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ABSORPTIVE MIND AND BRAIN PLASTICITY: MONTESSORI MULTISENSORIALITY FROM A NEURODIDACTIC PERSPECTIVE

MENTE ASSORBENTE E PLASTICITÀ CEREBRALE: LA MULTISENSORIALITÀ MONTESSORIANA IN CHIAVE NEURODIDATTICA

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Abstract

Neuroscientific studies related to neuroplasticity and multisensoriality have made it possible to understand the importance of cross-modal stimulation in the learning phase. The present article presents the cerebral mechanisms involved, recalling and updating the studies of Montessori pedagogy, in a new educational reality, in which the corporeal medium becomes the "embodiment" of knowledge.

Gli studi neuroscientifici legati alla neuroplasticità e alla multisensorialità, hanno permesso di comprendere l'importanza di una stimolazione cross-modale in fase di apprendimento. Il presente articolo presenta i meccanismi cerebrali coinvolti, richiamando ed aggiornando gli studi della pedagogia montessoriana, in una nuova realtà educativa, in cui il medium corporeo diventa "incarnazione" della conoscenza.

Keywords

Montessori pedagogy, multisensory, neurodidactics, embodied cognition, neuroplasticity.
Pedagogia montessoriana, multisensorialità, neurodidattica, embodied cognition, neuroplasticità.

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1. Introduction

The lowest common denominator between Montessori pedagogy and neuroscience is represented by cerebral plasticity, a term not yet known to the pedagogue, whose reference to the concept was expressed by her as absorbing mind (Regni, Fogassi, 2019). The focal point is the understanding that the child's mind develops in relation to the experiences proposed to it, with the premise that multisensory stimulation aimed at perceptual anchacement is not predetermined but acquired through experience, and it is the latter that must be aimed at developing the child's cerebral and global plasticity.

Cognitive neuroscience provides a first point of understanding of learning processes to which pedagogy and psychology contribute. A neurodidactic perspective that provides concrete knowledge bases useful for rethinking school curricula. Montessori's experimental pedagogy, linked to the fundamental role assumed by the body in learning and the concrete experiences proposed, finds scientific validation and is open to a multidisciplinary comparison. A forerunner of the *embodied cognition* approach developed by neuroscience, as a combination of perception and corporeity (Gomez Paloma, 2009), her pedagogy was marked by the study of multisensory materials and the development of the child's intelligence in an ecological key, recalling what Ausbel (2004) claimed when he spoke of effective learning as a synthesis between adequate teaching materials and previous experience.

Awareness of these learning modes emerges as a guiding reference for education professionals, who have the task of reinterpreting didactics in a cognitive-constructivist and socio-culturalist key, in which body and corporeity become main vectors of knowledge and learning (Peluso Cassese, Torregiani, 2017). Knowledge is co-constructed by three variables: body, brain, environment. It is essential that this link is understood by professionals working in the educational field (Oliviero, 2008). "[...] it is primarily a matter of reflecting on: 1) those changes that are likely to see neuroscience and education working together; 2) the educational issues related to neuroscience that may arise even in the absence of such positive collaboration; 3) the effect of such changes on teachers' professional development" (Howard-Jones, 2008, p.1).

The pedagogical tradition has opened the way for neurosciences and these for didactic applications, aimed at improving general and special education to enable participation in the educational process of all pupils, and access to human culture (Cottini & Rosati, 2008), in a continuum of valuing differences and school and social inclusion.

2. Multisensoriality: anatomical-functional aspects

Perception: the "act by which one acquires awareness and knowledge of an external reality through the senses [...]". (Sabatini & Coletti, 2008). Contrary to what has been theorised in the past regarding the integration between information, in recent years the attentional focus has shifted to the interaction between sensory modalities that would favour cognitive processing, as well as mnemonic retrieval (Mastroberardino et al. 2008), identifying perception as naturally multisensory, in that it is signified as a mental co-construction generated by a perpetual flow of external inputs of different types.

From an anatomical point of view, in order to obtain a synthesis of environmental information, it is necessary that all the data converge towards a single brain region by means of the so-called phenomenon of fusion; this occurs following two states; the first involves the primary areas of the cortex, directly connected to the peripheral sensory receptors, the second is constituted by the passage of the sensory data in the superior associative areas through indirect connections, to then be integrated by the "multisensory neurons" present, in particular, in the superior colliculus, an area identified as responsible for the function under discussion (Stein and Meredith, 1993; Meredith, 2002). The latter, inside the midbrain, is organised in "layers", with the superficial ones representing visual information and the deeper ones analysing visual, auditory and tactile polymodal stimuli. This controls changes in orientation, reacting contralaterally to afferent input coming from ascending sensory fibres and projections from the cortex.

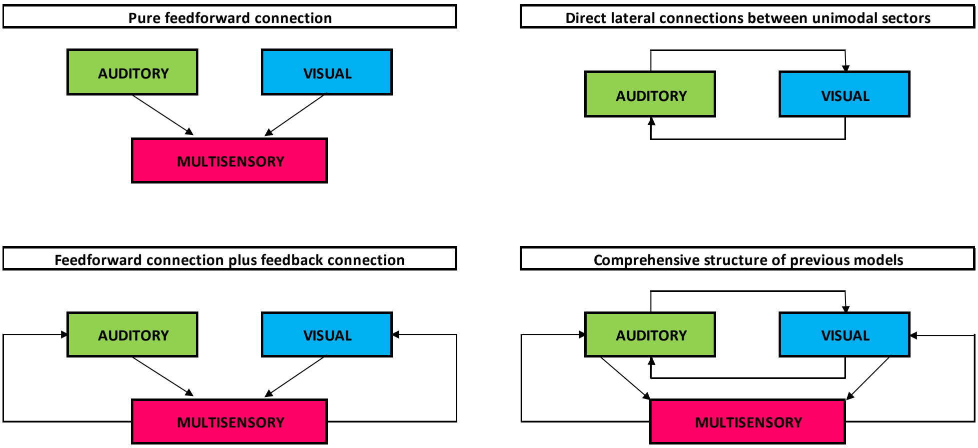
At a sub-cortical and cortical level, certain areas have been identified as being responsible for multisensory integration: the aforementioned superior colliculus, the insula (Calvert, Hansen, Iversen & Brammer, 2001; Bushara, Grafman & Hallet, 2001), the inferior parietal sulcus (Meienbrock, Naumer, Doehrmann, Singer, & Muckli, 2007) and the superior temporal sulcus (Calvert, Campbell & Brammer, 2000).

Neuronal multisensoriality can be interpreted according to a twofold meaning: the first sees a response to at least two different modalities of stimuli, with the evident possession by the neuron of a receptor field per modality; the second denotes a multisensory behaviour of the neuron when the response to a unisensory stimulus, of a defined modality, undergoes a conditioning (excitatory or inhibitory) by a second stimulus afferent from another different modality. This latter type is inherent to the neurons of the primary cortexes.

In order to understand the importance of multisensory integration, it is relevant to consider the effectiveness of the cross-modal combination with respect to that of each component taken individually in the output of the organism with respect to the criteria of amplitude (Stein & Meredith, 1993) and the time elapsed between encoding and motor action (Bell, Meredith, Van Opstal & Munoz, 2005).

As for the amplitude, comparing the response to a bimodal event with the summation of unimodal stimuli, we could observe: both a phase of multisensory enhancement, and depression, with consequent cross-modal computations of order super-additive (multisensory response arithmetically greater than the sum of the individual stimuli), or sub-additive (multisensory response arithmetically less than the sum of the individual stimuli) (Stein & Meredith, 1993). To this we could add a significant reduction in the time interval between the encoding phase and the motor command, with a latency shorter than that of the intervening stimuli (Rowland, Quessy, Stanford & Stein, 2007).

From a neurocomputational point of view, four possible models inherent in the structure of cross-modal connection have been identified (McDonald, Teder-Salejarvi, Di Russo, & Hillyard, 2003, 2005):



Considering, as a premise, the anatomical and functional study on the spatial reconstruction of the receptor surface, which sees the projection on adjacent cortical regions by adjacent sensory receptors in a spatiotopic manner for sight and touch, and tonotopic for hearing, it is necessary to enunciate three specific principles that regulate the integrative function of multisensory neurons (Stein & Meredith, 1993, Burnett, Stein, Perrault & Wallace, 2007):

Spatial Rule	Stimuli coming from two different modalities will be attributed to the same source, albeit originating in spatially different areas, until they converge on the space of the respective overlapping receptive fields (Meredith & Stein, 1986a, Meredith & Stein, 1986b, Stein & Meredith, 1993)
Time Rule	In order for the enhancement to take place, it is necessary to present the two unimodal components contiguously in a time interval between 50 and 150 ms (Meredith, Nemitz & Stein, 1987) as the response effect is oscillating between the maximum level of increment with temporal coincidence and independent processing if temporally separated (Stein & Meredith, 1993)
Inverse Efficacy Rule	"Multisensory enhancement is maximum by combining weak unimodal stimuli, compared to the combination of powerful unimodal stimuli" (Stein & Meredith, 1993). Therefore, the efficacy of the stimuli taken individually is inversely proportional to the activated neuronal response (Meredith & Stein, 1986a, Meredith & Stein, 1986b, Stein & Meredith, 1993)

3. "Plastic" learning: neurophysiological aspects

Nowadays, an "education professional" should promote a communicative-educational inter-relationship, not only through the man-man relationship, but also through the man-environment relationship, the latter being expressed and experienced in a multisensory way.

In order to better understand what has been stated above, it is crucial to clarify certain processes concerning the functioning of our brain.

From a cognitive point of view, environmental information, whether direct or mediated by a third person, becomes "knowledge" when it is signified through a process of mental representation which, following the transduction and encoding of the stimulus, allows a mentally categorical and physically neural allocation through the creation of new mnestic traces or, even of these, consolidation or depression, with the information possibly being retrieved at a later time. This system is limited by elements, both quantitative related to the capacity of the short-term memory, and qualitative related to the relevance that each subject assigns to the information. For these reasons, an excessive didactic or, more generally, informative "flooding" would produce a cognitive overload that would be detrimental to learning itself. Analyses (Clark et al. 2006; Clark 2010) point to the need for the teacher/trainer to introduce instructional procedures aimed at optimising the above cognitive load, such as chunking, sequencing, pacing, also considering its subdivision into three categories: "the intrinsic", conditioned by the subject's skills; "the extraneous", understood as not contributing to the specific cognitive purpose and its opposite; the "pertinent", useful for conceptual and categorical construction. This would favour, on the part of the "learner", a cognitive activation in "deep processing" (Anderson, 2009), free from any element of passivity, making it no longer a simple "container to be filled", but a thinking subject, constituting an operational and poietic node within the interrelational system, through the use of certain learning strategies, also of a multisensory nature, such as: "learning by mapping", "learning by drawing", "learning by enacting" (Fiorella and Mayer, 2015).

This new paradigm of "multisensory" learning, while considering the load, as well as the cognitive activity itself, envisages "in action" relating to the environment in a more global way, succeeding in optimising the learning process and, consequently, improving the abilities already possessed by the learner. It should be clarified that the "innate capacities" of a human being are underpinned by a set of functions called "executive functions" (Cantagallo, Spintoni, Antonucci, 2010), which would allow the person to adapt to the environment through flexible, intentional and targeted responses, also in a deferred form. These, classified by most of the doctrine as "Inhibition of the response", "Updating of the working memory" and "Cognitive flexibility" (Miyake et al., 2000; Diamond and Lee, 2011), as they are not immutable, can be "trained" and therefore increased through specific training, designed for each single process.

What has been reported above highlights the inescapable denial that mental abilities can be static and crystallised, as they are genetically predetermined. This line of thought has given rise to the concept of "brain-based learning" which, borrowing the appropriate knowledge from neuroscience, has developed teaching methods and strategies based on the analysis of those brain processes underlying learning (Caine, Caine, McClintic & Klimek, 2005; Given, 2002; Jensen, 2007; Olivieri, 2014; Rivoltella, 2012; Slavkin, 2004; Wolfe, 2001). The same cognitive psychology would have shown that the human brain, through a "plastic" process, would tend to deconstruct and restructure itself from a neural point of view, depending on the environmental inputs unconsciously and/or consciously perceived and processed (Nouchi & Kawashima, 2014; Thomas, 2012).

It is well known that perceptual and motor systems are of central importance in structuring the apparatus from which functions such as memory, learning and categorisation originate (Frauenfelder, Santoianni 2002). Hence, it would be possible to think of neural plasticity as a predisposition of the nervous system to modify its own structure, following environmental incipits (Siegel, 2012), through a process of plastic modulation originated by elements of environmental necessity and voluntary impulse of the subject himself, throughout our lives. It follows from the above that neural restructuring takes place in an active form, i.e., through the conscious and voluntary elaboration of the subject who encodes external inputs mainly through practice.

Several studies have been presented in support of this thesis: in 2007, using new imaging systems, it was possible to photograph the mechanism of proximal development. The same educational stimulation would have the capacity to produce a dendritic extension of about 30% (Lucangeli, 2012). From a neurophysiological point of view, neuronal modulation is activated differently depending on whether the learning is new or to be consolidated; in the first case, new branches and therefore new connections would be created; in the second case, there would be a strengthening of existing neural patterns, through the so-called myelination of dendrites, with consequent effects on mnestic processes and the speed of information processing. Neuroplasticity tends, therefore, to extend beyond the period of childhood, establishing itself as a phenomenon of neural creativity that also operates in adulthood, as it depends on the active experience that a subject carries out within the context of life (Malabou, 2004).

Another testimony, reinforcing the thesis of neural plasticity as a neuropsychological basis for learning, is given by Seung, who, through the concept of the connectome and mental maps, has broadened the scientific panorama by providing a new key to interpretation. The connectome is "an architecture that differentiates us as individuals, even in the case of identical twins, because the connectome changes over the course of a lifetime according to the experiences and events that are different for everyone" (Seung, 2013). Unlike the genome, which is static in the sequence of DNA nucleotides in the absence of pathologies, the connectome presents enormous variability, in fact covering the totality of the synapses that intervene between the 100 billion neurons present in our brain. As it evolves, this connective network assumes a dynamic homeostasis through what the author calls the ''four Rs'': potentiation or depression of connections by neuronal ''rethinking''; creation or elimination of synapses by ''reconnection''; circuit ''reformation'' by growth or retraction of branches; neuronal ''regeneration''.

Studies on multisensoriality have undergone a strong acceleration with the discovery of mirror neurons (Gallese, 2007; Rizzolati, Craighero, 2004), with which not only the mechanisms of motor resonance have been understood, but how this also involves the emotional sphere and empathic mechanisms. These results cannot be overlooked in the educational field and involve the relationship between teachers and learners, between learners and learners and between teachers-learners and the environment in a systemic way, qualifying the educational experience as a laboratory in progress of learning and experience.

There is therefore an overcoming of the traditionalist paradigm that identified the rigid functionalist schematic perception-cognition-action (Calvani, 1998) in favour of a higher function inherent in the sense-motor system.

4. Open-air education: towards a new neuro-scientific constructivism

The historical root of educational multisensoriality can be traced back to the Montessori approach and later deepened by Howard Gardner's (2013) studies on multiple intelligences. Both start from different study perspectives, one pedagogical and the other psychological, but both agree that human intelligence and child development are multicomponential and multi-factorial. It is up to the teacher to promote educational situations in which all the senses are involved in order to enhance existing abilities and develop those that are not. Maria Montessori bases her method on the combination of intelligence and movement as the foundational element of learning. The first meaningful relationship is therefore between body and mind, between emotions, movement and thoughts. The entire Montessori method is aimed at investigating this relationship, which always has movement as its unit of analysis and study, observed and proposed in a holistic way, as the fulcrum of integrated knowledge of oneself and of the world (Atti di convegno, 1931). Movement enables the child to learn by discovery. If we assume that the environment promotes learning, it must provide the right stimuli, in relation to the child's age, developmental stages and curiosity, and channel them into a perspective that involves physical, emotional and cognitive development (Montessori, 1948/2014). Quoting the words of the same pedagogue during an international course in Rome in 1931: "I do not consider the part of education that concerns movement as a beginning or as an integration, but I consider it as a fundamental part [...]. The man who has developed outside of [motor] activity is in a worse condition in life than the man without sight or hearing; perhaps the lack of one sense can be remedied by the greater development of another, but what else can be substituted for the lack of mobility along the same lines? [...]. In order to go to a higher life, one must first make a synthesis of the life of thought and of the motor, without which one remains broken" (Montessori, 2002, pp. 47-51). Nothing has changed in terms of scientific evidence. Movement is attributed the primacy of a mediator of learning, able to positively affect both emotional, moral, cognitive and social competences, as well as school performance and globally personality development (Valentini, Palmieri, & Lucertini, 2016). This movement does not coincide with the teaching of motor activity, but as an "In-movement" teaching. "Movements must come from within, dictated by the organisation of the inner life; it is this organisation that we call incarnation. The muscles are at the service of the will. Movements are the expression of a personality that acts" (Montessori, 2000).

Intelligence finds form and expression through language and its executive organ is the hand (Montessori, 1948/2014). In order to achieve this hand-mind biunivocity, it is necessary for the child to be systematically guided by the teacher, through multisensory materials prepared ad hoc, which are able to stimulate an increasing correctness of execution and make the child aware of the strategies used and help him to self-correct during execution. Trabalzini (2004), underlines how the importance attributed by Montessori to the exactness of the movements has positive repercussions on: memory, intelligence, self-control and coordination. It is through writing that one has the first experience of sensory integration, as it produces the involvement of auditory, visual, tactile and kinaesthetic memory. It is the child who develops and builds his or her intelligence and overall self, through the multiple sensory stimuli received.

What neuroscience offers us today in terms of results converge with the observations developed over the years by Montessori, whose discoveries are still undisputed by the scientific community and have benefited in recent years from renewed interest (Scoppola, 2014). Studies developed in the neuroscientific field have confirmed the extent to which movement is able to affect certain executive processes, memory and refinement of attentional skills. A forerunner of validations that would only arrive thanks to more advanced studies and methodologies, in "The Discovery of the Child" (introduction), the pedagogue wrote: "The nervous system can be distinguished in the grand sympathetic nervous system, which presides especially over visceral functions, and which corresponds greatly with emotional states; and in the central nervous system, with its infinite branches of nerves which, coming from the senses, connect the centres of the external world, and ending in the muscles establish their dependence on the will. Just these two indications, the emotions and the will, are enough to make it clear at once that the grand sympathetic system is a subordinate and dependent of the other. And this must be considered above all by those who aim at education [...]. The small organs of the sense are almost loopholes from which the soul absorbs the images necessary for psychic construction; however, the practical consequence of life is reserved for the muscles. All the work of the will is done with these wonderful instruments of movement. The purpose of the soul is to have, precisely, all these means of expression by which the idea becomes action, the feeling is realised in works" (Montessori, 1949, pp. 84-6). On the basis of these premises, the educational proposal inspired by her discoveries must be able to materialise concepts and contents to be learnt, through materials and exercises specifically conceived and organised in response to the needs of the child, to his or her inclinations and in respect of the times of development. Guided writing exercises, of grinding, tend to preserve the natural symmetry of the brain and not to confuse letters on the basis of their orientation. These exercises, combined with constant spelling of the letter being reviewed, improve reading and visual recognition skills and seem to be useful as a preventive measure for Specific Learning Disorders and praxic deficits.

For the sake of clarification, "[...] the tactile modality does not really facilitate the knowledge of letters and sounds, but rather their connections. Tactile exploration helps to establish connections between the orthographic representation of letters and the phonological representation of the corresponding sounds" (Bara et. al., 2004 p. 22). Also in the area of writing, there is evidence that the combination of visual-tactile and tactile-kinesthetic skills, together with phonetic exercises, even of short duration (Vinter & Chartrel, 2010, pp. 482-3), are predictive for the development of reading skills.

Considering the progressive use of technologies, with which we type, but do not write, these exercises seem to be an antidote to the sensory deprivation we are witnessing (Scoppola 2014).

The school must be an open-air laboratory and should make use of all the environments and educational potential offered to the teacher and the child, a recovery of the constructivist matrix of learning, which places the pupil at the centre of his or her own learning, as a subject who participates in and transforms knowledge. Knowledge that becomes co-constructed and shared with peers, produced and transformed within one's own experience. Bruner (1961/1964) argued that it is unthinkable to learn in a way that is decontextualised from concrete experience and from the environment in which the child lives and grows, experiences and learns, transforms and creates. A democratic educational approach that supports individual developmental stages, curiosity for knowledge and metacognitive processes.

This awareness of the multiple forms of learning and mental development of the child has led to an ecological view of learning, from which the body cannot be excluded as an exploratory medium of the surrounding environment. The child learns through manipulation and exploration, and to disregard this method is to disregard an important part of the developmental stages. In a way, the Cartesian dualism is recomposed, corrected in the light of the recent discoveries of neuroscience applied to learning processes (Damasio, 1995).

5. Conclusions: for an applied neurodidactics

The current synthesis in the field of neurolearning linked to the body in a multisensory key, comes from the contribution of Embodied Cognition, as a scientific approach including perception and action, aimed at centralising the role of the body as a mediator of learning (Gomez Paloma, 2009). This new paradigm provides a global and integrated vision of learning, based on the mechanisms through which it occurs, on the dimensions that it involves, including the emotional ones, proposing itself as an operational guide in the field of enabling-didactics (Borghi, Caruana, 2013; Gomez Paloma, 2013). Knowledge becomes, therefore, the product of an interrelation between body, brain and environment, strongly arguing that thought is not "divorced" from the body but, rather, is a function of the body we have (Peluso Cassese, Torregiani, 2017). The action of educating and that of learning best summarises the interdependence between mind-body and brain. One speaks, in this sense, of embodied cognition as a central aspect in the

Embodied Cognition perspective (Barsalou, 2008). "There is an ongoing movement in cognitive science to grant the body a central role in the formation of the mind. Proponents of embodied cognition have as their theoretical starting point not a mind that works on abstract problems, but a body that requires a mind to make it work" (Wilson, 2002, p.625). This growing attention to the mutual interdependence of the body, healthcare and learning, has inevitably led to the development of teaching practices applicable in everyday school life, in order not only to enhance learning, but also to achieve this while respecting the uniqueness of the individual pupil and the educational relationship that is established between teacher and learner (Gomez Paloma, Damiani, Ianes, 2014). Within the Embodied paradigm, an essential component is the emotional one and the relationship it establishes with the body and learning. "Emotions represent an emotional rudder to guide our judgement and actions... the original premise for which our brains evolved" (Immordino-Yang & Damasio, 2007, p.4). This proves that the brain values emotions on the basis of the emotional salience of the sensory stimuli that reach its processing.

Responding to this new neuroscientific evidence demands teachers to acquire integrated skills. Acquiring EC based skills (Gomez Paloma & Damiani, 2015) presupposes the establishment of an empathic resonance between learner and teacher, based on body awareness and mirroring with the other. The intersubjective process, as well explained by the functioning of mirror neurons (Gallese, 2007; Rizzolati, Craighero, 2004), presides over both motor and emotional functions, allowing the sharing of the experience lived at the same time.

From the point of view of applied didactics, working with ECs means activating a series of practices that allow the body to be used to experiment in vivo: concepts, shapes, letters, numbers. An example is the acquisition of the numerical concept and mathematical operators. Children could represent numbers and move to a greater or lesser extent depending on the operation required or experiment with various geometric shapes, such as the circle or the square, through large movements in the environment (Peluso Cassese, Torregiani, 2017) with the possibility of also including music, as a further sensory stimulus, able to rhythm and mark the stages of acquisition. It has also been observed that early musical initiation has positive repercussions for the learning of mathematics. Similar didactic situations with music and body could also be used for the teaching of the second language: miming songs, alone and in groups, stimulates creativity and curiosity, as well as creating a virtuous circle of positive emotions that are fixed in the learning process. The pedagogical tradition is thus enriched with new content, transforming bottom-up intuitions into an ECS-based curriculum, in which the body, multisensoriality and traditional didactics come together to promote ecological and intersubjective learning and whose assumptions are based on the extending mind (Gallese, 2008; 2013) and the relational dimension of the teaching/learning process, oriented towards the principles of equity and participation in social life in an inclusive way (Sen, 1984: 1989; Nussbaum, 2003; 2001). The peculiar characteristics of the functioning of the mind and its development, cannot and must not be relegated to the sole scientific treatment for the discussed effects on learning and, on the other hand, a specific orientation for teachers is essential, so that there is no dispersion of this knowledge or, even worse, a mystification of results and practices, leading in this way towards "Neuromyths or neuro-manias" (Legrenzi, Umiltà, 2009).

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