Acute stroke effects on emotions: an interpretation through the mirror system

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Purpose of review

The most recent reports on emotional consequences of stroke are hereby reviewed and analyzed. In particular the interpretation of some neurological presentations found in stroke patients, such as athymormia, dysprosody, emotional incontinence and emotional blunting is discussed. As current theories on mental functions do not provide satisfactory explanations for the above syndromes, a novel interpretative framework is proposed, based on neuropsychological experimental data on the 'mirror system'.

Recent findings

Recent findings support both the fundamental role of the mirror system in imitative processes as well as the relevance of imitation for the emotional part of human personality and behavior.

Summary

The mirror system appears to be of paramount relevance for empathy and social behavior. The model of analysis-by-synthesis is here discussed, together with neurological presentations resulting from stroke induced impairments of the mirror system. Speculations for further researches are also proposed.

Keywords

stroke, emotional disorders, mirror system, mood

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Introduction

Behavioural neurology and neuropsychology of emotion has generated increasing interest in recent years. Albert [1] originally divided neuropsychological functions into two categories: instrumental (communication, perception, praxis) and fundamental (memory, learning, set shifting). Subsequently, Cummings [2] elaborated on this framework by including other functions such as timing, arousal, mood, and emotions. Furthermore, an increased awareness about the role of abstraction, sequencing, and attentional focusing in human behavior suggested the scholarly definition of a third domain of neuropsychological functions, the executive/integrative one [3,4].

Cummings and Bogousslavsky [4], defining emotion as 'the experience and expression of feeling states', have proposed that emotional disorders after impairment of any of these three broadly defined neuropsychological domains by a focal lesion, such as stroke, could be conceptualized as follows: (1) instrumental function deficits would produce impairment of emotional comprehension, both in verbal and non-verbal domains; (2) lesions impairing fundamental functions would produce disorders of emotional experience; (3) lesions impairing executive/integrative functions would produce impairment of emotional control and expression.

According to this framework, understanding of emotions is a product of instrumental functions, experiencing emotions is a product of fundamental functions, and controlling/expressing emotions is a product of executive/integrative functions. Therefore, following this logic, a focal lesion such a stroke will produce a neurological picture that depends on the damaged structure/function. Anosognosia would be a key feature of disorders of instrumental functions. Deficit/productive syndromes (such as depression, mania, psychosis) would be caused by disorders of fundamental functions. Disorders of empathy, i.e. of the ability to imagine the emotional experience of another, would be the product of the impairment of executive/integrative functions.

An alternative framework is derived by combining evidence from single-cell recordings, computational considerations from motor control literature, and social cognitive neuroscience's increasing focus on emotions as studied within social relations. The relevant neurobiological model here focuses on 'mirror neurons', i.e. premotor

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neurons, first identified in the macaque brain, that fire when the monkey makes an action as well as when it observes somebody else making the same action [5,6]. This 'analysis-by-synthesis' of actions of others resembles the motor theory of speech perception [7], according to which we perceive speech sounds with the same neural structures we use to produce those sounds. Here, perception and action are two sides of the same coin, and even though they may sound similar to the concepts of 'experience' and 'expression' proposed by Cummings and Bogousslavsky [4], they are indeed quite different in that they do not represent two separate functions. Is there 'analysis-by-synthesis' in the domain of emotions? And what would be the functional mechanism supporting such 'analysis-by-synthesis'?

This review aims to discuss what is the effect of stroke on this 'mirror' mechanism for analyzing emotions perceived and for producing empathic-emotional responses.

Finally, is stroke a good 'model' to study mental functions? A first-ever acute stroke may spotlight, by revealing impairments that follow the damage of particular cerebral circuitries, the function of these circuitries.

The relational aspect of emotion: empathy

Preston and de Waal [8•] recently defined empathy as follows: 'Empathy refers to situations in which the subject has similar emotional state to an object as a result of perceiving the object's situation. Empathy is thought to preserve the distinction between self and other, with an emotional state that is object-focused … as a process, one is empathizing when they understand the state of the object by activating their own representation of the object's state.' This description resembles the well-known phenomenon termed as 'chameleon effect' by social psychologists Chartrand and Bargh [9]. They pointed out that individuals characterized by a high degree of empathy are those that tend to imitate others during social interactions [10]. The empirical link between empathic attitudes and imitative behavior suggests that a way of understanding the emotions of others is by modelling their motor behavior. The question is: why?

An appealingly simple solution is provided by the conceptual framework of forward/inverse models [11]. Here, a forward model predicts the sensory consequences of a planned action, whereas an inverse model retrieves the motor plan necessary to achieve a desired sensory state. During social interactions, the observation of the body postures and facial expressions of others activates an inverse model that retrieves the motor plan necessary to achieve the observed body postures and facial expression. A forward model then predicts the sensory consequences of those body postures and facial expression, including the emotional states associated with them.

In a recent experiment that evaluated, using functional magnetic resonance imaging, the activation of different cerebral areas in response to the simple observation and imitation of facial emotional expressions [12•], the mere observation of emotional expressions was reported to activate premotor areas. This is consistent with the hypothesis of an internal representation of motor actions mediating the understanding of others' emotional states. Furthermore, inferior frontal and posterior-superior temporal areas relevant to action representation, as well as the anterior part of the insula and the amygdala, demonstrated increased activity during imitation, compared with the mere observation of facial emotional expressions. The whole circuitry consisting of the premotor and temporal areas and the anterior insula and amygdala seems critical to our ability to recognize emotions in others. Is there evidence in the recent stroke literature in support of the mirror/internal modelling view of emotion?

Preliminary data on stroke patients [13] are consistent with the hypothesis. Furthermore, not infrequently, acute stroke patients show a particular emotional indifference, a perplexity that may later vanish, a confusion that will resolve, in particular when the affected hemisphere is the dominant one and the ischemic area involves the frontal regions [14].

The next section will address these questions directly.

Neuropsychological functions, emotions and stroke

The imaging data on imitating facial emotional expressions suggest a critical role of the motor system in emotional behavior. Stroke and behavioral disorders associated with it represent a good source of empirical data to test this hypothesis. The Lousanne group has accurately described emotional changes after stroke, from overt sadness to passivity, to aggressiveness, to dishinibition, and denial. Some emotional reactions, such as denial, appeared to be related to fear and depression. Other emotional reactions, such as happiness, sadness, irascibility, were dissociated from the patient's subjective experience [15] (see Table 1).

Post-stroke depression has been widely studied [15–17]. It is very frequent in the acute phase (up to 40%), but can occur in the same percentage 3 months, one year or 2 years after the stroke. Also the content of the depressive ideation may be very different from the acute phase to the chronic phase. How much the

Table 1. Instrumental, fundamental, executive and mirror functions confronted in terms of function, anatomical correlates, associated neurological symptoms, associated degenerative dementia, and other aspects

	Instrumental	Fundamental	Executive/integration	Mirror
Functions	Communication, motion, perceptual recognition and praxis	Information processing speed, mood and emotional states regulation and motivation	Abstract thinking, sequentiating, analysis, ability to direct attention and faculty of on-line answering to environmental actual changes	Perceptual recognition of motor finalistic actions, information processing through internal reproduction of motor plans, imitation, analysis-by-synthesis of others' actions.
Gray matter structures				
Cortical	Posterior heteromodal cortex (six-layered)	Hippocampus cingulated orbitofrontal cortex (three-layered and transitional)	Dorsolateral prefrontal heteromodal cortex (six-layered)	Right superior parietal lobule Left superior temporal sulcus Left inferior frontal cortex (operculum) Insula? Amygdala?
Thalamus	Pulvinar	Dorsomedial anterior	Dorsomedial	None?
Basal ganglion	None	Ventral striatum Pallidum	Dorsal striatum	None?
White matter tracts	Long intrahemispheric and interhemispheric association fibres	Medial forebrain bundle: mostly shorter tracts	Frontal-basal ganglia and thalamic–frontal connections	Long intrahemispheric and interhemispheric association fibres
Primary function	Direct information transfer	Modulation	Information transfer and modulation	Information transfer and modulation
Speed	Fast acting	Tonic	Fast acting and tonic	Fast acting
Organization	Serial linking of modules Hemisphere specialization (lateralization)	Little hemisphere specialization	Limited hemisphere specialization	Bilateral with hemispheric prevalence
Phylogeny	Recent evolutionary development	Primitive	Most recent evolutionary acquisition	
Ontogeny	Incomplete at birth; development continues through childhood	Functional at birth	Incomplete at birth, development continues through early adulthood	Primates and humans
Neurological disorders	Aphasia Agnosia Apraxia	Bradyphenia Avolition Reduced arousal Limbic system syndromes	Concrete thinking Distractibility Environmental dependency Frontal-subcortex circuit syndromes	Athymormia Dysprosody Emotional incontinence Catastrophic reaction Loss of empathy Disorders of emotions experience and expression Autism?
	Anosognosia	Deficit: Apathy Productive: Irritability, Depression, Mania, Anxiety Psychosis, Obsessive–compulsive disorders	Deficit: Loss of empathy	
	Disorders of emotional and facial comprehension	Disorders of emotional experience, mood, threat	Disorders of emotional expression (aprosodias) and of emotional control (pseudobulbar palsy)	
Dementia-associated	Cortical dementia (especially Alzheimer's disease)	Limbic system dementia	Frontal and subcortical dementia	Early SDAT APP

Part of the table is a modified version of a similar table from Cummings and Bogousslavsky [4] and Carota *et al.* [29•], and is reproduced with permission.

location of stroke correlates with depression is still unclear [17–21].

Denial and a severe difficulty in expressing emotions are frequent in right-sided strokes, and have been linked to an impairment of the patient's experience of fear [22]. In patients showing denial, it is very frequent to find depression and anxiety in the later stages. If this is true for fear, it appears that experiencing other emotions (such as happiness, sadness, disgust and anger) does not yield a relationship between the behavior in the acute phase and the subjective experience of the patient himself, or nosognosia [23].

With regard to the mirror/internal modeling framework, a patient with an insular and basal ganglia lesion was unable to experience disgust and to recognize disgust in others [24]. Furthermore, patients with Wernicke's aphasia (thus having lesions in the posterior-superior temporal cortex, also relevant to action recognition) [25] show violent emotional behavior in the acute phase, which decreases with recovery.

Catastrophic reactions have recently been fully described by Carota *et al.* [26] in patients with left hemispheric lesions, in particular when the lesion affected the temporal lobe cortex, the frontal opercular and the parietal cortex, and the insula. All these areas belong to the action recognition/mirror system in primates [10] or, as in the case of the insula, connect the action recognition/mirror system to the limbic system [12•]. Carota *et al.* [26], on the premise that 'The amygdala is a critical region forming stimulus-reinforced modality-specific associations in order to enhance behavioral responses through basal ganglia output', and that 'amygdala activation is known to be significant in the processing of danger elicited by language', concluded that damages of critical language areas in the left hemisphere cause loss of the modulatory amygdala effect and therefore catastrophic reaction. However, we would submit that focal lesions affecting the action recognition/mirror system may determine the inability to control emotions via inverse models and to predict emotional outcomes via forward models, thus resulting in profound emotional disturbances such as the catastrophic reactions described after stroke described by Carota and colleagues [26]. Accordingly, the patient reported by Wintermark *et al.* [27•] showed a severe catastrophic reaction when the penumbral areas involved the core of the mirror system in the human F5 area, a reaction that resolved when perfusion to this ischemic area was restored.

Athymormia and dysprosody

Other emotional disorders associated with lesions in the motor areas or with higher-order motor disorders have recently been described. A clinical entity, defined by Habib [28] as athymormia was recently identified in patients affected by bilateral strokes at the level of the globus pallidum and putamen, caudal nucleus, thalamus or of the internal capsular genu. Typical features of this syndrome are loss of motivation in the execution of motor actions, even in absence of damage in the motor system, mental emptiness, even in absence of cognitive impairment, and indifferent behavior, with loss of motor and affective motivation, but without other effects, usually correlated, such as anxiety or pain [29•]. It has been proposed that the lesions responsible for this syndrome, located in the basal ganglia, might indirectly adversely affect the functions of the frontal cortex by interrupting one of the five cortical–subcortical circuits, which, operating in parallel, interconnect the basal ganglia to the frontal cortex. This circuit is characterized by direct input originating from amygdala and the limbic cortex, which passes through the ventral striatum, the ventral pallidum and the thalamus, and reaches the premotor cortex, the motor cortex and then again basal ganglia.

In this view, the ventral striatopallidum, characterized by direct interconnections with limbic circuits, seems to be the conversion point where motivational processes are translated into motor outputs. When stroke lesions interrupt the circuit, the motor action remains deprived of any motivational component, thereby causing the appearance of athymormia.

The syndrome seems to reflect an impairment in the large-scale neural system that subserves the transfer of the motivational content originating from the limbic cortex and amygdala to the motor scheme production systems, located in premotor and motor cortex. In other words, athymormia may be explained as a direct consequence of damage in the mirror system, which appears to behave as the connection circuit between emotional content and the implementation of well-defined motor plans.

The term 'dysprosody' is defined as the loss of the capacity of understanding and generating speech features such as intonation, pauses, stress, cadences, as expressions of the emotional state of the subject [29•]. Strokes involving the right posterior-inferior frontal lobe are associated with dysprosody. Strokes located in the basal ganglia, in the temporal lobe and in the parietal operculum of the right hemisphere have been associated with disorders in comprehension of the emotional component of verbal expressions [30]. As it happens, most of these brain areas, with the exception of the basal ganglia, are associated with 'mirror-like' properties when studied with imaging techniques and activation tasks involving the observation, execution, and imitation of actions [31–33].

A close interdependence between the internal production of motor plans and emotional expressions coherent with external stimuli has been well documented in recent papers, focussing on emotional disorders resulting as clinical consequences of strokes located within the cerebral structures primarily deputed to motor functions, such as the basal ganglia and cerebellum. For example, Annoni *et al.* [34•] reported the case of M.F., who was affected by stroke located in the left posterior-inferior and anterior-inferior cerebellum. The patient exhibited a consistent emotional flattening, with loss of any property of feeling emotions, such as anger or joy, and with complete indifference to other persons' emotional status. These symptoms may be explained by a deficit in the inverse model, where the retrieval of the motor plan necessary to express emotions appropriate to the presented stimulus cannot occur.

Other brain areas of motor significance, if damaged, are associated with emotional disorders. For example, a recent study [35] reported that inability to control anger and aggression, a symptom that may result from deficit in the forward model that predicts the sensory consequences of motor plans, is associated with motor dysfunction and dysarthria, and lesions in posterior frontal lobe, striatum and lenticulo-capsular area. Furthermore, lenticulo-capsular strokes are also associated with occurrence of an emotional disorder, defined as post-stroke emotional incontinence [35–37], characterized by excessive and inappropriate laughing or crying, inadequate to the context. Similar findings have been described after anterior choroidal artery stroke [38].

Conclusion

Emotional disorders after stroke take many forms. This review focused on recent reports on stroke patients with emotional disorders, suggesting that large-scale neural systems relevant to understanding and programming actions are tightly linked with emotions. This behavioral evidence of clinical neurology fits well with emerging concepts in functional neuroimaging and cognitive neuroscience that view emotions as a pervasive element of human behavior, as opposed to an encapsulated function isolated from 'cognitive' functions. The emerging picture is rather complex, and this suggests that the heuristic value of relatively simple and abstract computational properties, mapped onto basic observations from single-cell studies, may be of use not only for the interpretation of existing data, but also for generating testable hypotheses in future studies. Stroke, and possibly first-ever acute stroke in particular, may represent an important and efficacious model to study mental functions.

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