The Challenges and Solutions for 'Real World' EEG

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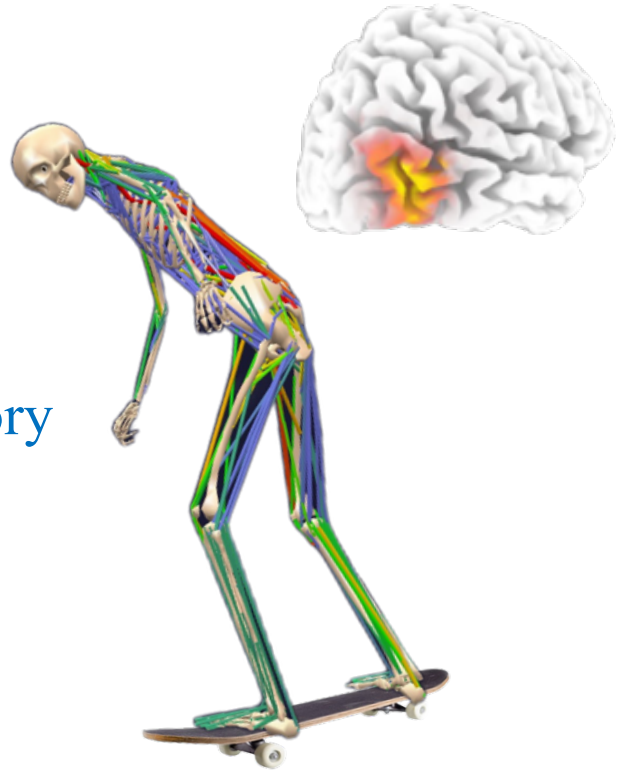


EEG in Real-World Settings

Open-Cockpit Biplane and Motion Platform

LSL Used to Synchronize EEG, Sound Presentation, and Flight Parameters and EEG

Cognionics EEG
64 Channel

Computer Receiving
Wireless EEG Data

Callan, Terzibas, Durantin (2015). Classification of single-trial auditory events using dry-wireless EEG during real and motion simulated flight. Frontiers in Systems Neuroscience.

Brain Recording in Real-World Environments using a Dry-Wireless EEG

64 Channel Systems

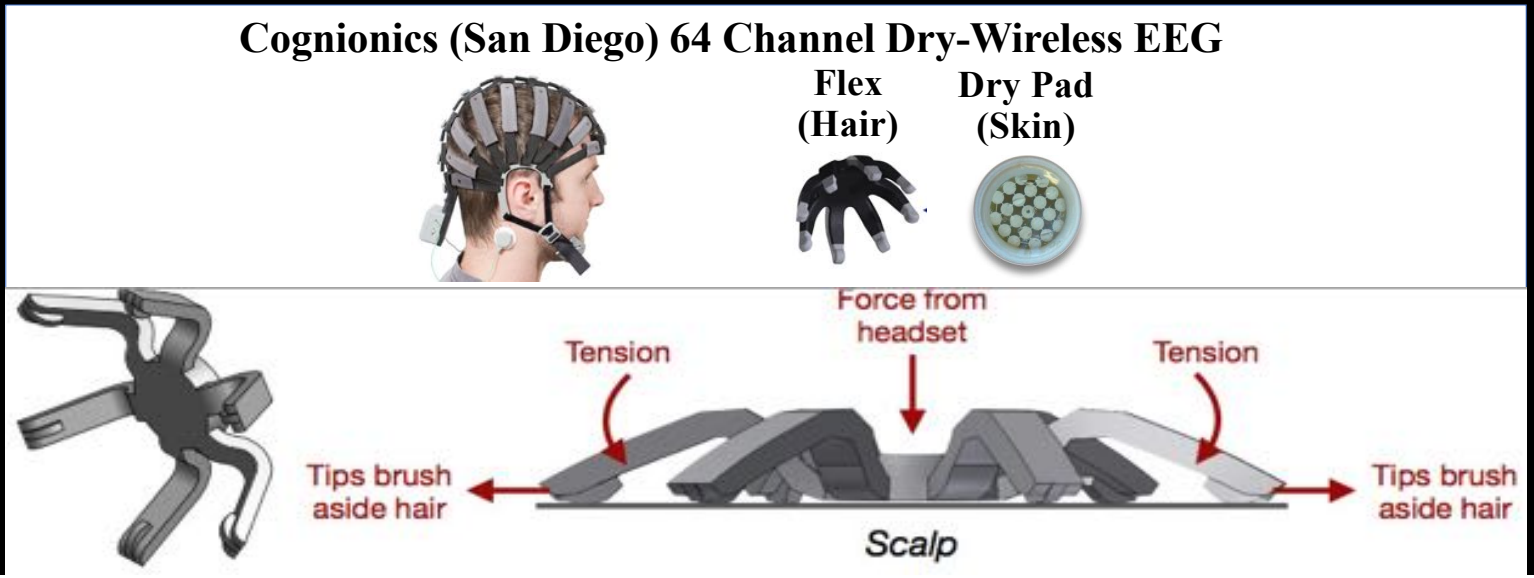
500 Hz Sampling Rate 24-Bit ADCs

Wireless Technology (Less than .01msec temporal delay)

Filtering 1 to 40Hz

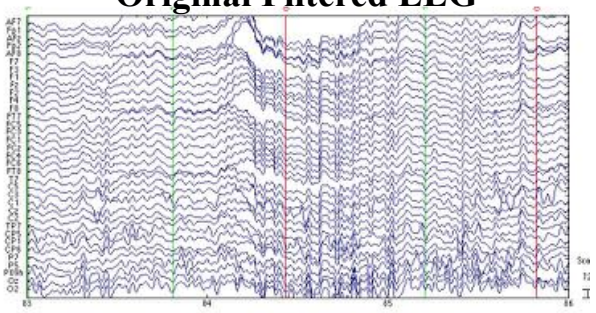
Remove Bad Channels, Interpolate, Average Reference

Artifact Removal (Artifact Subspace Reconstruction ASR and ICA)

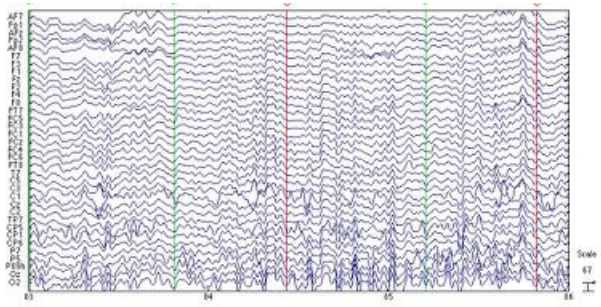


Biplane Engine On

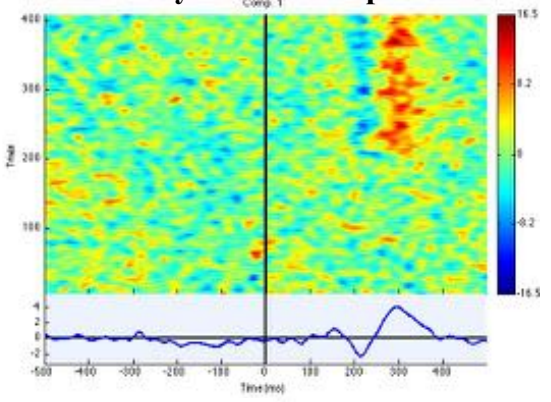
Original Filtered EEG



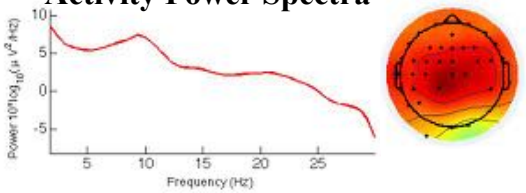
ASR Cleaned Filtered EEG



Independent Component Capturing Auditory Evoked Response



Activity Power Spectra



Classification Performance Using ASR + ICA

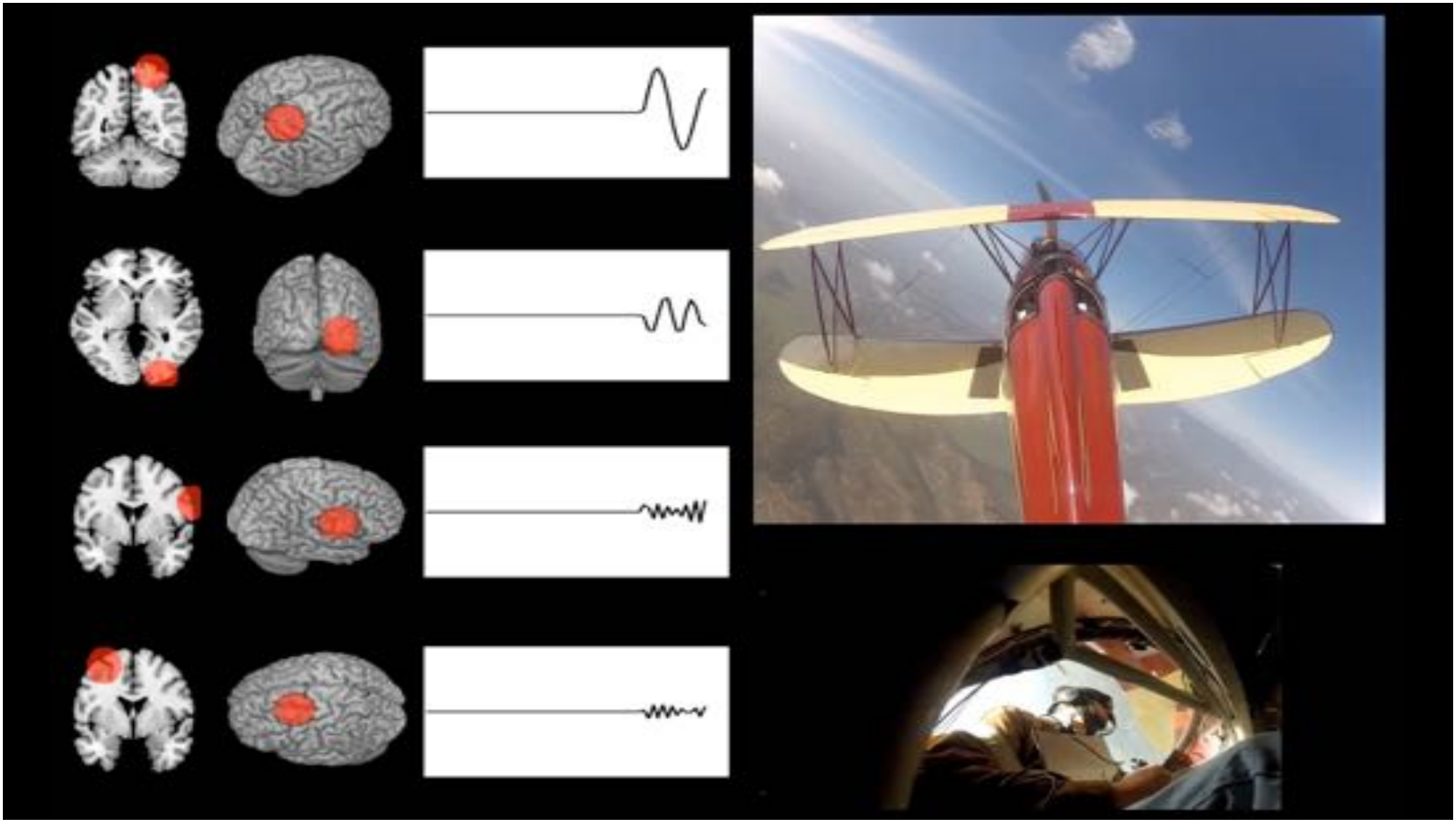
Engine On = 77.3%

Engine Off = 78.5%

Classification Performance Using ASR w/o ICA

Engine On = 66.1%

Engine Off = 77.4%



Important Findings

LSL can be used to synchronize multiple data streams such as EEG, flight parameters, and auditory triggers to facilitate experiments in real world environments under extreme conditons.

Clear Auditory Evoked Potentials AEP can be recorded in an open-cockpit biplane with the engine and avionics on using a dry-wireless EEG systems.

Band-pass filtering, ASR, and Independent Component Analysis is necessary to remove environmental and physiological artifacts.

Inattentional Deafness

Collaboration with Frédéric Dehais (ISAE)

Neuroergonomics and Aviation Safety 20 Year Grant

The experiment was approved by the European Aviation Safety Agency (EASA60049235) and supported by the AXA Research Fund (January 2014 – December 2034).

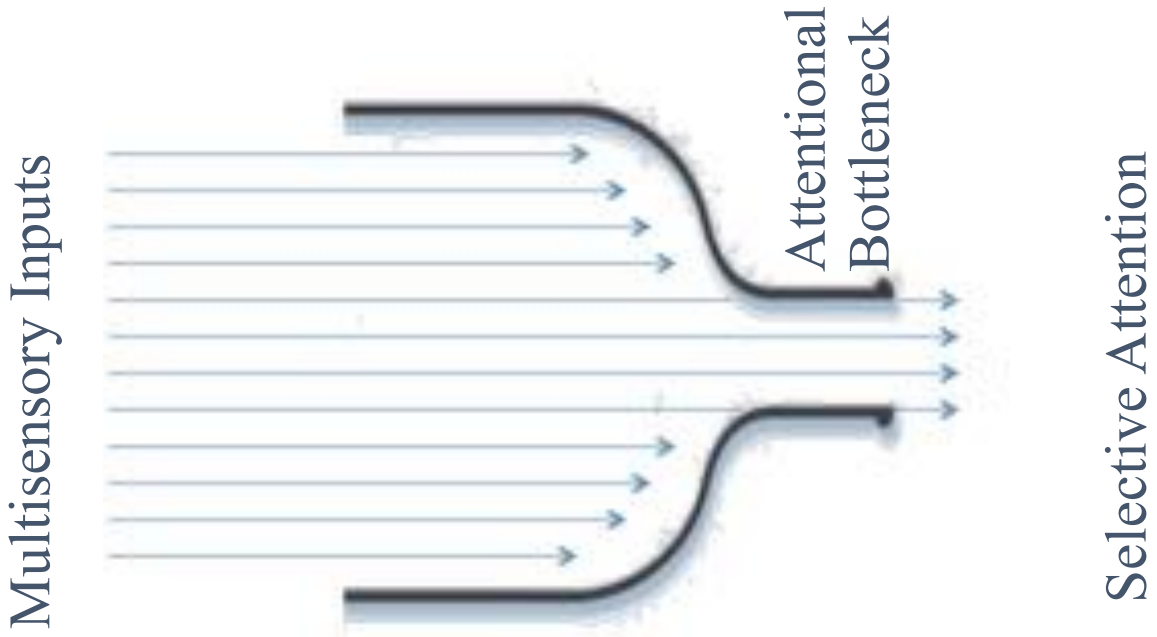
Dehais, F., Rida, I., Roy, R., Iversen, J., Mullen, T., Callan D. (2019). A pBCI to predict attentional error before it happens in real flight conditions. *IEEE Systems, Man, and Cybernetics*. October 6-9. Bari, Italy. Citations: 4 (1) 3.

Callan, D. E., Gateau, T., Durantin, G., Gonthier, N., & Dehais, F. (2018). Disruption in neural phase synchrony is related to identification of inattentional deafness in real-world setting. *Human brain mapping*, *39*(6), 2596-2608.

Durantin G, Dehais F, Gonthier N, Terzibas C, Callan D (2017). Neural signature of inattentional deafness. *Human Brain Mapping* *38*(11), 5440-5455. Doi 10.1002/hbm.23735.

Inattentional Deafness (fMRI Experiment)

Inattentional deafness is the failure to hear otherwise audible sounds (usually alarms) that may occur under high workload conditions and has been cited as the source of many aviation related accidents (Dehais et al., 2014, 2019; Giraudet et al., 2015; Causse et al., 2016).

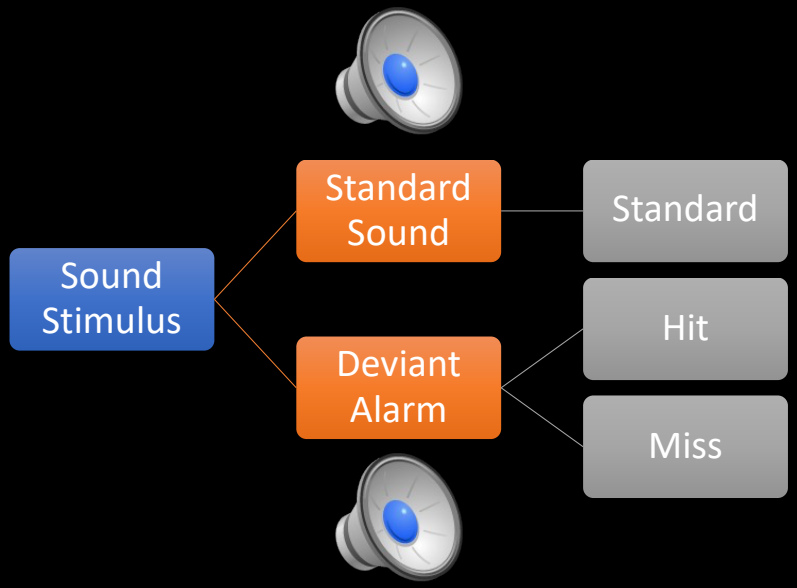


In-Flight Experiment

Experimental Aircraft
DR 400 Robin

Pilot and Instructor in Front
Research Engineer in Back

Sound Presentation During In-Flight Experiment



The experiment employed an auditory odd-ball task in which the pilots were to respond by button press when they heard the alarm chirp sound (deviant). Approximately 900 stimuli were presented every 2 to 5 seconds, 20% of which were alarms.

In-Flight Experiment

Various scenarios were used to induce high perceptual and cognitive loads for the pilot. These scenarios included:

- Navigation to a diverted flight plan
- Simulated engine failure
- Off-field emergency landing procedures
- Low altitude circuit patterns

LSL Synchronization for Aviation Based Experiments

Need to Synchronize Multiple Devices in Real World Conditions

Cognionics

EEG
EOG
EKG
Respiration

ILevil2 AW
Attitude Heading
Reference System

Sound Presentation

Button Response

Engine-Failure Emergency Landing

Performance on Auditory Task in Flight

	Deviant Sounds (20%: 180 Trials)					Standard Sounds (80%: 720 Trials)			
	Hits	Misses	Hit Rate	Subjective Percent Correct	Response Time	False Alarms	Correct Rejections	False Alarm Rate	d’
Sub1:DC	123	57	68.3%	65%	.744	15	705	2.1	2.51
Sub2:FD	99	81	55.0%	30%	.661	8	712	1.1	2.41
Sub3:CN	53	83	39.0%	50%	.770	0	532	0	2.60
Sub4:JC	109	71	60.6%	20%	.752	4	716	0.6	2.78
Sub5:MB	107	72	59.8%	70%	.862	2	718	0.3	3.00
Sub6:RL	78	101	43.6%	80%	.945	0	720	0	2.93
Sub7:ML	146	34	81.1%	75%	.728	18	702	2.5	2.84
Sub8:NR	63	118	34.8%	30%	.902	0	722	0	2.70
Sub9:GC	100	79	55.9%	50%	.768	8	712	1.1	2.44
Sub10:RM	133	47	73.9%	70%	.769	14	707	1.9	2.72
Sub11:RM	150	28	84.3%	90%	.692	22	698	3.1	2.87
Sub12:TB	116	60	65.9%	60%	.806	14	689	2.0	2.46
Sub13: VL	139	29	82.7%	75%	.904	8	652	1.2	3.20
	108.9	66.2	61.9%	58.8%	.792	8.7	691.2	0.13	2.73

EEG Processing Steps (EEGLAB: UCSD SCCN)

Filtering (Hamming Windowed Sinc FIR filter 1 to 30 Hz)

Automatic Channel Rejection

Artifact Subspace Reconstruction (ASR)

Independent Component Analysis (ICA)

Rejection of Artifact Components (SASICA, ADJUST)

Compute ERP Over Trials for Each Component

Select Independent Component with an ERP

ERSP and ITC (Hits and Misses)

Inter-Trial Coherence (Phase Resetting) and Attention

Entrainment or phase resetting of Neural Oscillations may be a mechanism of selective attention (Calderone et al., 2014 TICS).

Distraction reduces auditory Theta and low Alpha band (6-10Hz) inter-trial phase locking without modulation of total spectral energy (Ponjavic-Conte et al., 2012 Sensory and motor systems).

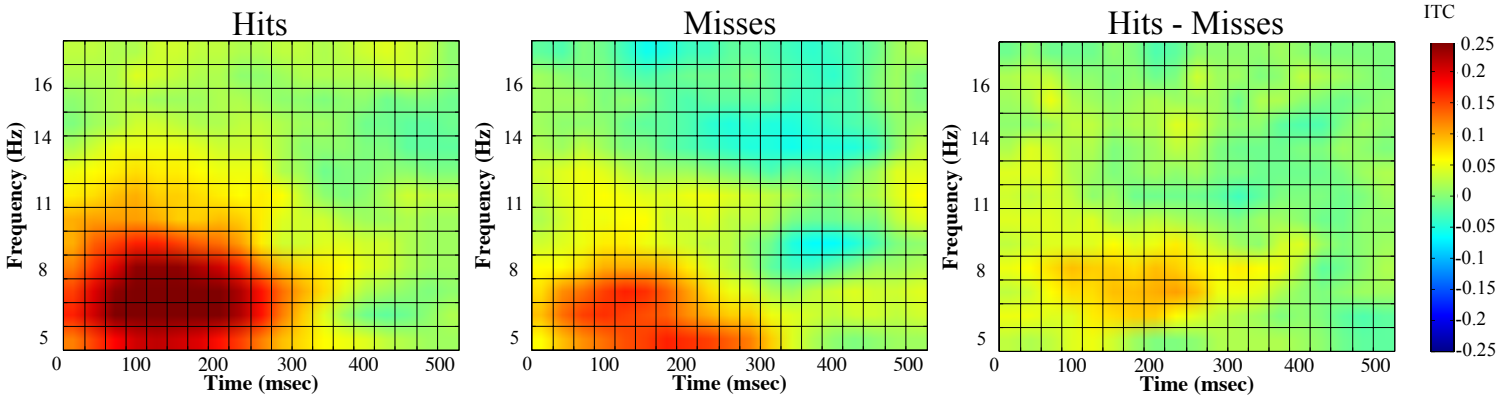
Auditory attention induces phase reset in Theta and low Alpha band range (6-10Hz). (Low et al., 2009 Physiological Measurement).

Phase Resetting in Theta and low Alpha band (2-10hz) predicts visual spatial attention performance (Yamagishi et al., 2008, Brain Research).

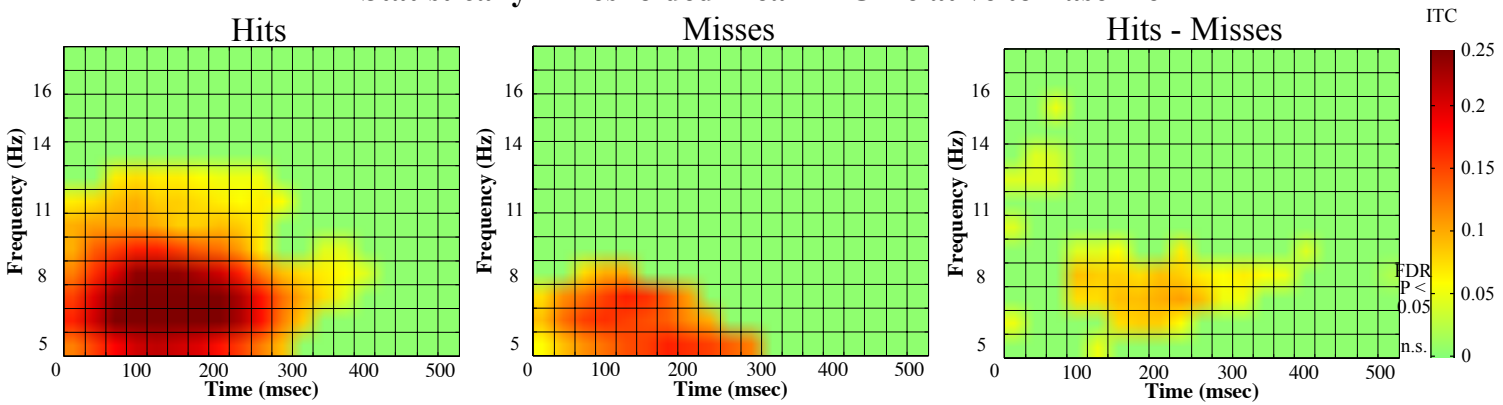
EEG Results

Post-Stimulus Onset Inter-Trial Coherence (ITC)

Mean ITC Relative to Baseline



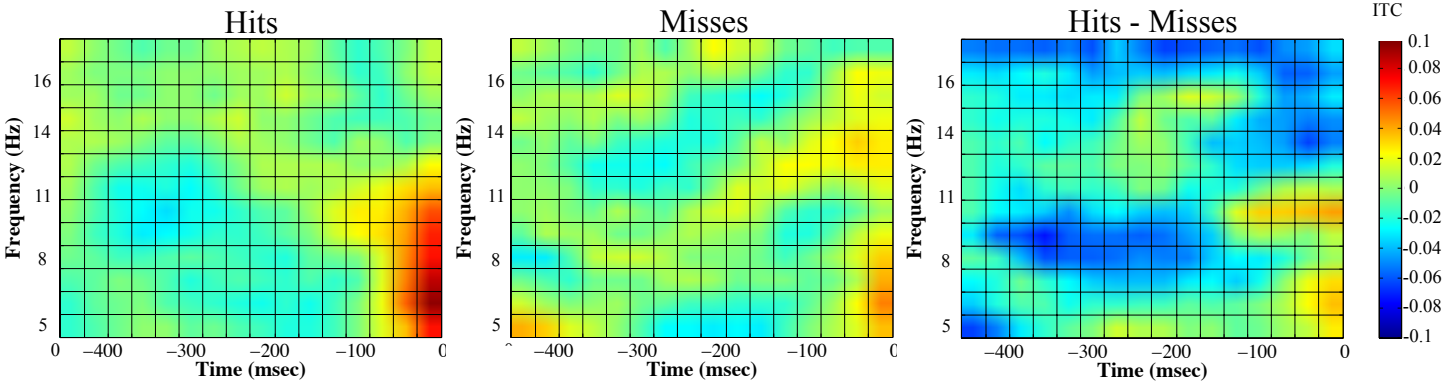
Statistically Thresholded Mean ITC Relative to Baseline



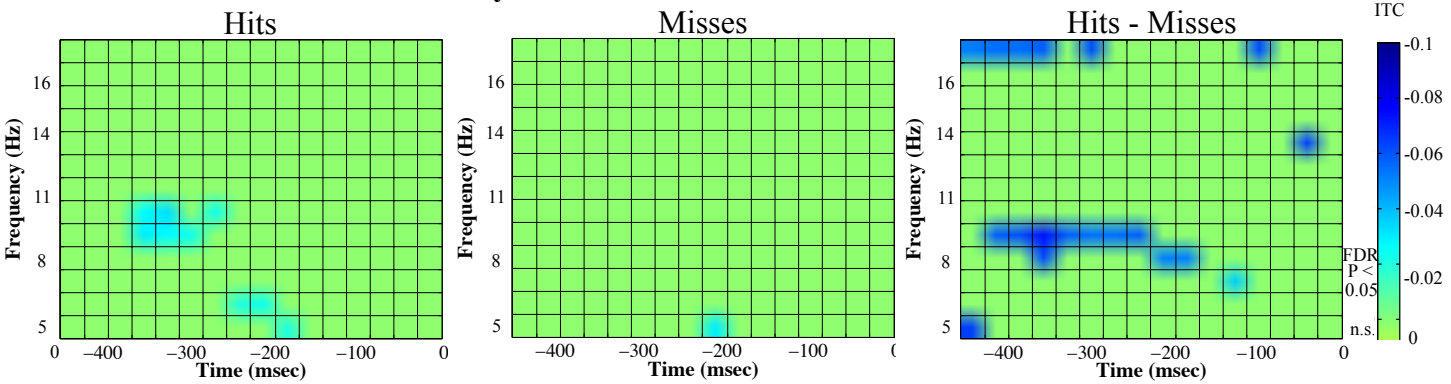
Pre-Stimulus Onset Inter-Trial Coherence (ITC)

Mean ITC Relative to Baseline

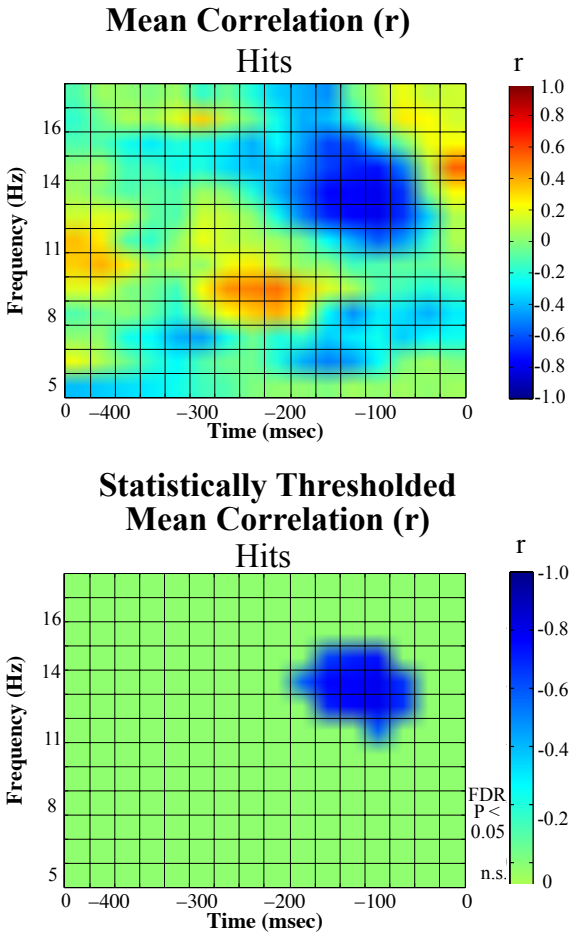
Direct Comparison between Mean ITC

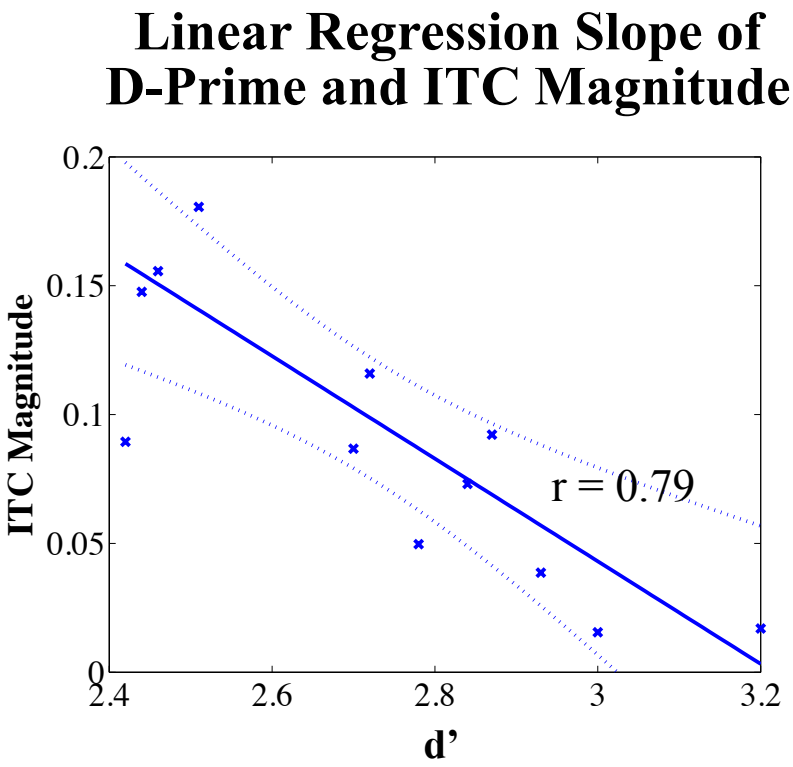


Statistically Thresholded Mean ITC Relative to Baseline

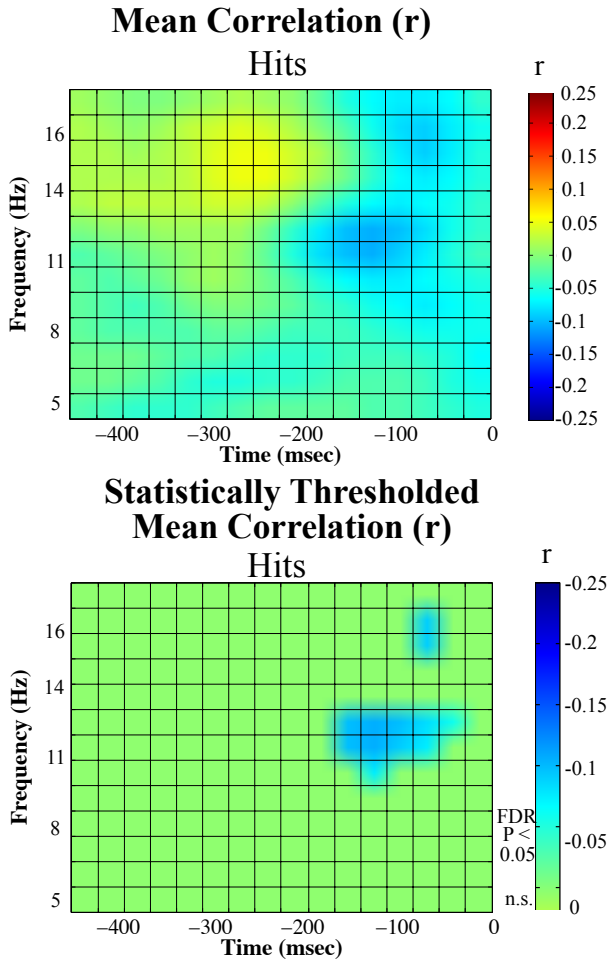


Pre-Stimulus Participant Level Correlation Between d' and Inter-Trial Coherence





Pre-Stimulus Mean Trial Level Correlation Between Response Speed and Wavelet Spectral Power



LSL Helps to Address Potential Confounds

• **Head Movement:** Although misses show greater head movement than Hits there was No Correlation between ITC value and head movement (accelerometer data in headset collected by LSL) for Misses or Hits.

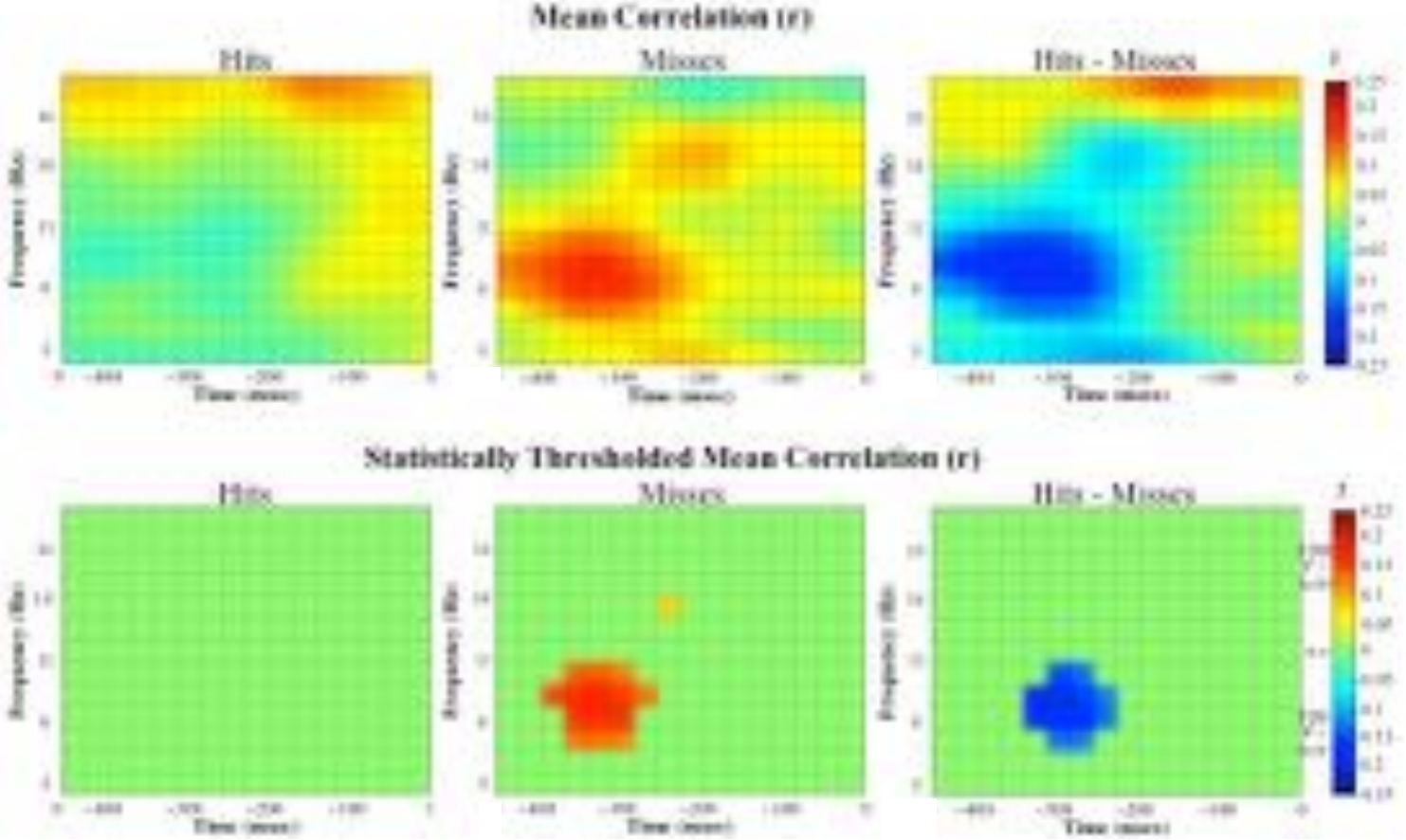
• **Acoustic Masking:** It is unlikely that auditory misses in our experiment are just a product of acoustic masking from louder environmental noise. Because the Missed alarm condition has negative vertical speed (Flight parameters synchronized by LSL) and the Hit alarm condition has positive vertical speed, it is highly likely there was more acoustic noise generated from the engine for Hits rather than Misses.

Flight Parameters Synchronized by LSL

Flight Parameter	Hit Mean (SE)	Miss Mean (SE)	T	p
Altitude Feet	1894 (54.2)	1771 (47.3)	2.11	0.056
Ground Speed Knots	81.81 (2.098)	80.97 (1.228)	0.49	0.633
Vertical Speed Feet/Minute	86.16 (38.062)	-98.47 (27.592)	4.25	0.0011*
Roll Degrees	5.74 (0.321)	6.61 (0.284)	-2.59	0.024*
Pitch Degrees	-1.25 (0.342)	-2.39 (0.255)	3.45	0.0048*
Inclination Degrees	3.65 (0.293)	3.29 (0.214)	3.50	0.0044*
Turn Rate Degrees/Sec	-0.272 (0.111)	-0.591 (0.234)	2.16	0.051
G-Load Gs	0.952 (0.002)	0.963 (0.0025)	-4.44	0.0008*

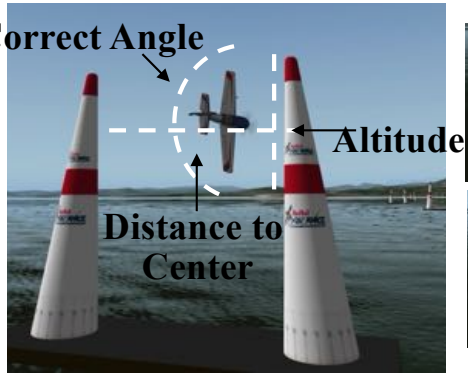
The flight parameters that significantly differed between Hits and Misses were associated with greater maneuvering (Roll, Pitch, G-Load) during descent (Vertical Speed, Pitch) likely occurring during simulated engine failure and landings when piloting workload is at its highest.

Pre-Stimulus Mean Trial Level Correlation Between G-Load and Wavelet Spectral Power

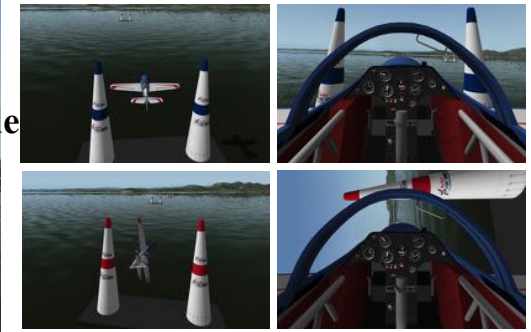


Inattentional Deafness (Motion Platform)

Evaluating Performance



Experimental Task
Fly Through Simplified Red Bull Air Race Course



Blue Gates
Horizontal Flight

Red Gates
Vertical Flight
'Knife Edge'

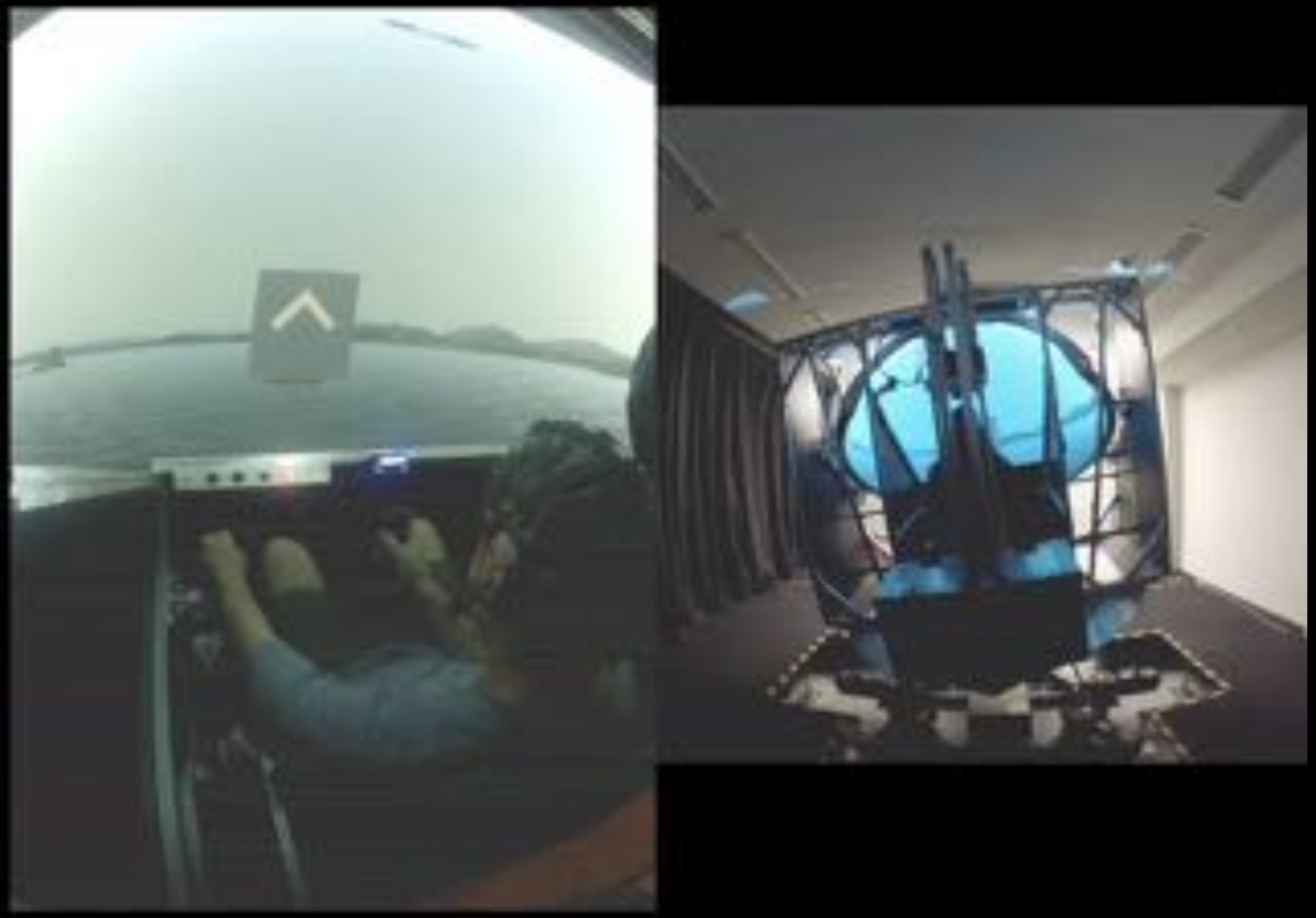
If the cockpit light indicated in the figure is on then the Instructions should be INTERVERTED
(Blue = vertical; red = horizontal)

INTERVERTED Instruction Light

Press Trigger Button when Hear or See Alarm

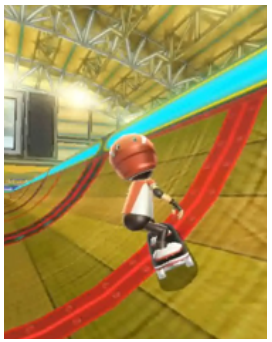
Visual Alarm

LSL used to Synchronize Timing of Trigger Responses and Presentation of Visual Instruction Lights via Raspberry PI Interface



LSL Used to Synchronize Multimodal Data During Dual Task

Wii Virtual Skateboarding and Audio Change Identification



Wii Skateboard Arena Task

Levels 1 to 5 Focus on Specific Tasks
Level 6 is a combination of tasks from all levels

Auditory Stimulus Change Detection Task

Task is to push button on Wii controller when the Chirp Stimulus Changes from One to Another (400 of each stimulus presented randomly): Approximately 375 Changes in Stimuli (No Background Game Sounds)

Button Response

Low Latency Insert Earpones

Level 1: Maneuver Over Targets on Ground

Level 2: Go up Ramps

Level 3: Go up Quarter Pipes

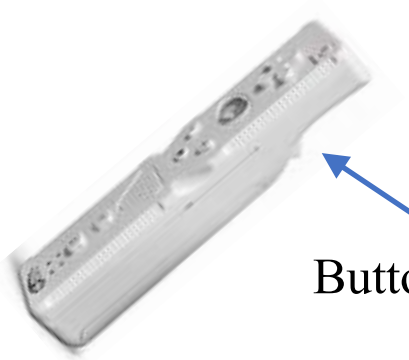
Level 4: Jump Over Rails

Level 5: Jump onto Box

Level 6: Combination of Tasks from Levels 1 to 5

Experimental Task
Auditory Stimulus Change Detection

Task is to push button on Wii controller when the Chirp Stimulus Changes from One to Another (400 of each stimulus presented randomly): Approximately 375 Changes in Stimuli (No Background Game Sounds)



Button Response

Chirp Down

Chirp Up

Low Latency Insert Earpones

Experiment Setup

Synchronizing Multiple Sensors

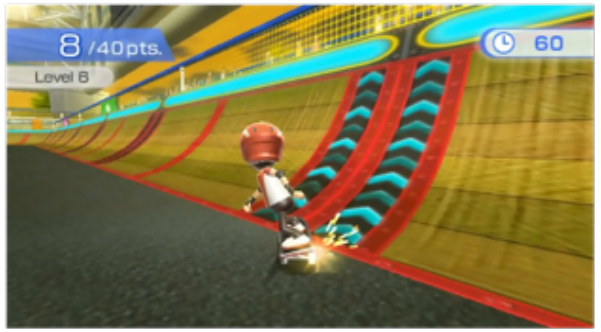
Multi-Modal Data Collection

Brain (EEG) | Muscle (EMG) | Foot Forces | MOCAP | Position | AV Game | Wii Mote

Lab Streaming Layer (UCSD)

Defining Event Onsets in Wii Game
Labstreaming Layer LSL (UCSD)
Synchronizing Multiple Sensors

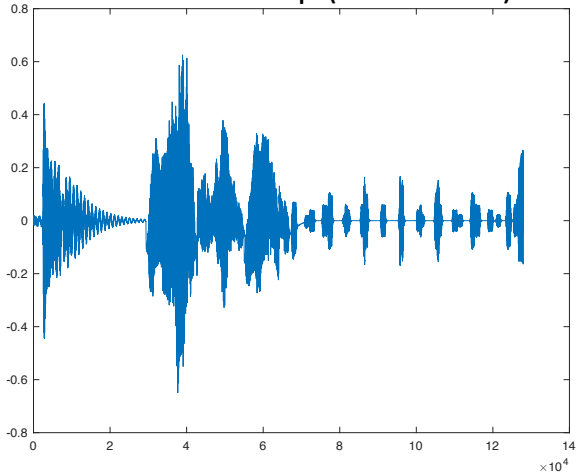
- LSL Can Capture Audio from Sound Card
- LSL Can Capture Bluetooth Wiimote Signal
- LSL Can Capture EEG and AIM
- LSL Can Capture Xsens MOCAP



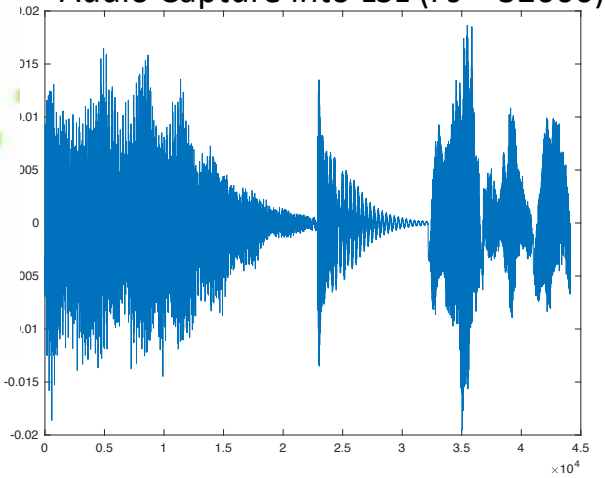
- Wii dumps Audio and Video Frames after game
- Loadsol uses android app. Need to use foot press trigger to identify time stamp in LSL and forces that can be easily detected in Loadsol Force data.

Alignment of Audio data from Wii and Audio Capture into LSL using Cross Correlation

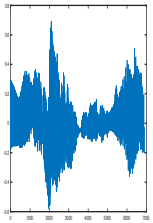
Wii Audio Dump (Fs = 32000)

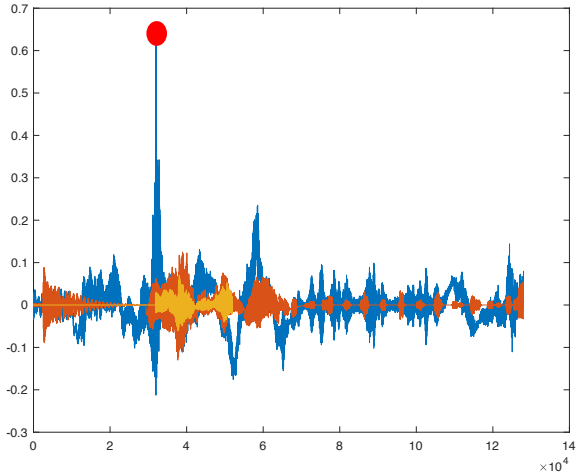


Audio Capture into LSL (Fs = 32000)



Template Aud Cap
'Starting Up'

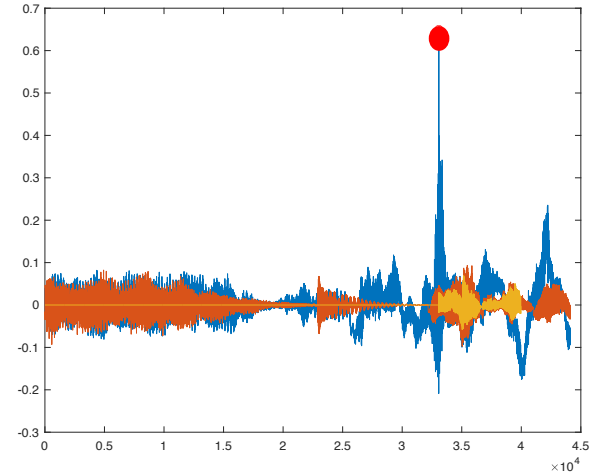




Wii Time Start = 229.463 sec

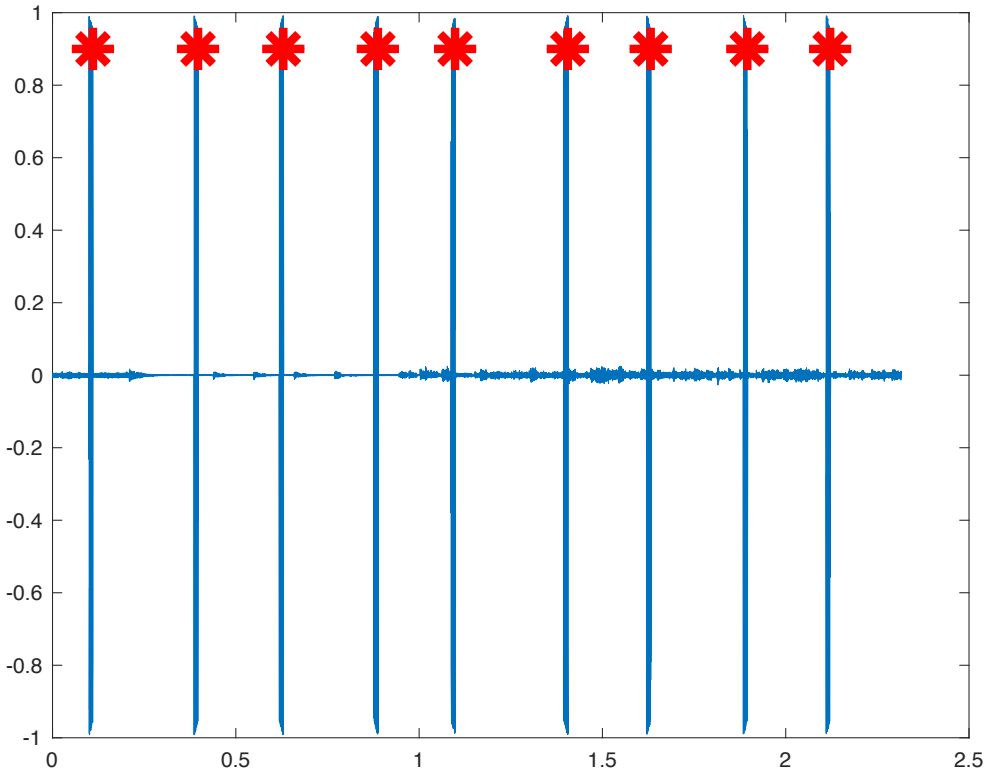
Blue = Cross Correlation
Red = Audio Signal
Yellow = Template

LSL Time Stamp
591878.598365425



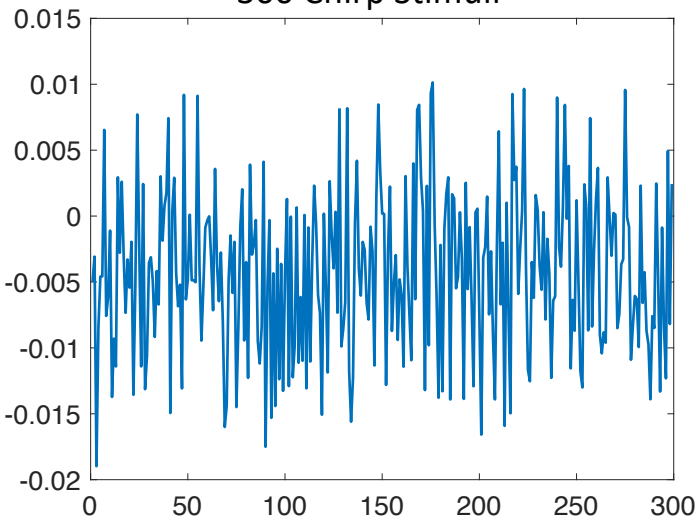
Wii Time Start = 75.931 sec

Alignment of EEG Markers and Audio Capture into LSL using Cross Correlation



Sound Wave from Audio Capture (EEG Marker shown in Red)
Chirps are High Intensity Compared to Background Wii Sound

Error Between EEG (500Hz) Marker
and Audio Capture (11025Hz)
300 Chirp Stimuli

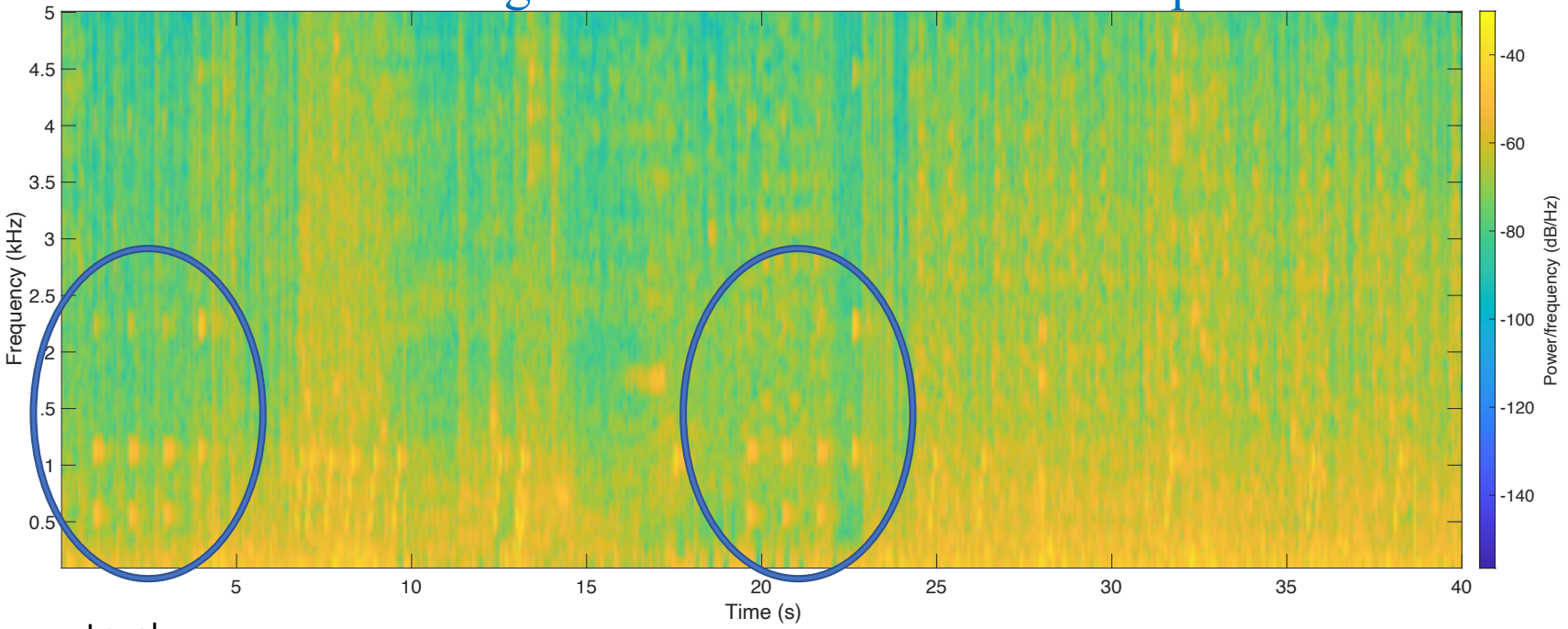


Range = 0.029 sec

Mean Offset Latency = -0.004 sec
(Marker Before Audio Capture)

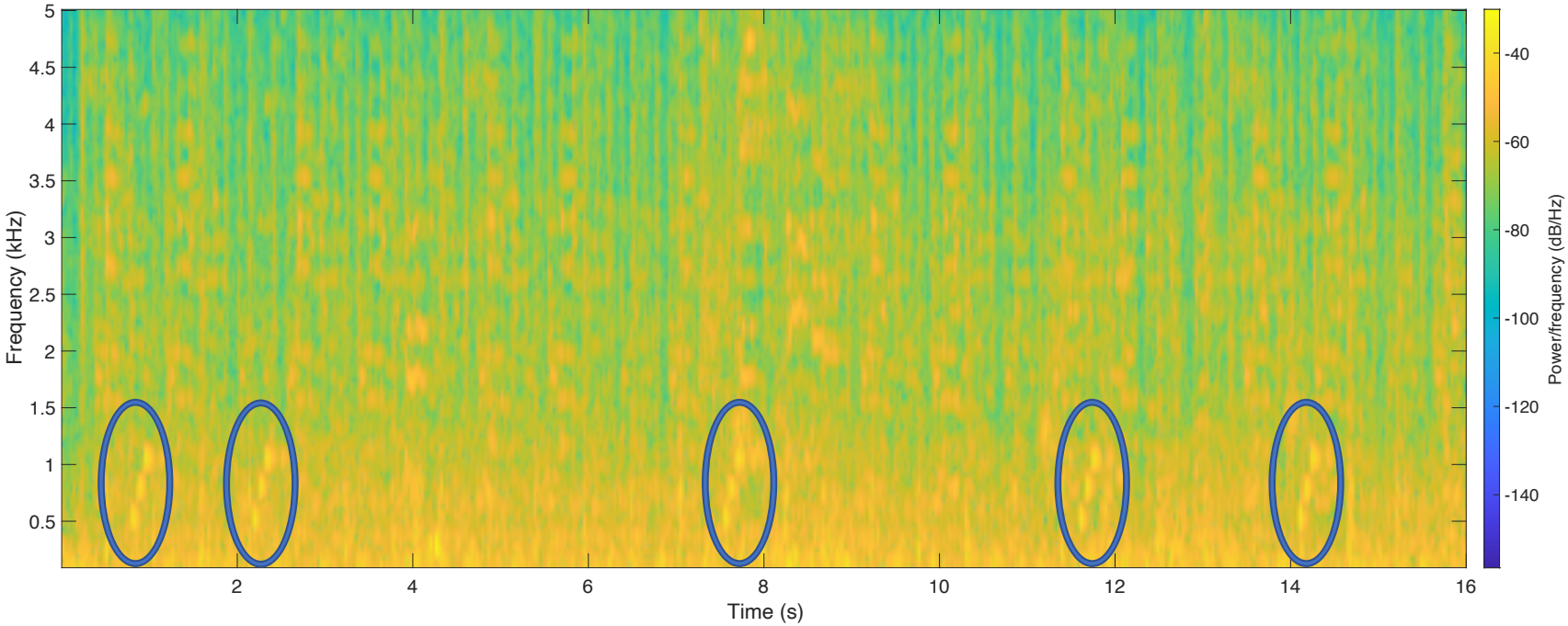
STD = 0.006 sec

Extracting Events from Wii Audio Dump



Level

Extracting Events from Wii Audio Dump

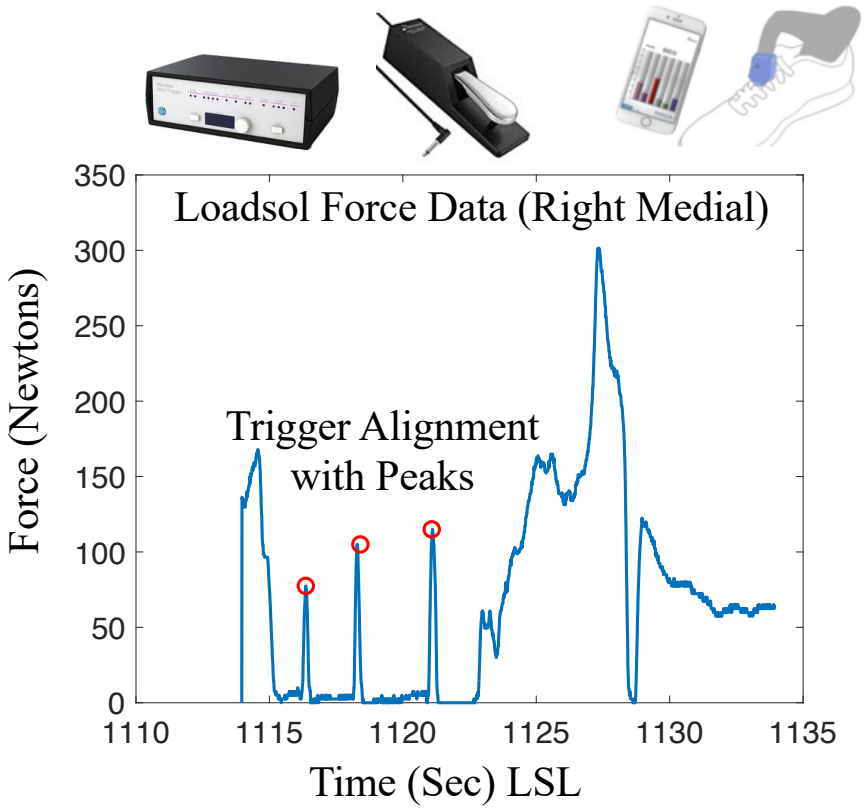


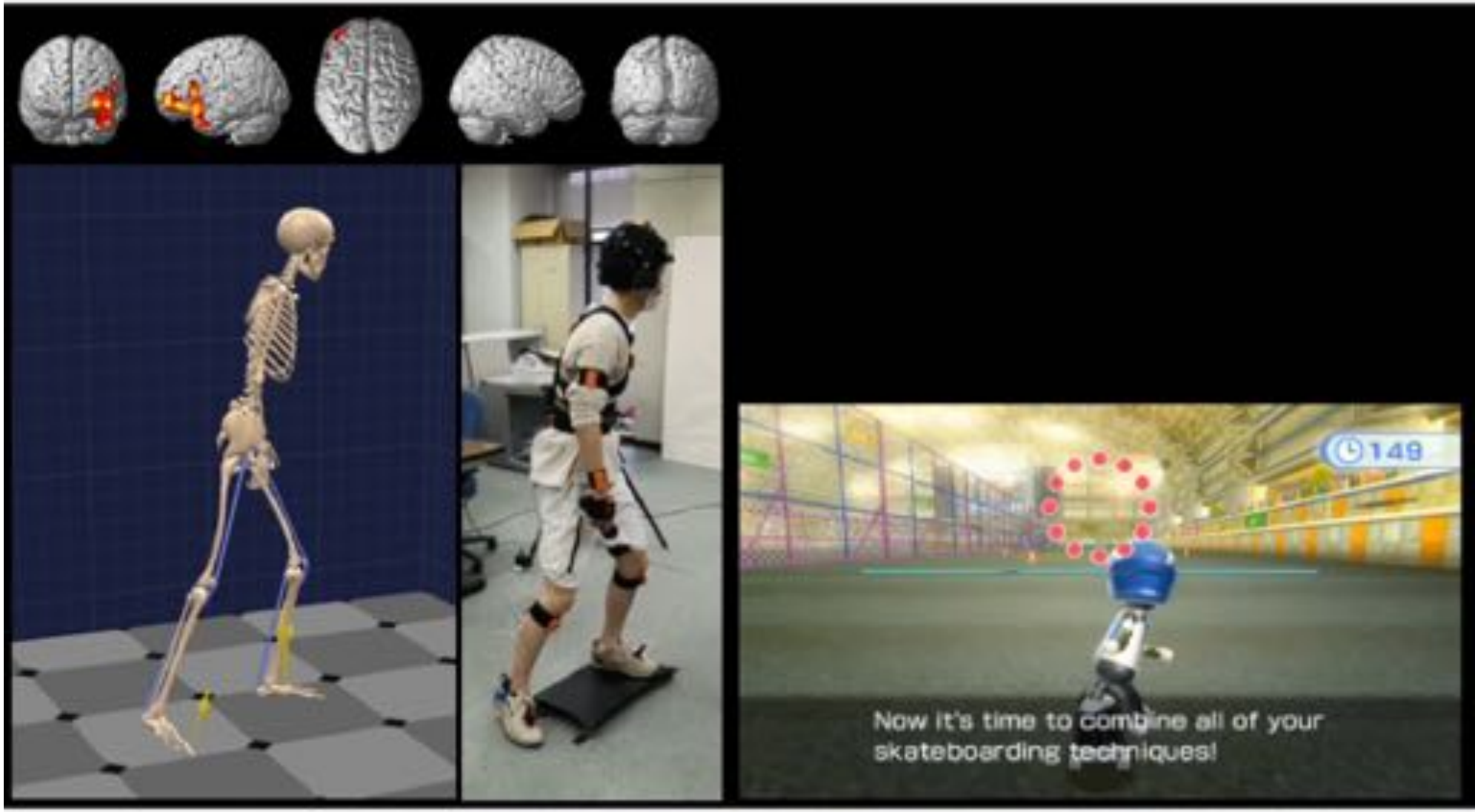
Extracting Number Events from Wii Frame Dump

Extracting Number Events from Wii Frame Dump

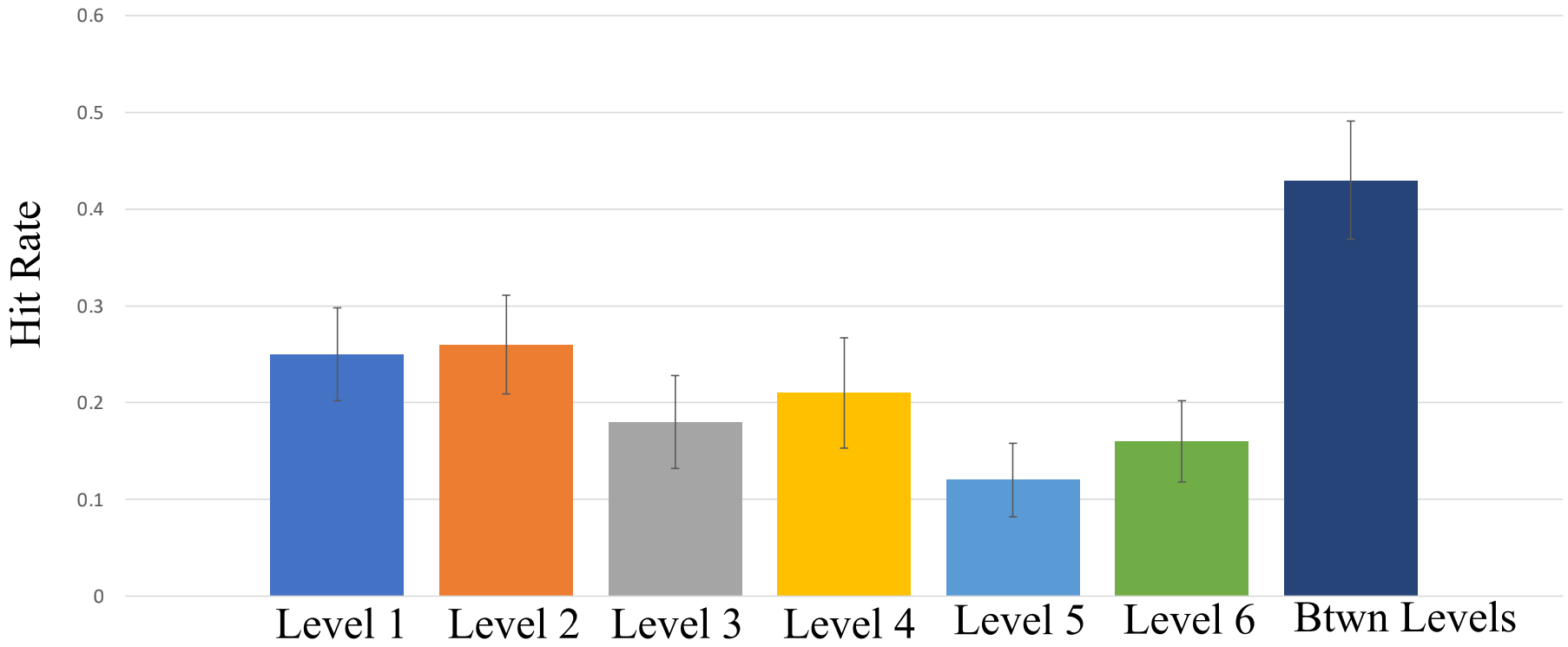
Synchronyzing Loadsol Force data and LSL Captured Data

'Old School Alignment' Trigger box with electric piano pedal that will send synchronization signal to LSL when pressed with foot. Peaks in Loadsol Force sensors can be aligned with LSL triggers.




148
Now it's time to combine all of your
skateboarding techniques!

Audio Task Hit Rate for Wii Levels



Utilizing a Dual Task to Investigate Role of Attentional Switching Between Wii Skateboard Task and Auditory Task

The fluctuation in pre- and post- stimulus power in the gamma frequency band is predicted to be modulated by attention

Studies have shown that increases in pre- and post- stimulus Gamma Activity is related to better performance (Fries, 2001; Womelsdorf et al., 2006; Wittenberg et al., 2018).

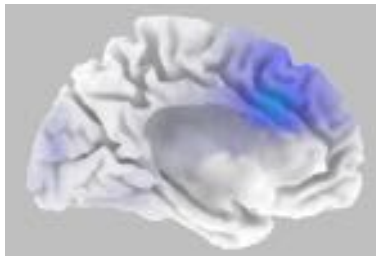
Preprocessing Steps to Remove Artifacts from EEG

- Bandpass Filtering 3 to 100Hz
- Regress Out Activity Correlated with 3 Accelerometers on EEG Headset
- Clean 60Hz Line Noise
- Remove Bad Channels
- Interpolate Electrodes that were Removed
- Average Reference the Channels
- Artifact Subspace Reconstruction (ASR) Correct Non-stationarity
- Average Reference the Channels
- Cut out Bad Segments
- ICA over Cut Data
- ICA weights applied to ASR non-cut data where all segments are included.
- IC Label to Extract Brain Components from Artifact Components
- Project Brain Components for Low Resolution Brain Electromagnetic Tomography LORETA Analysis (Gamma Band 30 to 50 Hz).

Primary Findings

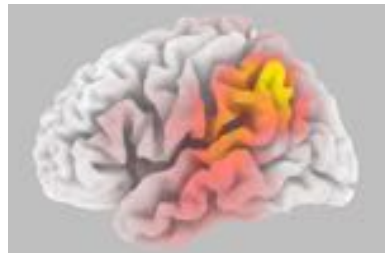
Greater Gamma band activity for Misses > Hits was present in Medial Prefrontal Cortex involved with divided and selective attention (Attentional Bottleneck).

Pre

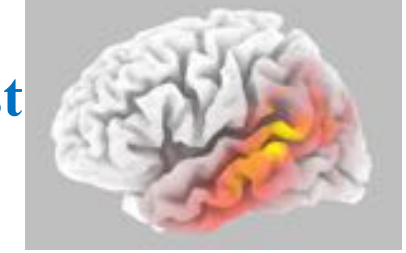


Enhancement of Gamma band activity pre- and post-stimulus onset in auditory processing brain regions is correlated with better participant auditory performance.

Pre

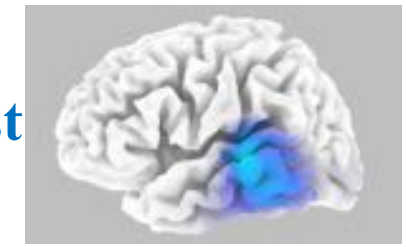


Post



Participants that do well at Wii Skateboarding game show decreased gamma band baselined activity in auditory regions (Active suppression of auditory processing).

Post



Wii Virtual Skateboarding: Brain Activity Related to Processing of Transitions into Motor Synergies for Jumping

Jump at Top of Ramp

Timing is Somewhat Flexible

Progress Continues Regardless of Success

Jump over Rail

Precise timing Related to Speed and Distance

Progress Hindered when Fail

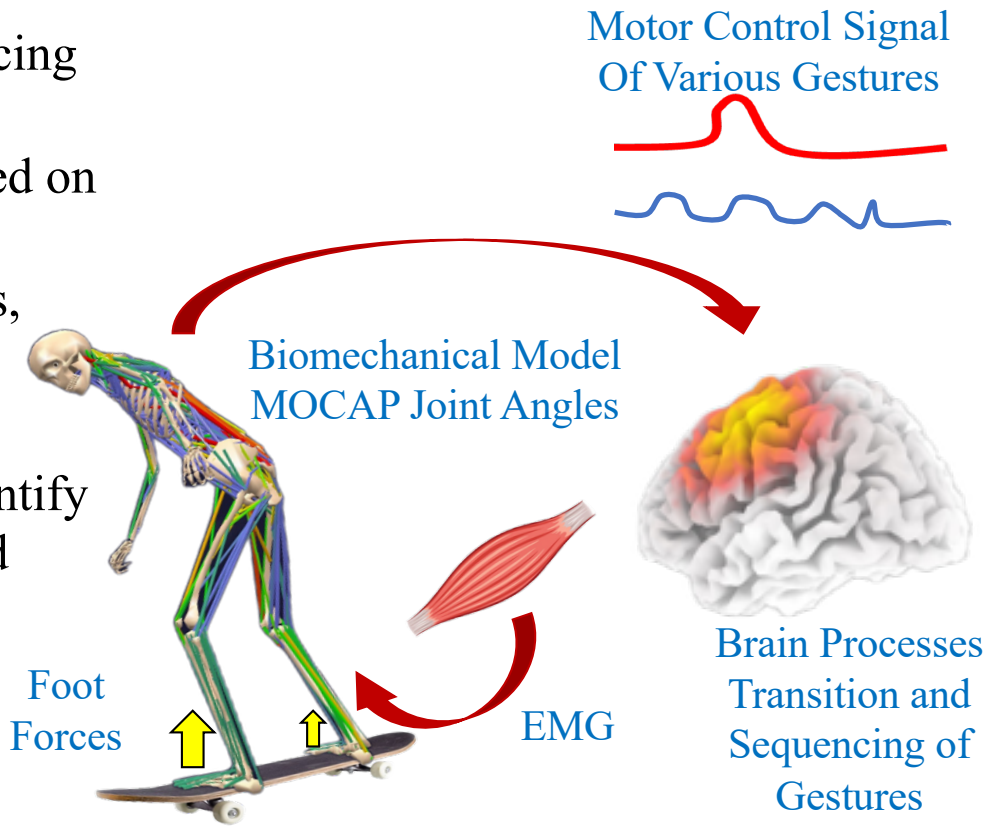
Onset of Jumps Defined by Peaks in Acceleration of lower and upper leg segments (Xsens MOCAP)

- **What Brain Regions are Differentially Involved with Transitions into these types of Jumps?**
- **What Brain Activity is Characteristic of Good Wii Skateboard Performers?**

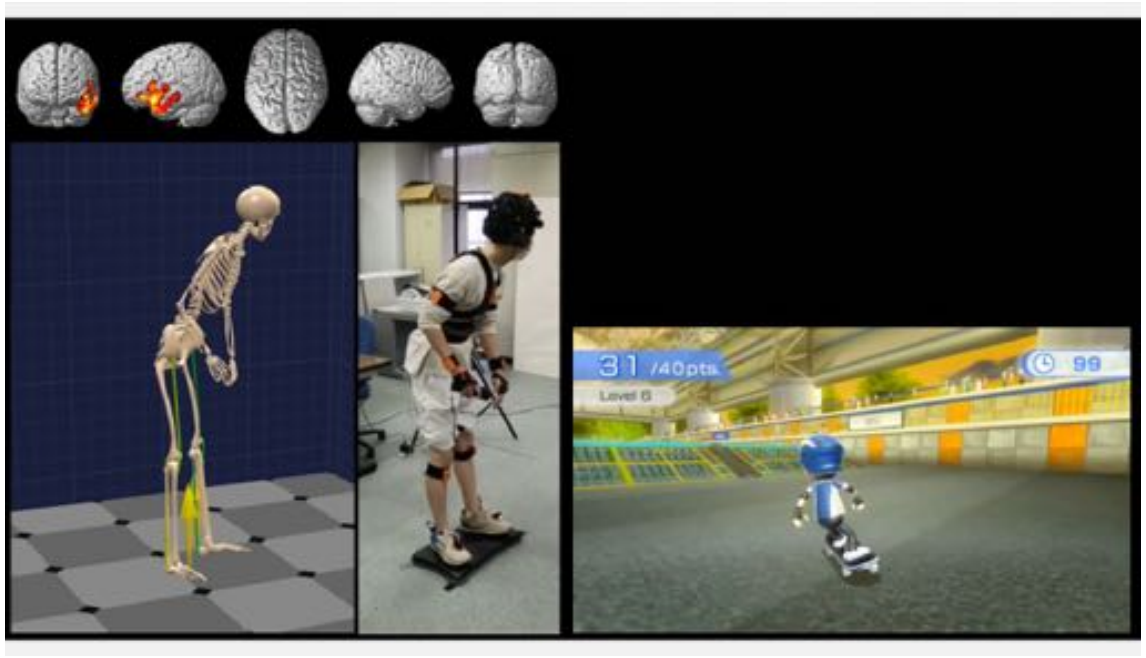
Motor Control and Biomechanics of Movement

The goal is to define the timing and sequencing of motor control signals underlying the execution of various gestural synergies based on a whole-body biomechanical model incorporating motion capture of joint angles, EMG muscle activity, and foot forces.

The motor control signal can be used to identify brain processes involved with transition and sequencing of coordinated movement.

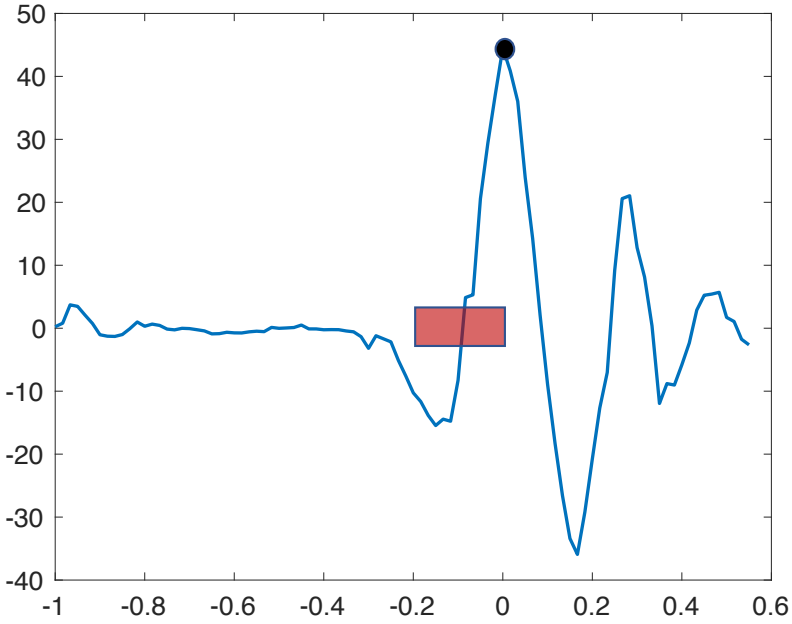


Jump at Top of Ramp

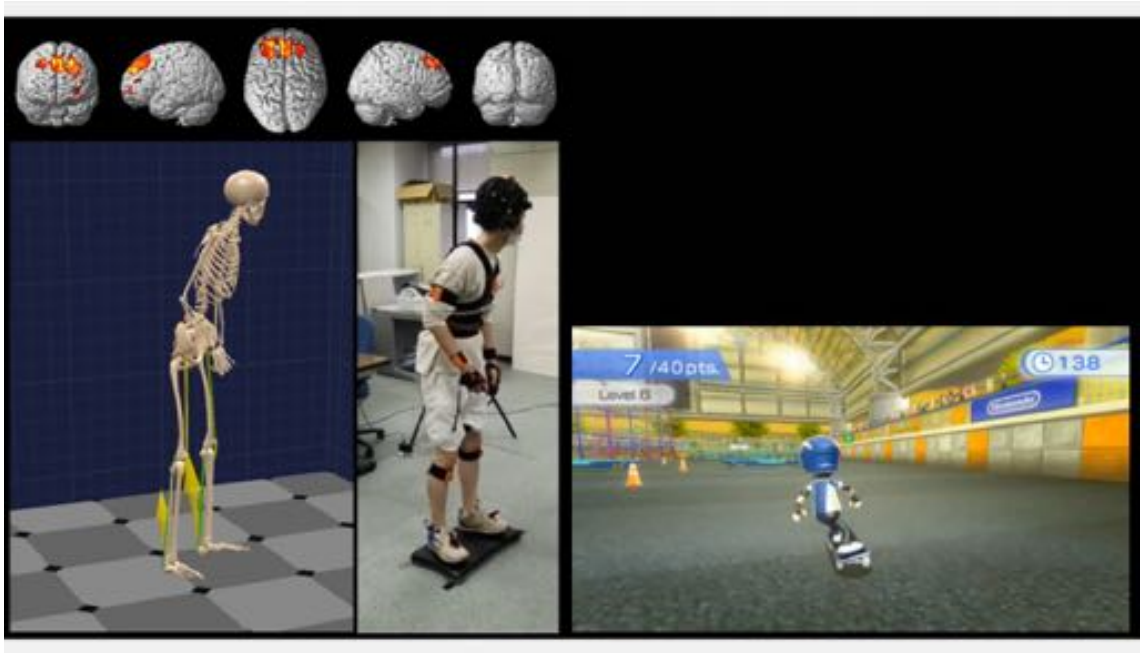


Sum of Acceleration in:

- Pelvis
- Left & Right Lower Leg
- Left & Right Upper Leg

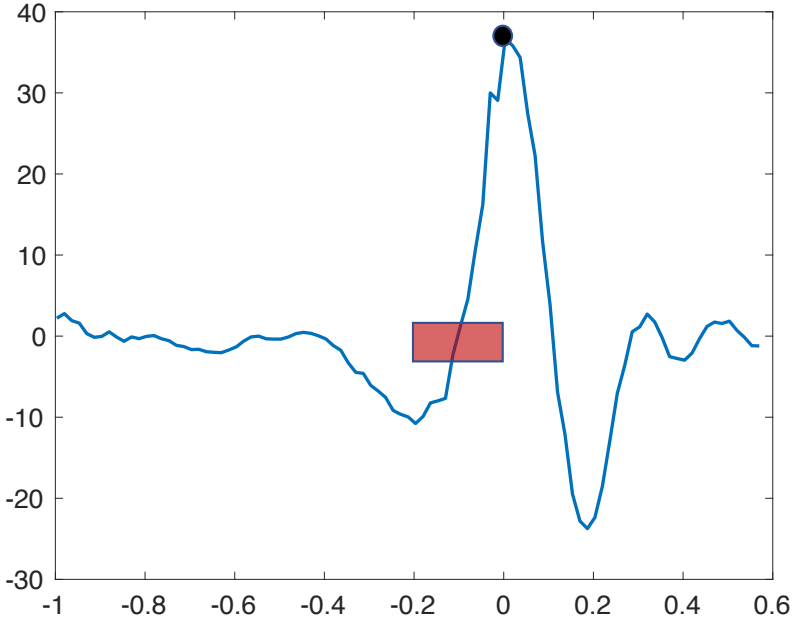


Jump Over Rail



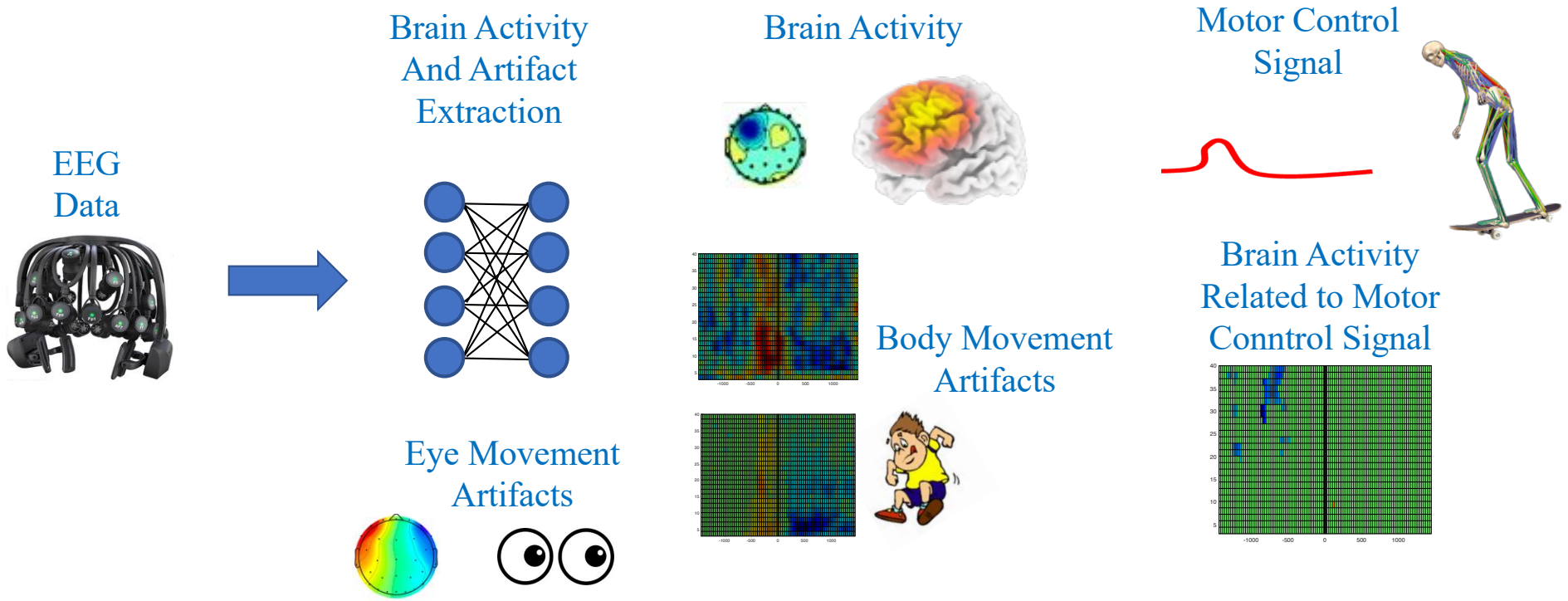
Sum of Acceleration in:

- Pelvis
- Left & Right Lower Leg
- Left & Right Upper Leg



Extraction of Brain Activity and Removal of Artifacts

Various techniques including artifact subspace reconstruction, independent component analysis are used to remove artifacts and extract brain activity related to motor control of sequencing and timing of gestures.

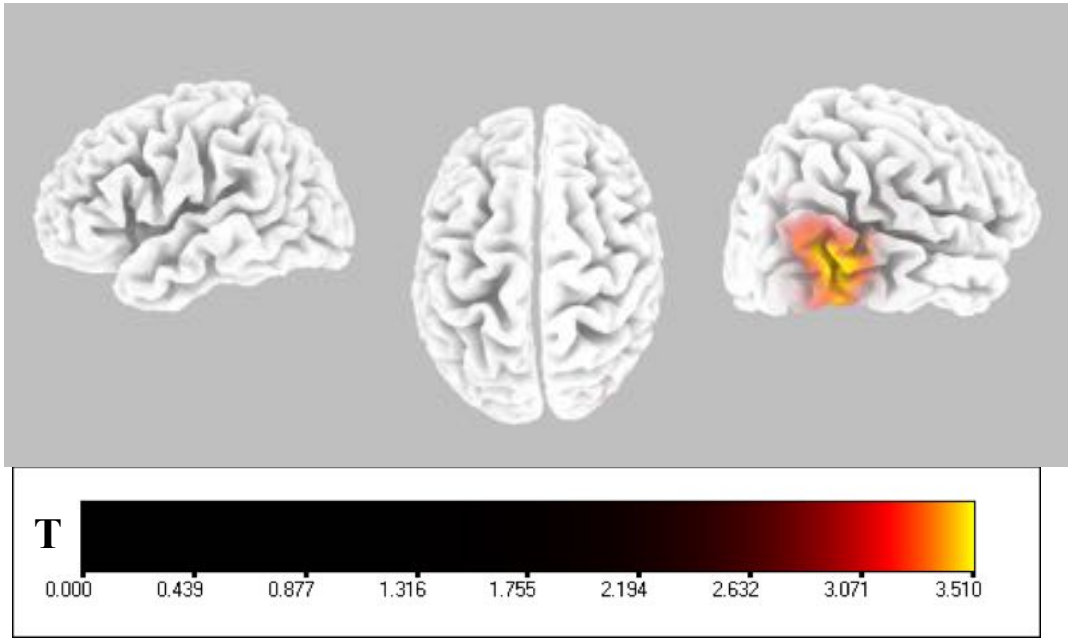


Predictions

- **What Brain Regions are Differentially Involved with Transitions into these types of Jumps?**
  - **Brain Regions involved with Timing of Movement Execution (SMA)**
  - **Brain Regions involved with Perceptual Processing of Visual Features Important for Predicting Time to Contact (V5/MT)**
- **What Brain Activity is Characteristic of Good Wii Skateboard Performers?**
  - **The Above Mentioned Brain Regions (SMA, V5/MT)**
  - **Brain Regions involved with Attention (Parietal, Frontal Brain Regions)**

Rail > Ramp

(-240 to 0 msec Pre-Max Joint Acceleration)

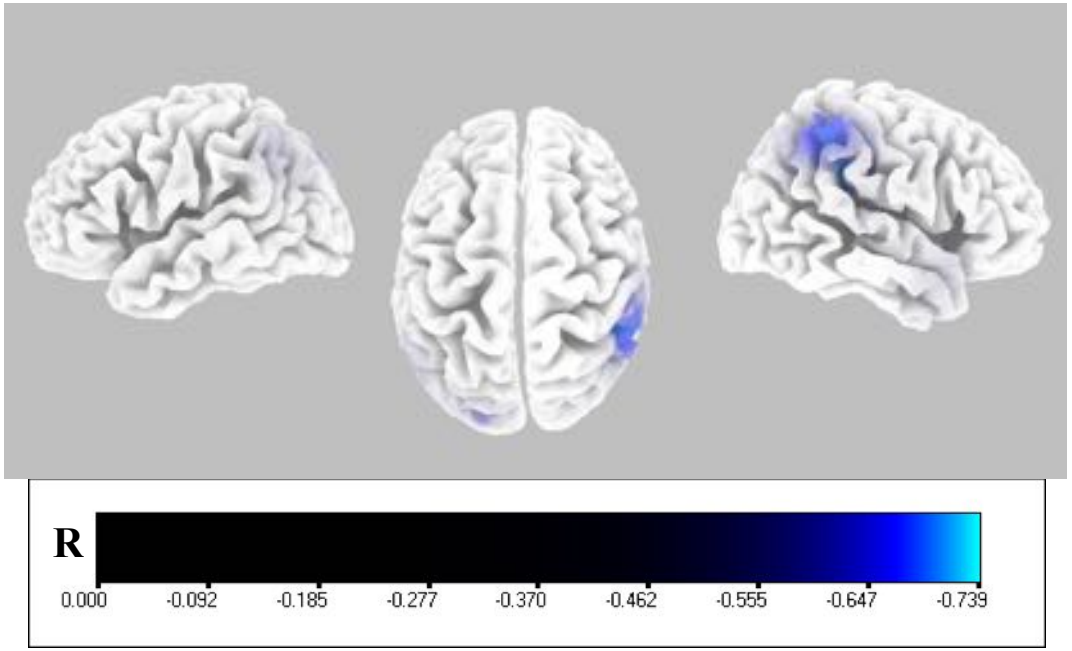


p < 0.05 SnPM Corrected using 5000 randomizations

Visual Motion Processing Area (MT/V5) shows differential brain activity for Rail over Ramp Jumping Conditions.

Correlation of Participant Wii Skateboard Game Performance with Brain Activity for Rail > Ramp

(-240 to 0 msec Pre-Max Joint Acceleration)

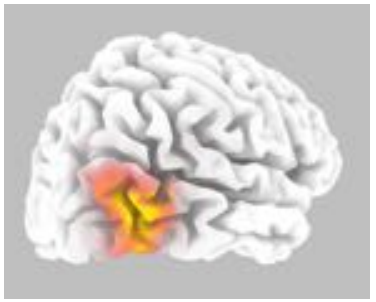


p < 0.05 SnPM Corrected using 5000 randomizations

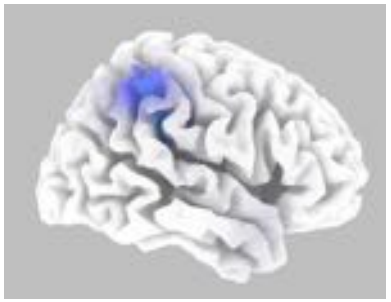
Participants with better Wii Skateboard Performance show Less activity in Inferior Parietal Lobule for the Rail > Ramp Contrast.

Primary Findings

Differential Activity in Visual Motion Processing Area (MT/V5) may be Related to Greater Dependence on Cues Signifying Time-to-Contact for Transition into Jumping Synergy for Rail > Ramp Contrast.



It is possible that the negative correlation between performance and Rail > Ramp brain activity in IPL found in our study reflects more automatic processing not requiring executive attentional processing.



Experiments on Real Skateboard Ramp: MOCAP, Foot Force, EMG, and EEG

EMG: Delsys Wireless System
16 Muscles Can be Recorded

MOCAP
Xsens Constrained by
VIVE Trackers

Foot Force
Loadsole

EEG: Cognionics 72 Channel Wireless System

Synchronizing The Signals: MOCAP, EMG, Foot Forces, and EEG

Trigger Box (Synchronizes MOCAP and EMG)

XSENS: MOCAP

Delsys: EMG

Problem for LSL: XSENS cannot keep up to process and send out data stream in real time.

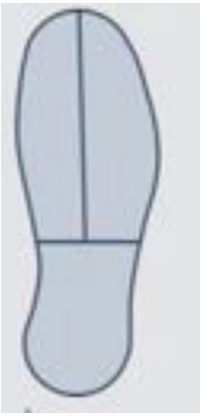
LSL is used to synchronize triggers (lasers and stimuli) with EEG

Synchronizing The Signals: MOCAP, EMG, Foot Forces, and EEG

Jump 3 Times: Accelerometer and Force Data Matching

XSENS: Accelerometer Foot

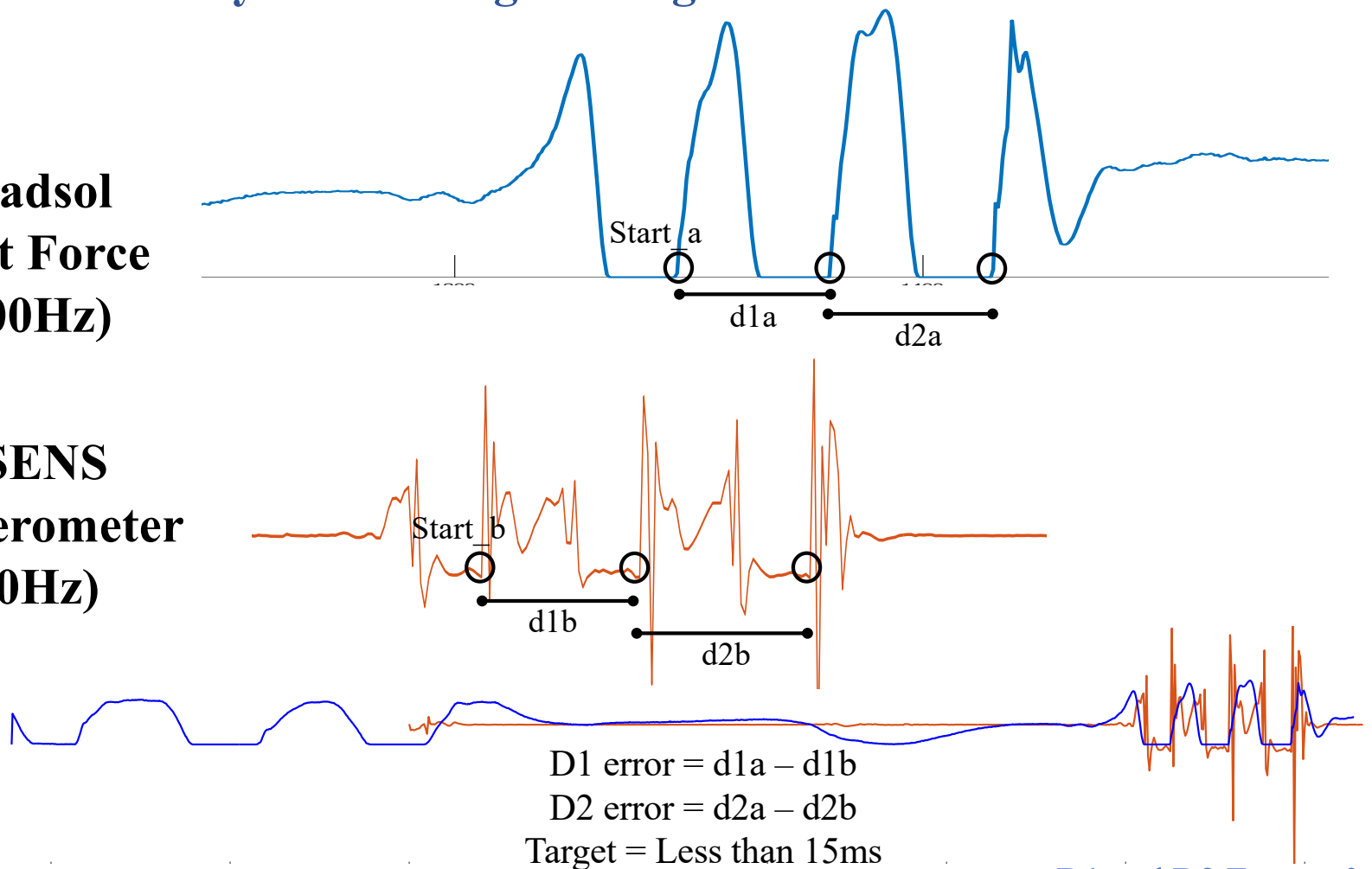
Loadsol: Foot Force



Offline Synchronizing The Signals: MOCAP and Foot Forces

Loadsol Foot Force (100Hz)

XSENS Accelerometer (60Hz)



D1 error = d1a – d1b

D2 error = d2a – d2b

Target = Less than 15ms

Delay = Start_a – Start_b

D1 and D2 Error = 0 ms

Synchronizing The Signals: MOCAP, EMG, Foot Forces, and EEG

Jump 3 Times: Accelerometer Data Cross-Correllation

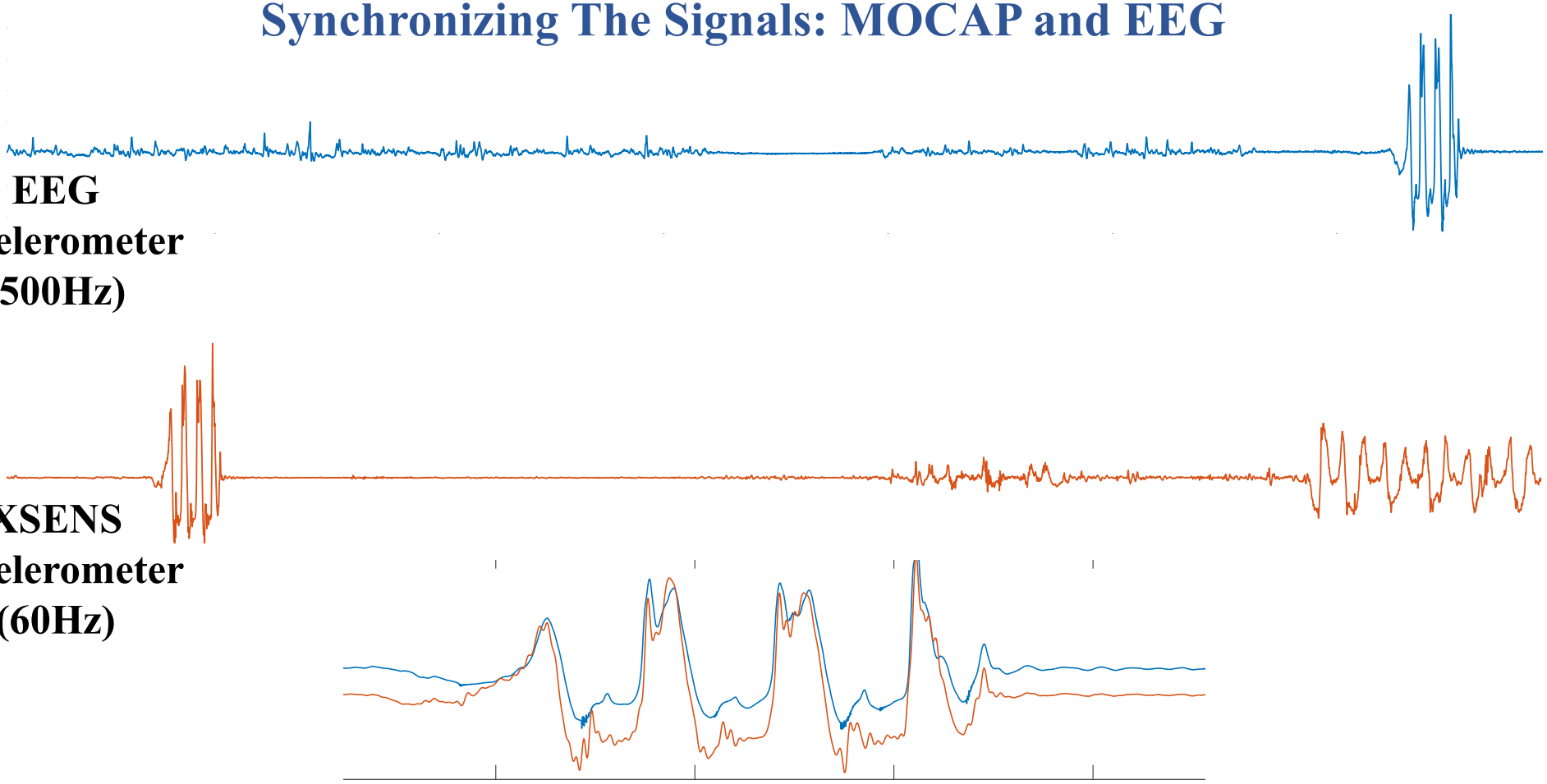
XSENS: Accelerometer Shoulder

EEG: Accelerometer Back

Synchronizing The Signals: MOCAP and EEG

EEG Accelerometer (500Hz)

XSENS Accelerometer (60Hz)



Delay is Determined by Time of Max Cross-Correlation for Jump part of Signals

Utilizing Auditory Evoked Potentials to Assess Robustness of EEG to Artifacts During Various Skateboarding Tasks

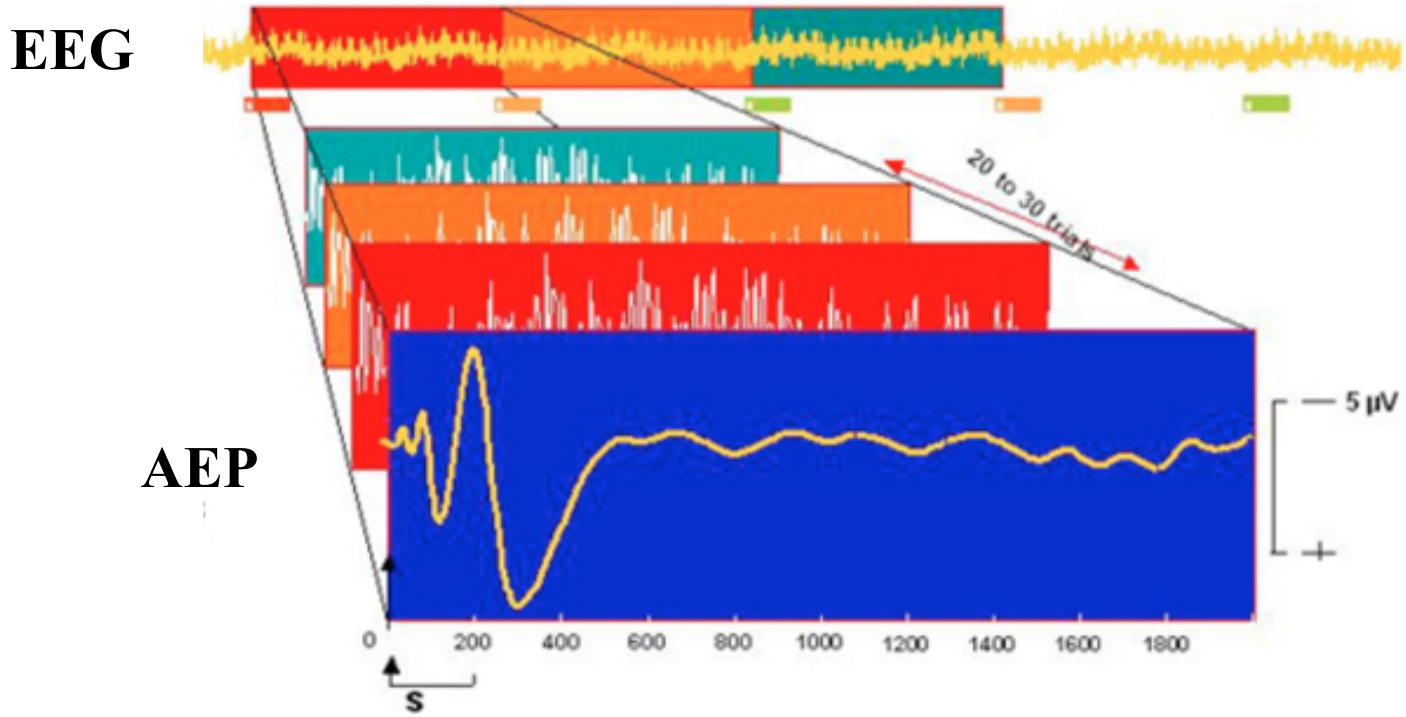
While Skateboarding Chirp Stimuli are Passively Presented via Low Latency Earphones

Chirp Down

Chirp Up

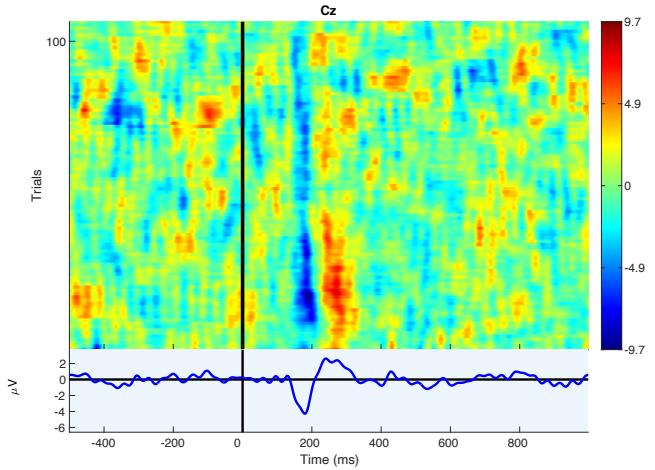
Low Latency Insert Earpones

Auditory Evoked Potential AEP and EEG Signal Averaging

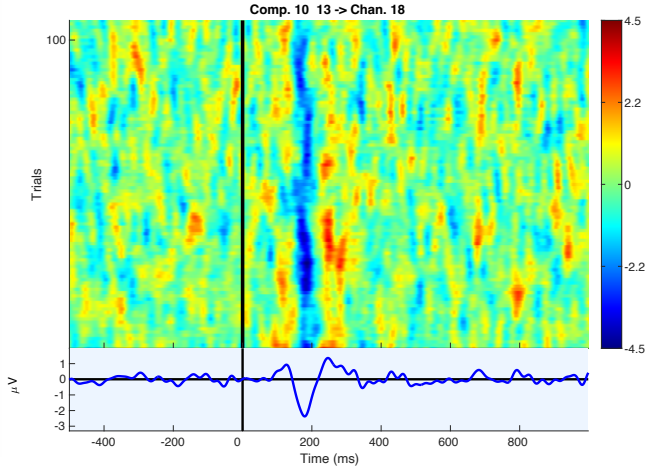


EEG Recorded During Pumping

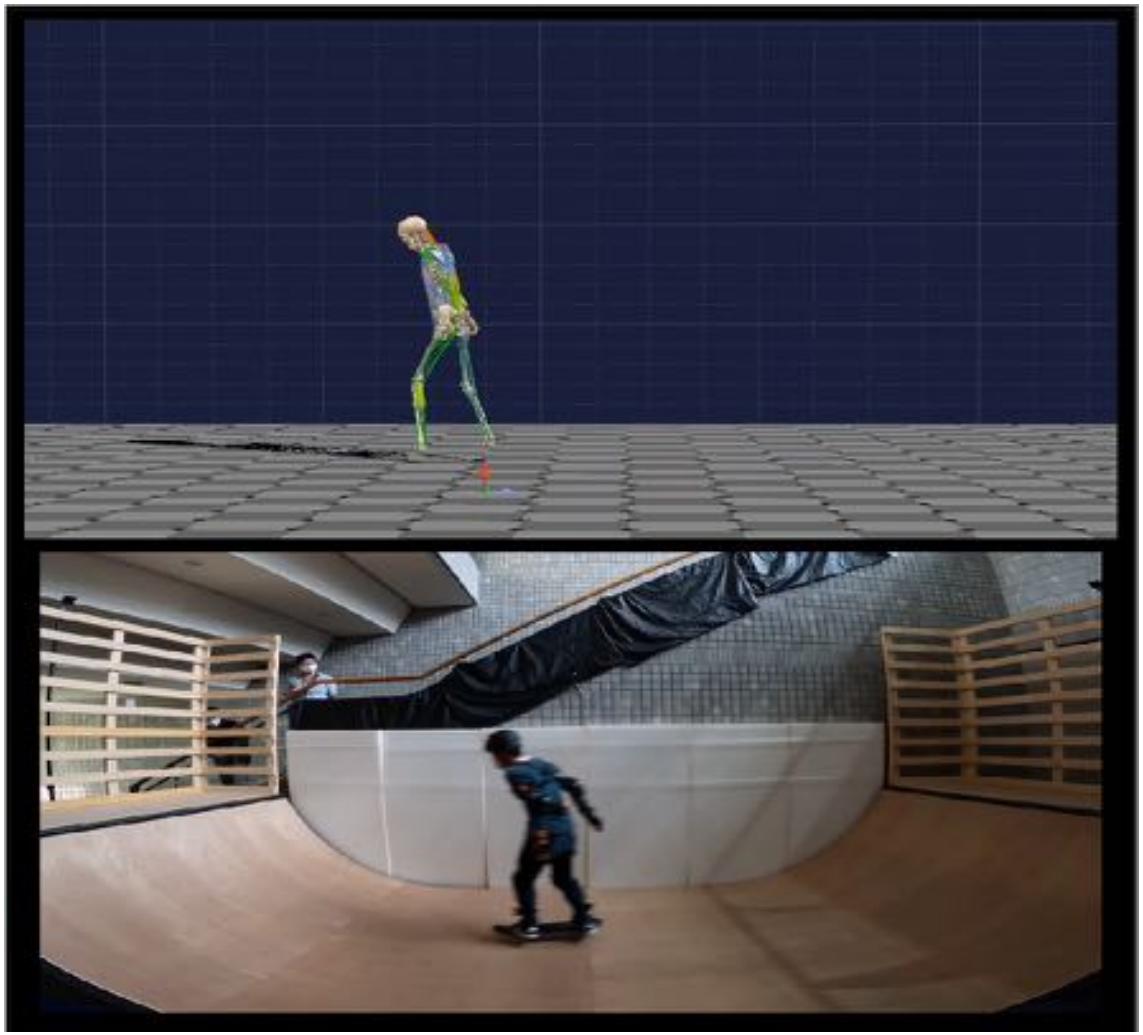
AEP w/o ASR and ICA



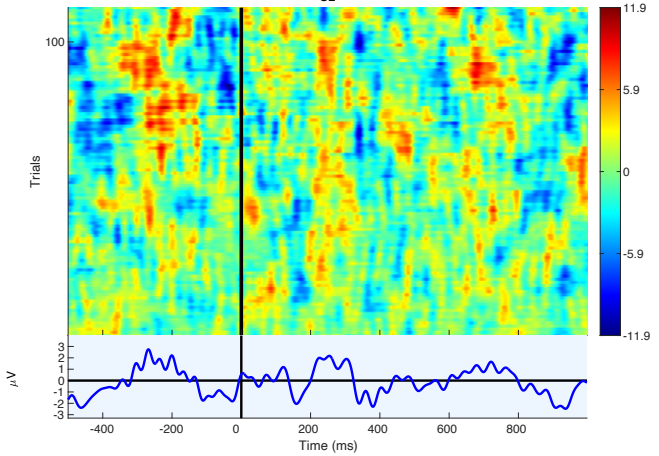
AEP With ASR and ICA



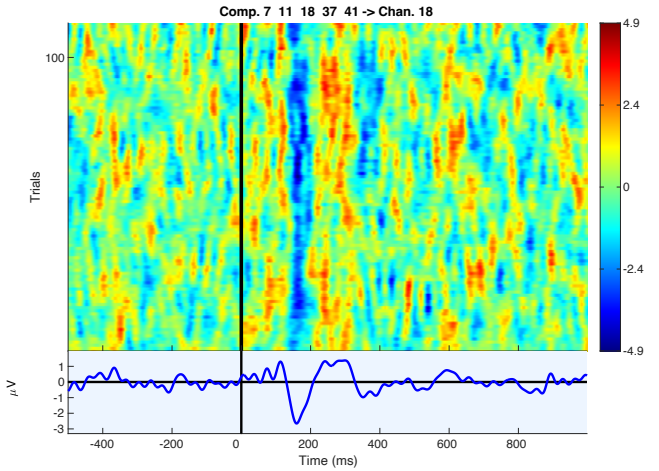
EEG Recorded During Kick Turns



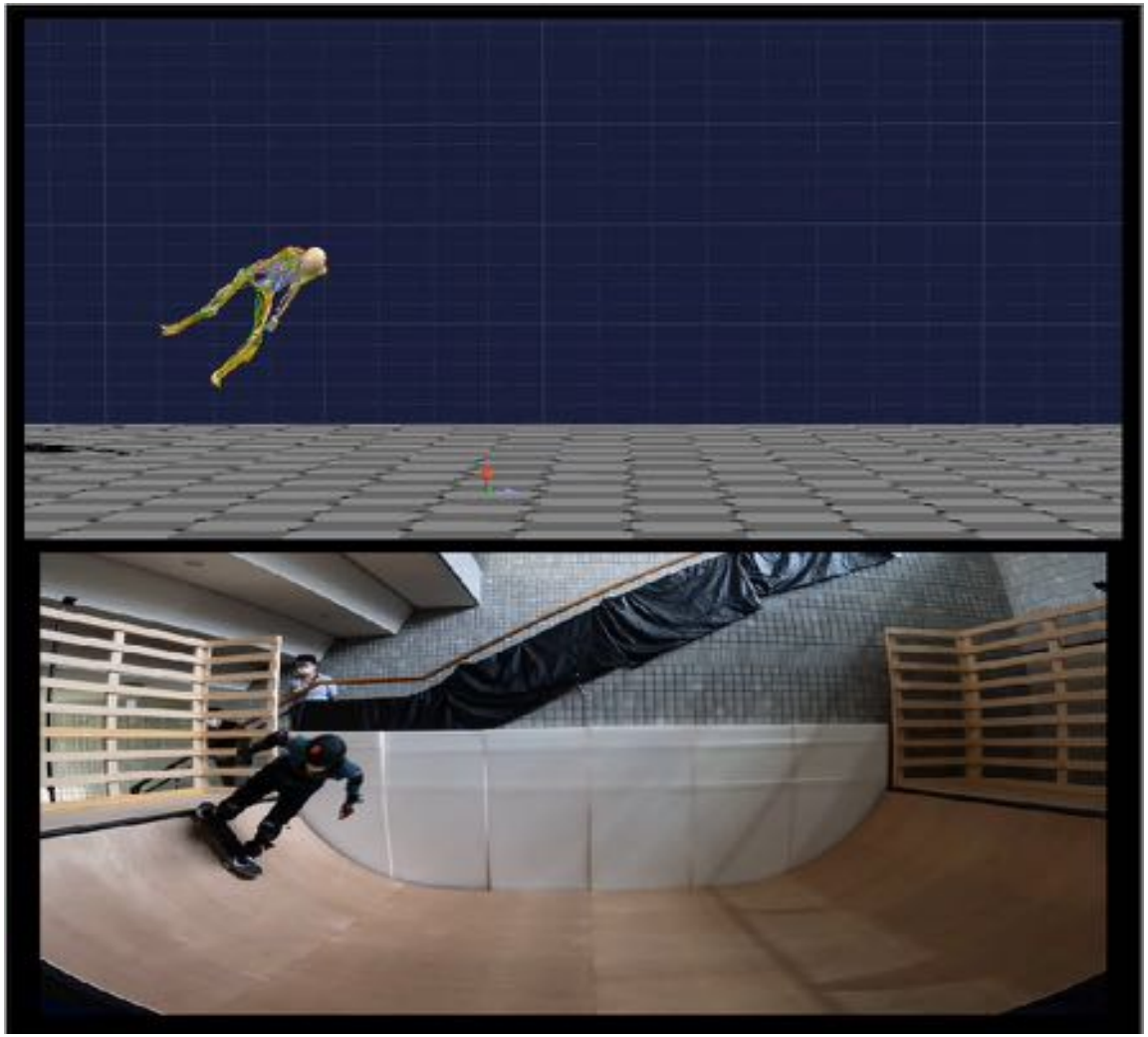
AEP w/o ASR and ICA



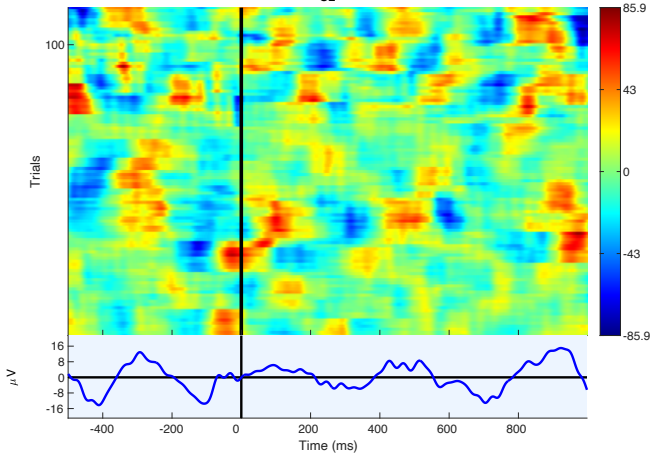
AEP With ASR and ICA



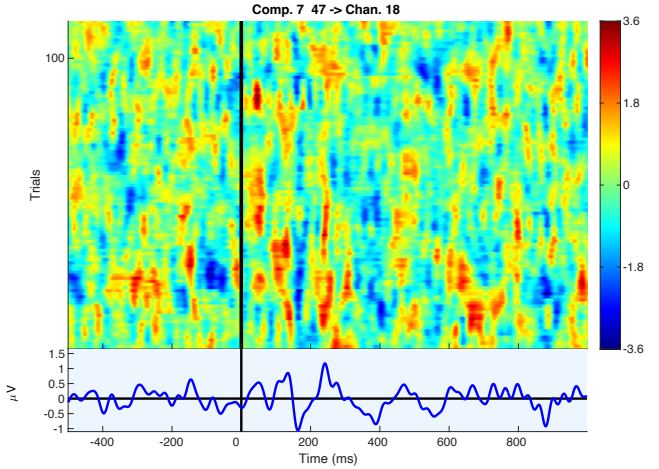
EEG Recorded During Copeing Tricks



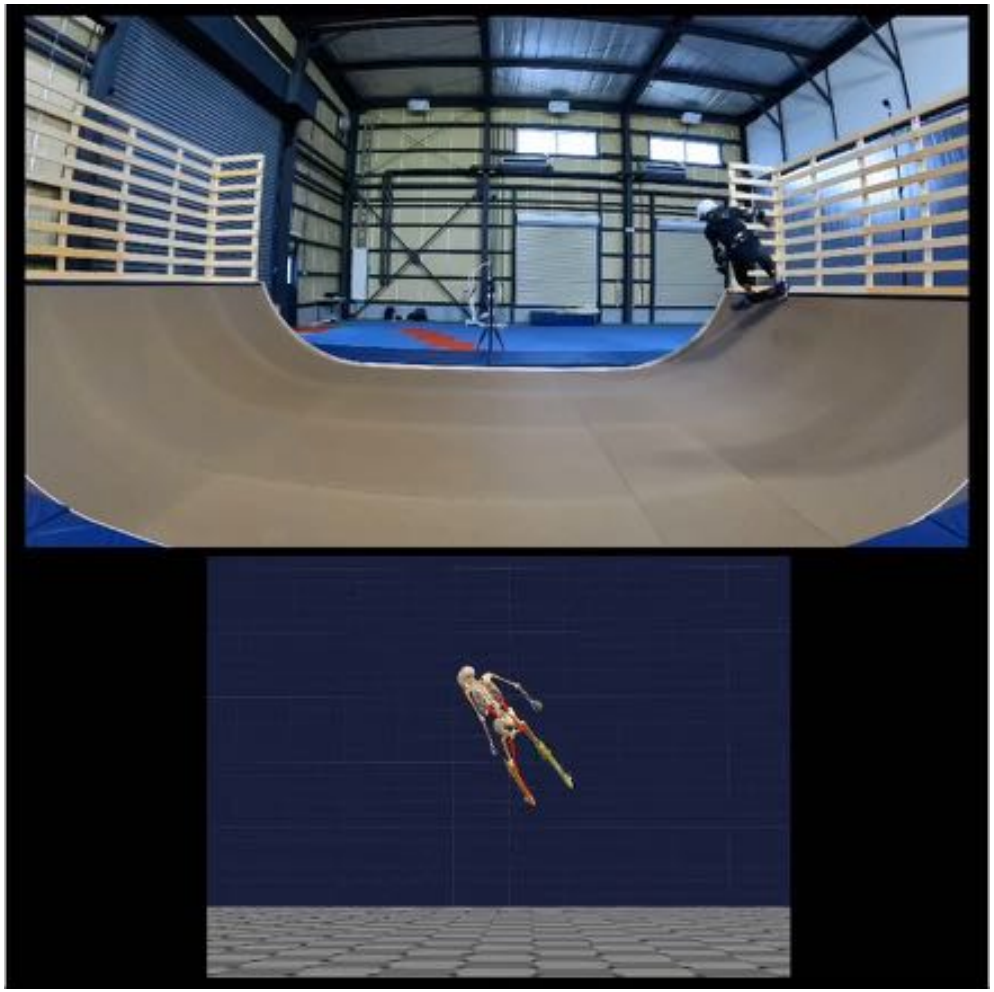
AEP w/o ASR and ICA



AEP With ASR and ICA



Reconstructing Whole Body/Segment Motion from EMG, Foot Forces, and EEG



Conclusions:

LSL is a Great Tool

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