[졸업작품전 – 작품]

In-ear EEG & EMG using shape deformable PVA stamp

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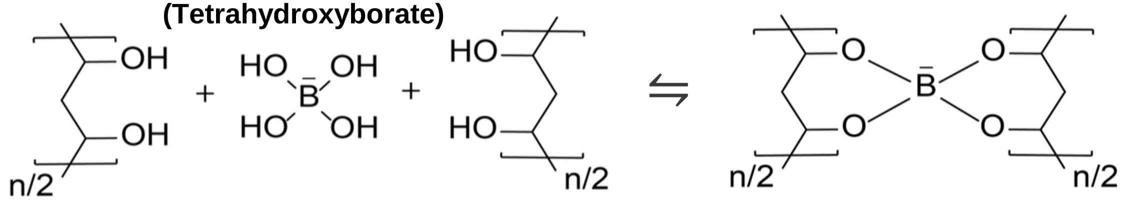
1. Limitation & Motivation

[PDMS (Polydimethylsiloxane) stamp]

[PVA stamp with activator]

Activator (Tetrahydroxyborate)



PVA (Polyvinyl alcohol) **PVA (Polyvinyl alcohol)** **Crosslinked PVA**

10:1

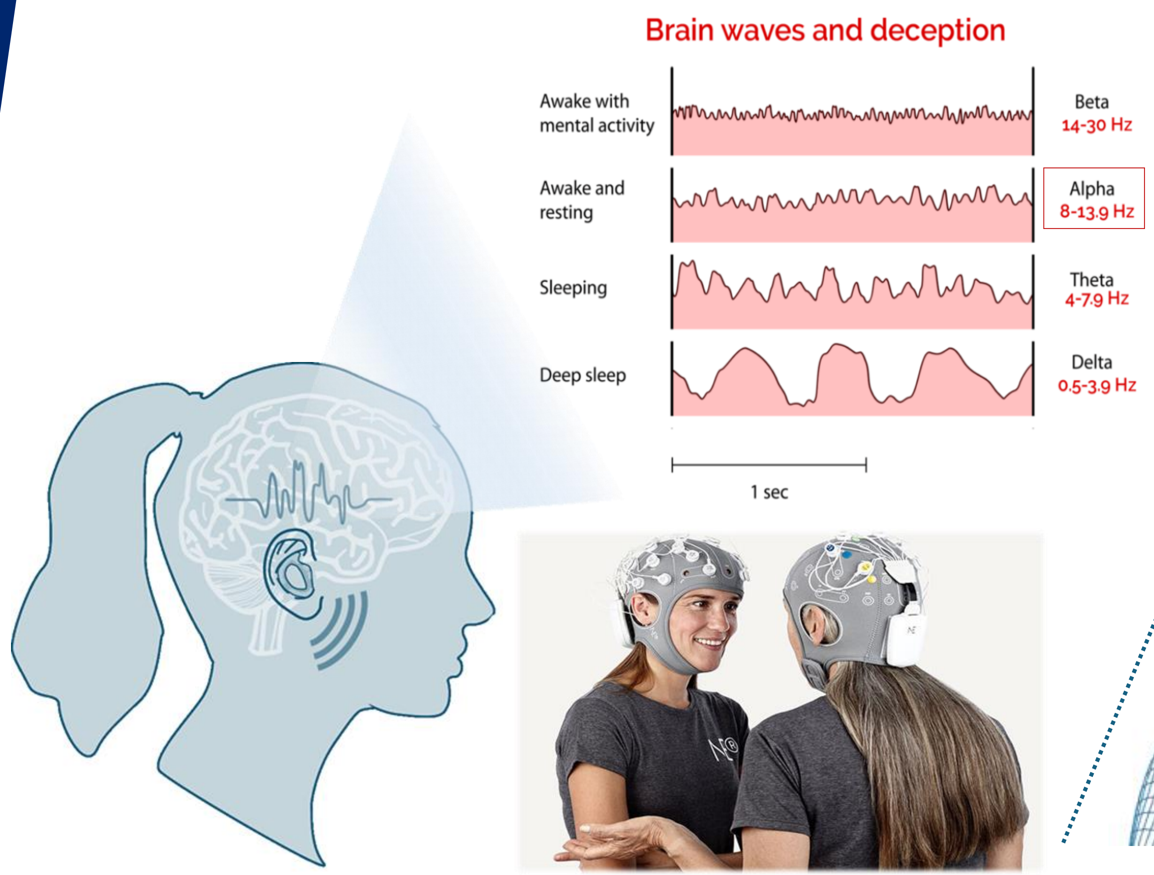
10:5

PVA : Activator %w/w

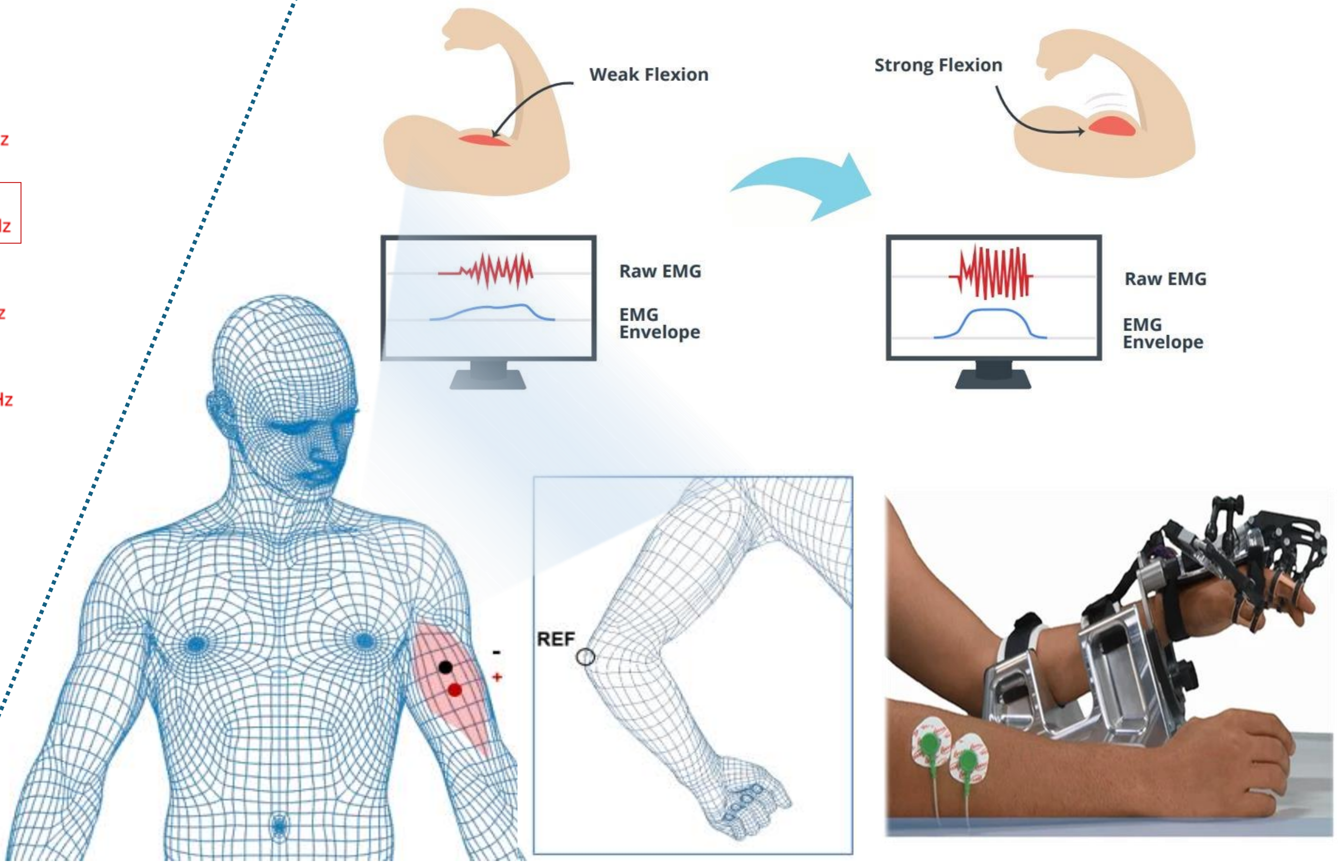
1. Limitation & Motivation

Why body's curvy surfaces are valuable?

[Electroencephalography (EEG)]

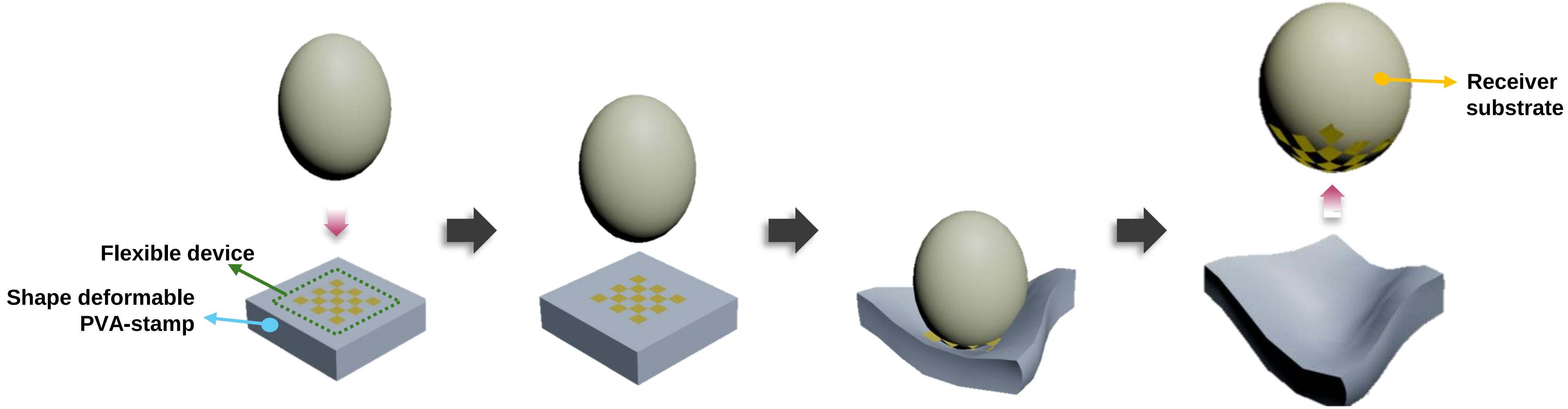


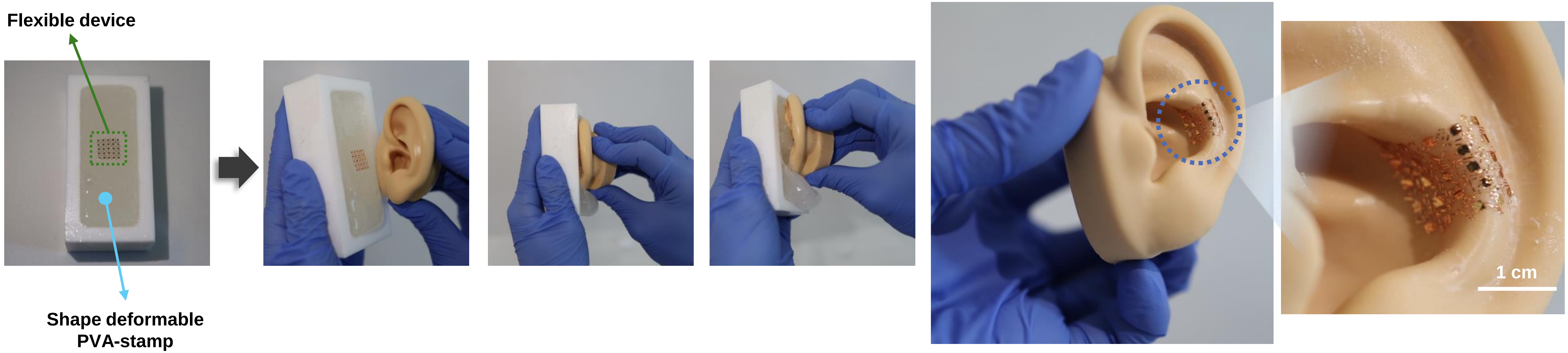
[Electromyography (EMG)]



- Body's curvy surfaces are important spots in measuring electrophysiological (EP) signals.

2. Transfer printing

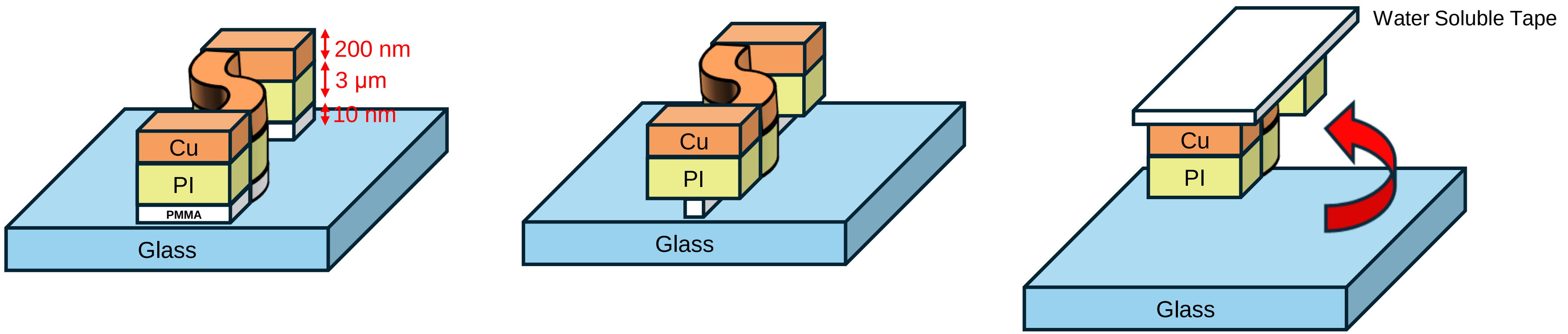




2. Flexible device

[Fabrication Process]

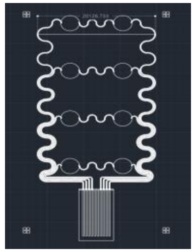
1) Patterning 2) Sacrificial layer release 3) Transfer



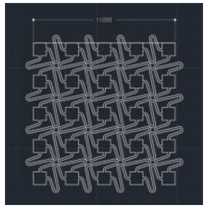
[Optimized fabrication]

Group #	Cu thickness (nm)	RIE source & amount	RIE run time (s)	Acetone time (min)	Success rate (%)
1	200	O_2 80 sccm	3000	60	66.7
2	**200**	**O_2 80 sccm**	**3600**	**30**	**81.3**
3	200	O_2 80 sccm	4000	20	38.5
4	200	O_2 80 sccm + CF_4 15 sccm	600	20	33.3
5	300	O_2 80 sccm	3600	30	60.0
6	500	O_2 80 sccm	3600	30	56.3

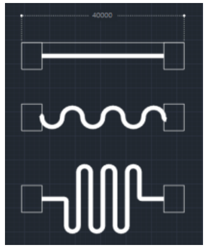
[Optimized patterns]



Practice pattern



Pattern for EMG REF
l = w = 1.1 cm



Pattern for in-ear EEG REC
l = 4 cm

- We developed the optimum condition by testing over 200 devices.

2. In-ear EEG & EMG measurement

Image comparison

[In-ear EEG]

Poor contact

Robust contact

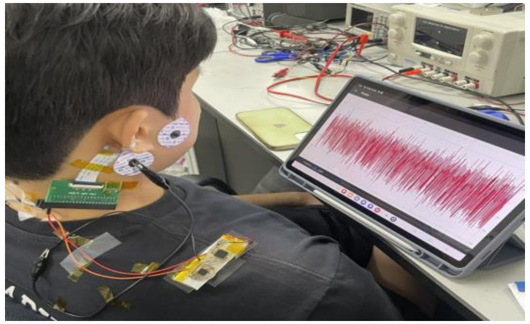
[EMG]

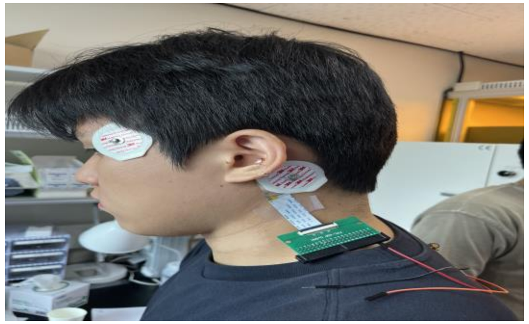
Poor contact

Robust contact

2. In-ear EEG & EMG measurement

[In-ear EEG real set-up]





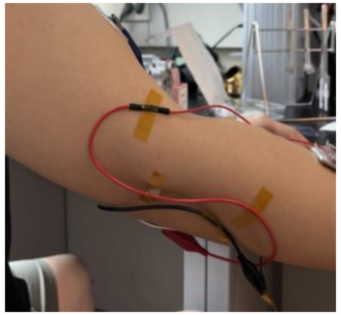
➢ **In-ear EEG REC device로서의 validation이 목적**

[In-ear EEG measurement goal]

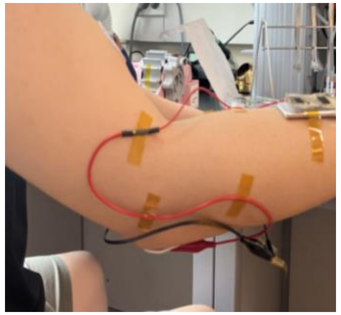
➢ **Conventional EEG spectrum이 나타남을 보일 것**

[EMG real set-up]

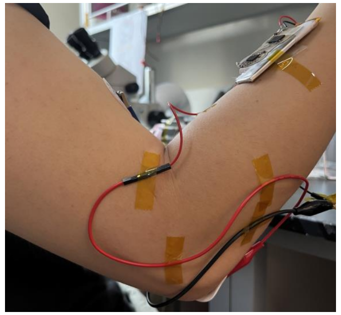
1) Extension



2) Partial flexion

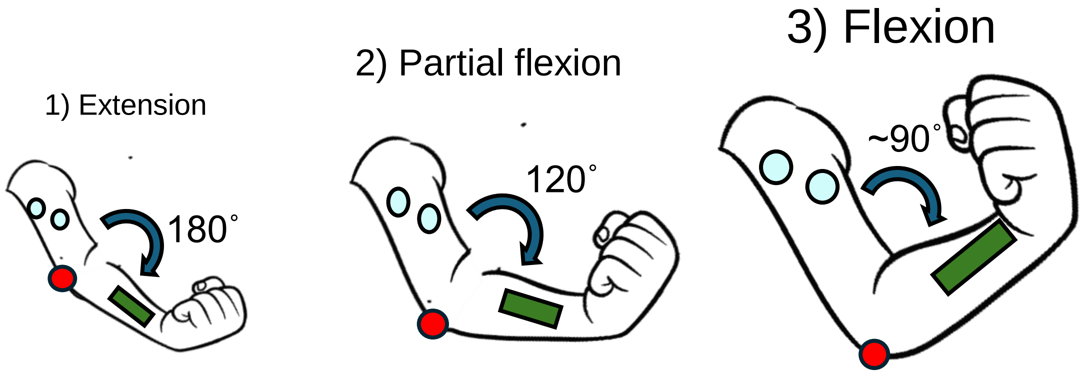


3) Flexion



➢ **EMG REF device로서의 validation이 목적**

[EMG measurement goal]

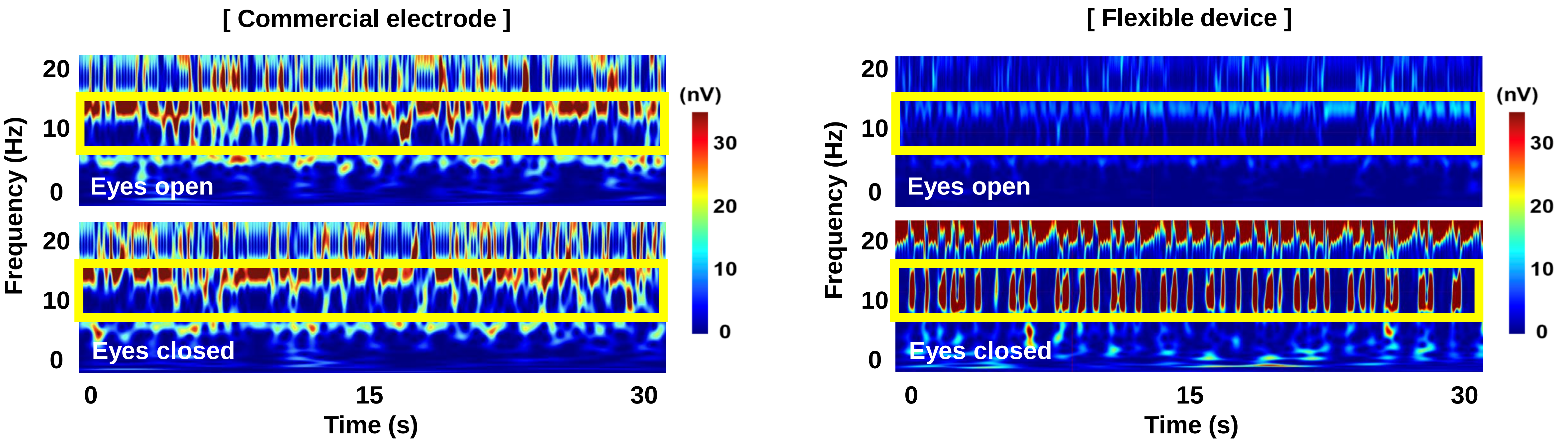


➢ **신뢰성 있는 SNR 확보할 것**

➢ **Force difference가 signal에 개연성 있게 반영됨을 보일 것**

2. In-ear EEG & EMG measurement

In-ear EEG results



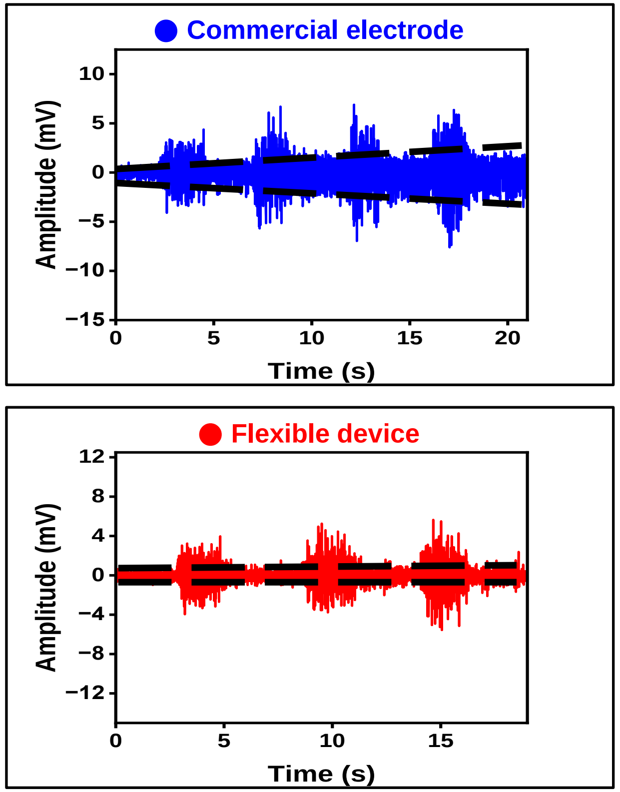
Alpha-wave (8~13 Hz) region

- Flexible device effectively reflects alpha-wave only in ‘eyes closed’ condition, while commercial electrode poorly reflects EEG signal difference.

2. In-ear EEG & EMG measurement

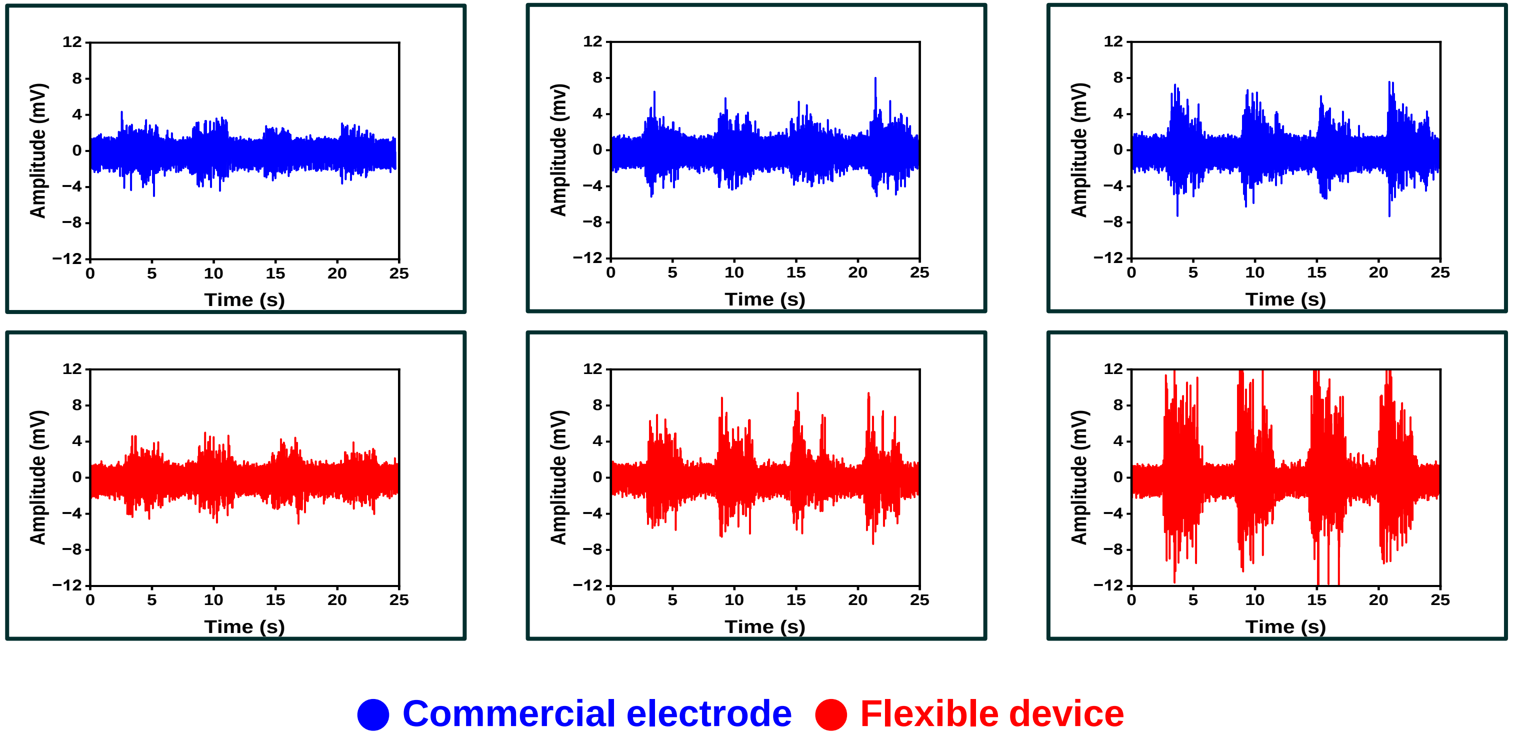
EMG results

[Stability test]



[Performance test]

1) Extension
2) Partial flexion
3) Flexion



- Commercial electrode shows unstable background noise levels compared to the flexible device.
- Flexible device effectively reflects power difference while commercial electrode poorly reflects power difference.

3. Summary & Suggestion

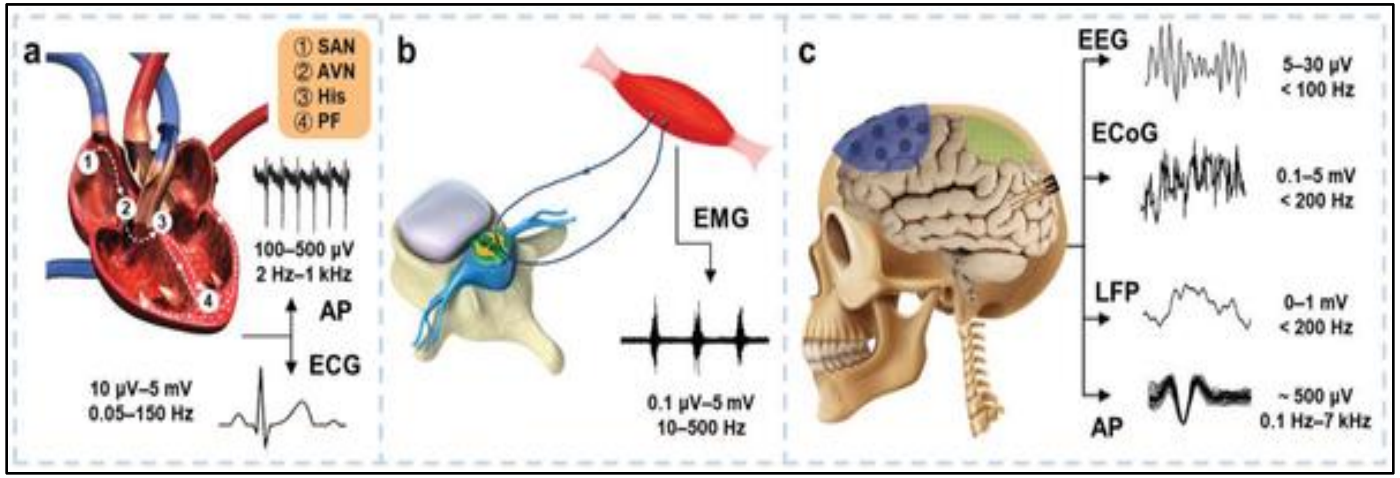
In-ear EEG & EMG using shape deformable PVA stamp

- In-ear EEG 스펙트럼 상 alpha-wave의 안정적 관찰
- EMG의 높은 SNR & 근육 수축력과 signal의 개연성

- Flexible device가 신체 굴곡진 표면에 안정적으로 부착

- Shape deformable PVA stamp가 기존의 stamp 한계를 효과적으로 극복

3. Future applications



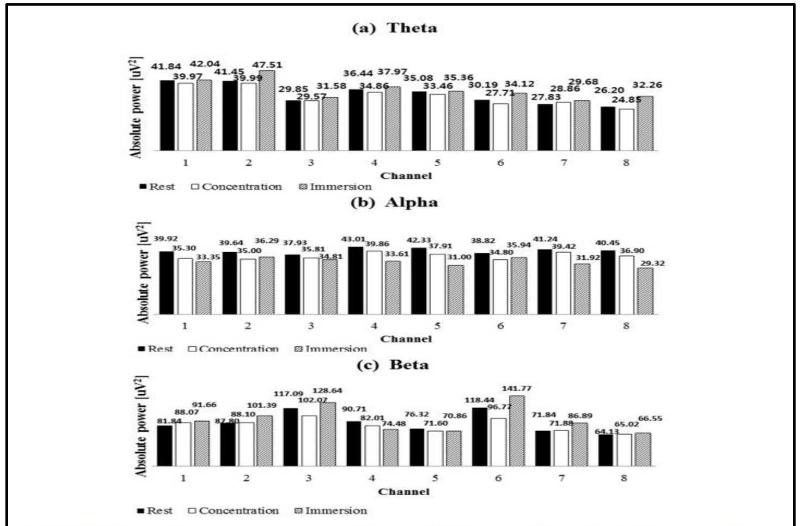
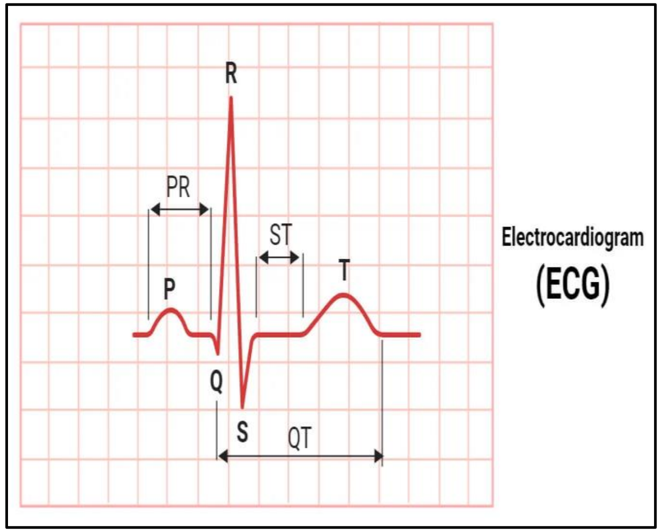
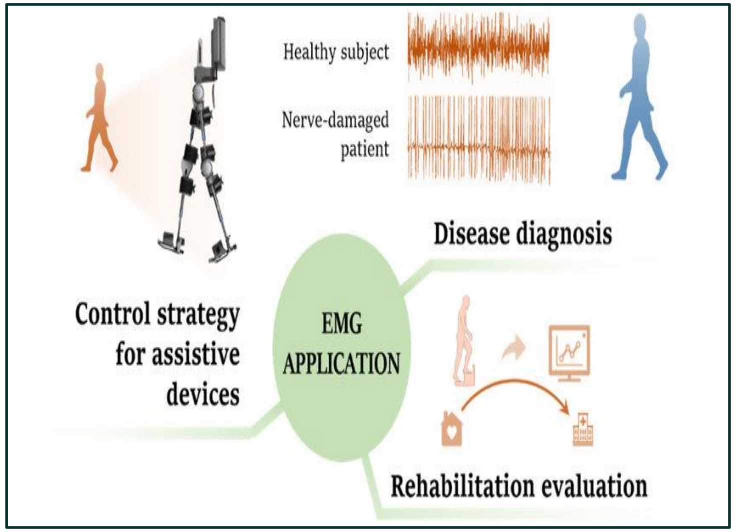
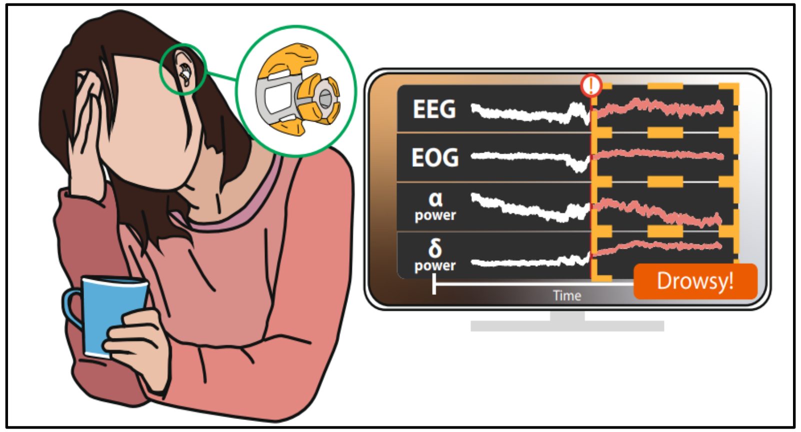


Figure 4. The absolute powers of Theta (a); Alpha (b) and Beta (c) bands are shown in the cases of rest, concentration and immersion.







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Demonstration
/
Q & A

2024.11.12. (Tue)

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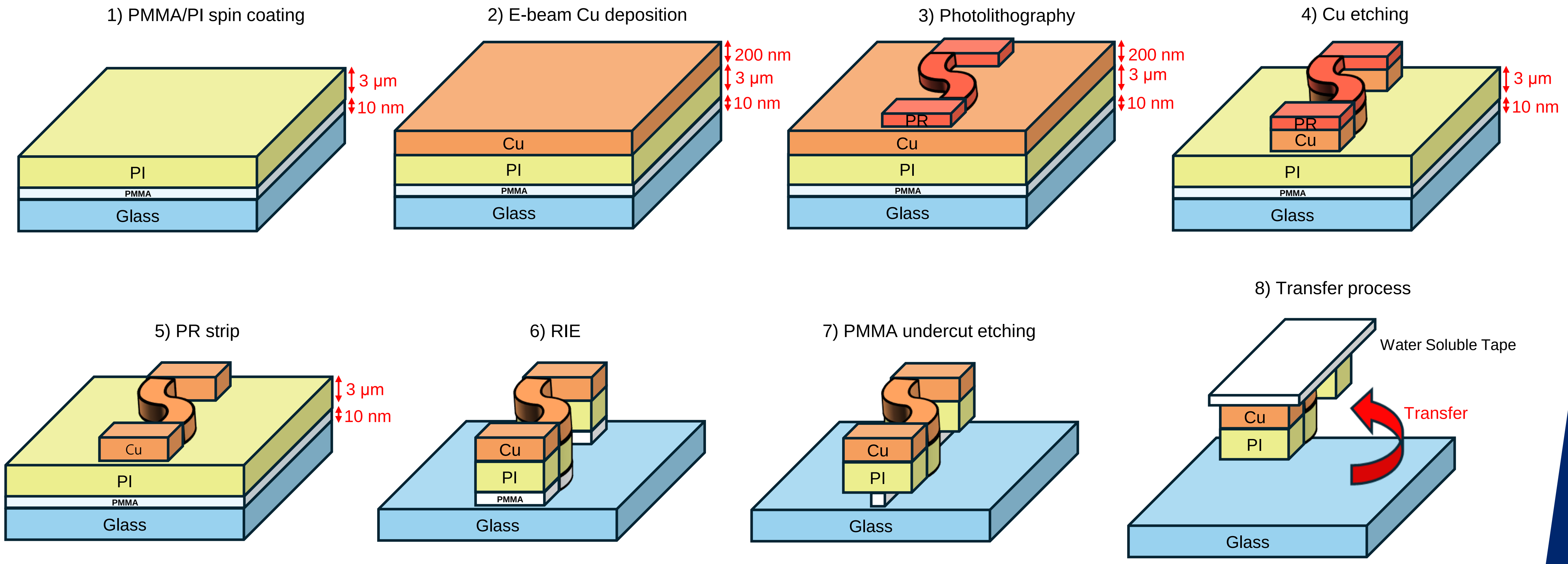
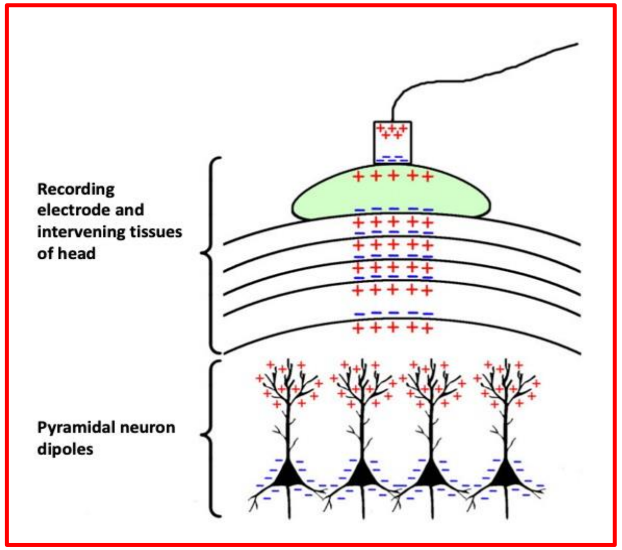
Appendix

Fabrication of flexible device

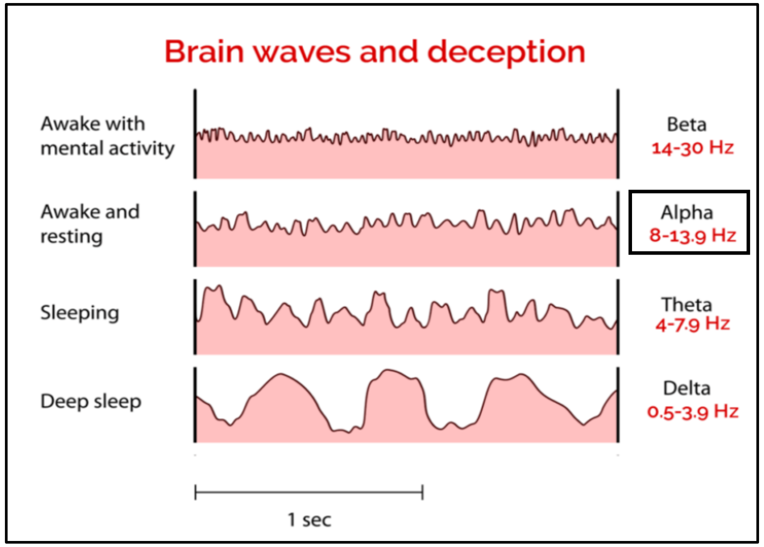


Appendix

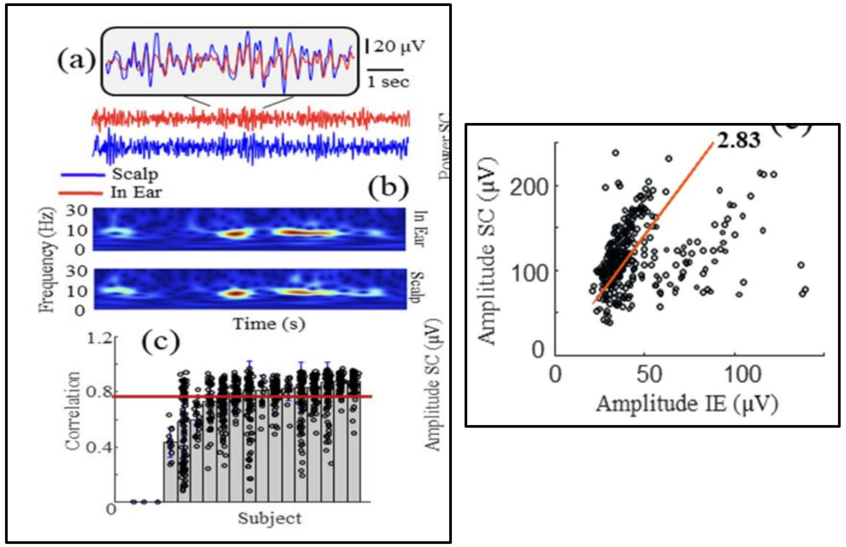
In-ear EEG



EEG source



Brain wave and deception



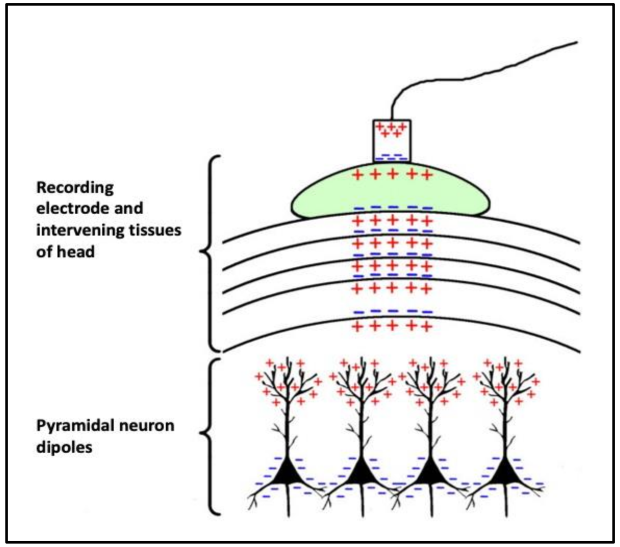
Scalp vs. In-ear EEG

- Electroencephalography (**EEG**): a noninvasive method for recording **the electrical activity of millions of neurons**
- EEG source: Dipoles are created in adjacent neurons due to postsynaptic EPSPs or IPSPs → Temporal and spatial summation of pyramidal cells → **Field potential** → EEG source

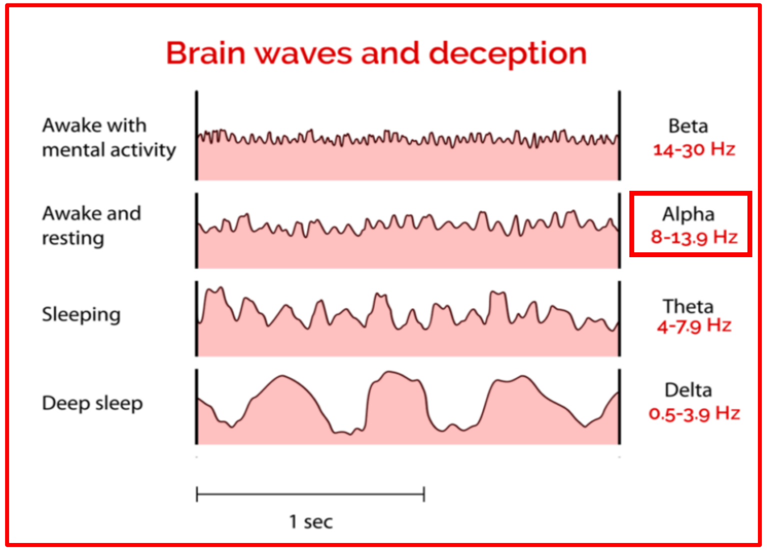
∴ **EEG mainly records extracellular currents that arise from synaptic activity in the dendrites of neurons.**

Appendix

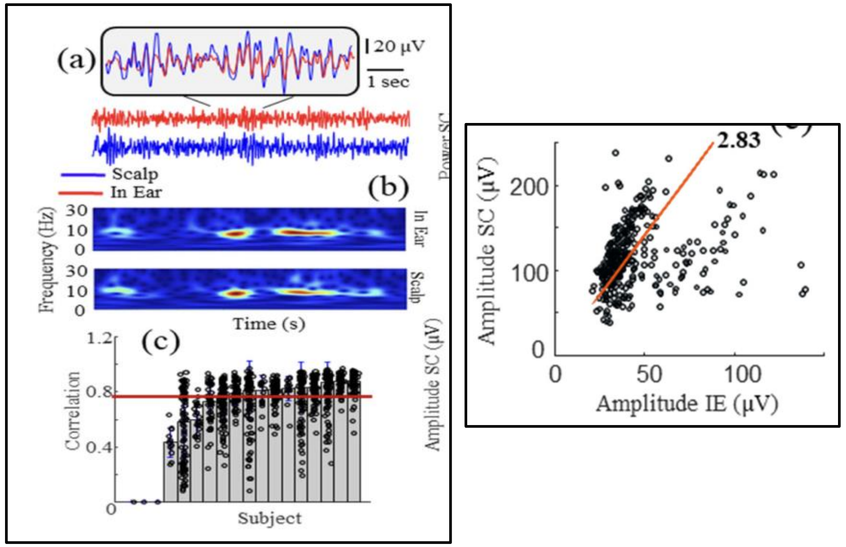
In-ear EEG



EEG source



Brain wave and deception



Scalp vs. In-ear EEG

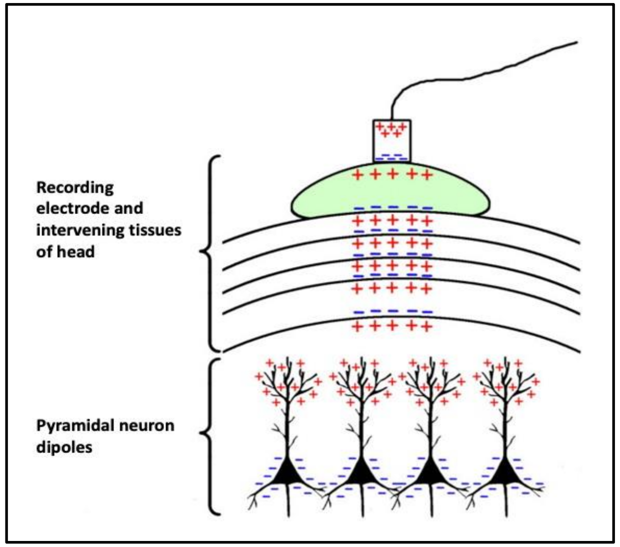
- Indeed, alpha rhythms are endogenous oscillations **in the 8–13 Hz frequency range that are primarily found during relaxed eye-closed**.
- The PDR (oscillatory, 8.5~12 Hz rhythm) **classically attenuates with eye opening because eye opening starts a stream of visual input that activates the visual cortex at the back of the head**.

∴ **Alpha rhythms are easy to be measured in laboratory condition.**

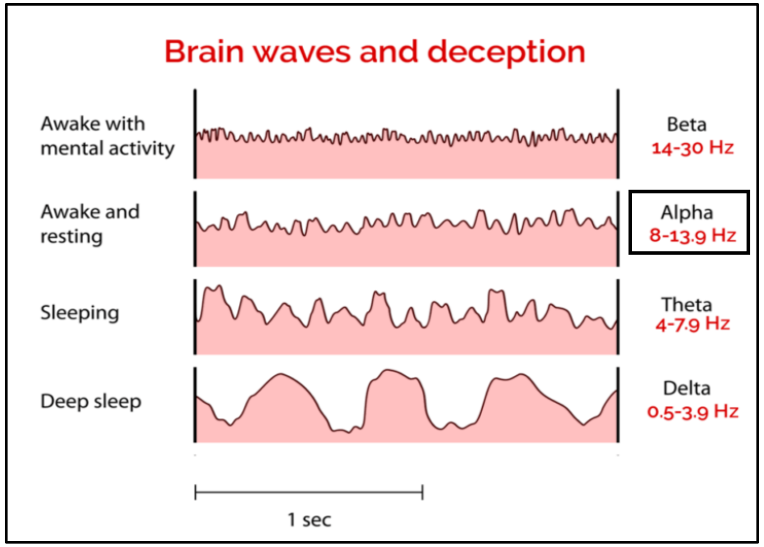
Appendix

In-ear EEG

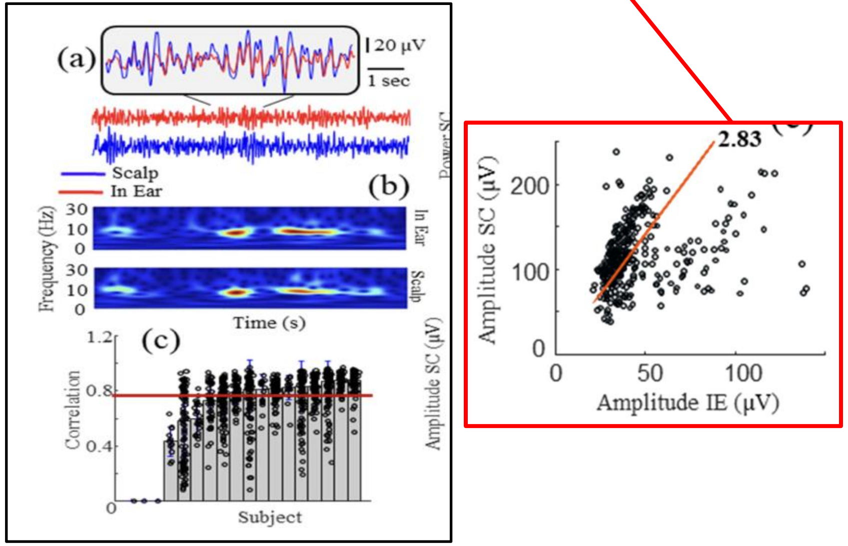
Fig 5. Artifacts amplitudes



EEG source



Brain wave and deception



Scalp vs. In-ear EEG

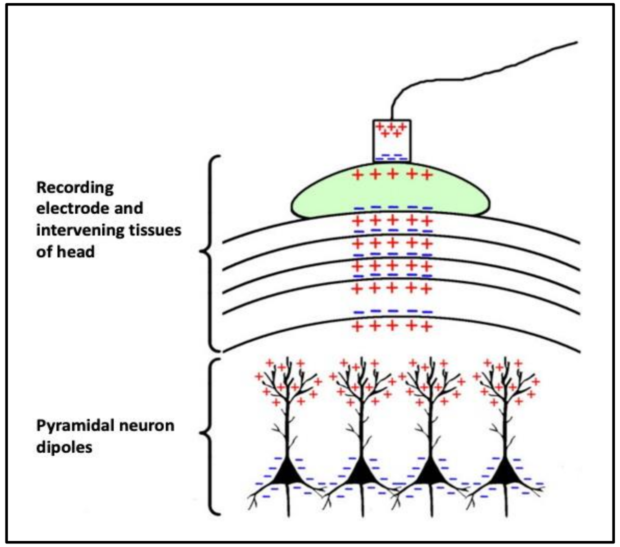
- Due to its proximity to the head, ear offers an unique spot to monitor the brain with the advantages of ①**less installation time compared to a traditional EEG setup**, ②**easy to wear**, ③**unobtrusive** and ④**less artifacts**.
- In-ear EEG systems **can be integrated as routine clinical tools** for continuously monitoring pathological signals outside clinical facilities (∵ demonstrated by recent studies.)

But, it should be similar to that of clinical facilities (conventional scalp EEG).

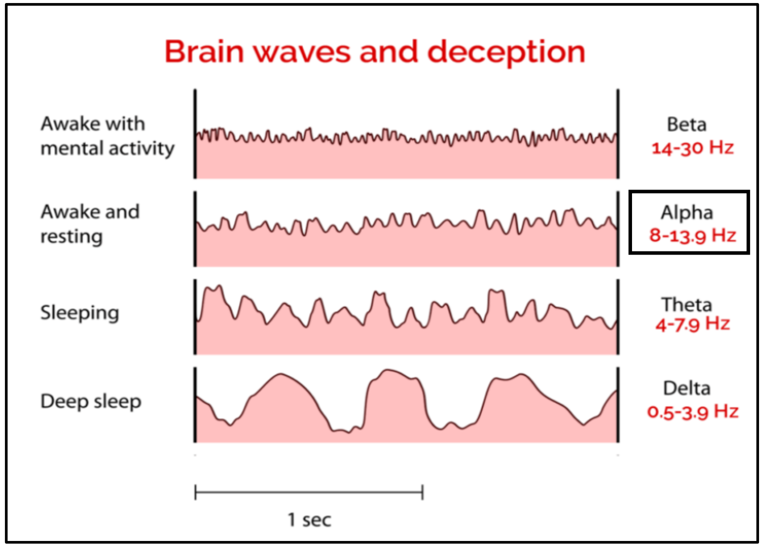
Appendix

In-ear EEG

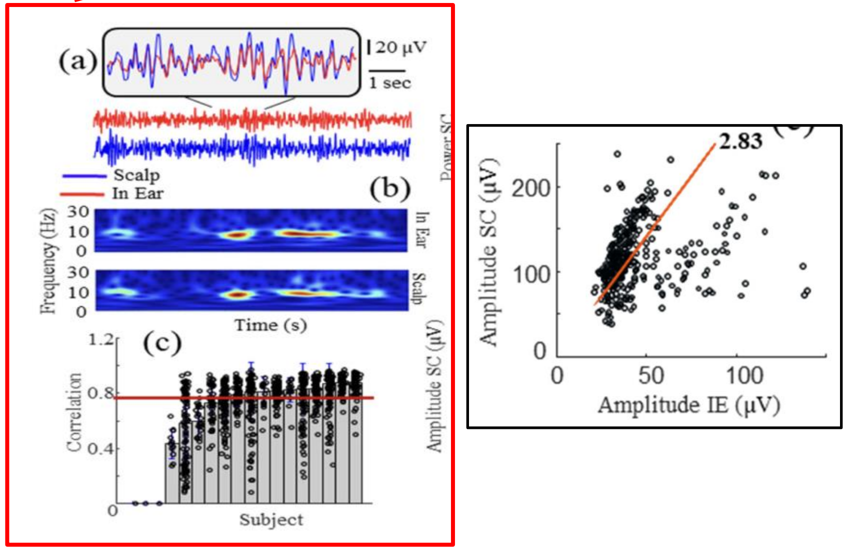
Fig 4. Correlation of α-wave when eyes closed



EEG source



Brain wave and deception



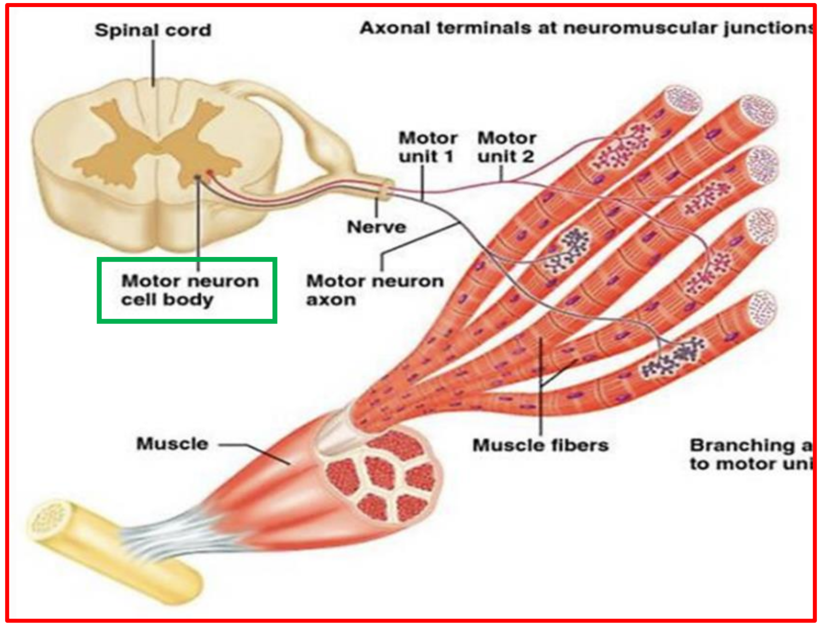
Scalp vs. In-ear EEG

- (Fig 4(a),(b)) An example of a short time segment of in-ear and scalp EEG signals for a subject with **a high cross-correlation** (subject 8) and **the corresponding relative spectrogram**
- (Fig 4(c)) The results consistently demonstrate **a broad range of correlations of alpha wave when eyes closed**, ranging from approximately 0.43 to 0.88, with a mean value of **0.76 ± 0.19 (mean ± std)**.

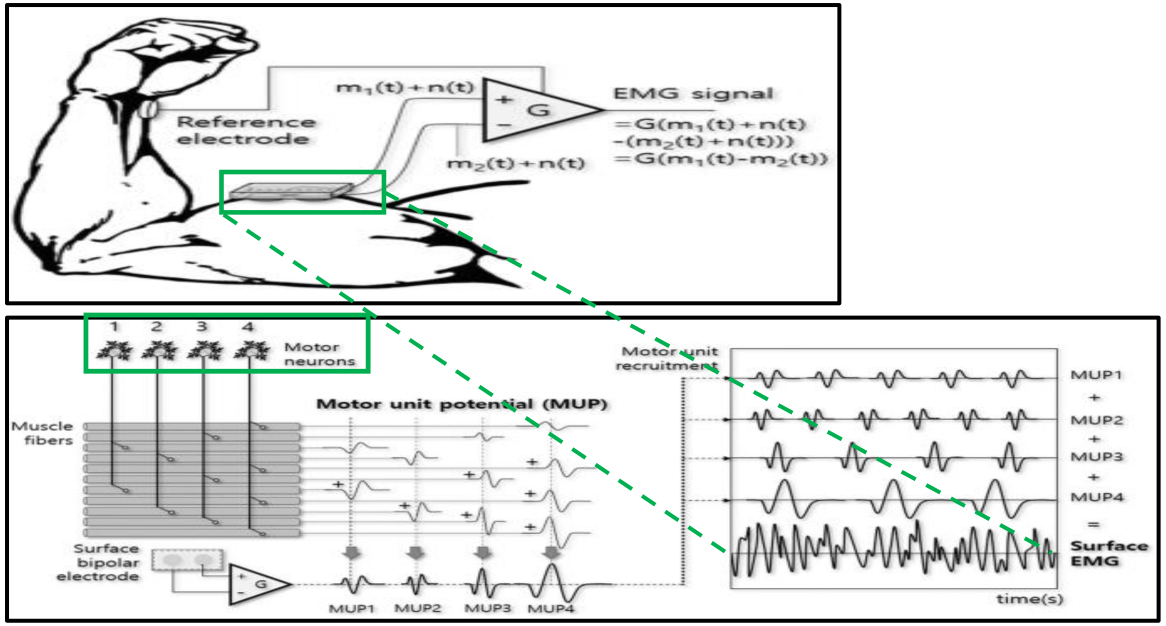
∴ **Similarities are proven. → We can expect measuring brain alpha wave in ear.**

Appendix

EMG



Neuro-muscular junction



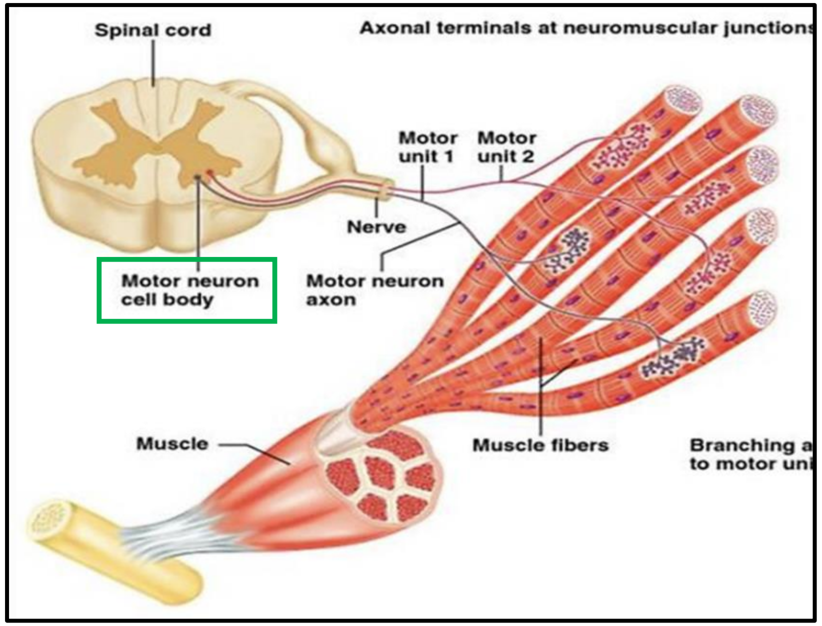
EMG measurement principle

- Electromyography (EMG): a method that measures the **action potentials of muscle fibers**
- When your brain tells your muscle to flex, it sends an electrical signal to your muscle to start recruiting motor unit.
- **The harder you flex, the more motor units are recruited to generate greater muscle force**.

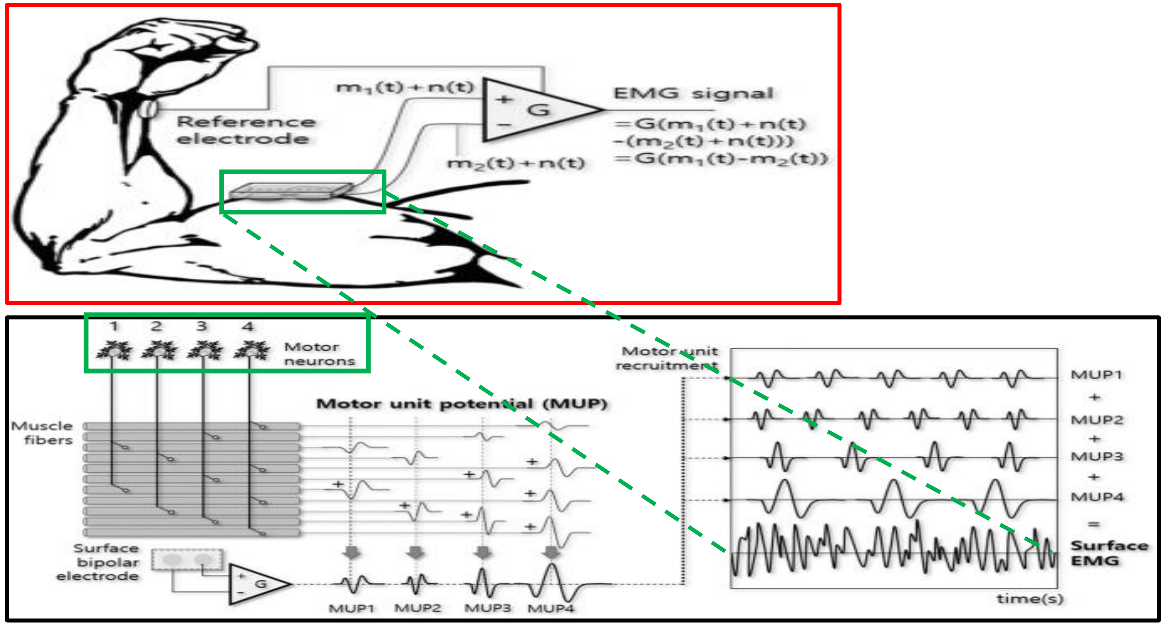
∴ **EMG measurement should reflect the hardness of flexing.**

Appendix

EMG



Neuro-muscular junction



EMG measurement principle

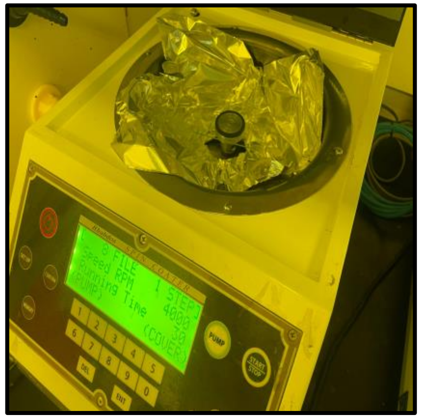
- The electrode should be placed **between two motor points**. And signals that are different at the two sites will have a "**differential**" that will be amplified.
- The reference electrode (at times called the ground electrode) is necessary for **providing a common reference** to the differential input of the preamplifier in the electrode. For this purpose, **the reference electrode should be placed as far away as possible and on electrically neutral tissue (say over a bony prominence).**

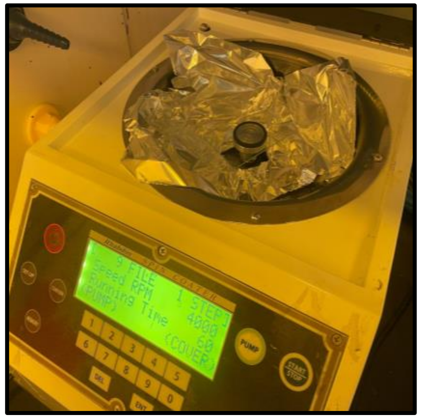
∴ **We decide this position to be an elbow.**

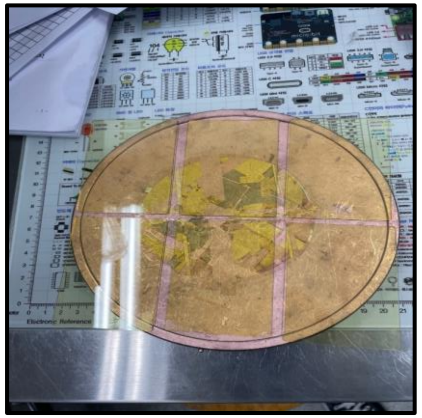
Appendix

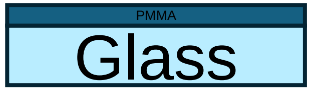
Flexible device fabrication process

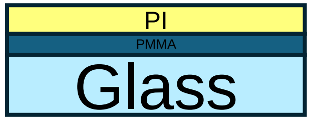
Glass cleaning & UV ozone	→	PMMA coating	→	PI coating	→	Vacuum oven
• Air gun, IPA • 3 min, UV ozone		• 4000 rpm, 30 s (10 nm) • 180 ℃, 3 min hard bake		• 4000 rpm, 60 s (3 μm) • 150 ℃, 5 min hard bake		• 300 ℃, 1 h

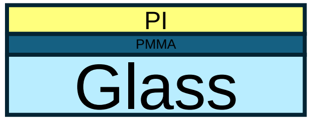












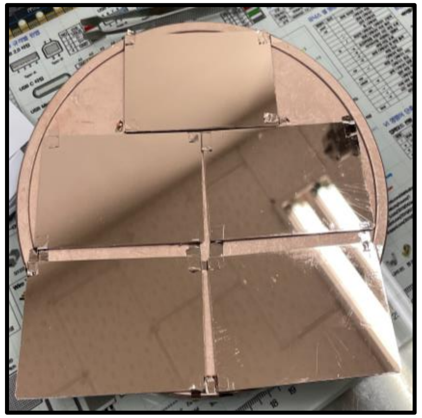
Appendix

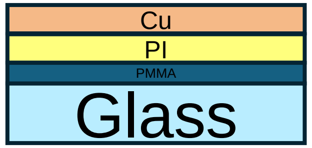
Flexible device fabrication process

Cu deposition → **Cleaning** → **PR coating** → **Exposure**

Cu deposition

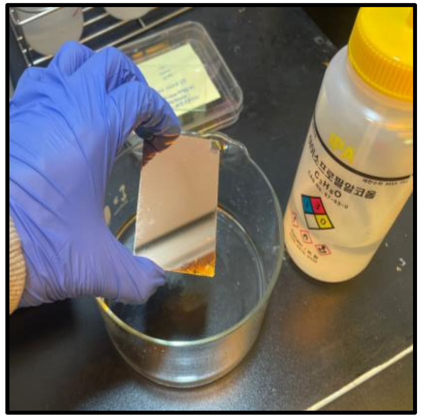
- E-beam evaporator
- 200 nm

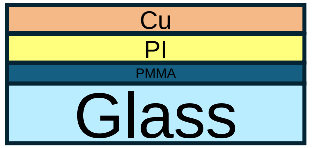




Cleaning

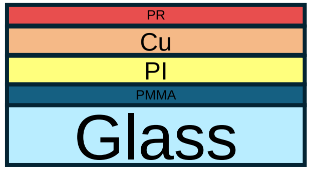
- IPA, acetone rinsing





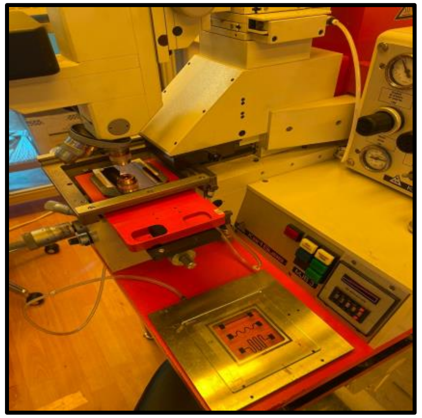
PR coating

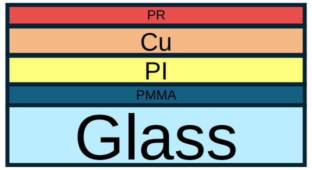
- 4000 rpm, 30 s
- 110 ℃, 1 min soft bake



Exposure

- 1 min

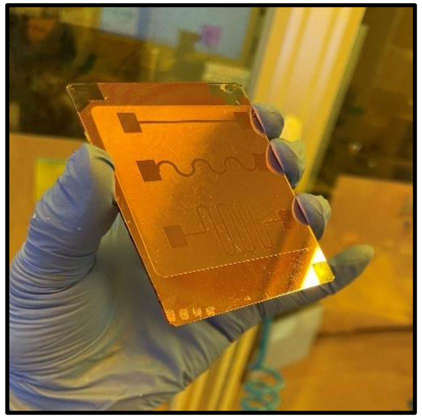


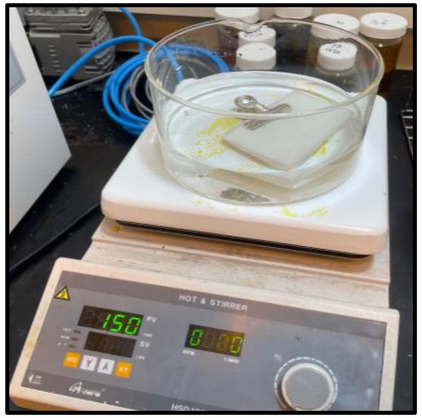


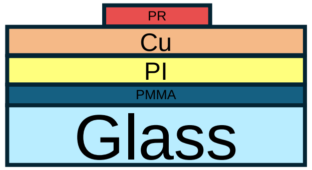
Appendix

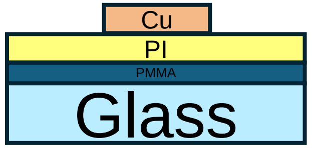
Flexible device fabrication process

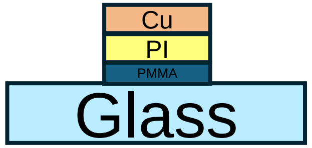
Develop	Cu etching	PI/PMMA etching	PMMA release
• Developer, 2 min • 110 ℃, 2 min PEB	• Cu etchant, 2 min • Acetone rinsing	• RIE • 3600 s, O_2 80 sccm	• Acetone, 150 ℃, 30 min

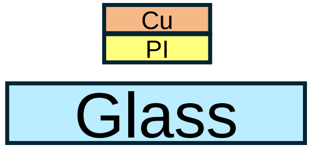




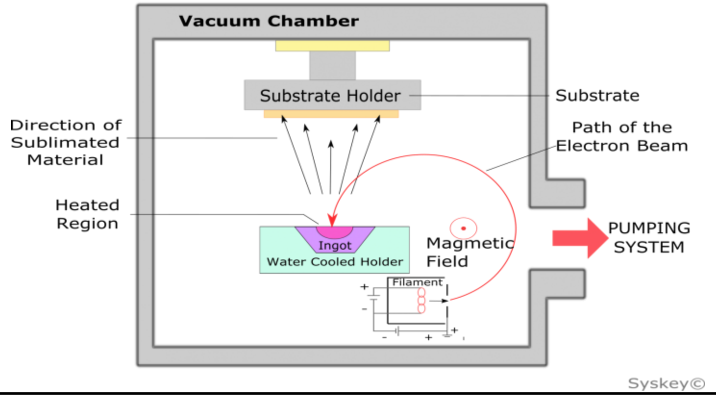
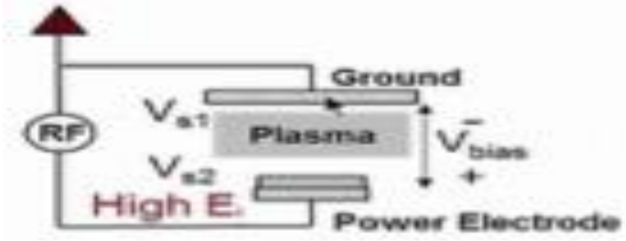






Appendix

Optimized recipe of fabrication

	E-beam evaporator	RIE
Purpose	Cu deposition	PI/PMMA dry etching
Equipment model	대동하이텍 Super high speed Evaporator System	AXIC Inc. PlasmaSTAR100
Equipment properties	• **<u>Cu</u>**, Al, Ag, Etc metal process • TSV & Process for plating substitute	• Pre-bond cleaning, **<u>polyimide etching</u>** • Water cooled (temperature controlled) parallel plate electrodes for RIE
Parameters	• Cu thickness (unit: Å or nm) 	• Etching source • Gas dose (unit: sccm) • Running time (unit: sec) • Source power (400 W fix) 

Appendix

Optimized recipe of fabrication

Device #	Cu thinkness (nm)	RIE source	RIE run time (sec)	Acetone dipping time (min)	Successful soldering	Qualified?	성공률
1	200	O2 80 sccm	3000	60	O	O	
2	200	O2 80 sccm	3000	60	O	X	
3	200	O2 80 sccm	3000	60	O	O	
4	200	O2 80 sccm	3000	60	O	X	
5	200	O2 80 sccm	3000	60	O	O	
6	200	O2 80 sccm	3000	60	O	X	
7	200	O2 80 sccm	3000	60	X	–	
8	200	O2 80 sccm	3000	60	O	O	
9	200	O2 80 sccm	3000	60	O	O	
10	200	O2 80 sccm	3000	60	O	O	10 of 15
11	200	O2 80 sccm	3000	60	O	X	
12	200	O2 80 sccm	3000	60	–	–	
13	200	O2 80 sccm	3000	60	–	–	
14	200	O2 80 sccm	3000	60	O	O	
15	200	O2 80 sccm	3000	60	O	O	
16	200	O2 80 sccm	3000	60	O	O	
17	200	O2 80 sccm	3000	60	O	O	
18	200	O2 80 sccm	3000	60	O	X	
19	200	O2 80 sccm	3600	30	O	O	
20	200	O2 80 sccm	3600	30	O	O	
21	200	O2 80 sccm	3600	30	O	O	
22	200	O2 80 sccm	3600	30	O	X	
23	200	O2 80 sccm	3600	30	O	O	
24	200	O2 80 sccm	3600	30	O	O	
25	200	O2 80 sccm	3600	30	O	X	
26	200	O2 80 sccm	3600	30	O	O	
27	200	O2 80 sccm	3600	30	X	–	13 of 16
28	200	O2 80 sccm	3600	30	O	O	
29	200	O2 80 sccm	3600	30	O	O	
30	200	O2 80 sccm	3600	30	O	O	
31	200	O2 80 sccm	3600	30	O	[illegible]	
32	200	O2 80 sccm	3600	30	–	[illegible]	
33	200	O2 80 sccm	3600	30	O	[illegible]	
34	200	O2 80 sccm	3600	30	O	[illegible]	
35	200	O2 80 sccm	3600	30	O	O	
36	200	O2 80 sccm	3600	30	O	O	

O | qualified
X | unqualified
- | failed before transferring

$$\text{성공률} = \frac{\text{O 개수}}{(\text{O} + \text{X})\text{ 개수}}$$

*** Qualified = ① Qualitive: fine critical dimension, ② Quantitative: < 20 Ω device resistance before transferring**

Appendix

Optimized recipe of fabrication

Device #	Cu thinkness (nm)	RIE source	RIE run time (sec)	Acetone dipping time (min)	Successful soldering	Qualified?	성공률
37	200	O2 80 sccm	4000	20	O	X	5 of 13
38	200	O2 80 sccm	4000	20	O	X	
39	200	O2 80 sccm	4000	20	O	O	
40	200	O2 80 sccm	4000	20	O	X	
41	200	O2 80 sccm	4000	20	O	O	
42	200	O2 80 sccm	4000	20	O	O	
43	200	O2 80 sccm	4000	20	–	–	
44	200	O2 80 sccm	4000	20	–	–	
45	200	O2 80 sccm	4000	20	–	–	
46	200	O2 80 sccm	4000	20	O	X	
47	200	O2 80 sccm	4000	20	O	X	
48	200	O2 80 sccm	4000	20	X	–	
49	200	O2 80 sccm	4000	20	O	X	
50	200	O2 80 sccm	4000	20	O	O	
51	200	O2 80 sccm	4000	20	O	X	
52	200	O2 80 sccm	4000	20	–	–	
53	200	O2 80 sccm	4000	20	O	X	
54	200	O2 80 sccm	4000	20	O	O	
55	200	O2 80 sccm + CF4 15 sccm	600	20	O	X	3 of 9
56	200	O2 80 sccm + CF4 15 sccm	600	20	O	X	
57	200	O2 80 sccm + CF4 15 sccm	600	20	O	X	
58	200	O2 80 sccm + CF4 15 sccm	600	20	–	–	
59	200	O2 80 sccm + CF4 15 sccm	600	20	–	–	
60	200	O2 80 sccm + CF4 15 sccm	600	20	–	–	
61	200	O2 80 sccm + CF4 15 sccm	600	20	–	–	
62	200	O2 80 sccm + CF4 15 sccm	600	20	–	–	
63	200	O2 80 sccm + CF4 15 sccm	600	20	–	–	
64	200	O2 80 sccm + CF4 15 sccm	600	20	O	X	
65	200	O2 80 sccm + CF4 15 sccm	600	20	O	O	
66	200	O2 80 sccm + CF4 15 sccm	600	20	O	O	
67	200	O2 80 sccm + CF4 15 sccm	600	20	–	–	
68	200	O2 80 sccm + CF4 15 sccm	600	20	–	–	
69	200	O2 80 sccm + CF4 15 sccm	600	20	O	X	
70	200	O2 80 sccm + CF4 15 sccm	600	20	O	X	
71	200	O2 80 sccm + CF4 15 sccm	600	20	O	O	
72	200	O2 80 sccm + CF4 15 sccm	600	20	–	–	

*** Qualified = ① Qualitive: fine critical dimension, ② Quantitative: < 20 Ω device resistance before transferring**

Appendix

Optimized recipe of fabrication

Device #	Cu thinkness (nm)	RIE source	RIE run time (sec)	Acetone dipping time (min)	Successful soldering	Qualified?	성공률
73	300	O2 80 sccm	3600	30	O	O	9 of 15
74	300	O2 80 sccm	3600	30	O	X	
75	300	O2 80 sccm	3600	30	—	—	
76	300	O2 80 sccm	3600	30	O	X	
77	300	O2 80 sccm	3600	30	O	O	
78	300	O2 80 sccm	3600	30	O	O	
79	300	O2 80 sccm	3600	30	O	O	
80	300	O2 80 sccm	3600	30	O	O	
81	300	O2 80 sccm	3600	30	O	X	
82	300	O2 80 sccm	3600	30	—	—	
83	300	O2 80 sccm	3600	30	—	—	
84	300	O2 80 sccm	3600	30	O	X	
85	300	O2 80 sccm	3600	30	O	X	
86	300	O2 80 sccm	3600	30	O	O	
87	300	O2 80 sccm	3600	30	O	X	
88	300	O2 80 sccm	3600	30	O	O	
89	300	O2 80 sccm	3600	30	O	O	
90	300	O2 80 sccm	3600	30	O	O	
91	500	O2 80 sccm	3600	30	O	X	9 of 16
92	500	O2 80 sccm	3600	30	—	—	
93	500	O2 80 sccm	3600	30	O	O	
94	500	O2 80 sccm	3600	30	O	X	
95	500	O2 80 sccm	3600	30	O	O	
96	500	O2 80 sccm	3600	30	O	O	
97	500	O2 80 sccm	3600	30	O	X	
98	500	O2 80 sccm	3600	30	O	O	
99	500	O2 80 sccm	3600	30	O	X	
100	500	O2 80 sccm	3600	30	O	O	
101	500	O2 80 sccm	3600	30	O	O	
102	500	O2 80 sccm	3600	30	O	X	
103	500	O2 80 sccm	3600	30	—	—	
104	500	O2 80 sccm	3600	30	O	O	
105	500	O2 80 sccm	3600	30	O	X	
106	500	O2 80 sccm	3600	30	O	O	
107	500	O2 80 sccm	3600	30	O	O	
108	500	O2 80 sccm	3600	30	O	X	

*** Qualified = ① Qualitive: fine critical dimension, ② Quantitative: < 20 Ω device resistance before transferring**

Appendix

Optimized recipe of fabrication

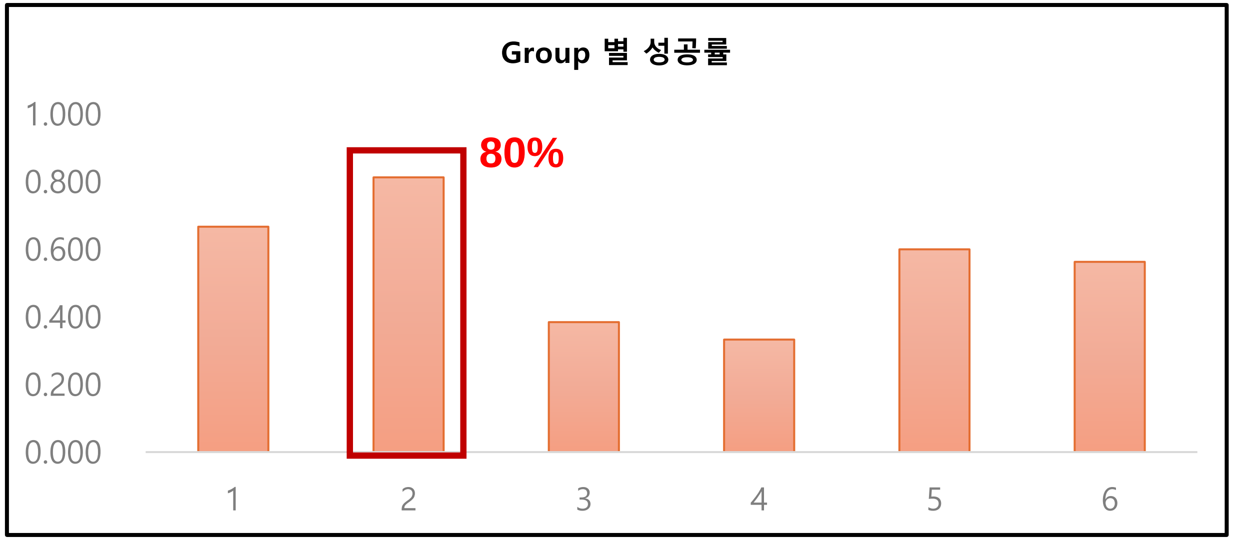
Group #	Cu thickness (nm)	RIE Source & Dose	RIE run time (s)	Acetone time (min)	Quantitative result
1	200	O_2 80 sccm	3000	60	10 of 15
2	200	O_2 80 sccm	3600	30	13 of 16
3	200	O_2 80 sccm	4000	20	5 of 13
4	200	O_2 80 sccm + CF_4 15 sccm	600	20	3 of 9
5	300	O_2 80 sccm	3600	30	9 of 15
6	500	O_2 80 sccm	3600	30	9 of 16

Group #	Qualitative reasoning
1	PI residue amount ↑
2	PI residue amount ↓, Patterns were stable
3	PI residue amount ↓↓, Patterns detached afterwards
4	PI residue amount ↓, Patterns detached afterwards, Toxic gas off necessary
5	Device detaching hardness ↑, Etching time ↑
6	Device detaching hardness ↑↑ , Etching time ↑↑

Appendix

Optimized recipe of fabrication

Group #	Cu thickness (nm)	RIE Source & Dose	RIE run time (s)	Acetone time (min)	Quantitative result
1	200	O_2 80 sccm	3000	60	10 of 15
2	200	O_2 80 sccm	3600	30	13 of 16
3	200	O_2 80 sccm	4000	20	5 of 13
4	200	O_2 80 sccm + CF_4 15 sccm	600	20	3 of 9
5	300	O_2 80 sccm	3600	30	9 of 15
6	500	O_2 80 sccm	3600	30	9 of 16



① E-beam Recipe

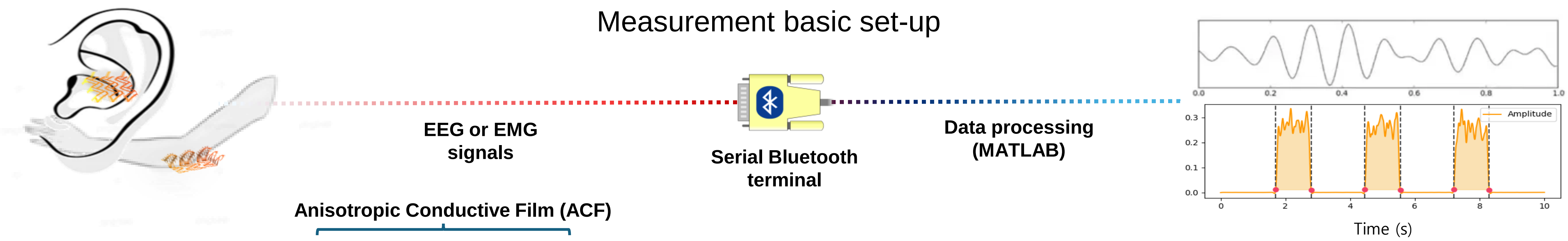
{Thickness: 200 nm}

② RIE Recipe

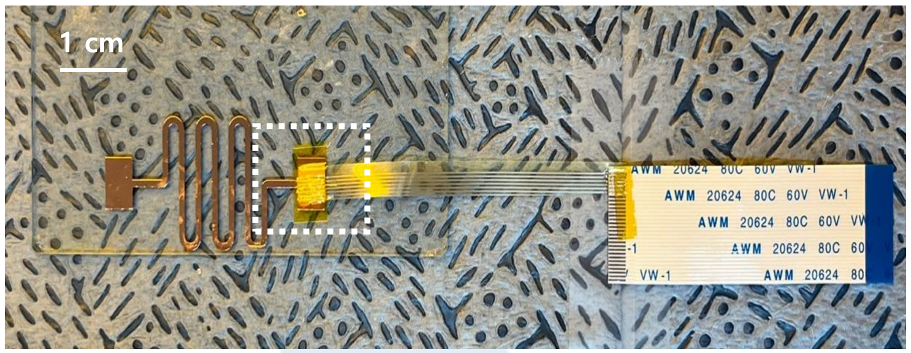
Frequency: 13.56 MHz
Power: 400 W
Source: O_2 80 sccm
Run time: 3600 s

Appendix

Measurement basic set-up

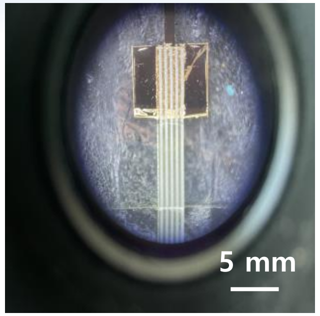


Anisotropic Conductive Film (ACF)

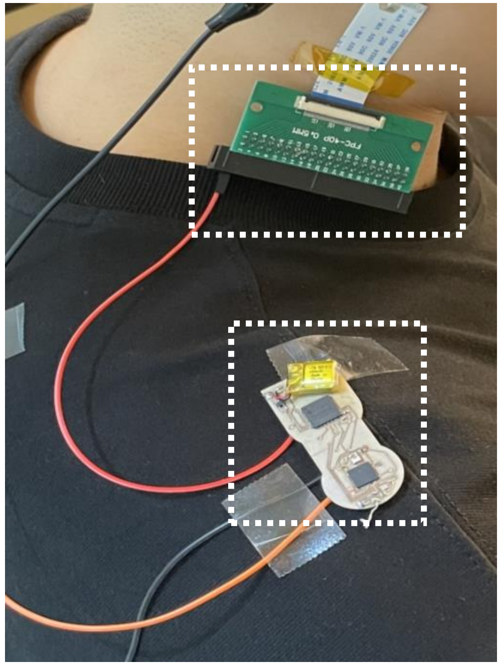


Flexible device

Flat flexible cable (FFC)



Connect through soldering

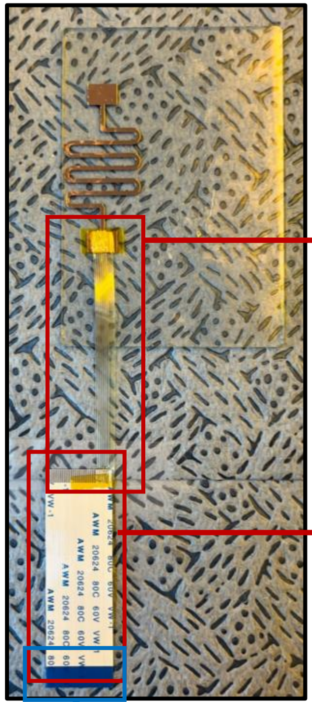


FFC adaptor

Bluetooth low-energy (BLE) transceiver circuit

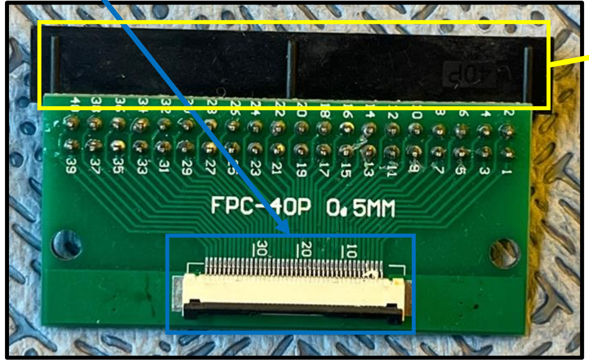
Appendix

EP measurement components



- **Anisotropic Conductive Film (ACF)**:
가열/가압 과정을 통해 한쪽 방향으로만 전류가 통하게 하는 도전막 → 225 ℃의 납땜기를 통해 flexible device와 FFC 사이를 연결

- **Flat Flexible Cable (FFC)**:
유연성이라는 장점으로 device와 회로 사이를 연결하는 케이블 → Transfer printing 과정에서의 안정성을 위해 ACF와의 연결 후 PI tape로 고정, FFC 끝 부분을 FFC adaptor와 연결



- **FFC adaptor**:
FFC와 회로를 안정적으로 연결, adaptor를 통하면 이후 와이어를 활용하여 쉽게 회로와 연결 가능

- **Bluefruit Connect**
- **Serial Bluetooth Terminal**

- **Bluetooth low-energy (BLE) transceiver circuit**:
Flexible device로 측정한 EP signal data를 Bluetooth를 통해 가까운 monitoring device로 전송.
500 mAh, 1.85 Wh, 3.7 V의 배터리를 회로에 연결하여 활용

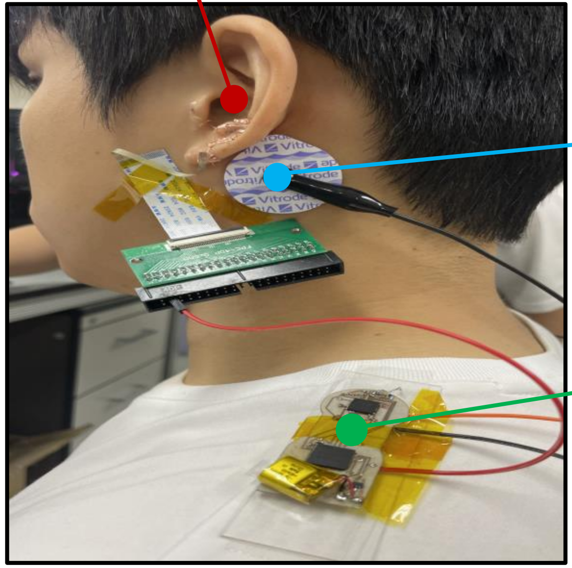
Appendix

In-ear EEG measurement scheme

- Alpha wave measurement (with conductive gel)

1. Eyes closed : 3 min
2. Eyes open: 3 min

- REC: flexible device
(for practical measurement)
→ 귀 안 / 귀 바깥



- REF/GND: commercial electrode
(for stable measurement)
→ 귀 뒤 – 귀 뒤 / 이마 – 귀 뒤

- Circuit with battery
→ 어깨 / 등 뒤

Appendix

In-ear EEG measurement preparation

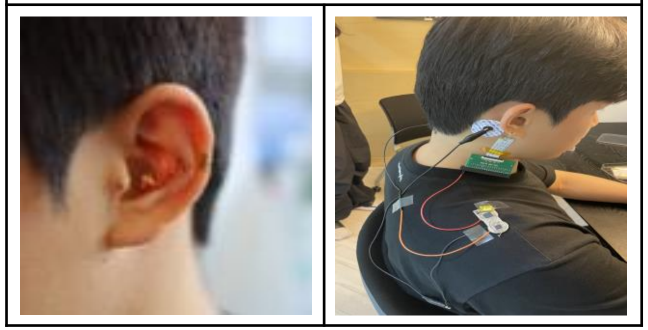
- 최적화한 recipe로 In-ear EEG용 소자 36개 제작 → **32/36이 적합 소자로 판명**

Device #	REC	REF&GND	Circuit	성공 여부
1	귀 안쪽	귀 뒤	어깨	X
2	귀 안쪽	귀 뒤	어깨	O
3	귀 안쪽	귀 뒤	어깨	O
4	귀 안쪽	귀 뒤	어깨	O
5	귀 안쪽	귀 뒤	등 뒤	O
6	귀 안쪽	귀 뒤	등 뒤	O
7	귀 안쪽	귀 뒤	등 뒤	X
8	귀 안쪽	귀 뒤	등 뒤	O
9	귀 안쪽	이마	어깨	X
10	귀 안쪽	이마	어깨	X
11	귀 안쪽	이마	어깨	X
12	귀 안쪽	이마	어깨	X
13	귀 안쪽	이마	등 뒤	X
14	귀 안쪽	이마	등 뒤	X
15	귀 안쪽	이마	등 뒤	X
16	귀 안쪽	이마	등 뒤	X
17	귀 바깥	귀 뒤	어깨	X
18	귀 바깥	귀 뒤	어깨	X
19	귀 바깥	귀 뒤	어깨	X
20	귀 바깥	귀 뒤	어깨	X
21	귀 바깥	귀 뒤	등 뒤	X
22	귀 바깥	귀 뒤	등 뒤	X
23	귀 바깥	귀 뒤	등 뒤	X
24	귀 바깥	귀 뒤	등 뒤	X
25	귀 바깥	이마	어깨	X
26	귀 바깥	이마	어깨	X
27	귀 바깥	이마	어깨	X
28	귀 바깥	이마	어깨	X
29	귀 바깥	이마	등 뒤	X
30	귀 바깥	이마	등 뒤	X
31	귀 바깥	이마	등 뒤	X
32	귀 바깥	이마	등 뒤	X

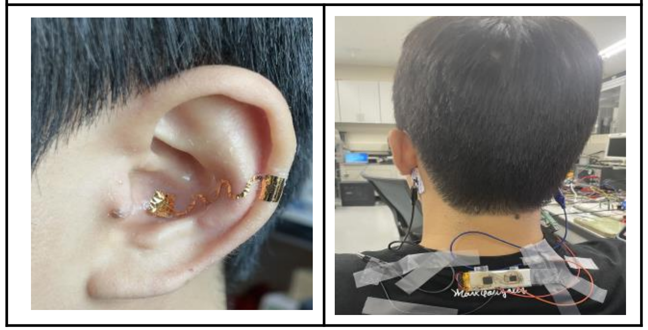
① ② ③ ④ ⑤ ⑥ ⑦ ⑧

- **REC 위치 / REF & GND 위치 / Circuit 위치를 기준으로 8개로 그룹화**

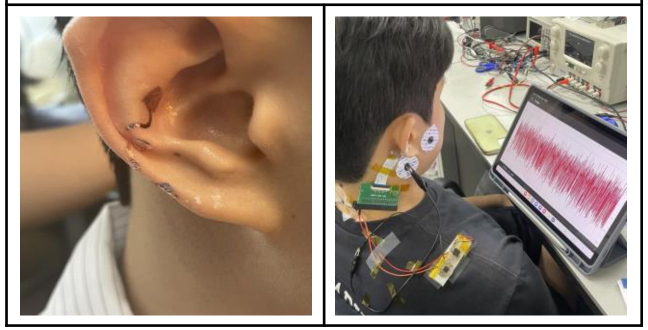
Group①: REC 귀 안쪽 / REF&GND 귀 뒤 / Circuit 어깨



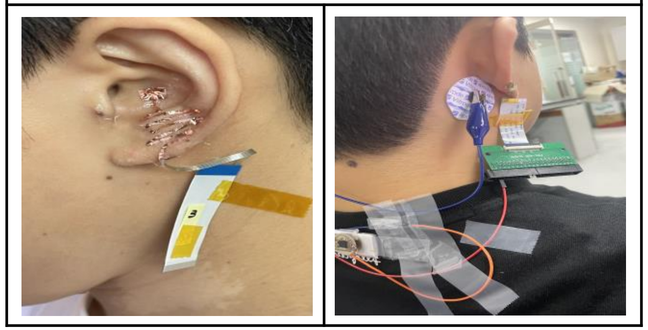
Group②: REC 귀 안쪽 / REF&GND 귀 뒤 / Circuit 등 뒤



Group③: REC 귀 안쪽 / REF&GND 이마 / Circuit 어깨



Group④: REC 귀 안쪽 / REF&GND 이마 / Circuit 등 뒤



Appendix

In-ear EEG measurement preparation

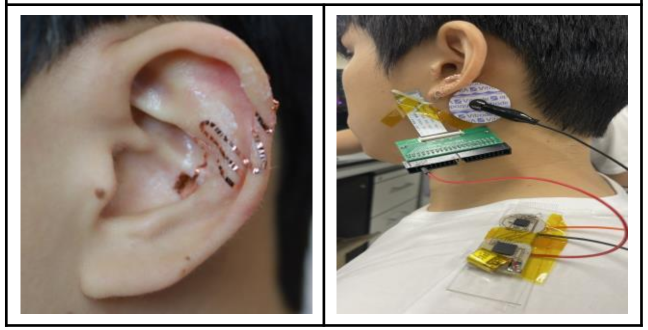
- 최적화한 recipe로 In-ear EEG용 소자 36개 제작 → **32/36이 적합 소자로 판명**

Device #	REC	REF&GND	Circuit	성공 여부
1	귀 안쪽	귀 뒤	어깨	X
2	귀 안쪽	귀 뒤	어깨	O
3	귀 안쪽	귀 뒤	어깨	O
4	귀 안쪽	귀 뒤	어깨	O
5	귀 안쪽	귀 뒤	등 뒤	O
6	귀 안쪽	귀 뒤	등 뒤	O
7	귀 안쪽	귀 뒤	등 뒤	X
8	귀 안쪽	귀 뒤	등 뒤	O
9	귀 안쪽	이마	어깨	X
10	귀 안쪽	이마	어깨	X
11	귀 안쪽	이마	어깨	X
12	귀 안쪽	이마	어깨	X
13	귀 안쪽	이마	등 뒤	X
14	귀 안쪽	이마	등 뒤	X
15	귀 안쪽	이마	등 뒤	X
16	귀 안쪽	이마	등 뒤	X
17	귀 바깥	귀 뒤	어깨	X
18	귀 바깥	귀 뒤	어깨	X
19	귀 바깥	귀 뒤	어깨	X
20	귀 바깥	귀 뒤	어깨	X
21	귀 바깥	귀 뒤	등 뒤	X
22	귀 바깥	귀 뒤	등 뒤	X
23	귀 바깥	귀 뒤	등 뒤	X
24	귀 바깥	귀 뒤	등 뒤	X
25	귀 바깥	이마	어깨	X
26	귀 바깥	이마	어깨	X
27	귀 바깥	이마	어깨	X
28	귀 바깥	이마	어깨	X
29	귀 바깥	이마	등 뒤	X
30	귀 바깥	이마	등 뒤	X
31	귀 바깥	이마	등 뒤	X
32	귀 바깥	이마	등 뒤	X

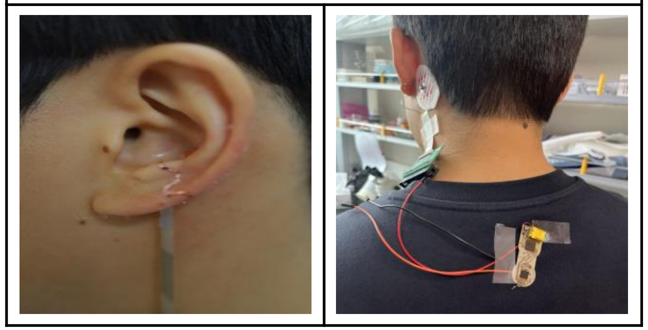
① ② ③ ④ ⑤ ⑥ ⑦ ⑧

- **REC 위치 / REF & GND 위치 / Circuit 위치를 기준으로 8개로 그룹화**

Group⑤: REC 귀 바깥 / REF&GND 귀 뒤 / Circuit 어깨



Group⑥: REC 귀 바깥 / REF&GND 귀 뒤 / Circuit 등 뒤



Group⑦: REC 귀 바깥 / REF&GND 이마 / Circuit 어깨

Group⑧: REC 귀 바깥 / REF&GND 이마 / Circuit 등 뒤

Appendix

In-ear EEG qualitative reasoning

Group #	Condition			Qualitative reasoning
	REC	GND&REF	Circuit	
1	**Inner concha**	**Behind ears**	**Shoulder**	**Inner concha, signals strong, minimum noise**
2	**Inner concha**	**Behind ears**	**Back**	**Inner concha, signals strong, minimum noise**
3	Inner concha	Forehead / behind ear	Shoulder	Forehead, blinking eyes cause noise
4	Inner concha	Forehead / behind ear	Back	Forehead, blinking eyes cause noise
5	Outer concha	Behind ears	Shoulder	Outer concha, signals weak
6	Outer concha	Behind ears	Back	Outer concha, signals weak
7	Outer concha	Forehead / behind ear	Shoulder	Outer concha, signals weak
8	Outer concha	Forehead / behind ear	Back	Outer concha, signals weak

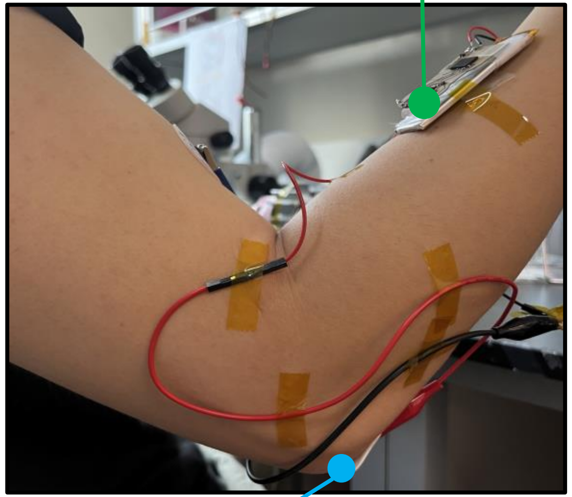
Appendix

EMG measurement scheme

- EMG measurement
  1. Tension
  2. Relax

- Why elbow?

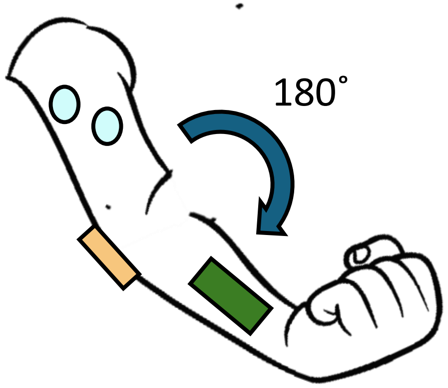
→ For stable measurement with minimum noise



Appendix

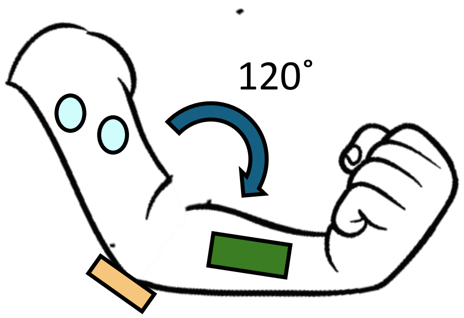
EMG performance test

- Extension



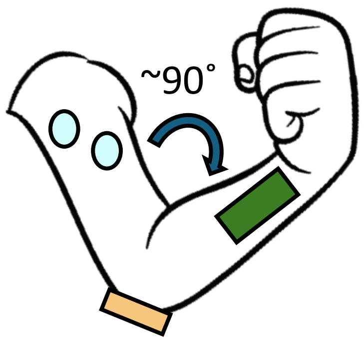
tension: 3s
relax: 3s
} x4

- Partial flexion



tension: 3s
relax: 3s
} x4

- Flexion



tension: 3s
relax: 3s
} x4

- 1 cycle: Extension → Partial flexion → Flexion
- Total 2 cycles

REF (commercial vs flexible) | **2 Signals (commercial)**

2. In-ear EEG & EMG measurement

Measurement basic set-up