the sender unit and the accumulator. Unscrew them with the cross-tip screwdriver.
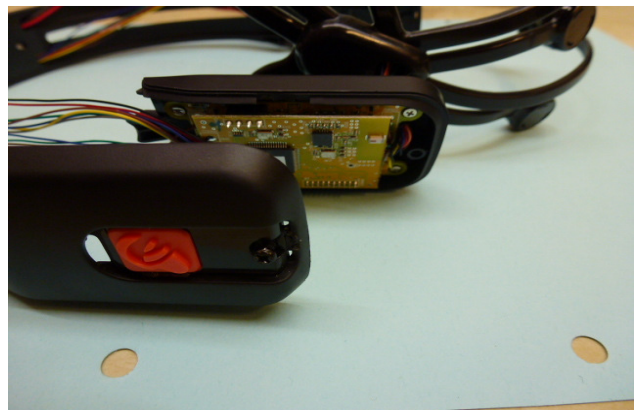

Fig. 7: Remove cover panels and unscrew sender-unit and accumulator

3. In the middle of the bail the charging-unit and the On/Off button are mounted: Remove the two screws and extract the unit.
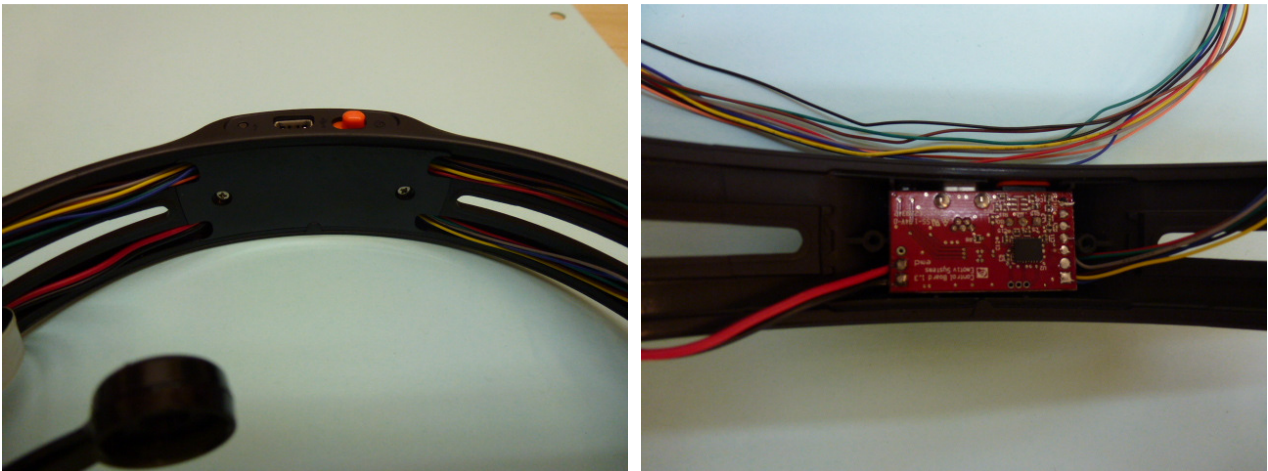

Fig. 8: Remove the screws and extract the charging-unit

4. The „sender-unit" consists of two PCB's, permanently mounted on top of each other. The larger one, with eyelets for the screws, admits the 16 cables coming from the electrodes, 8 on each short side. The smaller one admits 7 cables coming from the charging-unit.
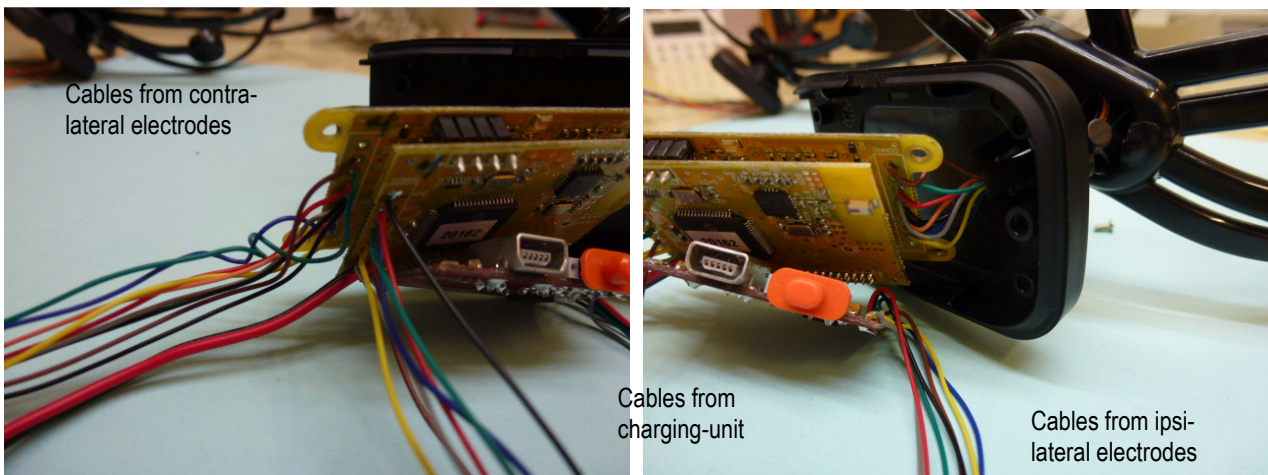

Cables from contra-lateral electrodes

Cables from charging-unit

Cables from ipsi-lateral electrodes

Fig. 9: Cut the contralateral and ipsilateral electrode cables 6 cm away from the sender-unit's circuit board. Do NOT CUT the cables leading to the charging-unit

Cut the electrode cables 6 centimeter (2,4 inch) away from the larger PCB. That means, especially for the ipsilateral electrodes you need to cut very near to where the cables vanish into the headset housing.

IMPORTANT: DO NOT CUT THE CABLES LEADING TO THE CHARGING UNIT.

5. Now all Emotiv electronic is separated from the bail and can be built and soldered into the EMOC BOX.
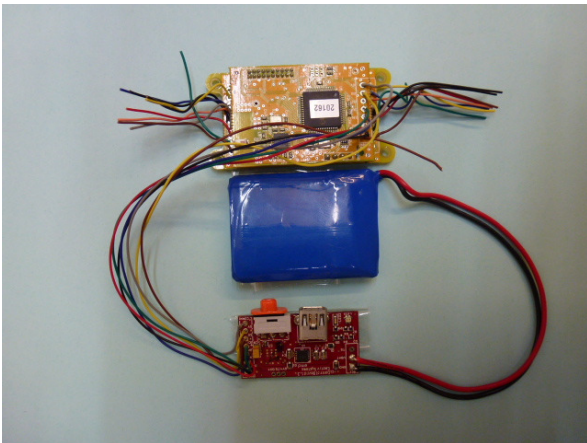

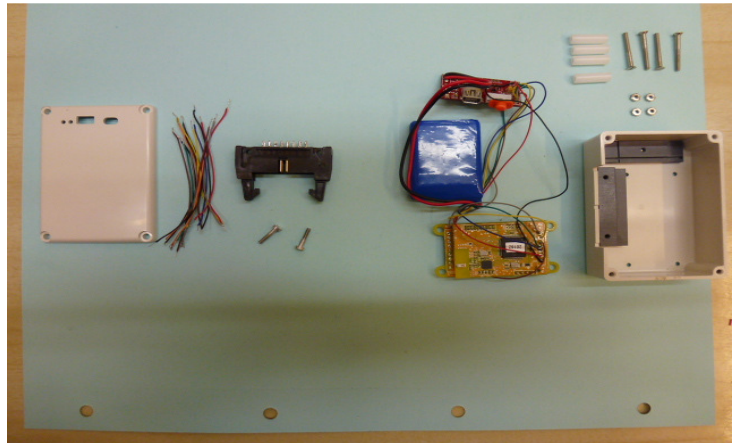**Fig. 10A**: Completely dissassembled Emotiv hardware

Fig. 10B: … to be built into the EMOC BOX

6. De-insulate 3 mm of the far end of the 16 electrode cables and pre-tin them with solder wire.

7. – Push the 4 long screws from below into the box and slide the spacer sleeve onto them.
   - Between these 4 sleeves put a piece of double-sided adhesive tape or similar and onto this fix the accumulator. Please see the best orientation in Figure 11.
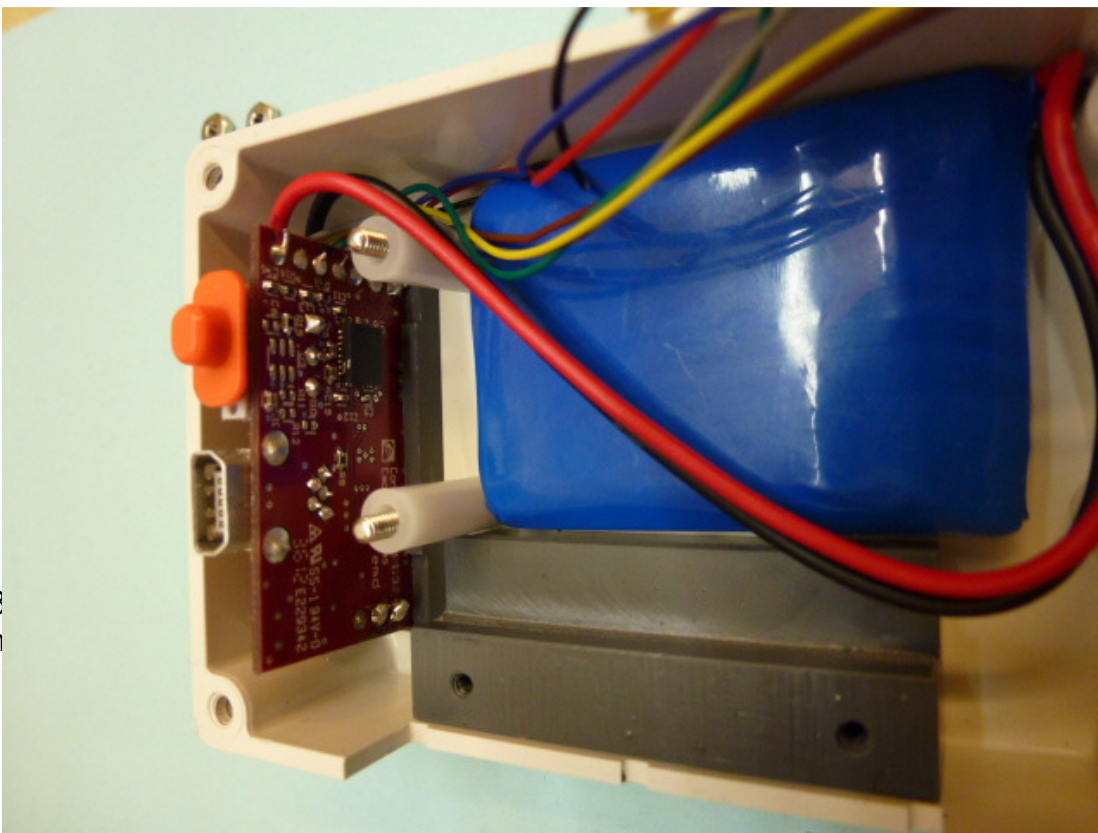   - Slip the charging-unit into the slot.

Fig. 11: EMOC BOX with spacer sleeves, showing orientation of accumulator and charging-unit

8. Soldering the electrode cables onto the 16-pin-male connector:

Now take the Sender unit with the electrode cables, which are cut at 6 cm (see above step 4) and pre-tinned (step 6). Figure 12 shows the channel-number-assignment of the solder points.
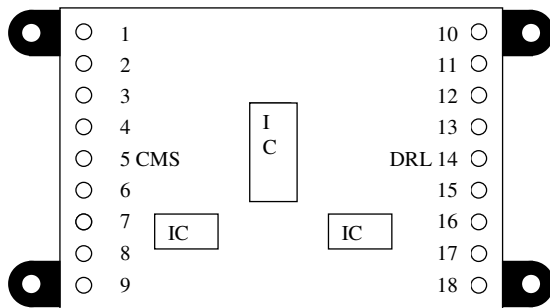

Fig. 12: Channel-Number-Assignment on the Sender-Unit-PCB

Now solder the electrode cables to their pins of the 16-pin-male connector according to the assignment of Table 2.

Pin 1 of the 16-pin-male-connector is marked by a triangle. Figure 13 shows the front view. The cables are soldered to the backside.
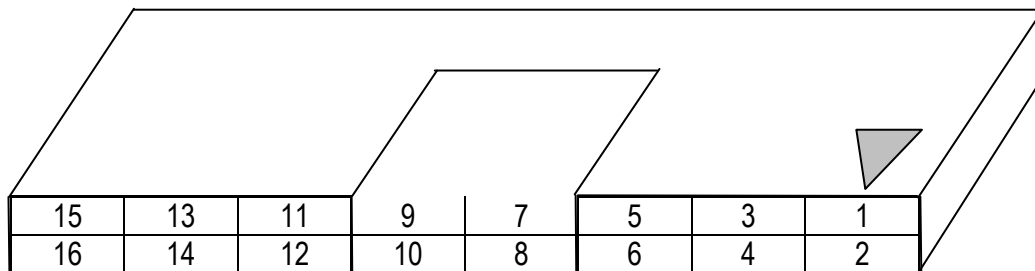

| 15 | 13 | 11 | 9 | 7 | 5 | 3 | 1 |
| 16 | 14 | 12 | 10 | 8 | 6 | 4 | 2 |

Fig. 13: Front view of 16-pin-male-connector, showing the triangle marking Pin 1

Note: Make sure to avoid short-circuits between the individual pins. We recommend to verify this with a multi-meter.

Table 2: How Pin-Number of 16-pin-male-connector and Sender-unit-PCB's solder points correspond to each other.

Pin Number of 16Ch-Connector (in box)	Emotiv PCB
1	1
2	2
3	3
4	4
5 CMS	5 CMS
6	6
7	7
8	8
	9 not used
	10 not used
9	11
10	12
11	13
12 DRL	14 DRL
13	15
14	16
15	17
16	18

9. Now stow the cables in soft bends into the housing and screw the 16-pin-male-connector into the recess using the slot-screws. The row with Pin 1 should be upwards.
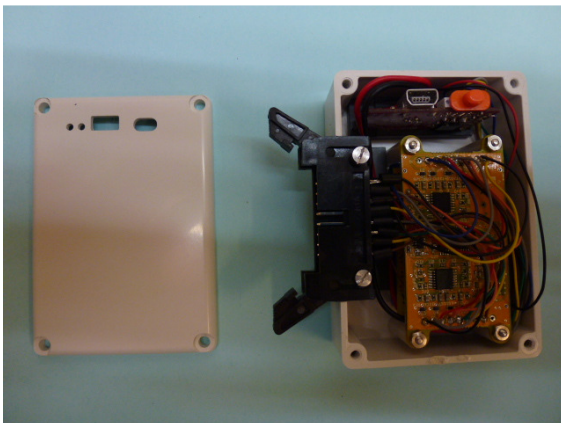

Fig. 14: 16-Pin-male-connector screwed into the housing with Pin 1 in the above row.

10. Finally the lid is affixed with the remaining 4 cross-tip screws.
To check the basic functions plug in the USB-cable (content of Emotiv-package) and the red LED will indicate charging. After removing the USB-cable again switch the ON/OFF-switch to ON and the blue LED should be on.

4. How to build the cap

4.1 Some considerations about electrode layout

Before starting to equip the cap with electrodes you must decide upon the electrode layout. The cap comes with openings for electrodes at all 74 sites of the 10%-system (Figure 4). Thus you are free to choose any subgroup of 14 recording sites that suits your experimental question. Additionally decide upon the sites for Ref (CMS) and Gnd (DRL). In most cases a laterally neutral site on the central line will be a good choice for Ref. Gnd can be placed anywhere where good contact is easy to achieve, e.g. at AFz.

It is important for data quality to keep the electrode cables as short as possible and to secure them against movement. Thus after deciding upon the layout the cables will be cut to only span the distance from electrode site to connector. However, leaving the cables some centimetres longer will degrade signal quality only minimally, it's just more effort to stow them underneath the cap. Thus, alternatively to confining oneself to only one fixed electrode layout, it is also possible to leave some or all electrodes longer, so that they can be buttoned into different sites.

Finally, please consider that the electrodes supplied cannot only be used in the cap, but also outside the cap, attached to the skin with washers (double-sided adhesive rings). Thus you do not need to restrict yourself to electrode sites in the cap, you can also leave them dangling down from the cap to reach e.g. the nose (nose reference), the infraorbital site (lower VEOG), sub-mentalis sites (EMG), or the clavicula (ECG). To avoid cable-movements such drop-down-electrodes should be covered with lots of sticking plaster or similar.

The below step-by-step instructions will follow the neutral passepartout electrode layout depicted in Figure 15. If you realize another layout please change the respective steps accordingly.
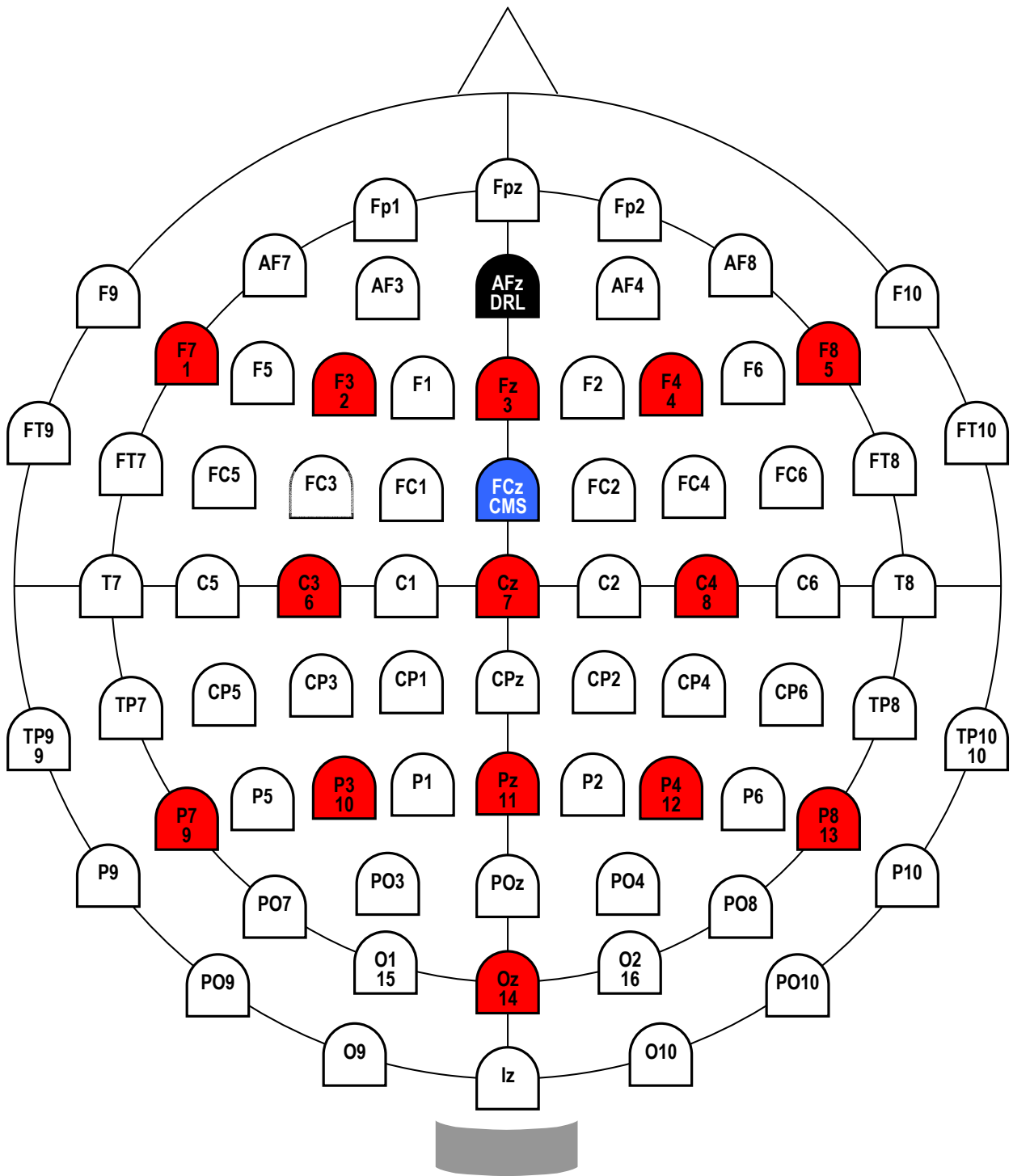
Fig. 15: A Standard- or Neutral Electrode Layout. Note the Velcro patch at and below the Inion.

4.2 Building the Cap Step-by-Step

1. Labelling the electrodes.

   Note: Labelling is only for handling comfort and reliability. If you are going to use a fixed electrode layout you might want to consider to leave the electrodes unlabeled. Instead you can note your channel assignment on a printout of Figure 4.

   Cut the heat-shrink-tube with the imprinted labels into pieces. Slide them onto the electrode cable until 2 cm before the sensor housing (Figure 16). Take care to orient all labels into the same direction. By exposing the tube to hot air it will shrink onto the cable. Make sure all printing is readable from the sensor's upper side.

   Note: The cable insulation is rather heat-sensitive. An air temperature of 170° Celsius is sufficient. Additionally confine the hot air only to the shrinking tube, and work precise and quick, so that exposure of the cable to your heat source is as short as possible.
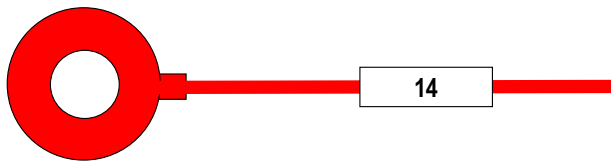

   Fig. 16: Place the label a little away from the sensor

2. Button in the electrodes

   The electrode housing has a circumferential groove. To button in the electrode stretch the fabric a little and let the fabric slip into the gap. Once this is done the electrode can be rotated in any direction.

   Button in all 14 electrodes, CMS, and DRL according to your layout and channel assignment.

3. Securing the cables

   The best way to secure the cables against movements is to weave them in and out of the cap (Figure 17), using openings in the cap not occupied by other electrodes.

   Braid in all electrodes orienting the cables towards the occipital region. Later the cable-connector and the hardware-box will be placed approximately at the Inion and below. After you found a good path for each cable you might want to register the pathways to make them repeatable.
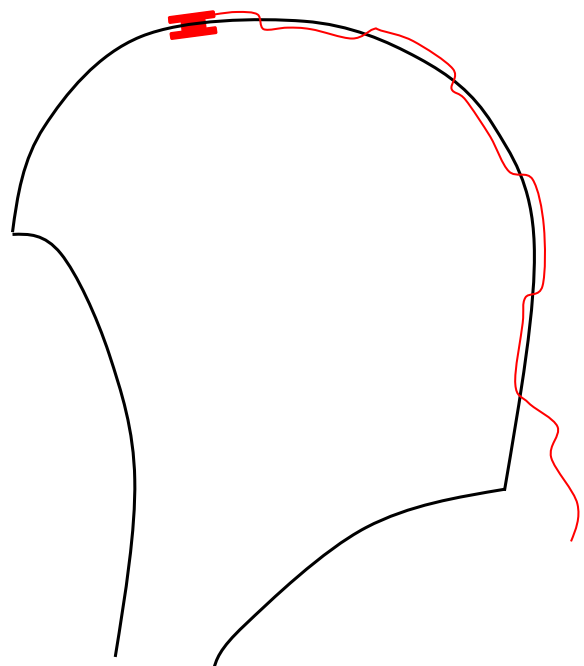

Fig. 17: Weaving the cables in-and-out of the cap

4. Determining the cable lengths

Now put the cap onto a head with a circumference similar to the cap size (better slithly larger than smaller). If you use a human subject he/she should stand upright, not bent in the neck. The front rim of the cap should be directly above the eyebrows, the back rim some 3 cm below the Inion. Grasp the left and right wing and pull the cap by repeated seesawing movements into an all-encompassing left-right-symmetry. This also accomplishes an even-spread tension throughout the whole cap fabric. Finally close the chin-belt to fix the cap in it's correct position.

Now tug the individual cable into a straight path from their electrode site until to where it leaves the cap the last time. Drop-down-electrodes must drop down the correct length. There should be no tension on the cables, leave them a bit of backlash. If you now look at the cap from behind all the cables will be dangling until beyond the Velcro patch (Figure 18).

This line, the lower edge of the Velcro-patch of a well-positioned cap, is a good mark to cut the cables.
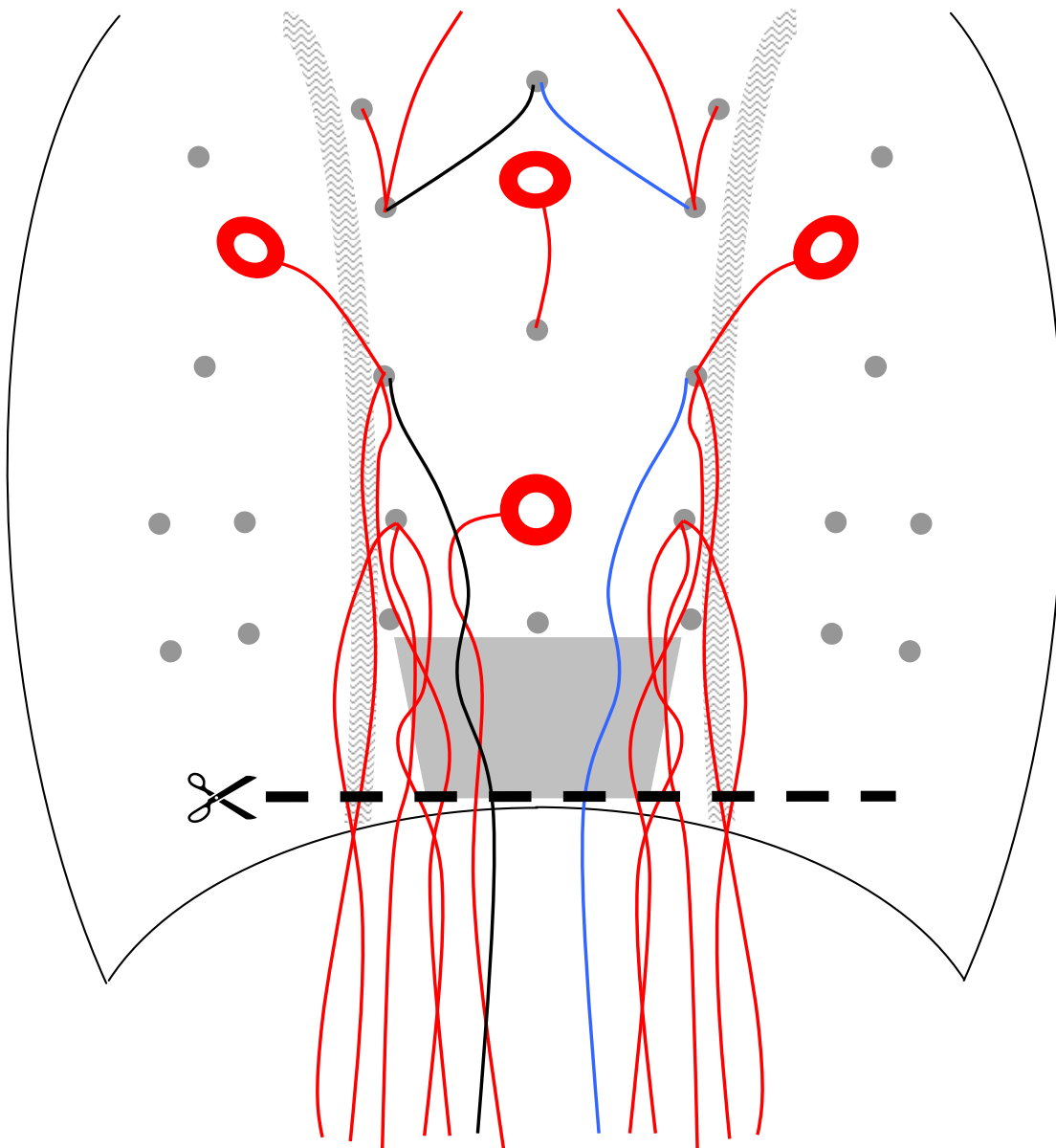

Fig. 18: After positioning cap, electrodes, and cables cut the cables at the lower edge of the Velcro-patch

Connecting the cables to the 16Ch-female-socket

After de-insulating the cut cables for 2-3 mm they should be crimped into the crimping sockets that come with the 16Ch-female-socket. Ideally you can use a crimping tool that produces onto the copper strands a crimped shape like the cross-section depicted in Fig. 19A, and that grasps the insulation like in Fig. 19B.

Fig. 19A: Crimping Profile   **Fig. 19B**: Crimped tension relief
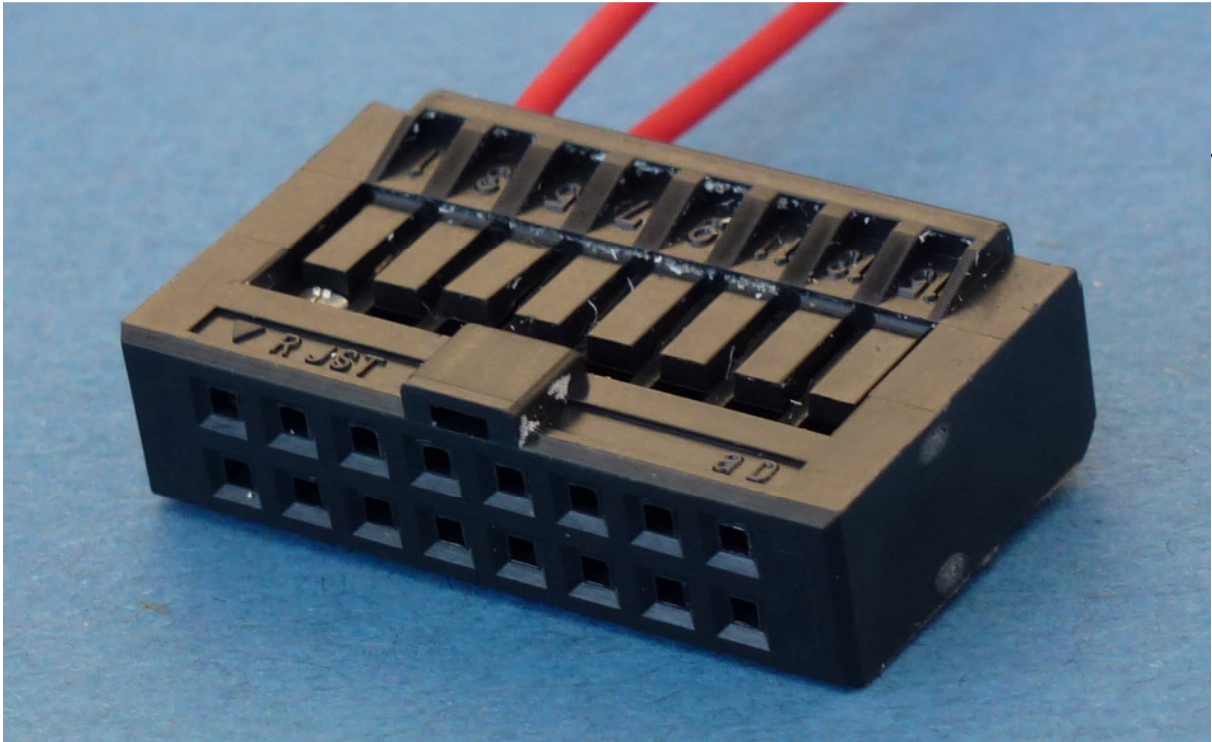

Fig. 20: 16Ch-female-socket housing, viewed from the front, with pin-numbering and the polarity-protection-hook visible. The crimped cables enter from the rear.

Now each cable is sled into it's corresponding pin-number-slot (Figure 20). If inserted correctly a detent will lock in, and the socket cannot be pulled out anymore. For the detent to work, the crimping socket must be oriented correctly: the side you see in Figure 19 B must face the outside of the housing, i.e. uneven numbers look upwards, even numbers to the bottom. The detent will give an audible click when snapping in. Otherwise you can still pull out the crimping socket.

The assignment of electrode-number to pin-number is given in Table 3.

1. **Table 3**: How Electrode Number and Pin-Number of 16-pin-female-socket correspond to each other.

Electrode Number	Pin Number of 16Ch-Socket (at end of electrodes)
1	1
2	2
3	3
4	4
CMS	5 CMS
5	6
6	7
7	8
8	9
9	10
10	11
DRL	12 DRL
11	13
12	14
13	15
14	16

**Note: To remove a locked crimping socket again lift the latching tongue a little bit with an appropriate tool (Figure 21).
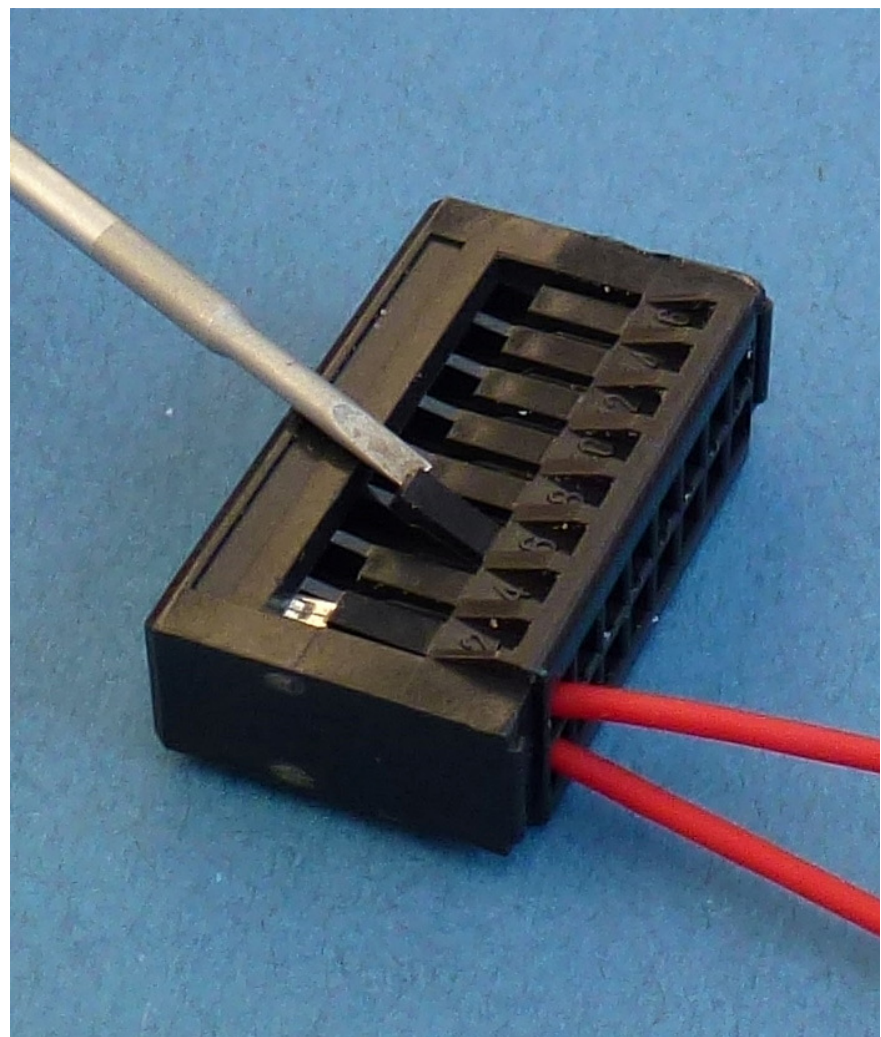Then the socket comes out easily.**

Fig. 21: How to unlock and remove a crimping socket again.

Finished! Now you can put the box into the tornister, mount the cap, velcro-attach the tornister to the cap and plug-in the cap's connector. After launching the software and switching on the box you can start recording.

To learn how to mount an EEG-Recording-Cap (positioning, impedance minimization, contacting with electrolyte, cleaning & care) please refer to the EasyCap Manual.

To learn how to install and operate the Emotiv Software please refer to the Emotiv Website and respective user groups.

Attachment I gives a rough overview how to connect the Emotiv Software with OpenVibe for further processing.

Feel free to contact the Debener-group for further questions on the software side at stefan.debener@uni-oldenburg.de .

Attachment I: Connecting to Open Vibe:

Only the Emotiv Research Edition SDK can be used with OpenVibe.
Instructions on how to interface the Emotiv Epoc and OpenVibe
1. Download OpenVibe from http://openvibe.inria.fr/downloads/
2. Install the program to your computer.
3. Open OpenVibe Designer
4. Drag Acquisition Client into the main screen
5. Drag Analog VRPN server into the main screen
6. Connect the two blocks
7. Open OpenVibe acquisition server
8. In the Driver selection menu, click the scroll box arrow and select Emotiv Epoc
9. Click Driver Properties: Set the Identifier to "0"
10. In the path to Emotiv Research SDK select other
11. Then navigate to the location of the SDK. Typically the location will be C:\Program Files (x86)\Emotiv Research Edition SDK_v1.0.0.5-PREMIUM
12. Click to enable 2 additional channels for gyroscope if desired
13. Click Apply
14. Click Connect