

MINDBEAGLE

BRAIN ASSESSMENT AND
COMMUNICATION

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Companies

g.tec medical engineering GmbH

Schiedlberg, Austria

Graz, Austria

Albany, New York, USA

Barcelona, Spain,

Vancouver, Canada

Hong Kong

Sapporo, Japan



Research Projects

- **H2020 Eurostars: seizureAI** – epilepsy monitoring and deep learning with EEG
- **H2020 Eurostars: ComaAid** – combination of EEG and fNIRS for DOC patients
- **H2020 Eurostars: EEG-DDS** – combination of EEG with decision support system
- **FFG: BrainGait** – combination of BCIs for rehabilitation with treadmills
- **H2020: MultiSense** – combination of DBS with physiology
- **FFG: recoveriX-Leg** – lower limb stroke rehabilitation with BCI
- **H2020: Rhumbo** – magnetic stimulation of the cortex



Research Projects

- H2020: HOPE – high frequency oscillation detection in epilepsy
- H2020 ITN: Pro-Gait – combination of BCIs with exoskeletons
- H2020 ITN: DOCMA – international training network for BCIs and DOC
- Marie-Curie: MoveAgain – combination of recoveriX with TMS, tDCS
- H2020: Astonish – fNIRS and EEG
- H2020 Eurostars: ComAlert – coma prediction
- EC Flagship: Graphene – development of Graphene electrodes
- BeMagic – magnetic stimulation of the brain



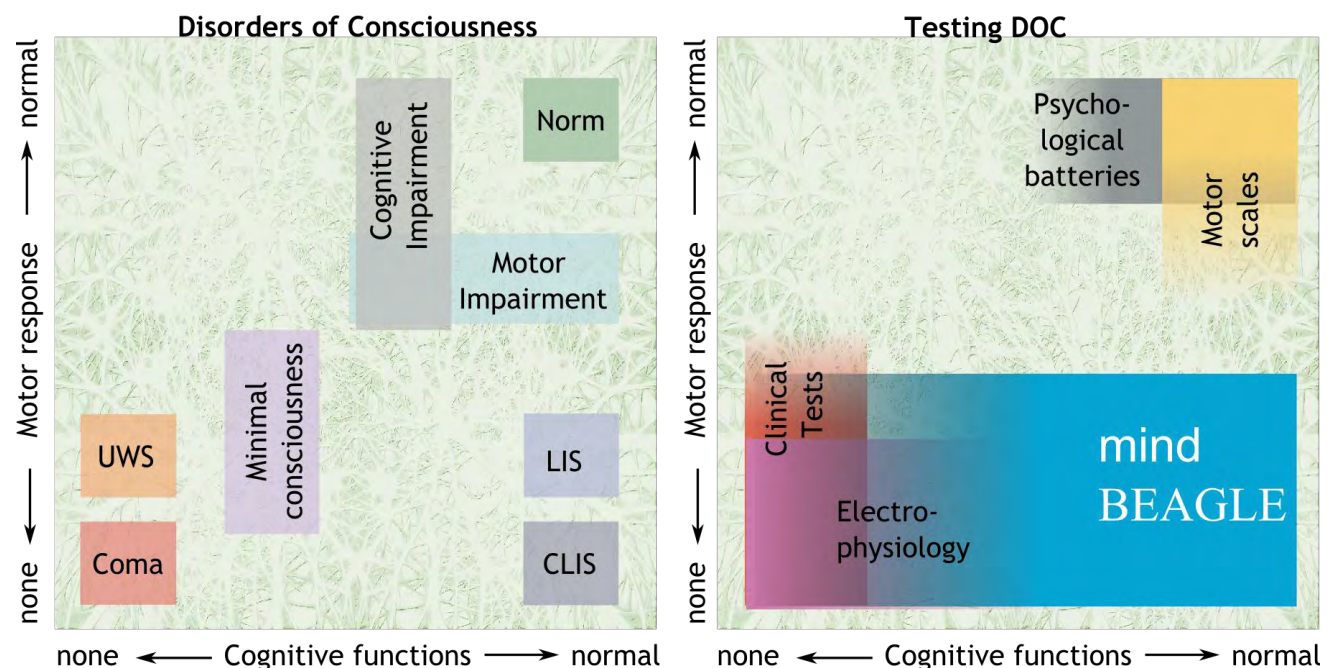
recoveriX

NEUROTECHNOLOGY



Motivation

43% of patients diagnosed as unresponsive wakefulness state (UWS) are **reclassified** as (at least) minimally conscious when assessed by expert teams



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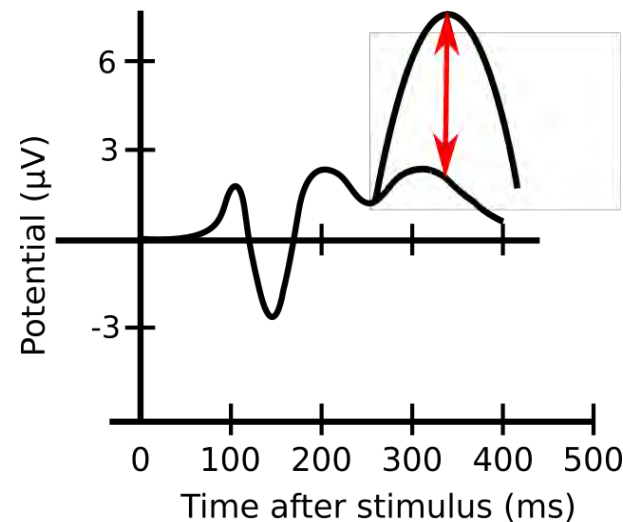
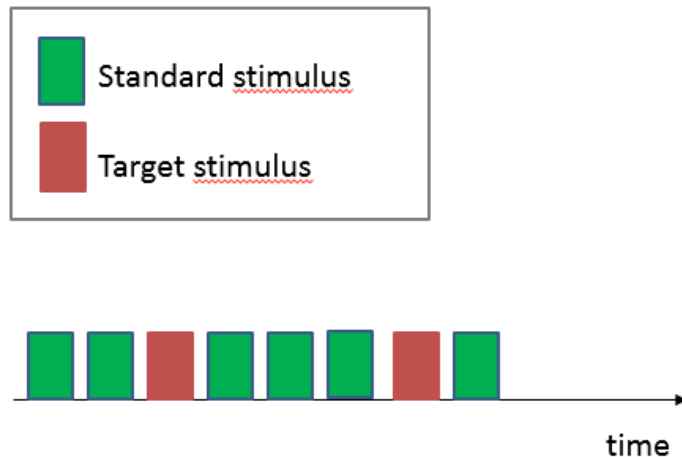


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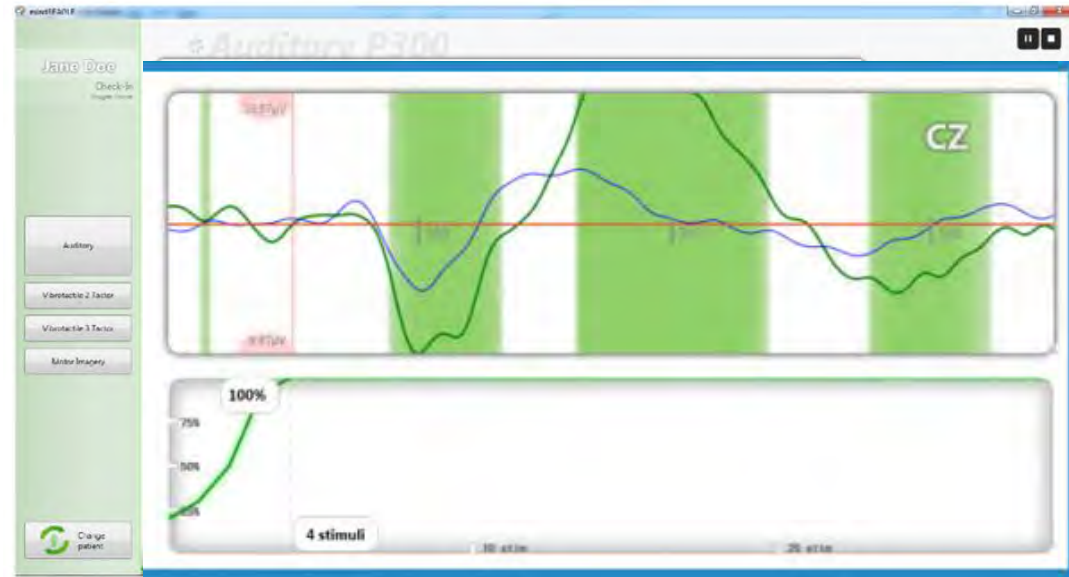
The oddball paradigm

- **Oddball stimulation:** A sequence of frequent standard stimuli is interrupted by rarely occurring deviant stimuli
- Stimuli can be different with regard to **duration** or **pitch**
- In a train of **standard** stimuli, there is an infrequent oddball stimulus, the **target** stimulus



Auditory and Vibro-tactile paradigms

- **Auditory paradigm**
8 min experimental time
Low versus high tones



- **Vibro-tactile 2 and 3 paradigm**
2.5 min experimental time
Attention to target vibrotactile stimulus



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YES/NO answers



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YES/NO answers



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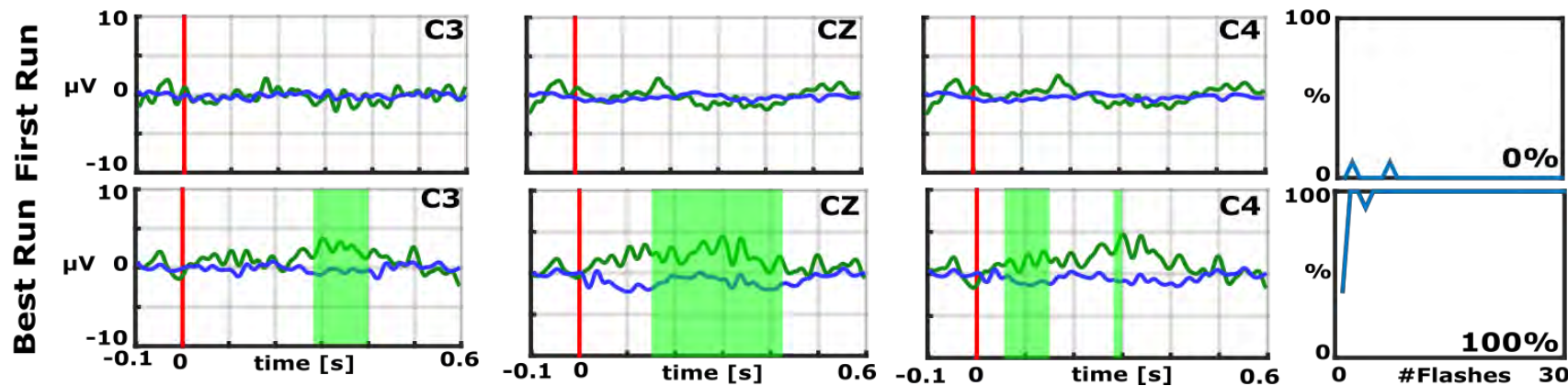
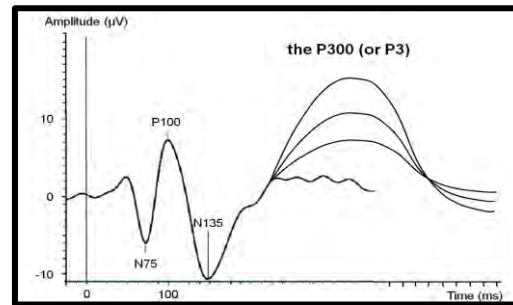
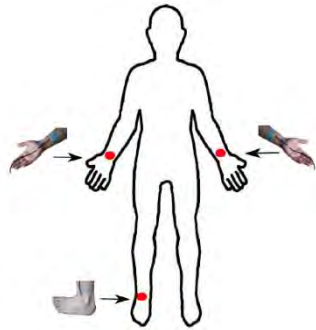
Evoked Potentials and Classification accuracy

SH-008

Age: 39

Female

Hypoxia, 19 months, UWS, CRS-R total: 4



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Assessment: no possible communication

UWS, but seemed to follow me in the room

T T T T
NT NT NT NT

The median accuracy is 20%

24 trials, out of 480, were classified as artifact. (5%)



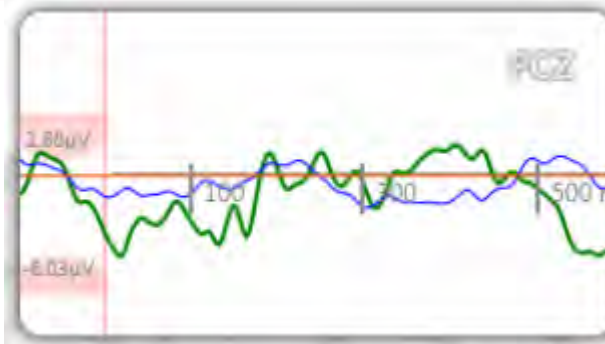
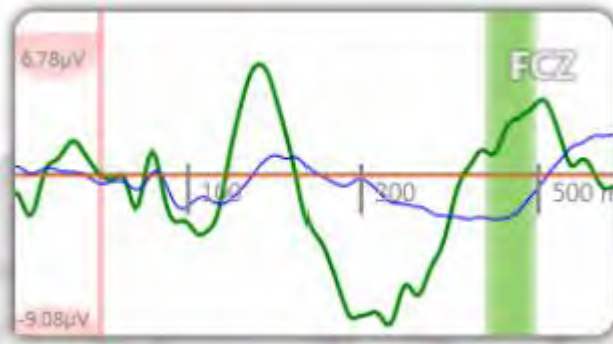
T T T T
NT NT NT NT

The median accuracy is 0%

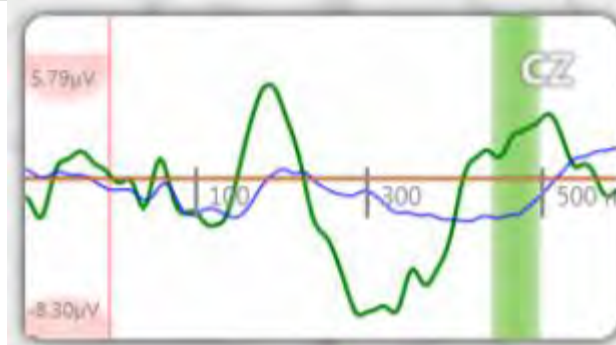
14 trials, out of 480, were classified as artifact. (2.9%)



VT2



AEP



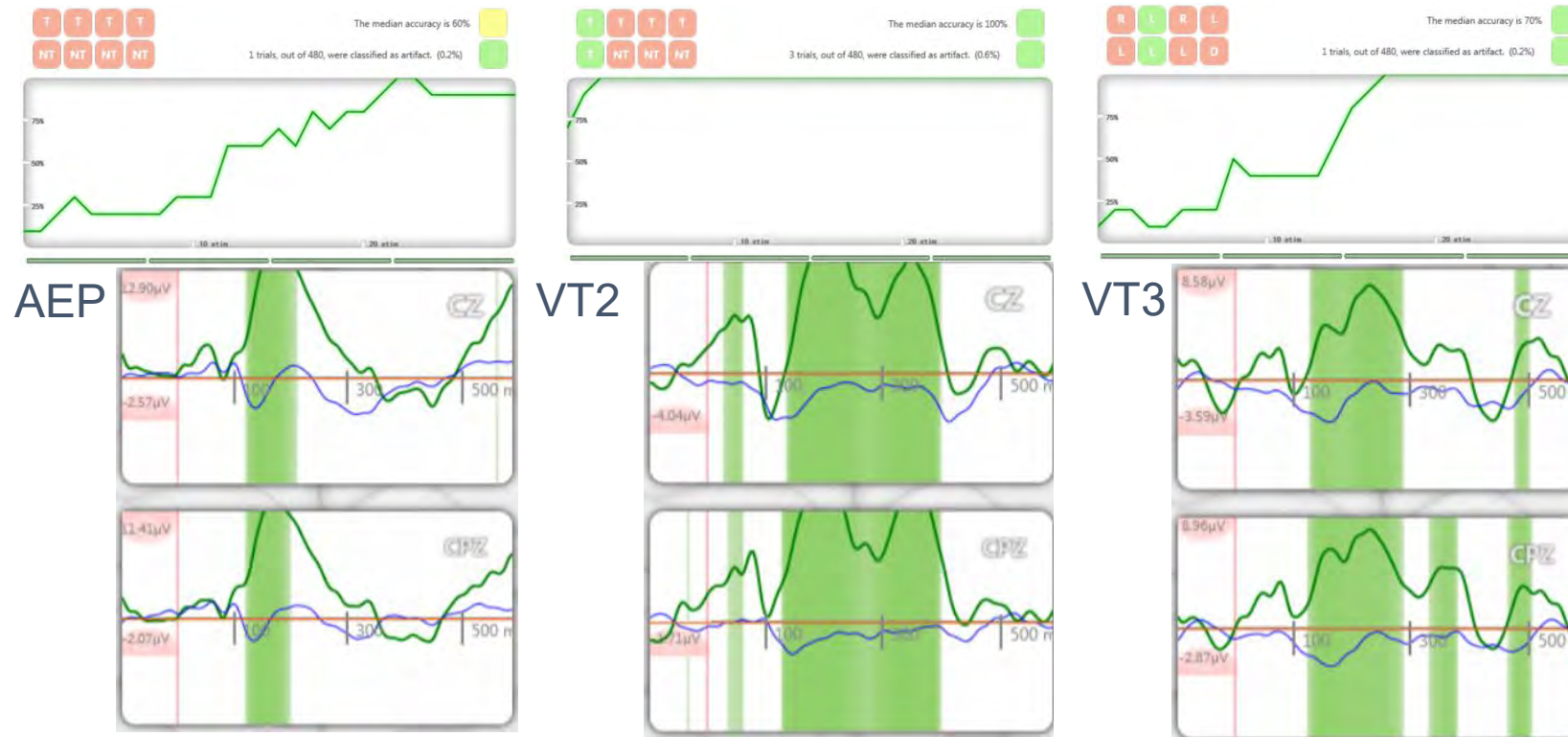
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Successful assessment

MCS- on day of mindBEAGLE

Tried communication with 8 questions, she only responded yes to: 'Do you want to go swimming?'



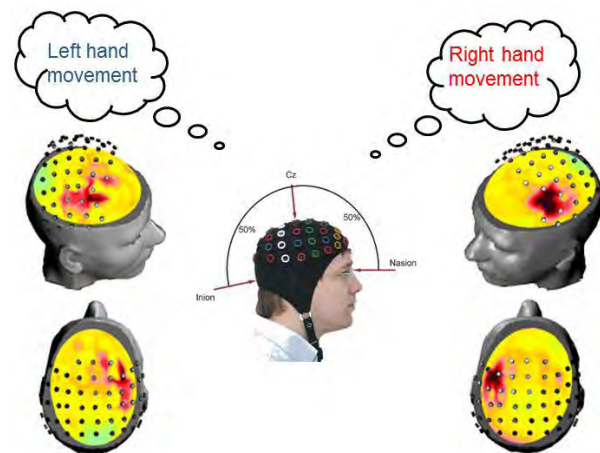
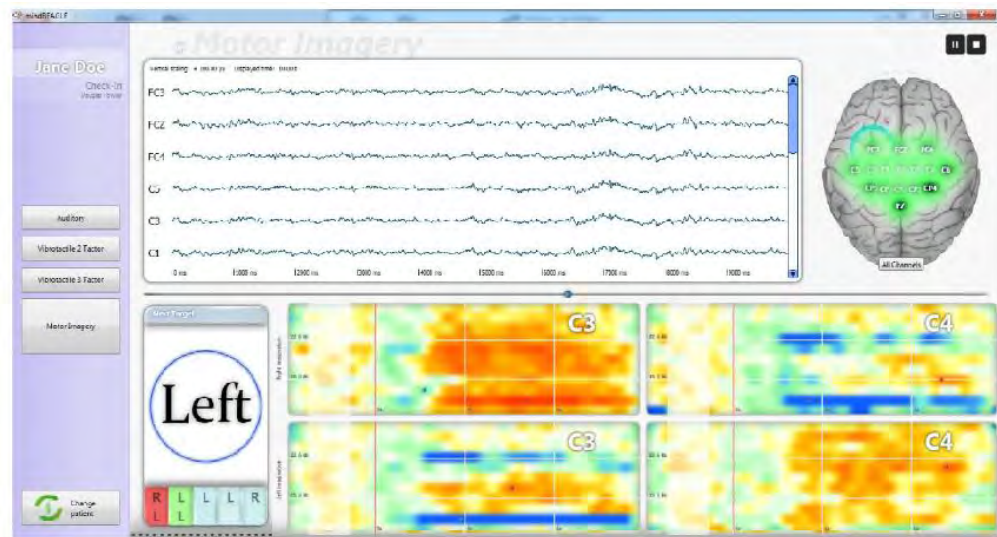
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Motor imagery paradigm

- **Motor imagery paradigm**
- 8 min experimental time

Imagination of hand movement causes an ERD which is used to classify the side of movement. The desynchronization occurs in motor and related areas of the brain.



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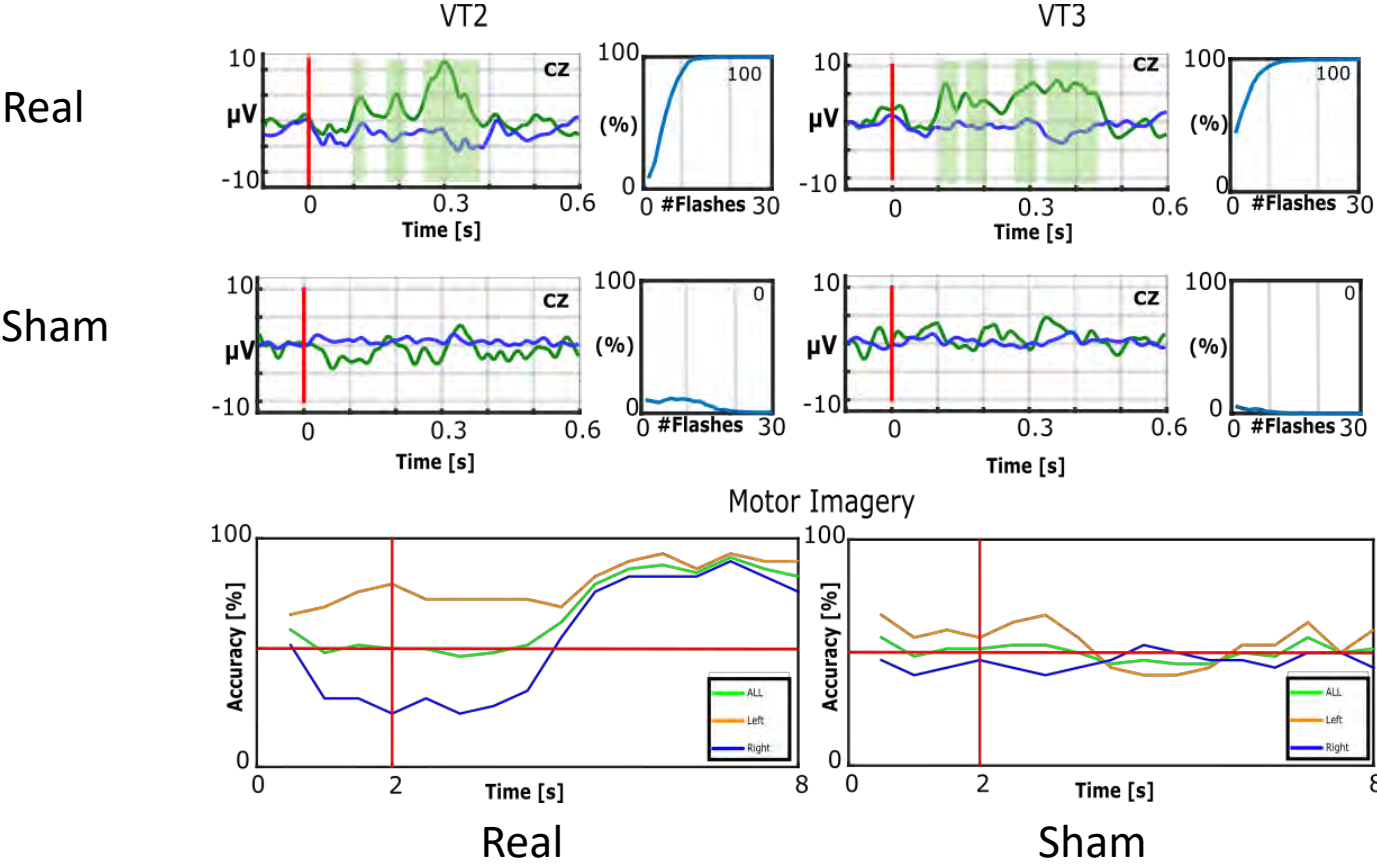


Healthy control results

Subject		S1		S2		S3		Total	
	Exp.	Ass. Acc. [%]	Comm. [%]; [correct/total]	Ass. Acc. [%]	Comm. [%]; correct/total]	Ass. Acc. [%]	Comm. [%]; correct/total]	Mean Ass. Accuracy [%]	Mean Commu. Acc. [%]
VT2	Run 1	100		100		65		88	
	Run 2	100		100		100		100	
	Sham	0		25		10		12	
VT3	Run 1	90	100, [5/5]	60	20, [1/5]	100	100, [5/5]	83	73,3
	Run 2	100	80, [4/5]	100	100, [5/5]	80	80, [4/5]	93	86,7
	Sham	0		10		10		6,6	
MI	Run 1	70	80, [4/5]	71	60, [3/5]	78	80, [4/5]	73	73,3
	Run 2	90	80, [4/5]	67	80, [4/5]	62	90, [9/10]	73	83,3
	Sham	55		50		59		57	



Healthy controls



University of Palermo

N.	Initials	Sex	Age	Diagnosis	Disease Duration (months)	Clinical Description	Mechanical ventilation
1	P.F.	M	19	TBI	12	UWS	no
2	L.C.	F	61	ALS	149	CLIS	yes
3	G.F.	M	67	ALS	97	LIS	yes
4	M.M.	F	76	ALS	145	LIS	no
5	P.A.	F	75	ALS	184	CLIS	yes
6	A.F.	F	68	ALS	89	LIS	yes
7	N.A.	M	63	ALS	27	LIS	yes

TBI: Traumatic Brain Injury; UWS: unresponsive wakefulness syndrome; ALS: Amyotrophic Lateral Sclerosis;
CLIS : Complete Locked-in syndrome; LIS: Locked-in syndrome

N.	Initials	Sess.	AEP	QT	VTP2	QT	VTP3	VTP3	MI	MI Com
		#	[%]		[%]		[%]	Com		
1	P.F.	1	10	-	100	No	40	no	-	-
		2	-	-		No	80	yes	-	-
2	L.C.	1	30	-	100	No	100	yes	50,7	No
3	G.F.	1	100	-	100	No	70	yes	73,3	Yes
4	M.M.	1	90	-	100	No	90	yes	58,7	No
5	P.A.	1		-	20	No	70	yes	47,3	No
6	A.F.	1	-	-	95	No	100	yes	83,3	Yes
7	N.A.	1	-	-	80	No	100	yes	55,7	No

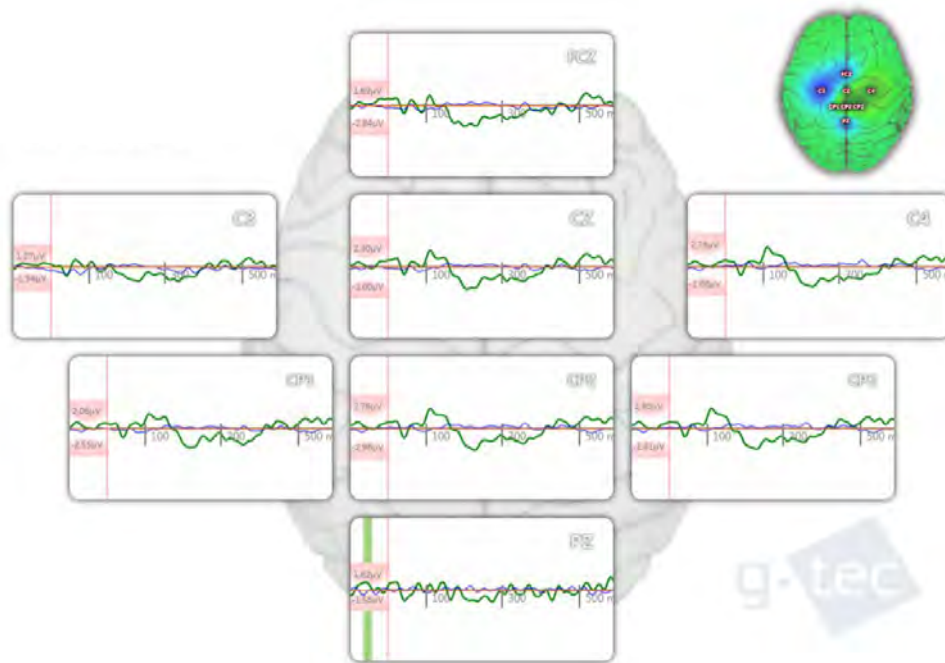
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Subject P.F., VT3 Session 1

University of Palermo

Vincenzo La Bella, Rossella Spataro



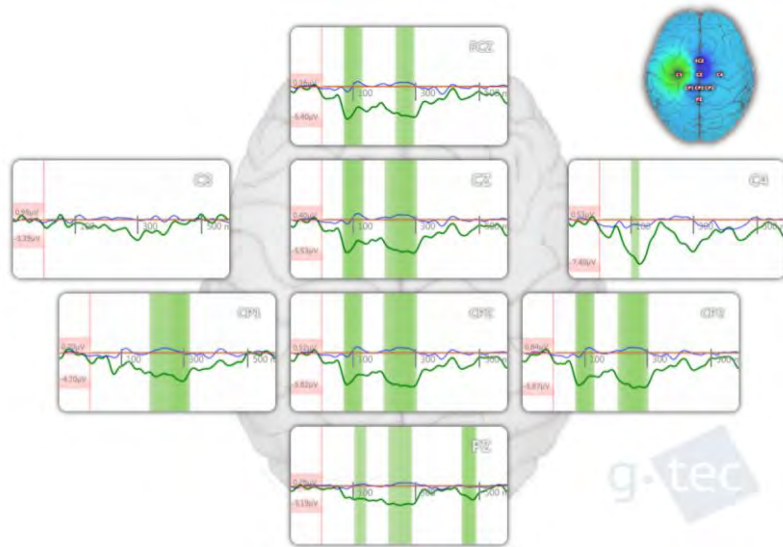
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Subject P.F., VT3 Session 2

University of Palermo

Vincenzo La Bella, Rossella Spataro



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University of Palermo, Vincenzo La Bella, Rossella Spataro

III. Detection of consciousness

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Communication video

NeuRED47

Age: 20

Female

Stroke, 9 months, MCS, CRS-R total: 9

Am I speaking in Italian? Expected answer: Yes.



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Communication video

NeuRED47

Age: 20

Female

Stroke, 9 months, MCS, CRS-R total: 9

Am I speaking in English? Expected answer: No.



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N.	Initials	Sex	Age	Diagnosis	Disease Duration (months)	Clinical Description	Mechanical ventilation
1	P.F.	M	19	TBI	12	UWS	no
2	L.C.	F	61	ALS	149	CLIS	yes
3	G.F.	M	67	ALS	97	LIS	yes
4	M.M.	F	76	ALS	145	LIS	no
5	P.A.	F	75	ALS	184	CLIS	yes
6	A.F.	F	68	ALS	89	LIS	yes
7	N.A.	M	63	ALS	27	LIS	yes

TBI: Traumatic Brain Injury; UWS: unresponsive wakefulness syndrome; ALS: Amyotrophic Lateral Sclerosis;
CLIS : Complete Locked-in syndrome; LIS: Locked-in syndrome

N.	Initials	Sess.	AEP	QT	VTP2	QT	VTP3	VTP3	MI	MI Com
		#	[%]		[%]		[%]	Com		
1	P.F.	1	10	-	100	No	40	no	-	-
		2	-	-	-	No	80	yes	-	-
2	L.C.	1	30	-	100	No	100	yes	50,7	No
3	G.F.	1	100	-	100	No	70	yes	73,3	Yes
4	M.M.	1	90	-	100	No	90	yes	58,7	No
5	P.A.	1	-	-	20	No	70	yes	47,3	No
6	A.F.	1	-	-	95	No	100	yes	83,3	Yes
7	N.A.	1	-	-	80	No	100	yes	55,7	No

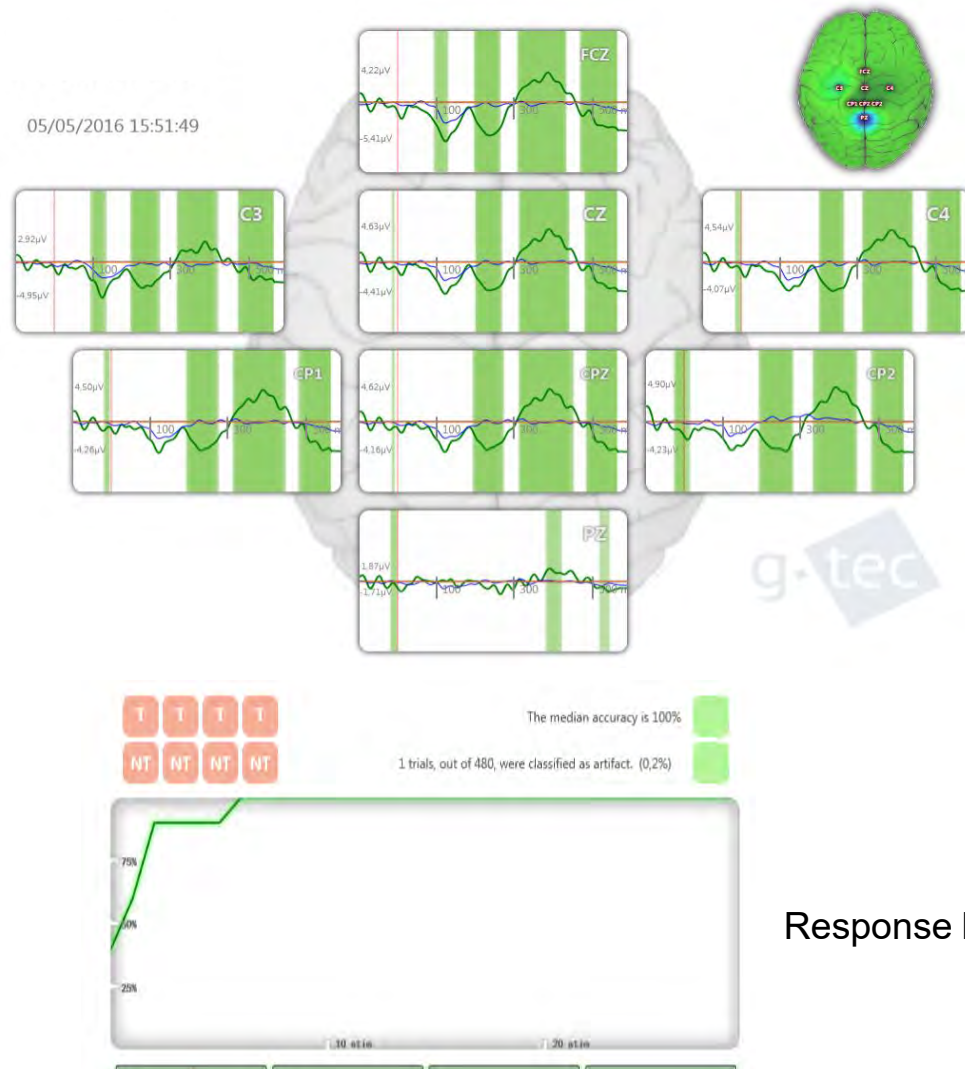
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Vincenzo La Bella, Rossella Spataro

Subject F.G., AEP, session 1



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N.	Initials	Sex	Age	Diagnosis	Disease Duration (months)	Clinical Description	Mechanical ventilation
1	P.F.	M	19	TBI	12	UWS	no
2	L.C.	F	61	ALS	149	CLIS	yes
3	G.F.	M	67	ALS	97	LIS	yes
4	M.M.	F	76	ALS	145	LIS	no
5	P.A.	F	75	ALS	184	CLIS	yes
6	A.F.	F	68	ALS	89	LIS	yes
7	N.A.	M	63	ALS	27	LIS	yes

TBI: Traumatic Brain Injury; UWS: unresponsive wakefulness syndrome; ALS: Amyotrophic Lateral Sclerosis; CLIS : Complete Locked-in syndrome; LIS: Locked-in syndrome

N.	Initials	Sess.	AEP	QT	VTP2	QT	VTP3	VTP3	MI	MI Com
		#	[%]		[%]		[%]	Com		
1	P.F.	1	10	-	100	No	40	no	-	-
		2	-	-		No	80	yes	-	-
2	L.C.	1	30	-	100	No	100	yes	50,7	No
3	G.F.	1	100	-	100	No	70	yes	73,3	Yes
4	M.M.	1	90	-	100	No	90	yes	58,7	No
5	P.A.	1		-	20	No	70	yes	47,3	No
6	A.F.	1	-	-	95	No	100	yes	83,3	Yes
7	N.A.	1	-	-	80	No	100	yes	55,7	No

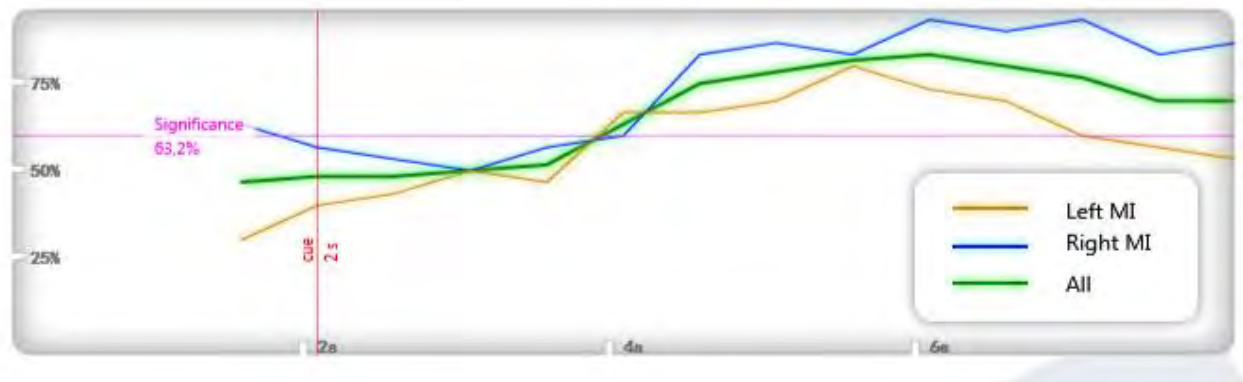
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Vincenzo La Bella, Rossella Spataro
Subject A.F., MI, session 1



Communicated successfully



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Nimes, France

N.	Initials	Sex	Age	Diagnosis	Disease Duration (months)	Clinical Description	Mechanical ventilation
1	M.P.	F	?	TBI	>24	MCS-	no
2	R.T.	F	~28	TBI	>24	MCS-	no
3	E.A.	F	?	TBI	>24	MCS-	no
4	A.A.	M	~28	TBI	22	MCS+	no

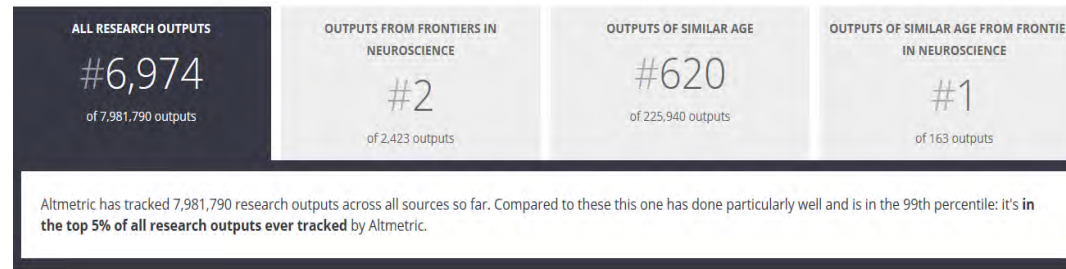
	Initials	Sess. #	AEP [%]	QT	VTP2 [%]	QT	VTP3 [%]	VTP3 Com	MI [%]	MI Com	
1	M.P.	1	80	Yes	85	Yes	80	no	53.83	-	
		2	100	Yes	100	Yes	100	no	44.33	-	
2	R.T.	1	0	-	0	-	-	-	-	-	
		2	100	Yes	0	-	0	-	59	No	
3	E.A.	1	40	-	30	-	0	-	58.8	No	
4	A.A.	1	40	-	75	Yes	90	no	58.33	No	

QT: Quick test, VTP3 Com: VTP3 Communication, MI com: MI communication

Quick test: uses classifier from previous session

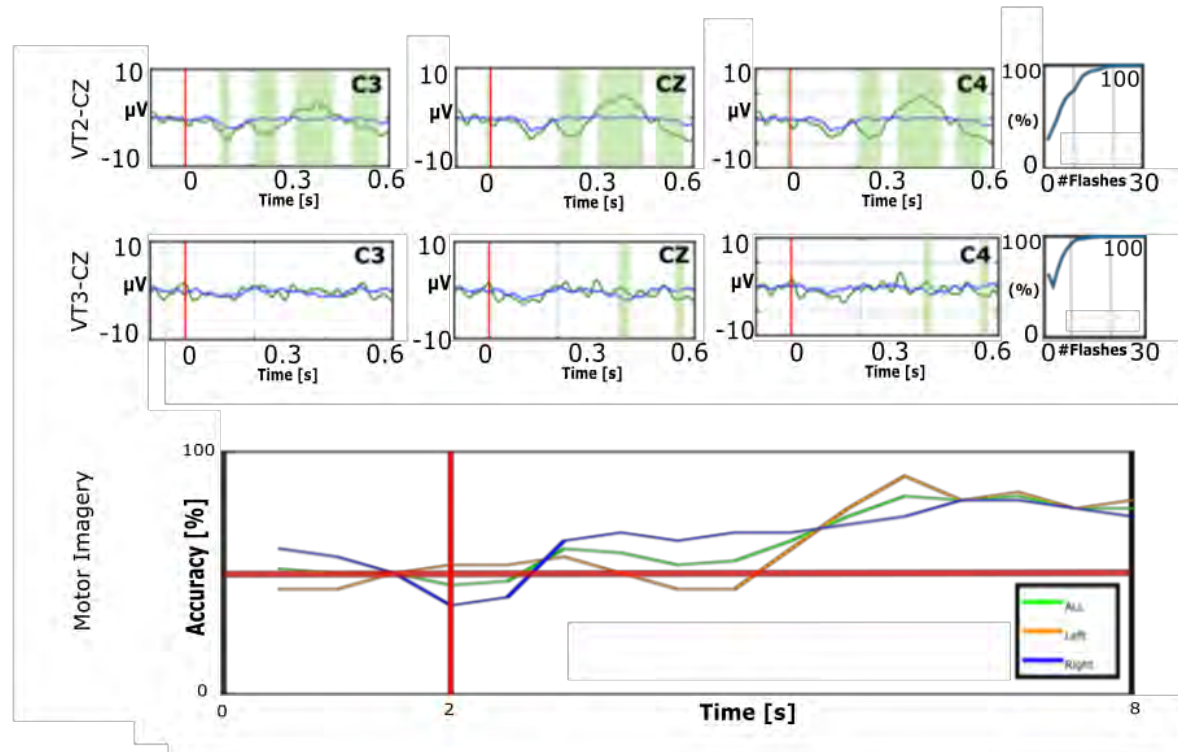


LIS results



VT2

VT3



Christoph Guger, Rossella Spataro, Brendan Z. Allison, Alexander Heilinger, Rupert Ortner, Woosang Cho, Vincenzo La Bella (2017) **Locked-in patients: Assessment and communication with vibro-tactile and motor imagery brain-computer interface tools.** *Frontiers in Neuroprosthetics*.

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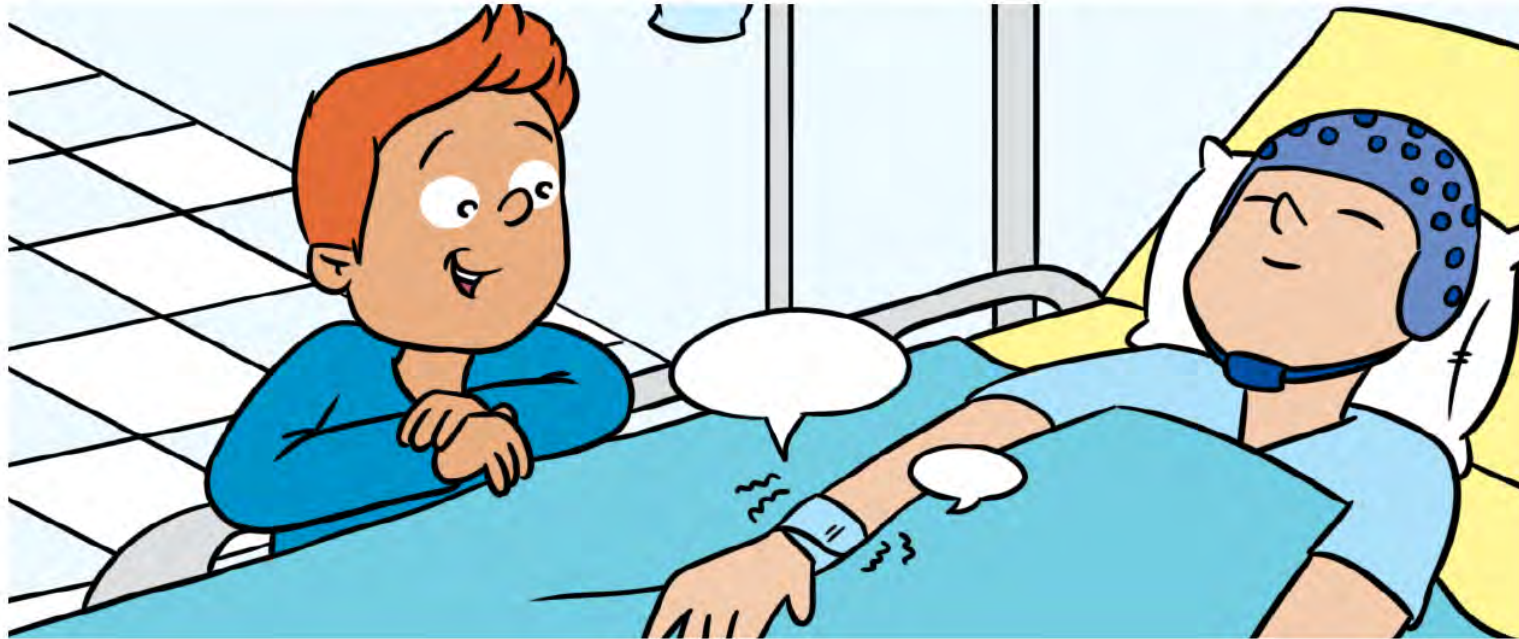


LIS results

Pat.	Sess. #	VT2 [%]	VT3 [%]	VT3 Com	MI [%]	MI Com
P1	1	100	100	9/10	51	-
P2	1	100	70	7/10	73	4/5
P3	1	100	90	8/10	59	-
P4	1	20	70	7/10	47	-
P5	1	99	100	9/10	83	5/5
P6	1	80	100	9/10	56	-
P7	1	40	40	-	-	-
	2	-	20	-	-	-
P8	1	70	100	8/10	49	-
P9	1	40	10	-	-	-
P10	1	100	50	-	54	-
	1	-	90	8/10	-	-
P11	1	70	20	-	52	-
	1	-	20	-	-	-
P12	1	100	60	-	42	-
	1	-	70	7/10	74	5/5
Average		76,6	63,1	8/10	58,2	4,7

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Frontiers Junior

How can completely locked-in persons communicate with a brain-computer interface?

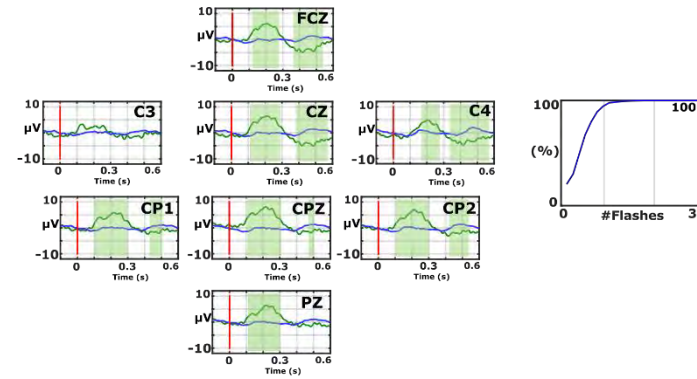
Christoph Guger, Rossella Spataro, Brendan Z. Allison, Alexander Heilinger, Rupert Ortner, Woosang Cho, Vincenzo La Bella

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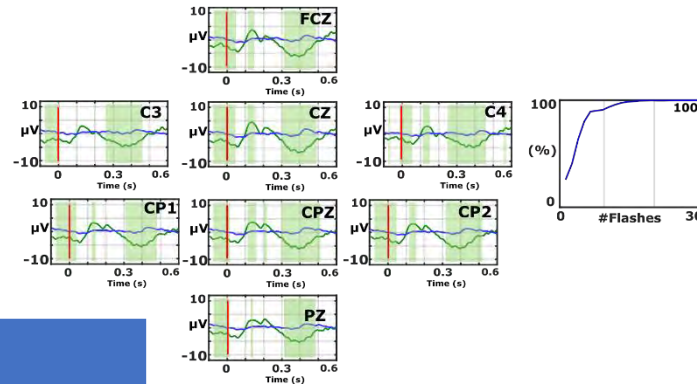


UWS results

VT2



VT3



Pat.	Sess. #	VT2 [%]	VT3 [%]	VT3 Com
P1	1	100	70	7 correct, 3 undetermined, 10 total
P2	1	100	100	9 correct, 1 undetermined, 10 total
P3	1	100	60	-
	1	-	70	7 correct, 3 undetermined, 10 total
P4	1	100	100	4 correct, 1 undetermined, 5 total
	2	100	100	4 correct, 1 wrong, 5 total
	3	-	100	4 correct, 1 undetermined, 5 total
	4	-	100	3 correct, 2 undetermined, 5 total
Average		100	87,5	38 correct, 1 wrong, 11 undetermined, 50 total

Christoph Guger, Rossella Spataro, Joanna Cakała, Brendan Z. Allison, Alexander Heilinger, Rupert Ortner, Woosang Cho, Vincenzo La Bella, Krzysztof Malej, Günter Edlinger (2018) **Locked-in and unresponsive wakefulness state patients: Assessment and communication with brain-computer interface.** Frontiers

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UWS results

- VT3 used to show covert command following
- 41% showed signs of covert command following
- 2 patients could answer YES/NO questions

Patient	Session #	VT2 assessment accuracy 4 instructions [%]	VT3 assessment accuracy 4 instructions [%]	VT3 Communication
UWS1	1	100	0	-
		-	40	-
	2	25	20	-
		80	80	6/10 (4 wrong)
UWS2	3	60	0	-
		-	5	-
	4	-	100	7/10 (3 wrong)
		30	20	-
UWS3	1	-	0	-
		45	10	-
UWS4	1	20	20	-
		-	30	-
UWS5	1	30	0	-
UWS6	1	20	0	-
UWS7	1	20	50	-
UWS8		-	0	-
	1	0	15	-
UWS9	1	50	30	-
		-	60	-
UWS10	1	10	0	-
UWS11	1	5	0	-
UWS12	1	80	70	-
		-	80	4/5 (1 undetermined)
Median		38.3	26.3	17/25 (7 wrong/1 undetermined)

Christoph Guger, Rossella Spataro, Frederic Pellas, Brendan Z. Allison, Alexander Heilinger, Rupert Ortner, Woosang Cho, Ren Xu, Vincenzo La Bella, Günter Edlinger, Jitka Annen, Giorgio Mandala, Camille Chatelle and Steven Laureys **Assessing Command-Following and Communication With Vibro-Tactile P300 Brain-Computer Interface Tools in Patients With Unresponsive Wakefulness Syndrome**, *Frontiers in Neuroscience*, 2018.

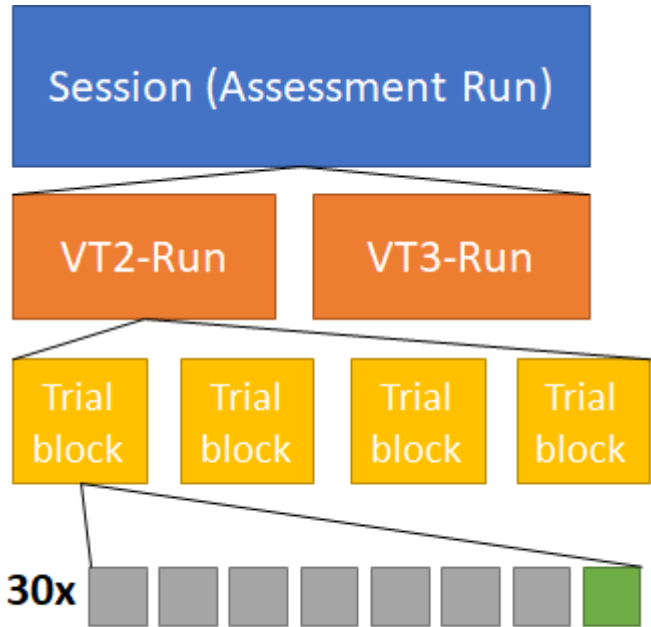
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PRESERVED SOMATOSENSORY DISCRIMINATION PREDICTS
CONSCIOUSNESS RECOVERY IN UNRESPONSIVE WAKEFULNESS
SYNDROME

Rossella Spataro, Alexander Heilinger, Brendan Allison, Domenico De Cicco, Santino

Marchese, Cesare Gregoretti, Vincenzo La Bella, Christoph Guger, Clin. Neurophys.



Patient	VT2 Accuracy	VT3 Accuracy	6 Months Outcome	Initial CRS-R	6 Months CRS-R
UWS 1	80	80	MCS	6	15
UWS 2	30	10	deceased	6	-
UWS 3	45	10	UWS	3	6
UWS 4	20	30	UWS	6	3
UWS 5	30	0	deceased	6	-
UWS 6	20	0	UWS	5	5
UWS 7	50	60	MCS	6	13
UWS 8	50	20	UWS	5	6
UWS 9	50	50	Awake	6	23
UWS 10	0	15	UWS	4	4
UWS 11	20	0	UWS	5	5
UWS 12	10	0	UWS	5	5
UWS 13	5	0	deceased	6	-
Average	31.53	21.15			



VIBRO-TACTILE REHABILITATION PROTOCOL FOR PATIENTS WITH DISORDERS OF CONSCIOUSNESS



Neurobehavioral rating scales

- **CRS-R**, Coma Recovery Scale—Revised
- *43% of patients misdiagnosed

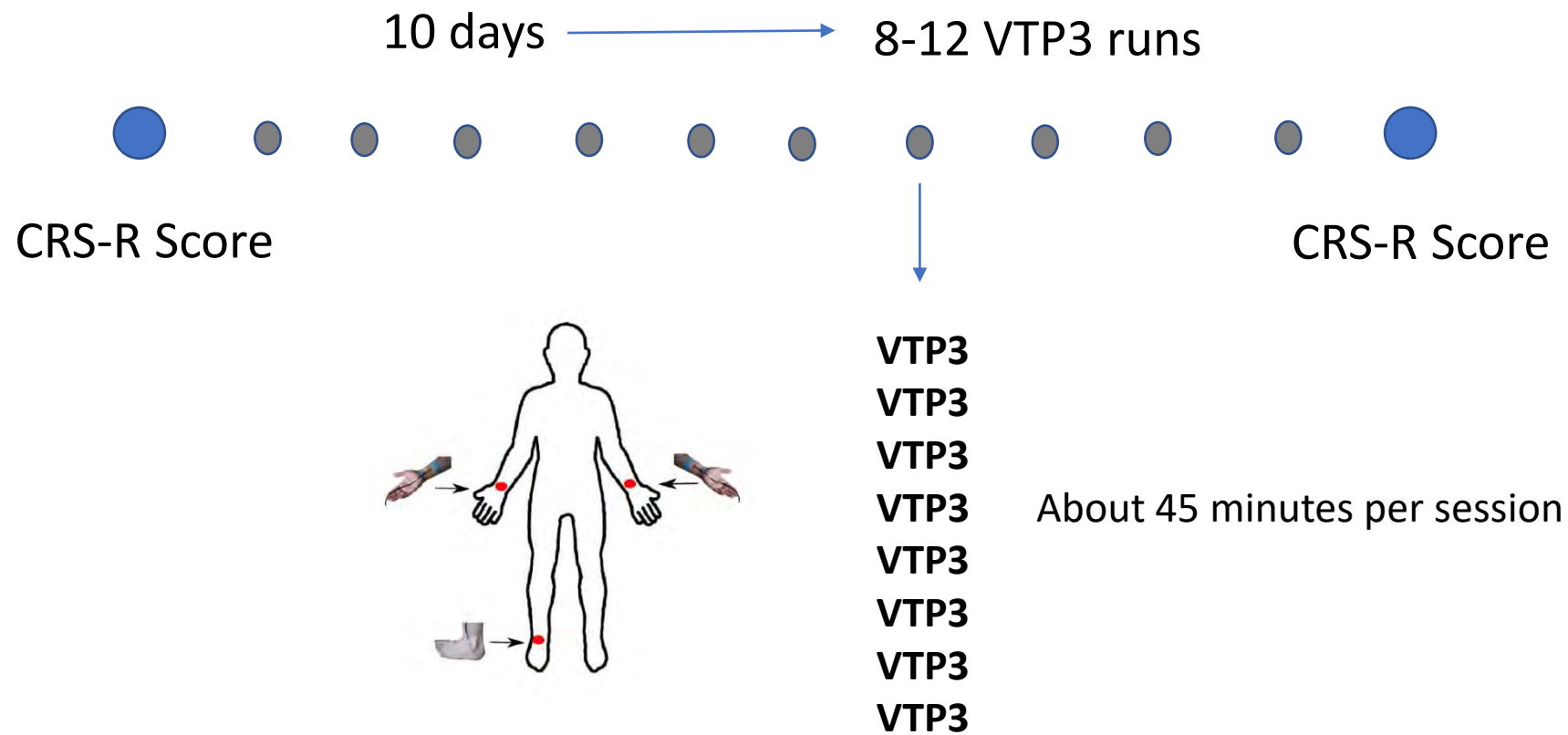
JFK COMA RECOVERY SCALE - REVISED ©2004																	
Record Form																	
This form should only be used in association with the "CRS-R ADMINISTRATION AND SCORING GUIDELINES" which provide instructions for standardized administration of the scale.																	
Patient:		Diagnosis:					Etiology:										
Date of Onset:		Date of Admission:															
	Date																
	Week	ADM	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
AUDITORY FUNCTION SCALE																	
4 - Consistent Movement to Command *																	
3 - Reproducible Movement to Command *																	
2 - Localization to Sound																	
1 - Auditory Startle																	
0 - None																	
VISUAL FUNCTION SCALE																	
5 - Object Recognition *																	
4 - Object Localization: Reaching *																	
3 - Visual Pursuit *																	
2 - Fixation *																	
1 - Visual Startle																	
0 - None																	
MOTOR FUNCTION SCALE																	
6 - Functional Object Use †																	
5 - Automatic Motor Response *																	
4 - Object Manipulation *																	
3 - Localization to Noxious Stimulation *																	
2 - Flexion Withdrawal																	
1 - Abnormal Posturing																	
0 - None/Flaccid																	
OROMOTOR/VERBAL FUNCTION SCALE																	
3 - Intelligible Verbalization *																	
2 - Vocalization/Oral Movement																	
1 - Oral Reflexive Movement																	
0 - None																	
COMMUNICATION SCALE																	
2 - Functional: Accurate †																	
1 - Non-Functional: Intentional *																	
0 - None																	
AROUSAL SCALE																	
3 - Attention																	
2 - Eye Opening w/o Stimulation																	
1 - Eye Opening with Stimulation																	
0 - Unarousable																	
TOTAL SCORE																	

Denotes emergence from MCS[†]
Denotes MCS *



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Protocol

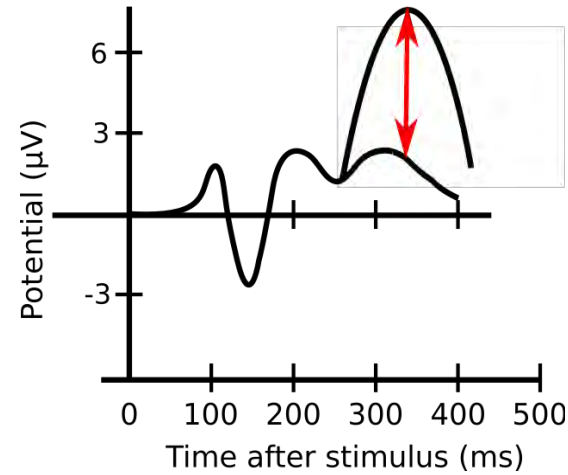


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VTP3 paradigm

- 480 stimuli per run, with 60 groups of 8 stimuli.
- Subject is instructed to concentrate and silently count vibrotactile pulses on either their left or right wrist.
- All vibrotactile stimuli lasted 100 ms with a 100 ms pause between stimuli.
- The whole paradigm (i.e. one run) required around 2.5 minutes per run.



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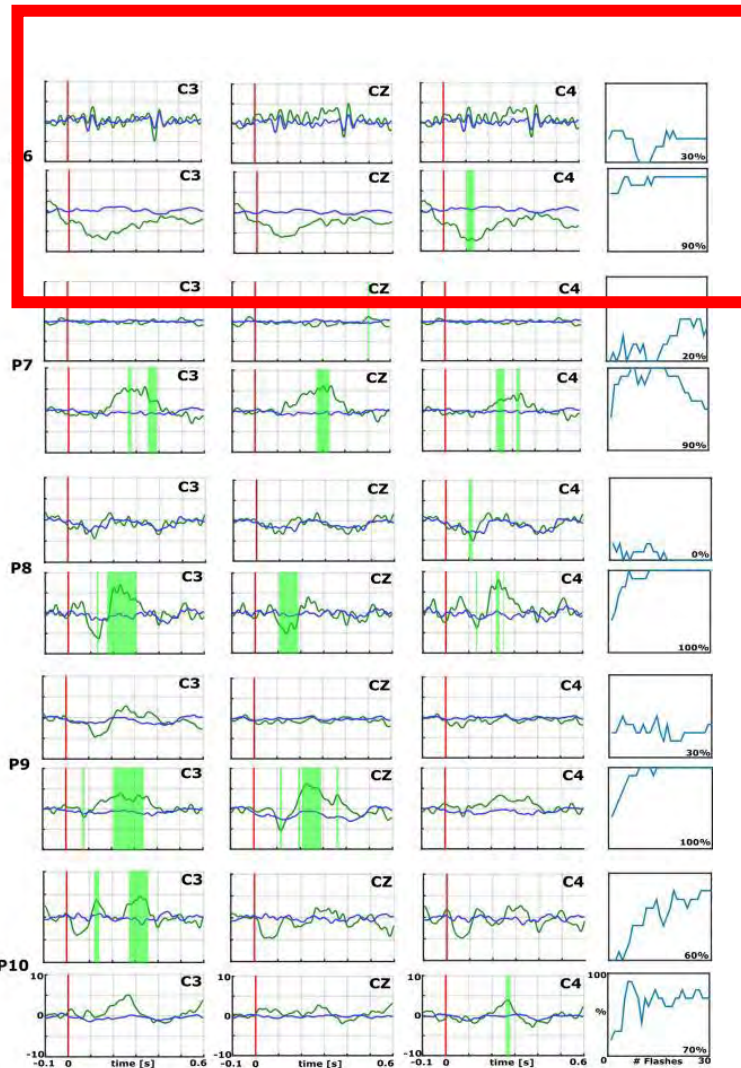
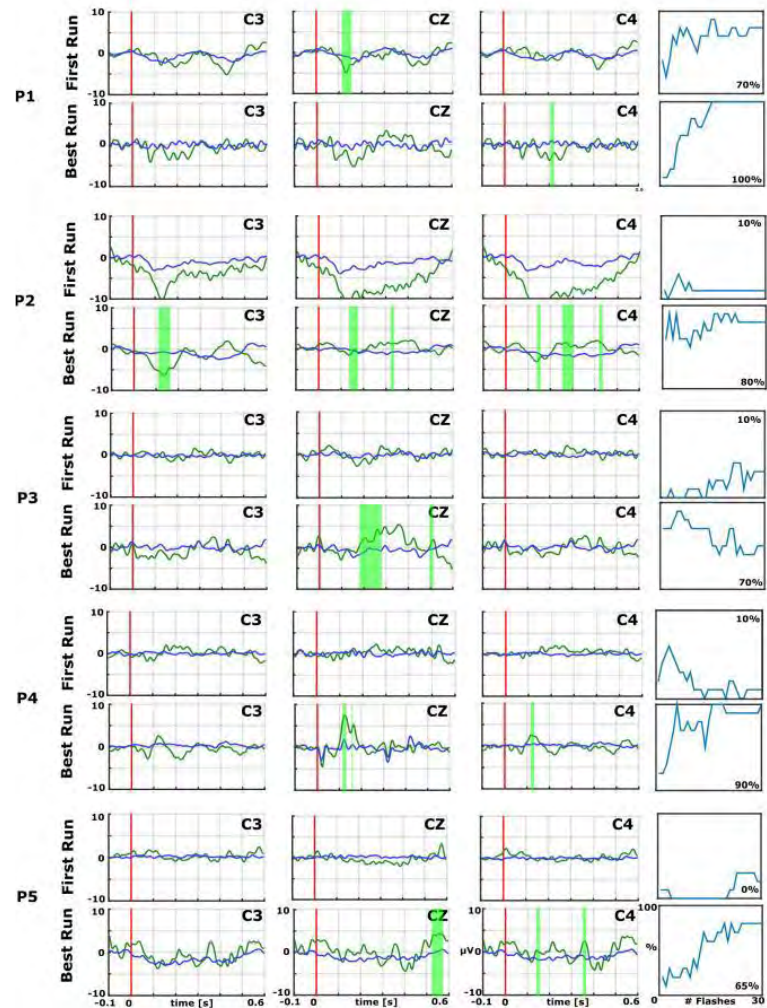
Subjects

#	Age Range (years)	Sex	Diagnosis	Disease Duration at first session (months)	Mechanical ventilation	Clinical State
P1	36-40	F	CH	8	no	MCS
P2	21-25	F	BT	2	no	UWS
P3	36-40	F	TBI	13	no	UWS
P4	56-60	F	HBI	2	no	UWS
P5	26-30	F	ENC	4	yes	MCS
P6	16-20	F	BT	4	yes	UWS
P7	16-20	M	CH	11	no	UWS
P8	41-45	M	TBI	6	no	UWS
P9	16-20	M	TBI	24	no	UWS
P10	26-30	M	TBI	13	no	UWS
P11	61-65	M	IS	13	no	UWS
P12	56-60	M	HS	13	no	UWS
P13	41-45	M	HS	12	no	UWS
P14	66-70	M	TBI	24	no	MCS
P15	56-60	M	CH	20	no	MCS
P16	36-40	F	AN	19	no	UWS
P17	66-70	M	HT	60	no	UWS
P18	56-60	M	HT	48	no	MCS
P19	66-70	M	AN	16	no	MCS
P20	61-65	F	SDH	48	no	MCS

F: Female; M: Male; CH: Cerebral hemorrhage; HBI: Hypoxia-Ischemia Brain Injury; SAH: Subarachnoid Hemorrhage; IS: Ischemic stroke; HS: Hemorrhagic stroke; BT: Brain Trauma; ENC: Mitochondrial Encephalopathy; SDH: Subdural Hematoma; HT: Hematoma; AN: Anoxia; UWS: Unresponsive Wakefulness Syndrome; MCS: Minimal Conscious Syndrome.



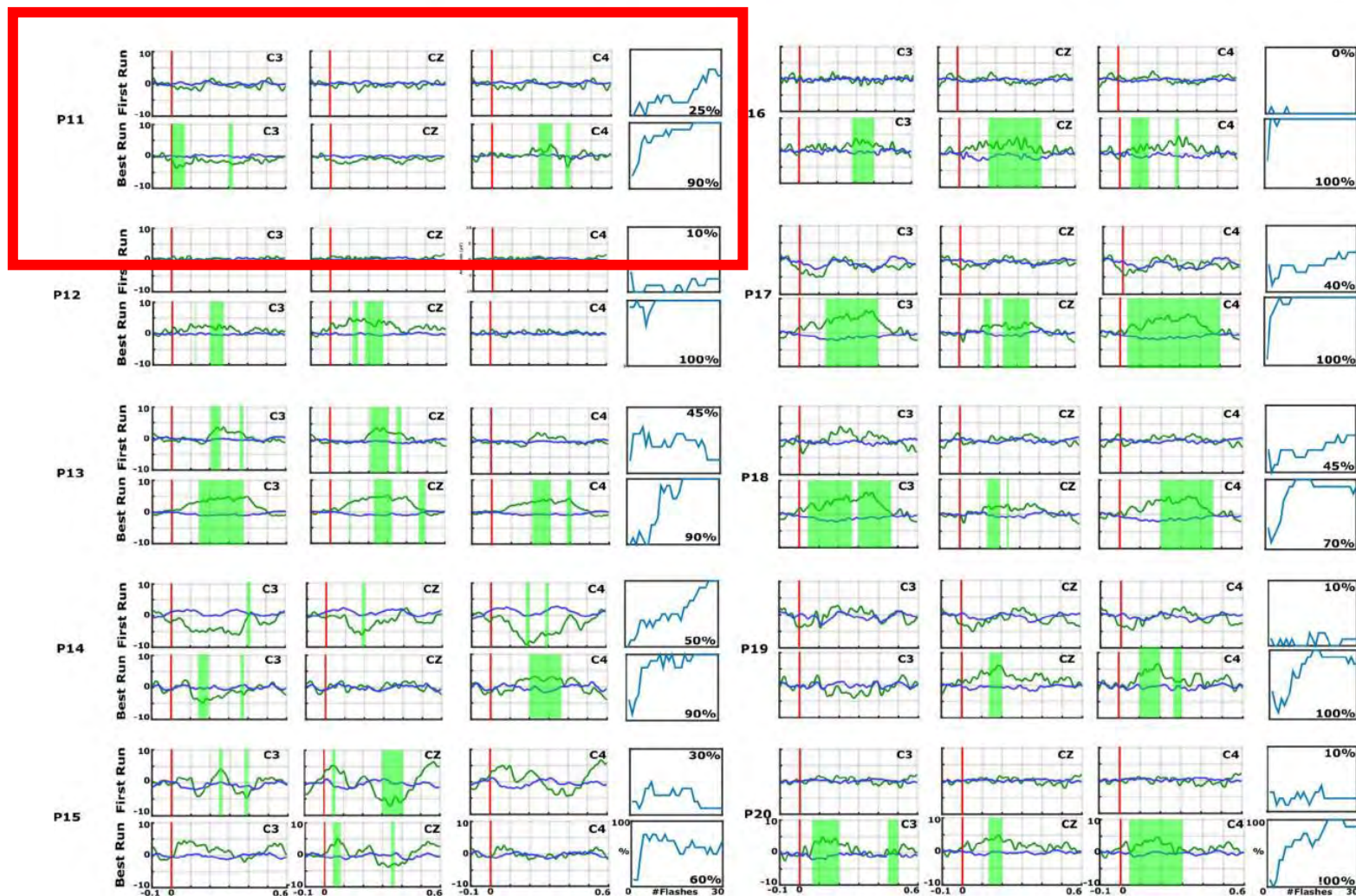
EP results



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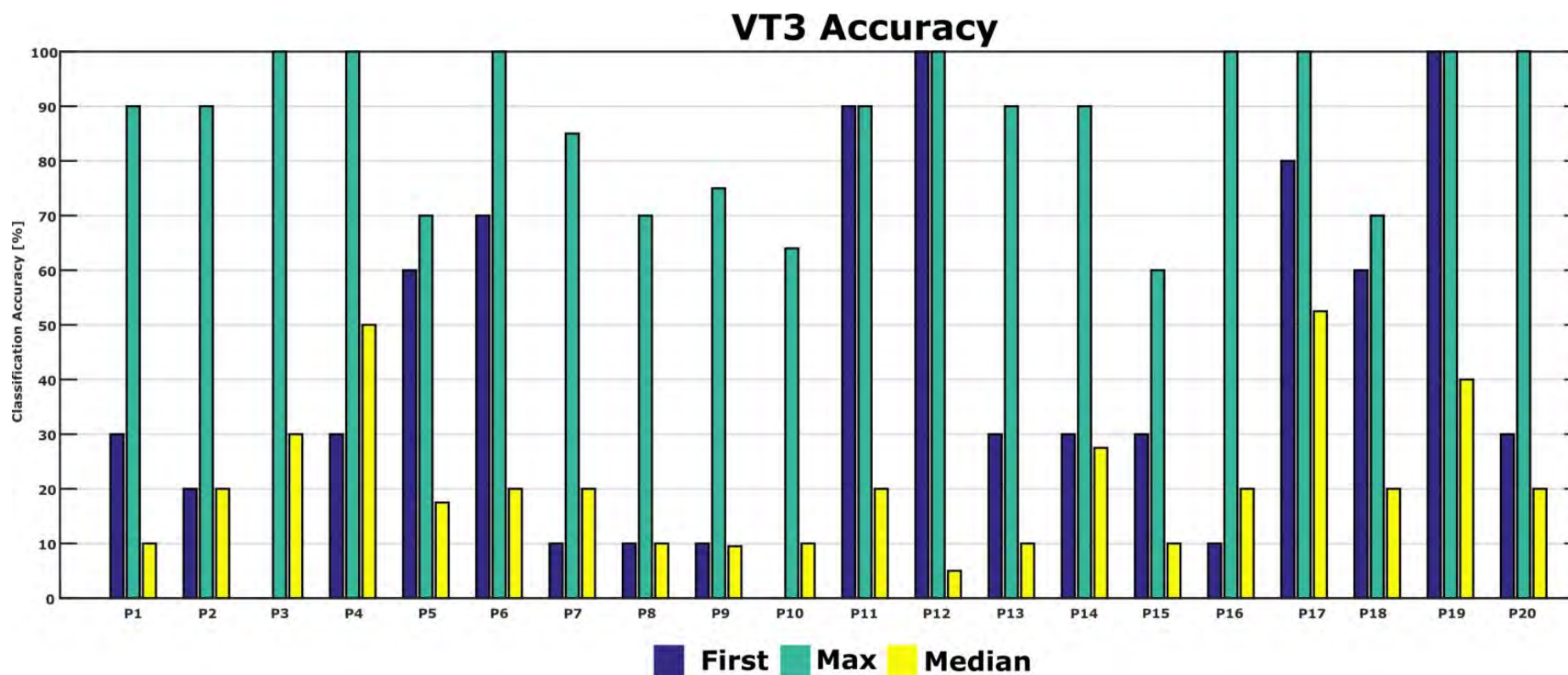
EP results



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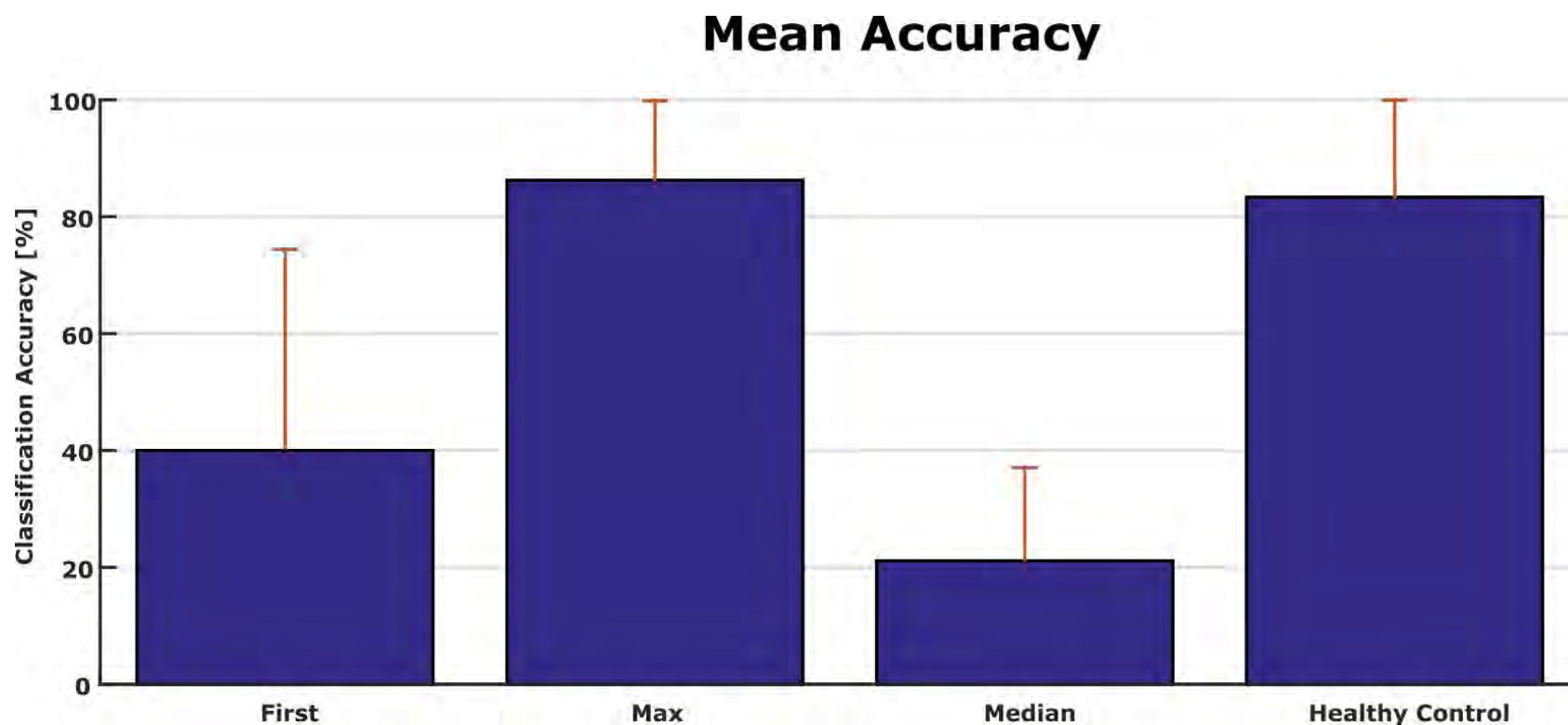
VT3 accuracy results



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Mean Accuracy results



Comparison of accuracies from patients in the present study and a healthy 531 control group with only one session (N=6 (Spataro et al. 2018)).

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Results

#	CRS-R Before	CRS-R After	Δ CRS-R	
P1	11	11	0	
P2	6	9	3	●
P3	5	5	0	
P4	5	5	0	
P5	12	15	3	●
P6	6	7	1	●
P7	6	6	0	
P8	10	10	0	
P9	6	8	2	●
P10	8	11	3	●
P11	2	5	3	●
P12	4	5	1	●
P13	3	6	3	●
P14	7	9	2	●
P15	7	6	-1	
P16	4	4	0	
P17	4	5	1	●
P18	7	9	2	●
P19	13	12	-1	
P20	7	14	7	●

Effects of a Vibro-Tactile P300 Based Brain-Computer Interface on the Coma Recovery Scale-Revised in Patients With Disorders of Consciousness

 Nensi Murovec^{1,2*},  Alexander Heilinger¹,  Ren Xu²,  Rupert Ortner³,  Rossella Spataro^{1,4},  Vincenzo La Bella⁵,  Yangyang Miao⁶,  Jing Jin⁶,  Camille Chatelle⁷,  Steven Laureys^{7,8},  Brendan Z. Allison⁹ and  Christoph Guger^{1,2}



Guidelines

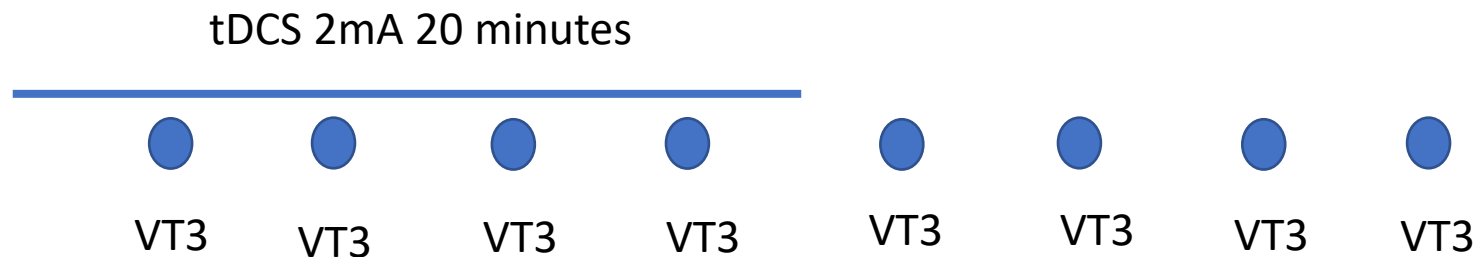
- Communication with patients
- Adjust to their schedule
- Not after other therapies
- Medications
- Primary language
- Including family

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Future plans

- Repeated VT3 measurements
- VT3 rehabilitation protocol combined with tDCS



Current Protocols

- Assessment with AEP, VT2, VT3 and Motor Imagery
- YES/NO communication as objective test
- Prediction with assessment accuracy
- Pre-frontal DC stimulation as rehabilitation protocol
- Functional Electrical Stimulation for less spasticity and muscle re-education
- VT3 rehabilitation protocol
- Resting-state analysis

