AUDIO VISUOMOTOR NEURAL REPRESENTATION OF MUSICAL GESTURE

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Learning to play an instrument is a highly complex task that involves the interaction of several modalities and higher-order cognitive functions and that results in behavioral, structural, and functional changes on time scales ranging from days to years. One of the most prominent plastic change is the formation of novel neural connections between auditory, visual, motor and somatosensory cortex (basal ganglia, cerebellum, corpus callosum etc..)

**Synaptogenesis and synaptic pruning**
Multimodal representation

STS single cell recordings in monkeys

Humans (fMRI)
Auditory mirror voxels

- hand
- mouth
- overlapping regions
Random Movements vs. Pieces execution

Frontoparietal MNS and STS (audio–visuomotor circuit)

SEEING a familiar action activates the corresponding sound (also in music)
Action Representation of Sound: Audiomotor Recognition Network While Listening to Newly Acquired Actions

Amir Lahav,1,2 Elliot Saltzman,2,3 and Gottfried Schlaug1

Non-musicians were practising to play a melody for a couple of weeks. After this practise, fMRI scans showed that motor areas (left premotor, left IFG) in the brain were active when the subject listened to the same melody as had been practised.

Variations on the melody resulted in little or no activation.

Figure 1. Action-listening illustration. A, Music performance can be viewed as a complex sequence of both actions and sounds, in which sounds are made by actions. B, The sound of music one knows how to play can be reflected, as if in a mirror, in the corresponding motor representations.
A) Piano (sensorimotor-auditory) training compared to purely auditory training resulted in a stronger enhancement of the auditory MMN to unexpected tones in a short melody after 2 weeks of training. Claudia Lappe, Sibylle C. Herholz, Laurel J. Trainor and Christo Pantev (2008).

B) Training to play short melodies on a piano based on simple visual notation (auditory-visual-sensorimotor) resulted in stronger increases of responses to audio-visual incongruities (audio-visual MMN) than audio-visual training that did not involve an active motor component. 

Musical Training as a Framework for Brain Plasticity (Herholz and Zatorre, 2012)
In a short-term piano training procedure musically naive subjects were trained to play tone sequences according to a notation score [Auditory-Visual-Somatosensory group], while another group received audio-visual training only that involved viewing the notes and attentively listening to the music recordings.
Progetto di ricerca su rappresentazione audiovisuo-motoria

A. Testare l’esistenza di queste rappresentazioni in musicisti professionisti per i vari strumenti musicali (pianoforte, violino, clarinetto) vs. controlli

B. Con quale gradualità di formassero nel corso degli studi e dello sviluppo, se dipendessero da numero di ore di studio/età/expertise

C. Se l’expertise fosse strumento/timbro specifica

D. Se la loro attivazione fosse automatica e si rispecchiasse nell’osservazione degli altri (apprendimento per apprendimento oltre che per esercizio)
Music reading-Visuomotor transformation
From visual coding to motor commands
Musical expertise affects neural bases of letter recognition
Alice Mado Proverbio, Mirella Manfredi, Alberto Zani, Roberta Adorni
Neuropsychologia 51 (2013) 538–549

300 words, 300 music bars
Half targets/non-targets
Balanced for number of notes, metrics, length, frequency of use, imageability

Fig. 2. Example stimuli of different length used in the letter selection task.

Music measures were selected from Mozart and Schumann pieces for piano and for violin.
Hemisphere x Stimulus x Group

F(1, 26) = 5.7713, p = .02373
# Automatic audio/visuomotor transformation in musicians

| Magn. | T-x   | T-y   | T-z   | Hem. | Lobe | Gyrus                  | BA  | Notes/Analysis and Recognition                      |
|-------|-------|-------|-------|------|------|------------------------|-----|-----------------------------------------------------|
| 20.20 | −58.5 | −44.8 | −16.9 | L    | T    | Inferior temporal gyrus| 37  |                                                     |
| 10.83 | −28.5 | −15.3 | −29.6 | L    | Limbic | Uncus                  | 20  |                                                     |
| 10.80 | −48.5 | −78.2 | 3.8   | L    | O    | Middle occipital gyrus | 19  |                                                     |
| 10.76 | 21.2  | −81.1 | 30.6  | L    | O    | Middle occipital gyrus | 19  |                                                     |
| 10.47 | −28.5 | −90.3 | 20.8  | L    | O    | Middle occipital gyrus | 19  |                                                     |
| 10.79 | −38.5 | 43.4  | 23.9  | L    | F    | Middle frontal gyrus   | 10  | Working memory and decision making                 |
| 10.54 | 40.9  | 32.4  | 32    | R    | F    | Middle frontal gyrus   | 9   |                                                     |
| 10.33 | 21.2  | −24.5 | −15.5 | R    | Limbic | Parahippocampal gyrus | 35  | Spatial analysis of pentagram                      |
| 10.44 | 11.3  | −9.4  | −14   | R    | Limbic | Parahippocampal gyrus | 34  | Note/sound conversion, “absolute pitch”           |
| 10.38 | 21.2  | 9.1   | −27.5 | R    | T    | Superior temporal gyrus| 38  |                                                     |
| 10.37 | 50.8  | −0.6  | −28.2 | R    | T    | Middle temporal gyrus  | 21  | Visuo/motor transformation, first—sight reading    |
| 10.24 | 60.6  | −44.8 | −16.9 | R    | T    | Inferior temporal gyrus| 20  |                                                     |
| 10.17 | −38.5 | 2.4   | 29.4  | L    | F    | Precentral gyrus       | 6   |                                                     |
| 10.04 | 60.6  | −30.4 | 34.9  | R    | P    | Inferior parietal lobule| 40  |                                                     |
| 9.73  | 40.9  | −40.6 | 34    | R    | P    | Supramarginal gyrus    | 40  |                                                     |
| 10.82 | 1.5   | 2.4   | 29.4  | R    | Limbic | Anterior cingulate    | 24  | Response regulation                               |

| Magn. | T-x   | T-y   | T-z   | Hem. | Lobe | Gyrus                  | BA  | Notes/Analysis and Recognition                      |
|-------|-------|-------|-------|------|------|------------------------|-----|-----------------------------------------------------|
| 11.57 | 50.8  | −66.1 | −10.9 | R    | T    | Fusiform gyrus          | 19  | Visual analysis and object recognition              |
| 11.46 | 31    | −79.2 | 12.7  | R    | O    | Middle occipital gyrus  | 19  |                                                     |
| 11.45 | −38.5 | −79.2 | 12.7  | L    | O    | Middle occipital gyrus  | 19  |                                                     |
| 11.45 | −38.5 | 43.4  | 23.9  | L    | F    | Middle frontal gyrus    | 10  | Working memory and decision making                 |
| 11.42 | 1.5   | −15.1 | 54.4  | R    | F    | Medial frontal gyrus    | 6   |                                                     |
| 11.38 | 1.5   | 11.4  | 39.2  | R    | Limbic | Cingulate gyrus       | 32  | Response regulation                               |
Notation → Fingering → Motor commands
Encoding and recall of finger sequences in experienced pianists compared with musically naïve controls: A combined behavioral and functional imaging study

Fig. 1. Design. Demonstration of the task-design. During the first condition (“encoding”) the finger sequence was presented for $24\,\text{s}$. The participants were asked to remember the sequence without actually moving their fingers. During the second condition (“retrieval with auditory feedback”, a) the participants were asked to retrieve the finger sequences by performing them on the keyboard without any visual control but with auditory feedback. They continued playing until the fixation cross was shown. During the third condition (“retrieval without auditory feedback”, b) participants were instructed to play the sequence but did not receive any auditory feedback.
Association between BOLD in left S1 during encoding and later error rate during the later retrieval task

Fig. 5. BOLD-response in left primary somatosensory cortex (S1) was positively associated with outcome in the later retrieval condition.

CODING --> VISUOMOTOR TRANSFORMATION
Primary somato-sensory cortex (S1),
  left, (BA) Brodmann area 1,2,3
S1, right, BA 1,2,3
Primary motor cortex (M1), le, BA 4
M1, ri, BA 4
Supplementary motor area (SMA), le, BA 6
SMA, ri, BA 6
Dorsal premotor cortex (dPMC), le, BA 6
dPMC, ri, BA 6
SPL, le BA 7
Inferior parietal lobe (IPL), le, BA 39,40
IPL, ri BA 39,40
Inferior frontal gyrus (IFG), le, BA 44
Aim of the present study:
Investigating how piano musical gestures are neurally represented by comparing the bioelectrical response to audiovisual congruent vs. incongruent stimuli (impossible vs. possible piano fingering) in professional pianists and controls
Tapping at multimodal connections
Participants
- 22 right-handed pianists (10 for validation), 12 controls

Stimuli
- 120 pictures of a pair of hands
- 120 scores with correct fingering
- 240 audio/visual pairing (120 CONG, 120 INCONG)

Extended = not playing
Flexed = playing
- 180 BPM, 4/4 measures
- Sounds onset was concentrated in the first half of the bar
- Harmonically correct
- Ascendent or descendent progressions
- An octave distance between the left and right hand
- Notes from A to F
VALIDATION

10 judges (mean age= 37.9 ys.) mostly piano/harpsichord teachers of Claudio Abbado Civic Music School of Milan

Explicit congruent vs. incongruent categorization. Stimuli categorized correctly by at least 80 % of the judges were used for the experiment (216 stimuli).
Stimuli were iso-luminant and audio intensity was balanced

| Luminance (fL) – i |
|-------------------|
| **Congruent**     | **Incongruent** |
| 7,22              | 7,11           |

\[F(1,13) = 0.00274, p = 0.95906\]

| Volume (dB) – |
|---------------|
| **Congruent** | **Incongruent** |
| -9,7          | -11,13         |

\[F(1,39) = 0.39216, p = 0.53482\]
Rare targets (10%), Duration 3 sec
(ISI) 1700-1900 ms randomly varying 200 ms.
128 scalp sites EEG recordings
Sampling rate = 512 Hz
Band-pass filter: 0.016-100 Hz
ERPs

ERN  AF7  AF8  F3  POz

Cong  Incong
ERN in pianists
1000-1400 ms

CONDITION x HEMISPHERE x GROUP
F(1, 22)=4.5270, p=0.04481

Error-Related Negativity (1000-1400 ms)
ERROR-RELATED NEGATIVITY

Subjects were tested on a two-choice letter discrimination task in which they made speeded responses with either the right or the left hand. Errors were obtained by emphasizing speed and by flanking the targets with irrelevant distractors. Evoked potentials for incorrect responses deviated from those obtained on trials with correct responses just after the onset of peripheral motor activity (EMG onset). This error detection signal is maximal over a central electrode positioned over the anterior cingulate (Gehring et al., 1993).
Modulation of activity in medial frontal and motor cortices during error observation
Hein T van Schie, Rogier B Mars, Michael G H Coles & Harold Bekkering
Nature Neuroscience 7, 549 - 554 (2004)
| Magnitude In nAm | T-x [mm] | T-y [mm] | T-z [mm] | Hem. | Lobe | Gyrus | BA | Notes |
|---------------|---------|---------|---------|-----|------|-------|----|-------|
| 10.88         | -28.5   | 55.3    | 7       | L   | F    | Middle Frontal Gyrus | 10 | Error Related Negativity |
| 7.726         | 1.5     | 65.3    | 7.9     | R   | F    | Medial Frontal Gyrus | 10 | |
| 9.903         | 50.8    | -0.6    | -28.2   | R   | T    | Inferior Temporal Gyrus | 20/21 | “Hand” neurons |
| 8.292         | -68.5   | -18.2   | 0.1     | L   | T    | Superior Temporal Gyrus | 22 | Auditory association cortex |
| 9.895         | 60.6    | -2.1    | -13.3   | R   | Limbic | Uncus | 20 | Affective reaction to incongruence |
| 5.253         | -8.5    | -0.6    | -28.2   | L   | Limbic | Uncus | 28 | |
| 5.523         | 40.9    | -75.2   | -19.1   | R   | Cerebellum | Posterior Lobe | |
| 3.952         | 31      | -82.1   | 39.5    | R   | Parietal | Precuneus | 19 | Somatosensory/Body representation |
| 3.728         | -8.5    | -91.3   | 29.7    | L   | O    | Cuneus | 19 | Visuomotor transformation |
| 2.887         | 1.5     | -33.4   | 61.6    | R   | Frontal | SMA | 6 | Automatized motor routines |
Anterior Cingulate Cortex

Superior Temporal gyrus
Conclusions

The automatic perception of an incongruent audio-visuomotor coupling in skilled pianists elicited an ERN related to the action simulation.

The analysis of electromagnetic dipoles allowed to identify where these multimodal complex information are stored in the brain, after intense and prolonged learning.
2. Study on PUPILS

ORIGINAL RESEARCH ARTICLE
Front. Psychol. 02 April 2015 | http://dx.doi.org/10.3389/fpsyg.2015.00376

The effect of musical practice on gesture/sound pairing

Alice M. Proverbio¹, Lapo Attardo¹, Matteo Cozzi¹ and Alberto Zani²
Immagive visiva del movimento del Re

Nota/Suono associati al tasto del Re

1. Nota/Suono associati al tasto del Re

2. Risonanza nel sistema motorio

3. Suono associato al movimento
Music conservatory violin and clarinet students of pre-academic and academic levels with different chronological ages, ages of acquisition (AoAs) of musical ability, and academic degrees were tested.

They were shown ~ 400 videos in which a violinist or a clarinetist played the same musical score. Pitch (Hz), intensity (dB), tempo (beats per minute), and sound duration (ms) were matched across instruments. In one condition, the images and soundtrack were coherent, whereas in another condition, musical gestures were accompanied by a perfectly synchronized soundtrack that did not match in pitch with the sounds heard.
Nineteen musicians participated in this experiment: 10 violinists and 9 clarinetists, all from Milan Conservatory “Giuseppe Verdi.” Regardless of their age and grade, violinists tended to have more experience than clarinetists. Participants’ chronological age ranged from 14 to 24 years and averaged 17.68 years (SD = 3.2). The AoA of musical ability varied from 5 to 15 years across musicians and averaged 8.5 years. The years of study of the instrument ranged from 2 to 18 years. The chronological age of musicians averaged 16.8 years (SD = 2.94) for clarinetists and 18.67 years (SD = 3.35) for violinists.
The stimuli were presented to students or musicians found in the clarinet and violin classes at the Conservatory, waiting for their lessons. Participants were comfortably seated in front of a portable notebook PC in an empty testing room and wore headphones for sound stimulation.

The task was to evaluate whether the sound-gesture video clip combinations were correct or not by using a 3-point Likert scale (2 = congruent; 1 = I am unsure; 0 = incongruent).
Age vs. Accuracy
Pearson correlation: $r = -0.3997$
Expertise vs. Accuracy

Pearson correlation: $r = -0.7261$
The ability to detect an audiovisual incongruence (pitch/gesture) in musical performance is an excellent predictor of musical expertise with a given instrument. The bar chart illustrates the error percentages across different levels of study:

- Null (0)
- Pre-Academic (3-6)
- Academic (>6)
- Diploma (8-12)
- Master (>12)

Correlation between knowing how to play and sensitivity in audiovisual perception (musical cerebral resonance).
Audio-visuomotor processing in the Musician’s brain: an ERP study on professional violinists and clarinetists

Alice Medo Proverbio1, Marta Colbi1,2, Mirella Manfredi1,3 & Alberto Zani4

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Methods
32 right-handed participants
Musicians = 17 violinists (26 yrs. Age) and clarinetists (23 yrs.)
Controls= 15 Psychology students with null musical experience (23.5 yrs.) respectively.
Mean age of acquisition (AoA) for playing an instrument= 7 years (SD = 2.64) for violinists and 10 years for clarinetists (SD = 2.43).
The age ranges were 22–32 years for violinists and 19–28 years for clarinetists. The AoA ranges were 4–11 years for violinists and 7–13 years for clarinetists.

EEG recordings
128 scalp sites
Filtering: 0.016–100 Hz.
Sampling rate= 512 Hz
Electrode impedance was maintained below 5 KOhm.
STIMULI
Stimulus size $15 \times 12$ cm ($7^\circ 30' 6''$). Duration = 3000 ms (1 sec prep. 2 sec sound). The inter-stimulus interval was 1500 ms.

**TASK:** To keep the subject focused on audiovisual stimulation and ensure the task was feasible for all groups, all participants were instructed to press a response key with the index or the middle finger to a 1-note vs. a 2-note stimuli, respectively (left and right hands alternately)
MMN is a response of the brain that is generated primarily in the auditory cortex. The amplitude of the MMN response depends on the degree of variation in the expected auditory percept, thus reflecting the cortical representation of auditory-based information.

Fig. 1. (Left) Frontal (Fz) event-related potentials (ERPs) (averaged across subjects) to randomized 1000 Hz standard (80%, black line) and to deviant (20%, green line) stimuli of different frequencies (as indicated on the left side). (Right) The difference waves obtained by subtracting the standard stimulus ERP from that of the deviant stimulus for the different deviant stimuli. Subjects were reading a book. Adapted, with permission, from Sams et al. (1985a).
Table 1 | Talairach coordinates (in mm) corresponding to the intracortical generators that explain the surface voltage recorded during the 1500–2000 ms time window in response to incongruent vs. congruent clips in the musicians' brain during scenarios incorporating their own musical instrument. Magn. = Magnitude in nAm; H = hemisphere, BA = Brodmann areas.

| Magn. | T-x  | T-y  | T-z  | Hem. | Lobe      | Gyrus              | BA | Function                        |
|-------|------|------|------|------|-----------|--------------------|----|---------------------------------|
| 11.38 | −8.5 | 64.4 | 16.8 | L    | Front     | Sup. Frontal       | 10 | Cognitive Discrepancy           |
| 11.05 | −28.5| 53.4 | 24.8 | L    | Front     | Sup. Frontal       | 10 |                                 |
| 9.46  | 40.9 | 55.3 | 7    | R    | Front     | Middle Frontal     | 10 |                                 |
| 8.08  | 50.8 | −0.6 | −28.2| R    | Temp     | Middle Temporal    | 21 |                                 |
| 7.59  | 31   | 9.1  | −27.5| R    | Temp     | Sup. Temporal      | 38 |                                 |
| 7.23  | 60.6 | −55  | −17.6| R    | Temp     | Fusiform Gyrus     | 37 |                                 |
| 7.02  | 50.8 | −33.7| −23.6| R    | Temp     | Fusiform Gyrus     | 20 |                                 |
| 6.82  | −38.5| −8   | −28.9| L    | Temp     | Middle Temporal    | 21 |                                 |
| 6.77  | −58.5| −8.7 | −21.5| L    | Temp     | Inferior Temporal | 20 |                                 |
| 6.07  | 40.9 | −75.2| −19.1| R    | Cerebellum |                    |    |                                 |
| 7.08  | −18.5| −8   | −28.9| L    | Limbic    | Uncus             | 36 | Affective reaction              |
| 4.76  | −58.5| −30.4| 34.9 | L    | Pariet    | Inf. Parietal Lobule| 40 | Action                           |
| 4.31  | 21.2 | −91.3| 29.7 | R    | Occip     | Cuneus            | 19 | Visual sensory                  |
| 3.9   | 1.5  | −85.4| −19.8| R    | Cerebellum |                    |    |                                 |
| 3.88  | −8.5 | −1.1 | 65   | L    | F         | Sup. Frontal      | 6  |                                 |
| 3.55  | −58.5| 14.3 | 12.5 | L    | F         | Inf. Frontal      | 44 | Mirror neurons                  |
| 2.94  | −18.5| −63.8| 59   | L    | P         | Sup. Parietal Lobule| 7  | Somatosensory                   |
| 2.37  | 11.3 | 29.5 | 58.7 | R    | F         | Sup. Frontal      | 6  |                                 |

Incongruent-Congruent (500-1000 ms) - Power RMS = 51.8
CONCLUSIONS

Only in musicians, for their own instruments, was a N400-like/MMN deflection elicited by the incongruent audiovisual information.

The data indicate the existence of audiomotor mirror populations responding to incongruent sensory information, thus suggesting that they may encode multimodal representations of musical gestures and sounds.

These systems may underlie the ability to learn how to play a musical instrument.
4. Study on PROFESSIONAL MUSICIANS

Effect of familiarity for a given musical instrument during processing of coherent musical executions
The effect of musical expertise on prefrontal audiovisual coding

• Hypothesis: We expected to find a differential effect in the amplitude of prefrontal activity as a function of being or not a musician, and (within the musicians’ group) as a function of the specific familiarity with the two instruments (violin vs. clarinet).

• Indeed several studies have shown a strong enhancement of prefrontal activity while processing novel as compared to old items, thus reflecting their degree of visual or auditory familiarity.
PET studies of encoding and retrieval:
The HERA model

LARS NYBERG, ROBERTO CABEZA, and ENDEL TULVING
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Encoding

Recall
Prefrontal Cortex and Episodic Memory: Integrating Findings from Neuropsychology and Functional Brain Imaging

Charan Ranganath¹ and Robert T. Knight

Figure 2. Electrophysiological evidence for attenuated responses to novel stimuli in patients with prefrontal damage (Knight, 1997). In these experiments, event-related brain potentials were recorded while patients with prefrontal damage and matched controls performed target detection tasks. In the auditory modality, targets and repeated nontarget stimuli were pure tones, and occasionally, irrelevant, novel distractors (e.g., a dog bark, a ringing bell, etc.) were presented. In the visual modality, targets and repeated nontarget stimuli were pure upright and inverted triangles, and occasionally, irrelevant, novel distractors, such as line drawings of objects or complex patterns were presented. In the somatosensory modality, targets and repeated nontarget stimuli were taps to the finger and occasional novel distractors consisted of brief random shocks to the median nerve. Novel stimuli across all modalities elicited a potential identifiable as the novelty P300, or the P3a. The magnitude of this potential was attenuated in patients with prefrontal damage, whereas electrophysiological responses to target and repeated nontargets were intact.
Wilding’s and Rugg’s studies on familiarity vs. recollection

Figure 2. Grand-average ERPs from regions of interest used in ANOVAs. Regions are depicted with black channel groups. LAS is left/anterior/superior. RAS is right/anterior/superior. LPS is left/posterior/superior. RPS is right/posterior/superior.
Instrument-specific effects of musical expertise on audiovisual processing (clarinet vs. violin) *Music Perception, 2015 in press*
Isocolour topographical voltage maps of FN400’s distribution recorded in the 3 groups, regardless of condition, in between 800-1100 ms of latency.
Conclusions
The data provide solid evidence that, besides a general effect of musicianship, musical training is also instrument-specific, being wired on specific sensorimotor abilities that permanently change the way the brain processes information relative to the particular musical instrument played.
5. Study on PROFESSIONAL PIANISTS vs. MUSICIANS

Più di 10.000 ore di pratica
16 Pianisti professionisti
3.000 ore di pratica
16 Musicisti professionisti
con esame di Pianoforte complementare

| STRUMENTO PRINCIPALE |
|---------------------|
| Viola da gamba      |
| Flauto Traverso     |
| Corno               |
| Flauto Traverso     |
| Tromba Naturale     |
| Arpa                |
| Contrabbasso        |
| Liuto               |
| Viola               |
| Violino             |
| Viola da gamba      |
| Violoncello         |
| Viola               |
| Clarinetto          |
| Violoncello         |
Effects of Piano practice on ERN amplitude

10,000 hours
AFz
Fz

3,000 hours
AFz
Fz

DIFERENCE WAVE
ERN 750 - 950 ms

Pianisti
Non Pianisti
### Pianisti - Stimoli INCONGRUENTI

**ERN 750-950 ms**

| Magnit. | T-x [mm] | T-y [mm] | T-z [mm] | Emisfero | Lobo                | Giro                         | BA  |
|---------|----------|----------|----------|-----------|--------------------|------------------------------|-----|
| 26.3    | 11,3     | 45,3     | 6,1      | Destro    | Cingolato Anteriore| 32                           |
| 25.6    | 1,5      | 48,2     | -17,2    | Destro    | F                   | Giro Frontale Medio          | 11  |
| 23.9    | 31       | 37,2     | -10,5    | Sinistro  | F                   | Giro Frontale Medio          | 11  |
| 14.3    | -58,5    | -35,7    | -8,8     | Sinistro  | T                   | Giro Temporale Medio         | 21  |

### Non Pianisti - Stimoli INCONGRUENTI

**ERN 750-950 ms**

| Magnit. | T-x [mm] | T-y [mm] | T-z [mm] | Emisfero | Lobo                   | Giro                          | BA  |
|---------|----------|----------|----------|-----------|------------------------|-------------------------------|-----|
| 25.7    | 11,3     | 44,4     | 15       | Destro    | F                      | Giro Frontale Medio           | 10  |
| 23.8    | 1,5      | 48,2     | -17,2    | Destro    | F                      | Giro Frontale Medio           | 11  |
| 23.2    | 31       | 37,2     | -10,5    | Destro    | F                      | Giro Frontale Medio           | 11  |
| 11.7    | -58,5    | -56,9    | -2,8     | Sinistro  | T                      | Giro Temporale Inferiore      | 37  |
| Magnitude | T-x [mm] | T-y [mm] | T-z [mm] | Hemisp. | Lobe | Gyrus | BA | Description |
|----------|---------|---------|---------|---------|------|-------|----|------------|
| 8.44     | -38.5   | -0.4    | 56.1    | L       | F    | Middle Frontal Gyrus | 6  | Premotor cortex |
| 4.04     | 31      | -8.5    | 64.2    | R       | F    | Precentral Gyrus     | 6  | Mirror Neurons |
| 4.04     | 31      | -8.5    | 64.2    | R       | F    | Precentral Gyrus     | 6  |              |
| 5.69     | 31      | 9.5     | 57      | R       | F    | Middle Frontal Gyrus | 6  |              |
| 6.12     | -58.5   | -29.4   | 26      | L       | P    | Inferior Parietal Lobule | 40 | AIP (action representation) |
| 8.42     | -48.5   | 22.4    | 31.1    | L       | F    | Middle Frontal Gyrus | 9  | Attentional supervisor system |
| 6.92     | 50.8    | 45.3    | 6.1     | R       | F    | Middle Frontal Gyrus | 46 | DLPFC |
| 8.26     | -8.5    | 64.4    | 16.8    | L       | F    | Superior Frontal Gyrus | 10 |              |
| 7.30     | -48.5   | -65.1   | -18.4   | L       |      | Cereb Posterior Lobe, Declive |    |              |
| 6.70     | -18.5   | -91.3   | 29.7    | L       | O    | Cuneus              | 19 |              |
| 6.65     | -8.5    | -99.4   | 11      | L       | O    | Cuneus              | 18 |              |
| 6.57     | -58.5   | -57.9   | 5.6     | L       | T    | Superior Temporal Gyrus | 22 | Sound |
| 3.74     | 60.6    | -44.8   | -16.9   | R       | T    | Inferior Temporal Gyrus | 20 | Hand/Sound |
| 3.71     | 70.5    | -36.6   | -1.3    | R       | T    | Middle Temporal Gyrus | 21 | Sound |
| 6.08     | 50.8    | -71     | 31.4    | R       | T    | Angular Gyrus        | 39 |              |
| 5.69     | 31      | 9.5     | 57      | R       | F    | Middle Frontal Gyrus | 6  |              |
| 4.89     | 21.2    | -96.5   | -13.1   | R       | O    | Lingual Gyrus        | 18 |              |
| 4.63     | 21.2    | -98.5   | 2.1     | R       | O    | Cuneus               | 18 |              |
| 4.09     | -38.5   | -62.8   | 50.1    | L       | P    | Superior Parietal Lobule | 7  |              |
1. Il processo attraverso il quale il cervello registra un’incongruenza motoria si manifesta come componente negativa nota in letteratura col nome di *Error related negativity* (ERN). La ERN si rileva sia quando siamo noi stessi a commettere l’errore, sia quando a sbagliare sono gli altri, grazie all’attivazione dei neuroni specchio audio visuo-motori.

2. Lo studio ha dimostrato che quando il cervello rileva un errore, anche se compiuto da altri, mette in atto dei **processi di correzione automatica** che, modificando l’organizzazione delle informazioni, favoriscono l’apprendimento.

3. La ricerca ha evidenziato, inoltre, che la sola osservazione del movimento stimola direttamente l’attività della corteccia premotoria del nostro cervello, come se a compiere un dato movimento fossimo noi stessi. Ecco perché anche la semplice visione di filmati, o la dimostrazione dal vivo da parte dell’insegnante o dell’istruttore è fondamentale per l’apprendimento di discipline motorie, musicali e di altro tipo.