Embodied Cognition
Introduction to Cognitive and Affective Neuroscience

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Theory of Pain Laboratory

What is Embodied Cognition?

How the brain codes the world via the body

Embodied Cognition

**Embodiment Thesis:** Cognition is deeply dependent upon features of the physical body of an agent.

The agent’s body (beyond the brain) plays a significant role in his/her cognition.

The body is not peripheral to understanding the nature of mind and cognition.
What is the role played by the body in cognition?

1) the body is a \textit{constraint}.

Body features can make cognition easier or more difficult.


2) the body is a \textit{distributor}.

Body shares part of the computational load with neural structures.

Embodied Cognition

What is the role played by the body in cognition?

3) the body is a **regulator**.

The body regulates (e.g. through feed-back) cognitive activity through space/time.

Ensures cognition-action coordination.
Although both objects exist simultaneously in reality, they are available perceptually one at a time.

The subject's body (the eyes) automatically orient itself towards the stain or the bird.

Summary

- Human Mirror Neuron System
- Visual Processing of Gestures
- Embodied Language
- Embodied Social Cognition
The motor system, long confined to the mere role of action programming and execution, in fact, plays a crucial role in complex cognitive abilities.

**Area F5**: Execution & Observation of specific goal-directed movements (Mirror Neurons)

Craighero et al. (2014). The role of the Motor System in Cognitive Functions

Strong activation is present in F5 during observation of the experimenter's grasping movements, and while the same action is performed by the monkey (Rizzolatti et al., 1996).

Mirror neurons are engaged by the interaction between the effector (hand) and an object. Object or movements alone don't activate F5.

Few exceptions (lip-smacks) involve intransitive actions which have a goal.

Action Schema, regardless of who implements it.

Craighero et al. (2014). The role of the Motor System in Cognitive Functions
The brain codes others’ actions as if these were executed in first person.

How the brain codes others’ via one’s own body.

Mirror neurons become so popular that have been hypothesized to underlie many (diverse) cognitive processes in animals and humans.

- Imitation
- Identify the goals of others
- Theory of Mind
- Speech abilities
- Share emotions
- Autism (broken mirror)

Activation foci during the observation of hand actions that were non-object related – mimicking grasping an object (d) and object related – actually grasping an object (d).

Human Mirror Neuron System

Activation foci during the observation of hand actions that were non-object related – mimicking kicking an object (e) and object related – actually kicking an object (f).

Human Mirror Neuron System

Not only premotor!
Neuroimaging studies searched regions exhibiting cross-modal properties modulated by both the perception and execution of a given movement and its execution (Dinstein et al., 2008).

- regions showing activation of motor-related regions (e.g., premotor cortex) when observing movements in others.
- regions showing regions who are active both when executing a movement and when observing someone else performing it.
- regions showing activation when an action is executed and observed at the same time, but not when this is only executed or only observed.

Human Mirror Neuron System

fMRI records the activity from a large volume of grey matter in which many subpopulation of neurons coexist.

The activation on many regions, both when observing and executing a given action, might reflect the recruitment of different subpopulations of regions, none of which has cross-modal properties.

Repetition Suppression

Neural cells with selective functional properties rapidly adapt when their preferred stimulus occurs repeatedly.
Repetition Suppression

Neural cells with selective functional properties rapidly adapt when their preferred stimulus occurs repeatedly. Any decrease of neural activity when two conditions are presented into rapid sequence, reflects the recruitments of the same neurons.

Human Mirror Neuron System

Dinstein et al. (2007). *J. Neurophysiology*
No region exhibited cross-modal repetition suppression. Whereas there are several regions coding for specific movements within visual and motor modality, there is no evidence of regions coding the same action regardless of whether it is seen or executed.

Dinstein et al. (2007). J. Neurophysiology

Although not all studies were consistent with one another, there is evidence that the inferior frontal cortex (human homologue of F5) and the inferior parietal cortex exhibit bilateral repetition suppression. This has been replicated subsequently with both fMRI (Press et al., 2012) and EEG (Press et al., 2012).

Repetition Suppression is only one of the possible techniques to investigate the human Mirror Neuron System.

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The popularity of the neurophysiological findings about the Mirror Neuron System influenced/revitalized heavily theories about the visual processing of people’s actions.

**Theory of Event Coding**: (late) perception & (early) action share a common representational code. Perceived events (perceptions) and to-be-produced events (actions) are equally represented by integrated, task-tuned networks of feature codes.

Hommel et al. (2001). BBS

**Visuomotor priming effect**

Brass et al. (2000, 2001): visuomotor priming effect for intransitive actions, with hand moving index or middle finger as a task-irrelevant cue.

Action observation is facilitated by long-term motor practice.

Aglioti et al. (2009). Nat. Neuroscience
Action observation is facilitated by long-term motor practice.

Visual experience matters, but not as motor practice.

Expert dancers have long-lasting practice in performing gender-specific dancing movements. They have long-lasting practice in seeing all kinds of dancing movements.
Action observation

Action observation is facilitated by long-term motor practice

- Left dPM
- Left IPC
- Right Cerebellum

Calvo-Merino et al. (2006). Current Biology

Apparent-motion task


Apparent-motion task

Point-light Displays

Example at:
http://www.biomotionlab.ca/Demos/BMLwalker.html

- You can recognize the gender/identity of the walker
- Whether it is walking forward/backwards
- The mode of the deambulation (e.g., heavy/light)
- The emotional state of the walker (e.g., happy/sad, nervous/relaxed)
- Non-walking movements (e.g., sign language)

Point-light Displays

- Embodied interpretation → observers’ motor system binds the visual system contributing to understanding the seen displacements (Prasad & Shiffrar, 2009)
  
- Visual experience interpretation → observers have life-time practice at perceiving human kinematics and, consequently, specifically sensitive to these kinds of movement (Johansson, 1973)
  
Point-light Displays

How does brain damage that causes hemiplegia lead to deficits in the recognition of point-light displays?

How does brain damage that causes hemiplegia lead to deficits in the recognition of point-light displays?


Record movements from patients’ spared arm.

Create point-light displays

Flip horizontally the point-light displays so that they can be plausible movements of the hemiplegic arm

Flip vertically the point-light displays so to create alterations of the configural body processing

Point-light Displays
Action recognition task: what movement are you seeing?


Loula et al., (2005)
Embodied effect
Visual expertise effect

Summary

Embodied Cognition
✓ Human Mirror Neuron System
✓ Visual Processing of Gestures
✓ Embodied Language
✓ Embodied Social Cognition
The Symbol Grounding Problem

Let's assume to be in a chinese city, with only a chinese dictionary.

Who do I know where to go?

I look at the dictionary what symbols in the street mean. Then look what the symbols in the dictionary mean. etc…

Symbols are abstract and arbitrary, and cannot be understood solely through their connection with other abstract, arbitrary symbols.

They can only be understood by being «grounded» in some other representational format that it is understood in itself.
Embodied Theories resolve the symbol grounding problem by asserting that abstract, arbitrary linguistic forms (words, phrases, abstract syntactic templates) are understood through their grounding in our bodies’ system of perception and action planning.

E.g., The word violin is tied with sensorimotor representations (simulations) of what it means to see, hear and play this instrument.

Motor Simulations

To understand the word give or kick involves the recruitment of the motor systems to simulate giving and kicking actions

Motor simulations play a major role in the comprehension of words and sentences about actions

Stimulus-Response Compatibility

- Clockwise sentences: «Jenny screwed in the light bulb»
- Counterclockwise sentences: «Eric turned down the volume»

Task: «is the sentence meaningful or not?»

Individuals are faster to produce a response compatible with the meaning of the sentence (Yes/No)

Clockwise & Counterclockwise sentences presented one bit at the time.

Matching effect as soon as the action verb is presented.

Imaging studies have shown that passive reading or listening to action language activated motor and premotor areas (e.g., Hauk et al., 2004).

**Motor activity for verbal stimuli**

MEG studies have shown that passive reading or listening to action language activated motor and premotor areas (e.g., Pulvermüller et al., 2005).

A pulse of current flowing through a coil of wire generates a magnetic field. If its magnitude changes with time, then it will induce a secondary current in any nearby conductor (THE BRAIN).

Transcranial Magnetical Stimulation (TMS)

200 ms from the word onset lexical-semantic access should take place.
Motor activity for verbal stimuli

TMS of M1 facilitates the performance ONLY during the motor imagery task.

Embodiment or Imagery?

Are sensorimotor simulations necessary for language comprehension? If so any task requiring access to the semantic knowledge of action words should be achieved through sensorimotor simulation.

Alternatively, sensorimotor simulations are epiphenomenal. They spontaneously occur (e.g., through a mechanism of motor imagery) but they are not necessary for the interpretation of the semantic content of texts.
Imagine the sentences:
• Pick up the pen \textit{(positive)}
• Don’t pick up the pen \textit{(negation)}

Is the understanding of a negative sentence associated with a motor simulation?

If word meaning is «grounded» in one’s sensorimotor representation, its understanding should elicit a motor simulation, even if in negative form.
Imagine the sentences:

- I pick up the pen (1° person)
- He picks up the pen (3° person)

Is the understanding of a 3° person motor verb associated with a motor simulation?

If word meaning is «grounded» in one’s sensorimotor representation, its’ understanding should elicit a motor simulation, even if in 3° person form.

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Motor activity for verbal stimuli

Activity of left primary motor cortex as measured by TMS-induced motor evoked potentials (MEPs, mV) recorded from the First Dorsal Interosseus muscle of the right hand.

Experimental design: 2 verb-category (hand-action versus non-action) X 2 person (first versus third person).

Stimulus-Response compatibility studies confirm that sensitivity judgments on action sentences are faster when the motor response is compatible with the meaning of the sentence.

Neuroimaging studies confirm the presence of motor and premotor activity during action sentence comprehension.

However, a great part of this activity can be interpreted in terms of epiphenomenical simulation (motor imagery) rather than automatic simulation necessary for text comprehension.

Motor Simulations

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Facial expressions

Many demonstrations of how bodily experiences can augment emotion processing come from research on the recognition of emotional facial expressions.

According to embodied accounts, recognition of emotional facial expressions is much more than visual detection of most relevant features, but highlights the role played by sensorimotor representation of one’s face in the process.

Recognition of facial expression is achieved through facial mimicry: an automatic, reflex-like process with the observer’s facial expression matching the observed facial expression.
Facial expressions

Zygomatic muscle

Corrugator muscle

Happy Face

Angry Face

Dimberg et al. (1982). Psychophysiology

Facial expressions

Orbicularis Oculi

Corrugator Supercilii

Levator Labii Alaeque Nasi

Happy Face

Angry Face


Facial expressions

Happy Sad

Task: When the face stops being happy/sad?

Pen in the mouth blocks partially facial mimicry

Niedenthal et al. (2001). Cognition & Emotion
Facial expressions

Niedenthal et al. (2001). Cognition & Emotion

Task: When the face stops being happy/sad?
Pen in the mouth blocks partially facial mimicry

Oberman et al. (2007). Social Neurosci

Facial expressions

Oberman et al. (2007). Social Neurosci

Facial expressions

Oberman et al. (2007). Social Neurosci
Reverse Simulation Model

**Motor Simulation:** The observer mimics covertly the other’s facial expression.

**Emotion Simulation:** Facial feedback generates an emotional state in the observer.

**Emotion Classification:** The other is feeling what the observer is simulating.

Lipps (1907). Psychologische Untersuchung
Goldman & Sripada (2005). Cognition
Pitcher et al. (2008). J Neurosci

Moebius syndrome

Moebius syndrome is a congenital, non-progressive condition characterized by facial paralysis, which is usually complete and bilateral, and impaired lateral movement of the eye.

The syndrome is associated with the maldevelopment or underdevelopment of the sixth and seventh cranial nerve nuclei which occurs early in prenatal life.
Moebius syndrome

Moebius syndrome that results in bilateral facial paralysis while typically sparing health and cognitive function.

People with Moebius syndrome experienced increased social interaction difficulty, and an emotion recognition deficit could contribute to these social interaction problems.

Moebius syndrome

Are individuals with Moebius syndrome impaired in their ability to recognize emotions from facial expressions?

<table>
<thead>
<tr>
<th>Emotion</th>
<th>Mean M</th>
<th>SD SD</th>
<th>t t</th>
<th>d d</th>
<th>Sig. Sig.</th>
<th>d d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anger</td>
<td>86.11</td>
<td>16.67</td>
<td>35</td>
<td>1.55</td>
<td>0.13</td>
<td>0.26</td>
</tr>
<tr>
<td>Contempt</td>
<td>32.41</td>
<td>27.87</td>
<td>35</td>
<td>1.51</td>
<td>0.14</td>
<td>0.25</td>
</tr>
<tr>
<td>Disgust</td>
<td>61.90</td>
<td>23.77</td>
<td>34</td>
<td>−0.12</td>
<td>0.90</td>
<td>0.02</td>
</tr>
<tr>
<td>Fear</td>
<td>69.44</td>
<td>22.71</td>
<td>35</td>
<td>−0.97</td>
<td>0.34</td>
<td>0.16</td>
</tr>
<tr>
<td>Happiness</td>
<td>85.65</td>
<td>5.85</td>
<td>35</td>
<td>0.97</td>
<td>0.34</td>
<td>0.16</td>
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<tr>
<td>Sadness</td>
<td>91.20</td>
<td>13.5</td>
<td>35</td>
<td>0.00</td>
<td>0.99</td>
<td>0.00</td>
</tr>
<tr>
<td>Surprise</td>
<td>89.05</td>
<td>18.05</td>
<td>34</td>
<td>1.06</td>
<td>0.30</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Bogart & Matsumoto (2010). Social Neuroscience

Empathy for Pain Paradigm

Emotional facial expressions can be recognized also without empathy.
Empathy for Pain Paradigm

Singer et al. (2004). Science

Painful faces

Botvinick et al. (2005). NeuroImage
**Painful faces**

Botvinick et al. (2005). *NeuroImage*

**Body Parts in Pain**


**Empathy for Pain Paradigm**

Lamm et al. (2011). *NeuroImage*
Empathy for Pain Paradigm


Multivoxel Pattern Analysis

The signal in each voxel depends on the amount of firing neurons within that voxel.

Multivoxel Pattern Analysis

This should yield to distributed patterns of activity reflecting the inhomogeneous distribution of one neuronal population across neighboring voxels.
Only the anterior insula displays common activity patterns between self-pain and other-pain.

Brain damage to the Pain Matrix

Gu et al. (2006). Brain

Placebo Analgesia

Placebo-induced Changes in fMRI in the Anticipation and Experience of Pain

Rütgen et al. (2015). *PNAS*

The Placebo-analgesia paradigm is applied to subjects that, not only were subjected to painful stimuli, but also observed facial expressions of individuals in pain.

Placebo not only decreased sensitivity to self-pain, but also to the pain of others.

Rütgen et al. (2015). PNAS
Placebo Analgesia

Placebo-analgesia decreased the activity in key regions of the Pain Matrix, not only during self pain, but also during others’ pain.


Placebo Analgesia

Placebo-analgesia is held to operate through the opioidergic system (similarly to real analgesics, such as morphine).

Opioid receptor antagonist naltrexone is supposed to block placebo-analgesia.


Empathy for Pain Paradigm

The sensitivity of the Pain Matrix to others’ pain is modulated by contextual information about the suffering person.

In particular more activity is documented the more the person in pain is close to the observer (e.g., loved-one).

Cheng et al., (2010). Neuroimage
The sensitivity of the Pain Matrix to others’ pain is modulated by contextual information about the suffering person. In particular less activity is observed when the person in pain...

- ...has been previously unfair in a transaction (Singer et al., 2006).
- ...is stigmatized by the social community (Decety et al., 2010).
- ...is a supporter of an opposing soccer team (Hein et al., 2010).
- ...is from a different ethnic group (racial bias, Xu et al., 2009).

Any feature of the observer person that can potentially decrease my empathic response towards others, decreases as well the sensitivity of the Pain Matrix.

The sensitivity of the Pain Matrix to others’ pain is modulated by the consistency between the cause of pain and the behavioral reaction of the suffering person. In particular less activity is observed when the person in pain...

- ...smiles instead of displaying distress (Han et al., 2009).
- ...has a relaxed posture (Lamm et al., 2009).
- ...displays a painful reaction although the observer knows that anesthesia was delivered (Lamm et al., 2007).

The sensitivity of the Pain Matrix to others’ pain is modulated by contextual information about the observer. In particular less activity is documented when the observer is familiar with processing others’ pain, e.g. physicians experts in agopunctures exhibit less Pain Matrix activity when seeing needles penetrating the human body than non-expert physicians (Cheng et al. 2007).
Empathy for Disgust?

- Seeing others in pain, hurts me.
- Seeing others disgusted, disgusts me.
- Seeing others in pain, disgusts me.
- Seeing others disgusted, hurts me.
- Seeing others in an unpleasant state, it is unpleasant.

Empathy for Happiness?

- Seeing others in pain, hurts me.
- Seeing others disgusted, disgusts me.
- Seeing others in pain, disgusts me.
- Seeing others disgusted, hurts me.
- Seeing others in an unpleasant state, it is unpleasant.
Although the insular cortex contain some coordinates specifically responding to somatosensory (both painful & painless), and painful stimuli, the majority of the region responds to relevant stimuli of multiple sensory modalities. Can we really speak of Pain Matrix?
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