Comics and studies on brain functions

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The important role of Comics, in communication related to popular contexts and with people of all ages is undoubted. The meaning of comics goes beyond the pure representation of an image with a text, and this is one of the reasons why Comics have been used, in some instances, to study brain functions related to emotions, humour appreciation, image comprehension and visual language.

In the past 20 years, the availability of instruments that could measure the activity of the brain *in vivo* has allowed us to develop experimental paradigms aimed at exploring the neural changes related not only to simple behaviours but also to increasingly complex functions such as emotions and consciousness. Modern neuroimaging includes functional Magnetic Resonance Image (fMRI), which is the most widely used brain imaging method to study human brain function. fMRI can be used to evaluate regional Cerebral Blood Flow (rCBF) and Blood Oxygen Level Dependent (BOLD) neural responses. This technique is based on the manipulation of hydrogen nuclei contained in water using a magnetic field that generates a signal transformed in an image. The image produced, in turn, depends on tissue properties as the brain engages in different activities. These methodologies, together with more classical electroencephalography methods (EEG) that measure electrical signalling in the brain and the electrophysiological event-related brain potential (ERP), provide important tools in the field of Neuroscience to discover the human brain. EEG and ERP provide excellent temporal resolution, allowing for the detection of brain events at the millisecond timescale, whereas the spatial localisation of these signals is not precise. In contrast, the temporal resolution of fMRI is measured in seconds, but the spatial localisation of fMRI signals is measured in millimetres.

The application of these tools to studies performed in the field of Comics have evidenced how this form of communication, although representing a new way of communication, touches some native qualities owned by humans, thus adding great interest to this form of representation and communication.

In this brief article, I shall describe some of the studies that have utilised Comics and delineate their importance for understanding the human mind. I will also describe the link between studies on Neuroscience and the different methods of representation that Comics utilise.

How the brain processes visual narrative

The use of verbal language for communication is a specific attribute of humans. However, verbal language is not always the only and best means to transmit information in interpersonal interaction. People can in fact share their understanding of the world using non-verbal cues such as facial expressions, gestures and postures.

Interestingly, the understanding of non-verbal messages is supported by the existence of mirror neurons contained in premotor and motor cortex of the brain. A mirror neuron is a neuron that is activated both when an animal acts and when the animal observes the same action performed by another. These neurons are important for understanding the intention and the actions performed by other people and for learning new skills by imitation (Rizzolatti - Craighero 2004). Mirror neurons have been studied in several contexts, including autism.

Analogous to the manner by which words are combined in verbal language, individual images can be combined to form larger elements that enable complex visual narratives. Constituent structures for verbal language or visual narrative differ both in their basic units (words or images) and in the rules by which they are combined. However, the brain, as demonstrated by Cohn et al. (2014), engages similar neurocognitive mechanisms to build a narrative structure to comprehend language or visual narrative sequences as in Comics. This makes our brain capable of perceiving Comics, as other abilities, like language.

ERP studies on N400 and N600, two event-related brain potential responses linked to meaning processing that can be utilised for examining language processing, showed that perception, attention, memory and language jointly participate in the neural events responsible for meaning processes. Moreover, the results suggest that linguistic and non-linguistic information rely on similar semantic memory networks (Kutas - Federmeie 2011; Cohn - Kutas 2015).

In a study using Comics in which ERPs were recorded, Manfredi et al. (2017) replaced visual narrative sequence with phonetically imitate action sounds (e.g. Pow!), or words that describe an action (e.g. Punch!), that were congruent or incongruent within their sequence contexts. The results showed that integration of word/letter/symbol strings within visual narratives elicited ERP patterns typically observed for written sentence processing, suggesting that the brain employs similar mechanisms for analysing the two different ways of expression. 'Narrative grammar', as in Comics, organises the semantics of event structures in sequential images as much as syntax organises meaning in sentences, and manipulations of this narrative grammar elicit ERP similar to manipulations of linguistic syntax (Cohn et al. 2014, Cohn –Kutas 2015).

Importance of faces

Attractiveness judgements using faces, studied by fMRI, have demonstrated that brain areas belonging to the socio-emotional structures participate in face judgement, evidencing how faces are the most important means to recognise other people intentions (Haist - Anzures 2017).

Faces are essential for the development of interaction among people. Faces attract the viewer's attention as demonstrated by studies on eye-tracking map, where they attract the gaze of the viewer's even when the viewer is asked to attend to different stimuli (Hari - Kujala 2009) (Fig. 1). The attractiveness of faces has a great social and commercial impact. Besides beauty and mood, the face communicates health, gaudiness, personality and ethnic background (Hari - Kujala 2009). The expression of face reflects the person's feelings. Through vision, we may therefore recognise basic sentiments such as fear, disgust and rage, which are processed by the 'limbic/primitive brain', the amygdala, the thalamus and the hypothalamus; however, one may also recognise face expressions that need cognitive processes, such as happiness and sadness, that are elaborated by brain structures classified as 'superior' and belonging to the neocortex such as the frontal cortex (FC), the cingulate cortex and the anterior insula (Fig.2).

This distinctive trait develops very early in human life as shown by newborn infants who recognise faces better than other objects (Grossmann - Johnson 2007). However, in line with the fact that the human brain reaches full maturation in terms of growth in size, connectivity, density of neurons and synapse during the first 20 years (Dekaban 1978; Innocenti - Price 2005), the development of face-

FIG. 1. *A* and *B*: gaze distribution of 20 persons on a painting (“Piipunsytyttäjät/Lighting pipes” by Juho Rissanen, 1902; copyright Ateneum Art Museum, Central Art Archives/Hannu Aaltonen, Finland). The gaze map is based on the data of 10 females and 10 males, who were allowed to view freely the image for 10 s. The eye tracking was performed with Tobii at the Laboratory of Computer and Information Science, Helsinki University of Technology. (Image courtesy to Marika Kaksonen.)

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Fig. 1

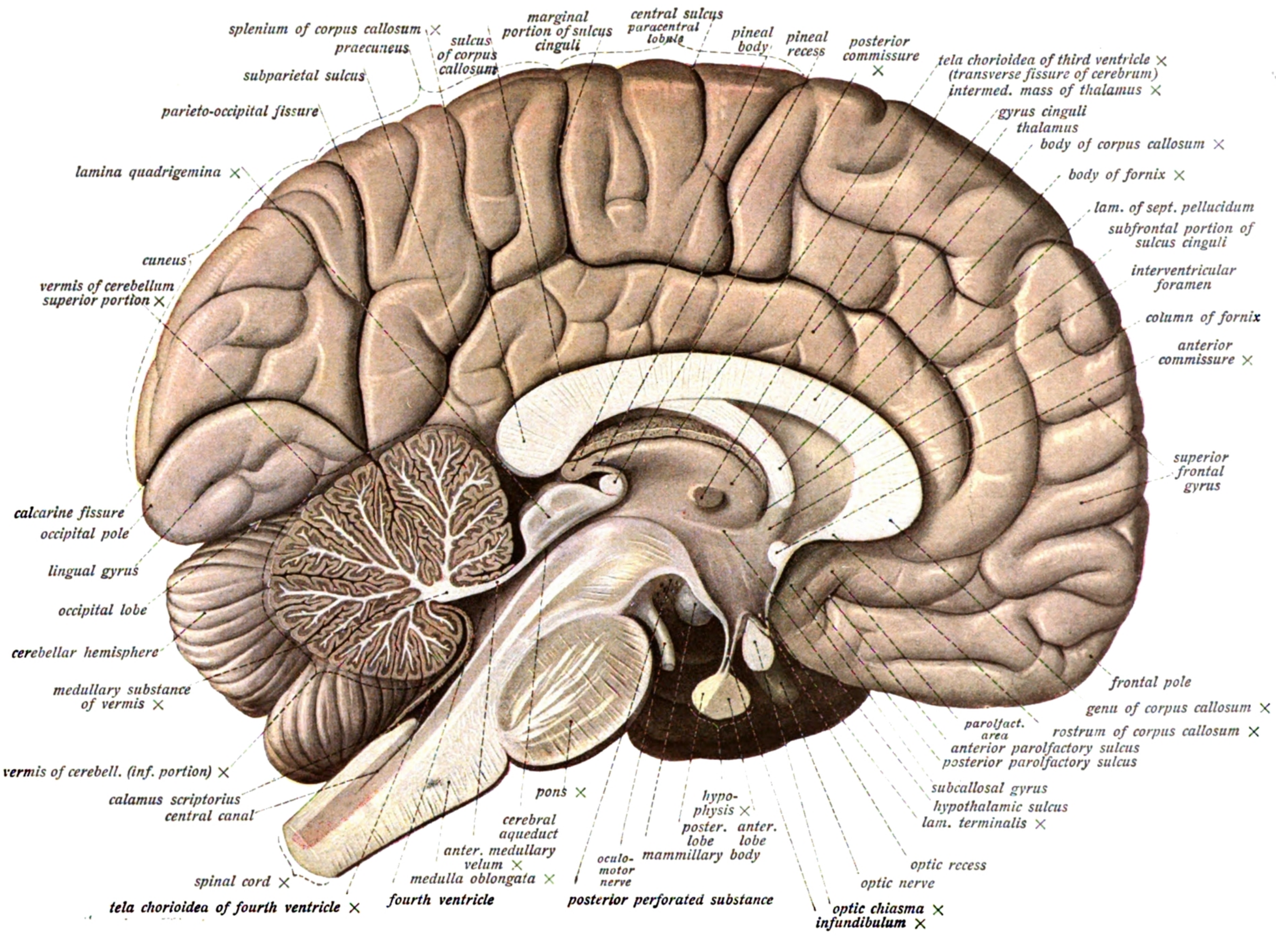
splenium of corpus callosum ×
praecuneus
sulcus of corpus callosum
marginal portion of sulcus cinguli
central sulcus
paracentral lobule
pineal body
pineal recess
posterior commissure ×
tela chorioidea of third ventricle ×
(transverse fissure of cerebrum)
intermed. mass of thalamus ×
subparietal sulcus
parieto-occipital fissure
gyrus cinguli
thalamus
body of corpus callosum ×
lamina quadrigemina ×
body of fornix ×
lam. of sept. pellucidum
subfrontal portion of sulcus cinguli
cuneus
vermis of cerebellum superior portion ×
interventricular foramen
column of fornix
anterior commissure ×
superior frontal gyrus
calcarine fissure
occipital pole
lingual gyrus
occipital lobe
cerebellar hemisphere
medullary substance of vermis ×
frontal pole
genu of corpus callosum ×
parolfact. area
rostrum of corpus callosum ×
anterior parolfactory sulcus
posterior parolfactory sulcus
vermis of cerebell. (inf. portion) ×
calamus scriptorius
central canal
pons ×
subcallosal gyrus
hypophysis ×
hypothalamic sulcus
cerebral aqueduct
poster. lobe
anter. lobe
lam. terminalis ×
anter. medullary velum ×
mammillary body
oculomotor nerve
optic recess
spinal cord ×
medulla oblongata ×
optic nerve
tela chorioidea of fourth ventricle ×
fourth ventricle
posterior perforated substance
optic chiasma ×
infundibulum ×

Fig. 2

processing ability matures slowly over the first two decades of life (Haist - Anzures 2017).

Therefore, the extensive representation of faces in Comics touches instinctive qualities, and Comics have been instrumental in studies aimed at recognising brain areas involved in the perception of pleasant or negative emotions (Hari - Kujala 2009).

Gesture, posture and movement

A typical representation in Comics are the motion lines that appear in graphic representations to depict the path of a moving object. A remarkable study on motion lines was performed by Cohn and Maher (2015) through ERPs in a group of experienced comic readers among university students. Interestingly, the motion lines that delineate the direction of an action in Comics were not perceived as basic biological aspects of the visual system, but they were recognised as vocabulary of the visual language. These results suggest that motion lines are not tied to aspects of the visual system but are components of the 'vocabulary' of the visual language.

Reward system and humour Comics

Several preclinical and clinical studies have revealed that one of the most important neurotransmitters, dopamine, which is enriched in brain areas that constitute the reward system (mesolimbic system, ventral striatum/nucleus accumbens, ventral tegmental area), is activated by pleasant food assumption, sex and drug abuse (Di Chiara and Bassareo 2007).

In this frame, pleasant feelings such as those produced by humour Comics have been the object of several interesting investigations, which have demonstrated how comical Cartoons activate the same brain areas activated by rewarding stimuli, providing the experimental evidence of a neurobiological link between reward and humour (Mobbs et al. 2003; Berns 2004; Samson et al. 2008).

Osaka and Osaka (2005) successfully demonstrated the hypothesis of reward components of laughter by fMRI and showed that visualisation of mimic words and emotional facial expression words, highly suggestive of laughter, significantly activate striatal reward centres, including the putamen/caudate/nucleus accumbens, the prefrontal cortices (PFCs), the dorsal anterior cingulate cortex and the supplementary motor area (SMA), whereas non-mimic words under the same task that did not imply laughter did not activate these areas in humans.

Several studies have applied Comics to provide a neurobiological link between theories of humour and hedonic processes. Comics are, in fact, one of the most common humour medium by showing pictures containing incongruous elements that have to be detected and resolved to understand the punch line.

Funny Comics have been used by several fMRI studies to examine the association between humour intensity and the network of cortical and subcortical regions involved in the degree of reward elicited by the stimulus. The results of those studies revealed an association between humour intensity and brain activation in cortical areas important for cognitive processes, such as the temporo-occipital junction (TPJ) and FC, and subcortical areas such as the ventral striatum, the nucleus accumbens, the anterior thalamus, the ventral tegmentum, the hypothalamus and the amygdala (Berns 2004; Samson et al. 2008). These studies identified, through Comics, the brain 'humour appreciation network'. Supported by the study of Mobbs et al. (2003), it is reasonable to conclude from these studies that activation of the nucleus accumbens reflects the hedonic feeling that accompanies humour, whereas the activation of amygdala is of clinical interest as this region has been implicated in the pathological features of several affective disorders, and diminished dopaminergic tone in the amygdala has been implicated in the emotional memory dysfunction and anhedonia observed in depression. In addition, TPJ and FC and the temporal cortex have been claimed to be involved in the incongruity resolution process that allows the comprehension of the scene or generally in humour perception.

In addition, these studies, by showing activation by funny Cartoons and, as mentioned below, by funny films, of the SMA suggest the presence of a strong motor component and propose that laughter is an important component of this hedonic process. At the same time, activation of the left lateral inferior frontal lobe, including Broca's area, would possibly reflect the language-based decoding of the stimuli.

Iwase et al. (2002) investigated the rCBF by positron emission tomography (PET) during laughter or smile induced by visual material in funny films and the facial muscle contraction evaluated by electromyogram (EMG) and demonstrated a significant correlation of the two in the SMA and the putamen, two brain areas important for movement, but not in the primary motor area (M1), which is also involved in motor performance. In contrast, with voluntary facial movement, a significant correlation between rCBF and EMG was found in both M1 and the SMA. In addition, laughter or smile, as opposed to voluntary movement, activated visual association areas, the temporal cortex and the orbitofrontal and medial PFCs, whereas voluntary facial movement did not. These results allow the demonstration of specific cognitive neural substrates of facial expression during pleasant emotion as opposed to voluntary, not emotional, facial movement.

The fMRI study conducted by Samson et al. (2008) focused in more detail on cognitive humour processing. These researchers used Comics representing three different conditions based on visual resemblance, pure semantic relationships, or Cartoons that required additional mentalising abilities. The results revealed a network of TPJ, inferior frontal gyrus and ventromedian PFC involved in pure semantic relationships, whereas visual resemblance showed activation in the extrastriate cortex, and Comics that required additional mentalising abilities activated median PFC, TPJ, the posterior superior temporal sulcus and the posterior middle temporal gyrus. Their study on examination of different Comics revealed that processing of different logical mechanisms underlying cognitive humour processing depends on separate neural networks (Samson et al. 2008).

In an ad-hoc study conducted by Osaka et al. (2014), fMRI was used to evaluate humour appreciation. A four-frame sequence comic, Manga that included introduction (first scene), development (second scene), turn (third scene) and conclusion (fourth scene, punch line), was utilised. The most amusing scene appeared in the last scene and was essential for understanding the humour of the Manga. Beginning with the second frame (development scene), activation of TPJ was observed, followed by activations of the temporal and PFC during viewing of the third frame (turn scene). During the fourth frame (punch line), strongly increased activations were detected in the median PFC and the cerebellum. The study revealed that activation of the left TPJ initiates the early stages of the comprehension process of the humour story line. This activation then reached the superior temporal sulcus and the median PFC, which produced humour appreciation for the punch line and the cerebellum. Thus, expectation before presentation of the punch line plays an important role in the appreciation of humour. Activation of brain areas by funny and non-funny Manga revealed no differences in brain activation for the first, second or third frame. However, a significant increase in activation of the cerebellum in both hemispheres for the funny Manga in the fourth frame was observed. Interestingly, distinguishable differences in activation of the cerebellum between funny and non-funny conditions were also found for the fourth frame (Osaka et al. 2014). Activation of the left cerebellum in response to humour has been reported by previous studies showing that affective components of humour are related to activation of the left cerebellum (Bartolo et al. 2006). Interestingly, the cerebellum, which is critical in social cognition, has reciprocal connections with the PFC via the thalamus.

One key finding is that comprehension accuracy levels correlated with humour-comprehension responses in the left TPJ, as measured by BOLD neural responses (Campbel et al. 2015). This finding represents a novel and precise neural linkage to humour comprehension. A second key finding is that the superior frontal gyrus was uniquely associated with humour appreciation, suggesting that a complex cognitive processing underlies humour appreciation. Therefore, Campbel et al. (2015) provided an operational distinction between humour comprehension and appreciation.

Psychiatric disorders

Theory of mind (ability to attribute mental states to others) and empathy (ability to infer emotional experiences) are both important abilities to understand disorders characterised by impairments of social cognition. Vollm et al. (2006) performed an fMRI study using different Cartoons to understand disorders characterised by impairments of social cognition, such as autism and psychopathy. The results showed that theory of mind and empathy are associated with common areas of activation such as the medial PFC, the TPJ and the temporal poles. In addition, theory of mind revealed increased activations of the lateral orbitofrontal cortex, the middle frontal gyrus, the cuneus and the superior temporal gyrus. On the other hand, empathy was associated with enhanced activations of the paracingulate, the anterior and posterior cingulate Cortex and the amygdala. These results demonstrated that empathy requires the additional recruitment of networks involved in emotional processing (Vollm et al. 2006), underlining how the use of Cartoons can be instrumental in understanding both brain function and dysfunction.

Conclusions

One of the central challenges of the 21st century science is to understand the human mind in biological terms. The human brain is continuously hit by millions of information and continuously filters them unconsciously to make quick choices and judgement all the time. Neuroscience is important not only because it gives us a deeper understanding of what makes us what we are but also because it allows a significant series of dialogues between brain science and other areas of knowledge to help in understanding this spectacular part of our body.

Comics are apparently far away from classical investigations used to understand brain functions. However, thanks to their schematic and reproducible structure and, at the same time, the rich high emotional impact, they allow to easily measure complex brain responses that can be categorised in a more precise manner compared with more sophisticated tools of analysis.

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