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Abstract

Purpose – The purpose of this paper is to present a new core hypothesis on laughter. It has been built by putting together ideas from several disciplines: neurodynamics, evolutionary neurobiology, social networks, and communication studies. The hypothesis focusses on the social nature of laughter and contributes to ascertain its evolutionary origins in connection with the cognitive and social-emotional functions it performs.

Design/methodology/approach – An in-depth examination of laughter in the social communication context and along the life cycle of the individual is performed. This instinctive behaviour that appears as a "virtual", non-physical form of "grooming" would serve as a bond-making instrument in human groups. Further, the neurodynamic events underlying laughter production – and particularly the form of the neural entropy gradients – are congruent with a sentic hypothesis about the different emotional contents of laughter and their specific effects on bonding dynamics.

Findings – The new behavioural and neurodynamic tenets introduced about this unusual sound feature of our species justify the ubiquitous presence it has in social interactions at large and along the life cycle of the individual. Laughter, far from being a curious evolutionary relic or a rather inconsequential innate behaviour, should be considered as a highly efficient tool for inter-individual problem solving and for maintenance of social bonds.

Originality/value – Laughter, the authors would conclude, has been evolutionarily kept and augmented as an optimized tool for unconscious cognitive-emotional problem solving, and at the same time as a useful way to preserve the essential fabric of social bonds in close-knit groups and within human societies at large.

Keywords Social bonds, Laughter, Neural entropy, Sentic forms, Social brain hypothesis, Virtual grooming

Paper type Conceptual paper

1. Introduction: the need of new synthetic views

The resurgence of laughter research during last two decades (Provine, 2000) has been very fertile concerning specialized achievements in a number of fields. The exciting developments in neuroimaging, neurophysiological, sound analysis, physiological (respiratory and phonatory), ethological, evolutionary, social communication, computational engineering, and biomedical fields have dramatically changed the research panorama. However, the conceptual counterpart of putting together the most relevant strands of thought in order to gain more advanced synthetic views or to establish a new core hypothesis, or a set of hypotheses, has not been sufficiently developed. In this paper we will attempt that conjunction of ideas – though, inevitably, within a rather limited scope of contents. The authors are well aware of, and would like to abide by, Schrödinger's famous disclaimer: "[...] some of us should venture to embark on a synthesis of facts and theories, albeit with second hand and incomplete knowledge of some of them – and at the risk of making fools of ourselves". (cited in Stonier, 1990).

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Contemplating the study of laughter, it is curious that parallel to its scientific obscurity during past centuries, it has been ostensibly present in philosophical speculation. Most of the big names of philosophy could not help but expostulating some favourite hypotheses or tentative explanations about that enigmatic phenomenon, apparently exclusive of humans: Plato, Aristotle, Cicero, Quintilian, Hobbes, Kant, Schopenhauer, Spencer, Bergson, etc. (Kozintsev, 2010). Actually, some of the ideas they were handling look very close to pretty modern hypotheses, such as superiority, paradox, and incongruence. However, not being able to frame sensible accounts, those approaches were superseded along the advancement of more modern scientific studies, and obscured finally by the mentioned resurgence of laughter research in recent times (Morreall, 1987; Provine, 2000, 2006; Weems, 2014).

In the transition towards scientific approaches, one of the most brilliant research insights corresponded to G. Bateson (1953). In the Ninth Macy Conference, his oral presentation-related laughter and humour to the presence and voluntary acceptance of paradox, implying that the mental flux or entropy generated by the sudden conceptual disorder and the subsequent solution would allow for a new organization of experience and/or new premises for the codification of thoughts. In fact, a sort of "cybernetics of humour" was born with that presentation and with the excited discussion it provoked – for instance, when John Bowman counter-argued that "an electronic buzzer is laughing" (Kadri, 2015). The buzz continued along the conversational and "languaging" explorations of other cybernetic figures (Gordon Pask, Stafford Beer, Heinz von Forster, Humberto Maturana) and still keeps producing interesting literature (Donoso, 2004; Kadri, 2011, 2015). Actually, Bateson's reference to entropy reproaches the core hypothesis we are attempting herein.

The sounds of laughter, the underlying neurodynamic events, and the myriad ways this phenomenon surfaces in human relationships constitute essential traits for the cohesiveness of the present approach. As a preliminary step in the unifying direction, we will establish a coherent link between the evolutionary roots of human laughter and the natural social context in which language and an intense non-verbal communication took off in human groups (Section 2). Our analysis will be aligned with the "social brain" hypothesis (Allman, 1999; Dunbar, 2004). Later we will briefly examine the communication constraints of language in the life cycle of individuals, providing evidence for laughter's subservient use as an augmented form of "virtual grooming" and as a bond-making instrument (Section 3). Afterwards, looking at the underlying neurodynamic events, the analysis will focus on variational energy and entropy changes (Section 4). It will be argued that the gradient form of the entropy variation is at the essence of the unitary phenomenology of laughter (Collins and Marijuán, 1997). Then, the sound structure of laughter will be analysed, providing support to a sentic hypothesis on the informational/emotional content of the different classes of laughter (Section 5). It is a new idea which is also based on some classical works about the convergence of emotional expression via differentiated sensorimotor channels (Clynes, 1979). Laughter, will be concluded, has been evolutionarily kept and augmented as an optimized tool for unconscious cognitive-emotional problem solving, and at the same time it has been used as a way to preserve the essential fabric of social bonds in close-knit groups and within human societies at large (Section 6). Additionally, looking from the biomedical perspective, we will find out that the social-inclusive dimension herein delineated around the "bonds of laughter" becomes useful in order to make sense of the numerous therapeutic applications that laughter has in biomedical settings and even of its potential use as a diagnostic tool in mental health disturbances (Navarro *et al.*, 2014, 2016).

2. The evolutionary scenario of human laughter

Classical and recent ethological studies have unambiguously situated laughter within signalling contexts of play and socialization of advanced mammals, especially in relation with the grooming practices of anthropoid primates, but also in rodents and other species (Panksepp, 2005). So, contrary to the opinion of most classical philosophers, we humans are not alone in the instinctive laughing behaviour!

Whether anthropoid ritualized "panting" during play should be considered as the closest antecedent of human laughter is still a matter of debate, though factually settled down (Ross *et al.*, 2009). Anthropoids (chimps) "laugh" mostly when tickled and at chased games, noisily punctuating each inhalation and exhalation; but they are fundamentally unable to modulate a single exhalation and articulate it into discrete notes. What modifications were elaborated upon this primate precursor that made possible the appearance of human laughter? Undoubtedly, they were derived from the systemic adaptations involved in bipedestation, allowing an improved control of breathing by freeing the thorax of the mechanical demands of quadrupedal locomotion – and also freeing the hand with the subsequent emergence of human dexterity techniques, directly fuelling the neocortex expansion too. "In the beginning was the breath" (Provine, 2000).

But new social behaviours were also driving further evolutionary changes of the human species (mostly brain-centred), and they presumably included an increase of group size and the development of articulate communicative language, with decoupling of vocal production from emotions. In parallel, new feeding practices and an improved social sharing of food (including the cultural invention of exodigestion or "cooking") were being developed, as they were needed to compensate for the "energy crisis" that so large a brain was causing in the metabolic budget, probably already at the level of *Homo ergaster* (Allman, 1999; Wrangham, 2009; Pontzer *et al.*, 2016). Actually, an evolutionary trade-off took place between gut tissues and brain tissues: the great expansion of the brain in humans was accompanied by a commensurate reduction in digestive organ weight, almost "gram-by-gram" (Allman, 1999).

Nevertheless, obtaining a 20 per cent surplus of energy from a gut reduced to 50 per cent implied a series of unintended consequences – among them a largely stressed and fragilized gut microbiota or microbiome. This microbiome fragility was compensated partially with the mentioned exodigestion practices (cooking) and with the factual incorporation of external microbiomes by previously fermenting the food to be ingested – that is the case of the most basic "civilization foods", such as bread, cheese, wine, bier, etc. At the same time, those cultural practices granted relative independence from ecosystems' immediate affordances (Diamond, 1998). Preparing the food, and more or less generously sharing it, became collective enterprises of human groups at the very centre of their daily activities – and supporting the emergence of many other associated ceremonials and cultural practices.

The loss of bodily hair was behaviourally important too, both for heat dissipation in new hunting strategies based on long-distance running needed for the new diet, and for the appearance of new pair-mating behaviours and a stronger parental bonding (Jablonski, 2010). It further facilitated the evolution of new communicative signals, which were also accompanied by many other group communicational adaptations: laughter, crying, smiling and other facial expressions, blush, pallor, enhanced gaze discrimination, unison sense, rhythm, music, dance, etc. (Benzon, 2001).

This is, roughly speaking, the evolutionary context – interwoven tapestry of survival capabilities and communication skills – onto which laughter became so conspicuous, a trait in the social information processes of human groups. Indeed with the emergence of language, an evolutionary tipping point was reached, for laughter and for everything else human.

3. The social brain hypothesis and the emergence of language as "virtual grooming"

In the above evolutionary overlapping of highly consequential positive feedbacks, both of physical and behavioural nature, a crucial correlation occurred between social life and brain development (Dunbar, 1998; Allman, 1999; Badcock and Crespi, 2008). The social brain hypothesis posits that, in primate societies, selection has favoured larger brains and more complex cognitive capabilities as a mean to cope with the challenges of social life (Dunbar, 2004; Silk, 2007).

Contrary to conventional wisdom in the cognitive field and neurosciences, which assumes that animal and primate brains deal with basically ecological problem-solving tasks, what the large primate brains would accumulate in their expanded neocortex is not information about ecological happenstances but the computational demands of their complicated storylines: the important memory capabilities invested in other individuals, the ever changing coalitions, the mating alliances, the sharing of resources, the multiple conflicts, and so on. Social networks in primates seem to be very different from those found in most other mammals: they are cognitive, memory-loaded, based on bonded relationships of a kind found only in pairbonds of other taxa (Dunbar and Shultz, 2007).

Maintaining that special structure of social-cognitive bonds relies on grooming practices. "Bonds" are but shared memories: they consist of neural engrams encoding behavioural interactions that have been positively finalized (Collins and Marijuán, 1997). When altered in the behavioural "noise" of primate societies, bonds are rebuilt and emotionally restored throughout a variety of grooming practices: touching, scratching, tickling, playing, massaging, etc. up to 20 per cent of ecological time may be devoted to participation in grooming networks. The molecular cocktail activated by grooming is intriguing and not quite solved yet. Seemingly, it involves neuropeptides and relaxing hormones of the neural reward system, with effects in stress quenching, immune boosting, and also in learning processes (Shutt *et al.*, 2007; Nelson and Geher, 2007). These powerful neurotrophic mechanisms, very similar to those already authenticated for mammalian pairbonding (e.g. oxytocine, AVP), would reinforce the involved synaptic memories and would restore the bonding relationships (Allman, 1999).

Frequent pair-wise grooming in between individuals, however, imposes a strict time limitation regarding group size: depending on diet, 20 per cent of time is the upper ecological limit that grooming can reach. This factor necessarily restricts the size of grooming networks and, thus, of natural groups in primate societies (composed, at most, of a few dozen individuals). So, how could human societies have organized their social "grooming" within increasingly larger natural groups, of around 150 or 200 individuals? As Dunbar (1998, 2004) has argued, human language was the evolutionary solution.

Analysing the dynamics of group conversation, very robust data have been obtained that are consistent in a variety of cultural and social contexts (Dunbar, 1998, 2004). First, about the number of speakers in the conversation – statistically, the average talking group is of three-four individuals, within a maximum 10-12 of preferred clique size. In any non-formal conversation, frequent changes and instabilities occur as successive parties are added: 2, 3, 4, 5, etc. Almost inevitably, as the number of participants increases, the ongoing conversation splits into smaller "partitions", very frequently of two, three, and four individuals; so the average of three-four becomes the most probable size of a conversational group. As for the daily budget of conversation, it amounts to an average of three-four hours; being "gossiping" and "small talk" preferred contents rather than the exchange of factual information (only one-third of time).

According to Dunbar's version of the social brain hypothesis, these conversational data dovetail with the grooming needs of human natural groups, around three-four times bigger than other anthropoid societies. Considering small talk as the social grooming of our species, it would provide thrice as much virtual grooming on average than the strictly bilateral physical grooming characteristic of primates. By means of the talking/listening exercise, individuals would impart each other a mental massage: amusing themselves, actualizing their relationships, gossiping about absent third-parties, etc. in the long run maintaining the mutual bond. Human social networks so glued by the linguistic nexus will manifest a complex mixture of links: parenthood and family related "strong bonds" plus many other classes of more labile "weak bonds" (Granovetter, 1973). Curiously, as happens in the biomolecular realm, weak links turn out to be the genuine bonds of social complexity, those in which the growth of civility has been supported (Ikegami, 2005).

Laughter quite often breaks in amidst the talking/listening exchanges. It punctuates sentences as a sort of emotional valuation or as an enigmatic social "call", even in deaf people using the hand-sign language (Provine and Emmorey, 2006). In this sense, laughter production, far from interfering with language or competing as a "low level" process with the higher cognitive functions for access to the fonatory apparatus, becomes itself a cognitive solution, marking the occurrence of humourous incongruences as positively finalized items within the ongoing talking/listening exchange, and putting into action augmented grooming mechanisms. Further, what has been called "antiphonal laughter" or the chorus of laughing people (Smoski and Bachorowski, 2003; Smoski, 2004), may be seen as an effective extension of the talking massage effects in bigger groups, where the mere size precludes active participation of most individuals in the talk. The laughing together that follows brings the augmented neuromolecular grooming-effects of laughter available to everybody in the group, irrespective of the conversation share.

During conversation exchanges between genders, laughter participates as a *bona fide* indicator gauging the relative advancement of bonding processes in courtship – males usually are providers of laughter, "groomers", while females are consumers, "groomees" (Provine, 2000). Laughter contributes as well as a most lively tool in the establishment of parentofilial bonds (the babbling-laughing charms that babies and toddlers address to their parents). In general, the occurrence of laughter indicates that successful bonding processes of whatever type are in progress amongst the laughing individuals. It is the case of laughter addressed against someone outside the laughing chorus too. It is also the case of the evolutionary relationship between laughter and the "sharing of food".

Presumably, the pleasurable grooming activities of "languaging" and laughing coevolved as social bonding tools with the pleasurable "sharing of food" brought forth along the exodigestion cultural practices of cooking. In every culture, eating together maintains a ritual significance as a bond-building occasion, usually full of small talk and antiphonal laughter episodes. It is not a remote cultural trait of the past, as in contemporary societies "restaurants" are indeed feeding places, but even more they are group bonding places. The restaurant table in particular becomes a terrific scenario to watch the partitional dynamics of group conversation-transitions and the practice of choral, antiphonal laughter!

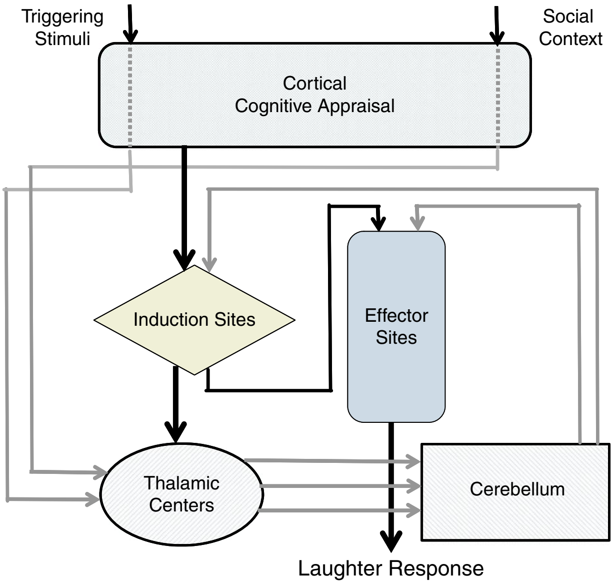
4. The abstract neurodynamic "stuff" of laughter

The great variety of stimuli and situations conducing to laughter – physical, chemical, sensorimotor, cognitive, relational, parental, courtship, playful, pathological, etc. – and even more the intriguing neuromolecular repercussions of this innate behaviour, become additional factors of complexity in order to systematically study it and to explain its neurodynamics. After almost two decades of neuroimaging works, for instance, almost any brain area has been related to humour and to laughter production. Like in the deepest problems of our cognition, no decisive results have been found regarding a unified neural explanation yet.

Actually, the study of pathological laughter in medicine (Poeck, 1985) pioneered the field over other behavioural and cognitive approaches to "normal" laughter. Lesion studies (e.g. damage to frontal cortex areas) have pinpointed the participation of many specific areas in humour perception and laughter production, and have also dispelled much too simple an assumption. Classical EEG studies have also generated an ample literature on cortical "wave" events accompanying laughter onset and the perception of humourous stimuli (Derks *et al.*, 1997). It has been authenticated that, unlike in emotional responses, relatively confined to specific areas, laughter is associated with activation of numerous regions: left, front, right, and rear of the cortex, as well as the motor areas, cerebellum, limbic system, and subcortical nuclei, hypothalamus, etc.

The classical view is that two main neural pathways, relatively independent, are controlling the expression of laughter (Ozawa *et al.*, 2000; Iwase *et al.*, 2002; Wild, 2003). The former is more "involuntary and emotional", and involves amygdalar, thalamo-hypothalamic, subthalamic, and dorsal mesencephalon areas; while the latter, more "voluntary and cognitive", originates in premotor/opercular frontal cortex, and links with the pyramidal tract and brain stem (Goel and Dolan, 2001). As Parvizi (2001) have noted, a more comprehensive scheme can be elaborated that includes the loops associated to the cerebellum and responds better to the cases of pathological laughter. See Figure 1 with a block diagram. Besides, it is interesting that systematic gender differences have been found regarding patterns of activation in cortical, hemispheric, and mesolimbic structures in response to humouristic stimuli (Azim *et al.*, 2005) – the mesolimbic structures activated by laughter and humour include the nucleus accumbens, a key component of the mesolimbic dopaminergic reward system, which is also involved in the pleasurable effects of physical grooming (Mobbs *et al.*, 2003).

Certainly, a unified neurodynamic explanation should integrate the multitude of potentially participating areas and nuclei into functional constructs with behavioural sense. Catchword terms such as "species call", "false alarm", "polarity change", "pathways collision", "release of tension", "collapse of strained expectation", and so on, have been historically proposed by scientists and philosophers to explain the role of laughter either in social, behavioural, or neurodynamic grounds (Ramachandran, 1998; Provine, 2000). The point of view advocated here, in the nearness of S. Freud, A. Koestler, G. Bateson, G. Pask, O. Rossler, and others (see Marijuán, 1999), attempts the exploration of the "minimization of incoherent excitation" construct for the explanation of laughter. It means relying on the conceptual track around the minimization (optimization) of structural and functional features of the vertebrate central nervous system. A substantial body of neuroscientific literature, starting with Neurophysiologist Ramón y Cajal's (1899) "Laws of Economy", has been developed during recent decades, including new ideas on optimality in the dynamics of connectivity among neural assemblies see (Edelman and Tononi, 2000; Marijuán 2001).



Notes: The initial stage is the cognitive appraisal (cognitive system), which mainly corresponds to the frontal cortex, together with the sensory and multimodal areas related to the kind of triggering stimuli (visual, auditory, tactile, linguistic). At this stage, the intensity, emotional content, and duration of laughter are not well gauged yet, as they should be in accord not only with the triggering stimuli, but also with the social context and with the reaction produced in the whole memory contents of the subject. Further, the emotionally laden induction sites (emotional system) comprehend the amygdala, ventral striatum, and anterior cingulated cortex. The motor or effector sites (motor system) include motor cortices, hypothalamus, and cranial nerve nuclei. The three previous systems (cognitive, emotional, motor) relay to the telencephalic structures, and from there to the cerebellum, which computes the different influences that shape the final laughter response conveyed through the motor system. Note the strong influence of the social environment. See Parvizi (2001) for a careful discussion of all these pathways and systems
Source: Taken from Navarro *et al*. (2014), with permission

Figure 1.
Main neural systems and pathways involved in laughter

Thereafter, most recent approaches to brain dynamics are relying on informational/entropic constructs (Friston, 2010; Carhart Harris *et al.*, 2014; Tozzi and Peters, 2016; Sengupta *et al.*, 2016). Following some of these views, the brain unifies its information processing by means of a distributed free-energy variable (variational energy) based on the coupling of excitation and inhibition, the informational entropy of which is maximized (optimized) in the ongoing search of adapting the sensory-motor states to the environmental demands. Given the mappings, gradients, circuit topologies, and self-organizing rhythms in the couplings between excitation and inhibition, the blind optimization of this brute "neural entropy" produces the outcome of well-fitted states.

In the human context, laughter would have been co-opted as a generalized information-processing tool, a finalizer accompanying the higher-level cortical processing (Collins and Marijuán, 1997). In the most general way, we laugh abstractly: when a significant neurodynamic constellation coding for some problematic circumstance suddenly vanishes, i.e., when a relatively relevant behavioural problem becomes unexpectedly channelled in a positive way and vanishes as such problem. Laughter is then spontaneously produced by the subject to display his/her own behavioural competence in an instinctive way. So, the "idle" excitation still circulating in the regular problem-solving of cortical and limbic structures is redirected towards the fonatory apparatus where it produces an unmistakable signature. It is the "call" of the species, a social signal of wellness after successful problem solving, of enjoying an effective mental massage. It is really important than those powerful neurodynamic, neuromolecular, and physiological resources internally mobilized do not imply any extra computational – cognitive burden upon the subject's ongoing conscious processes (Navarro *et al.*, 2014, 2016).

This problem-solving role of laughter would make a lot of sense in the really complex social world that the "talkative" human brain has to confront, surrounded by endless sensorimotor, cognitive, behavioural, and relational problems. In the conceptual-symbolic world of language, which is really crucial in the making and breaking of social bonds, emotional-relational problems may dramatically accumulate in extremely short periods of time (Dunbar, 2003, 2004). Thus, it makes a lot of evolutionary sense counting with these ultra-fast, extra-ordinary minimization resources: the information processing power of a hearty laugh, or of bursting out into tears!

Let us emphasize that when we laugh, the inner entropy generated along the optimization process is emitted to the outside, reflecting the occurring evolution of the neurodynamic processing gradients. This very neurodynamic entropy, transformed now in the Shannon-Wiener entropy of laughter sounds, becomes a characteristic difference with the better controlled sounds of spoken language (Bea and Marijuán, 2003), as it can be easily detected. The sounds of laughter appear to be a useful biomedical resource too, e.g., in order to detect systematic differences between the laughter of healthy controls and depressed patients (Navarro *et al.*, 2014, 2016). Those sounds may finally be an amazing window into our most basic informational operations.

5. The sounds of laughter: revisiting the sentic forms hypothesis

Laughter and infant crying are two of the more potent, affect-inducing vocal signals (Bachorowski and Owren, 2008); they are "evolutionarily designed" as species-specific relevant auditory stimuli that immediately provoke emotion-related responses in any listener. However, it is still unclear where the auditory emotional clutch localizes inside these innate human sounds. *En passant,* there is an intriguing symmetry between laughter and crying sounds, and also between their affective responses. Perhaps because they, respectively imply the making vs the breaking of social bonds, the beginning of lasting memories vs the loss of important memory constructs?

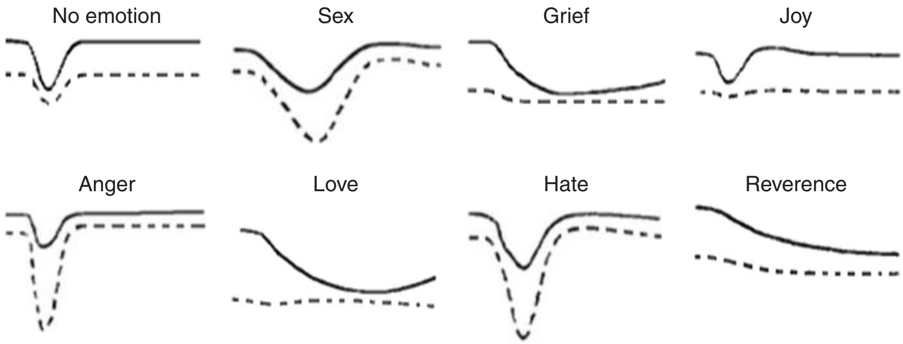
Far from being a stereotyped signal, laughter becomes one of the most variable acoustic expressions of humans, comparable to language except for the combinatory richness of the latter. Typical laughter is composed of separate elements or "calls" or "syllables", plosives, over which a vibrato of some fundamental frequency *Fo* is superimposed (Rothganger *et al.*, 1997). A typical laughter episode may last around one second (or slightly less) and will contain around five plosives (most often, in between two and eight). An important distinction to make is between "vocalized" and "unvocalized" laughter; even though the former induces significantly more emotional responses in listeners, the latter appears consistently in many laughter records, comprising a large variety of sounds (snort-like, grunt-like, giggles, chuckles, etc.)

In a landmark experimental study, Bachorowski *et al.* (2001) found that there are around 4.4 calls or plosives within each laughter bout, a single plosive having a duration of 0.11 s and a separating interval of 0.12 s (for voiced laughter). Call or plosive production is denser towards the beginning of laugh bouts, and inter-plosive durations gradually increase over the course of bouts. The average value of the fundamental frequency *Fo* for male laughs is 272 Hz (SD = 148) while for females is considerably higher and more variable 405 Hz (SD 193); only for voiced laughs, the respective values are 282 and 421 Hz. Usually *Fo* is much higher in laughter than in speech, thus, extremes of male *Fo* were found to be as high as 898 and as low as 43 Hz, while female extremes were in between 2083 and 70 Hz. The excursions of *Fo* along the bout trajectory represent an additional factor of variability, showing contours such as "flat", "rising", "falling", "arched", "sinusoidal", etc.

All of the previous elements could form part of the inbuilt cues to laughter identity, which have been proposed to play an important role in listener emotional responses (Bachorowski and Owren, 2001). In particular, the pitch or tone curve described by *Fo*, together with the distribution of plosives, would show consistent differences between laugh forms associated with emotional states of positive and negative valence (Devillers and Vidrascu, 2007). The main trend is that the energy and duration becomes higher for "positive" than for "negative" laugh, and vice versa for the relative presence of unvoiced frames, more frequent in ironic and hostile laughs than in joyful ones. Notwithstanding that, there is not much consensus yet – neither significant hypothesis to put to test – on how the interrelationship between plosives, tones, melodies, and other variables of laughter may be systematically involved in encoding and distinguishing the underlying emotional states (Bea and Marijuán, 2003; Bachorowski and Owren, 2008).

At this point, the sentic forms hypothesis, framed by M. Clynes in the 1970s, could help in the exploration of new directions for such open questions. If laughter contains inner "melodies" or pitch patterns of emotional character, how could they be structured? Following the sentic paradigm developed around tactile emotional communication by means of exchange of pressure gradients, there appears a set of universal dynamic forms that faithfully express the emotional interactions of the subjects (Clynes, 1979). The universality of these behavioural performances stems out from a common quality, a unique dynamic essentic form (or sentic, for short) that conveys the essential interactive information of each emotion. Moreover, irrespective of the sensory modality involved, or of the type of motor expression used, such patterns show a remarkable consistency. The nervous system is built in such a coherent way that it not only executes this dynamic form but also perceives it accurately and precisely. Subsequently, the whole set of sentic forms can be determined experimentally, and be measured, catalogued, etc. by means of the tactile expression of emotions; sentic forms can also be found reliably in musical phrases, facial expressions, and in the visual arts (Clynes, 1988, 1992). See Figure 2.

The crucial element to apply the sentic hypothesis to laughter is that the excursions of *Fo* along the succession of plosives are defining the emotional tone of the laugh, in correspondence with one or another of the different sentic forms. According to the neurodynamic interpretation herein sketched, the set of variables underlying the different classes of laughter would revolve around a fundamental value: the amount of



Notes: Each of these figures represents a differentiated emotion pattern of finger pressure obtained in laboratory from subjects who were asked to push a button in response to elicitations of eight different emotions. Figures are representing pressure (0-200 g/m^2) vs time (0-2 s). The upper lines represent downward-upward pressure, whereas the lower dashed lines represent forward-backward pressure
Source: Modified from Clynes (1979)

Figure 2. Representation of sentic forms

incoherent excitation instantaneously minimized. That is what the area subtended under the different classes of sentic curves means. It represents the way the excitation gradient of the global entropic variable has been handled, the kind of gradual increase and of sudden decrease suffered. This very trajectory would be manifest by means of the different emotional tones of the *Fo* vibrato superimposed to the plosives. The "idle" excitation redirected towards the fonatory apparatus tells by itself what kind of gradient variation occurred during the brisk outcome of the behavioural episode. Figure 3 represents a sonogram of laughter where one of these sentic forms may be detected.

In the different emotional states compatible with laughter expression, the coherence of their motor manifestations would imply that facial gestures, pitch melodies, and vocalic contents of the laughs should be congruent with each other. Therefore, in the extent to which emotions such as happiness, joy, hostility, timidity, or surprise are producing specific laughing signatures, they should be aligned with the other expressive components, and the resulting commonality should be susceptible of experimental checking relatively easily.

6. Conclusions: the consequences of laughter

Laughter is one of the most complex behaviours exhibited by humans. It integrates the innate and the cultural, the emotional and the cognitive, the individual and the social. Any unifying hypothesis is forced to contain an unwieldy heterogeneity of elements, even in order to attempt a very rudimentary synthetic closure. Besides, some of these elements may locate in well-trodden disciplinary paths and are relatively easy to discuss, while others neatly belong to the theoretical-speculative (at the time being) and become relatively disciplinary-independent. All of them, but particularly the latter, are in need of meticulous experimental approaches.

Let us summarize the main arguments herein proposed:

(1) Human laughter, derived from primate antecedents, becomes heavily "corticalized" and associated to language, fully participating in this new form of social grooming as the social brain hypothesis has described.

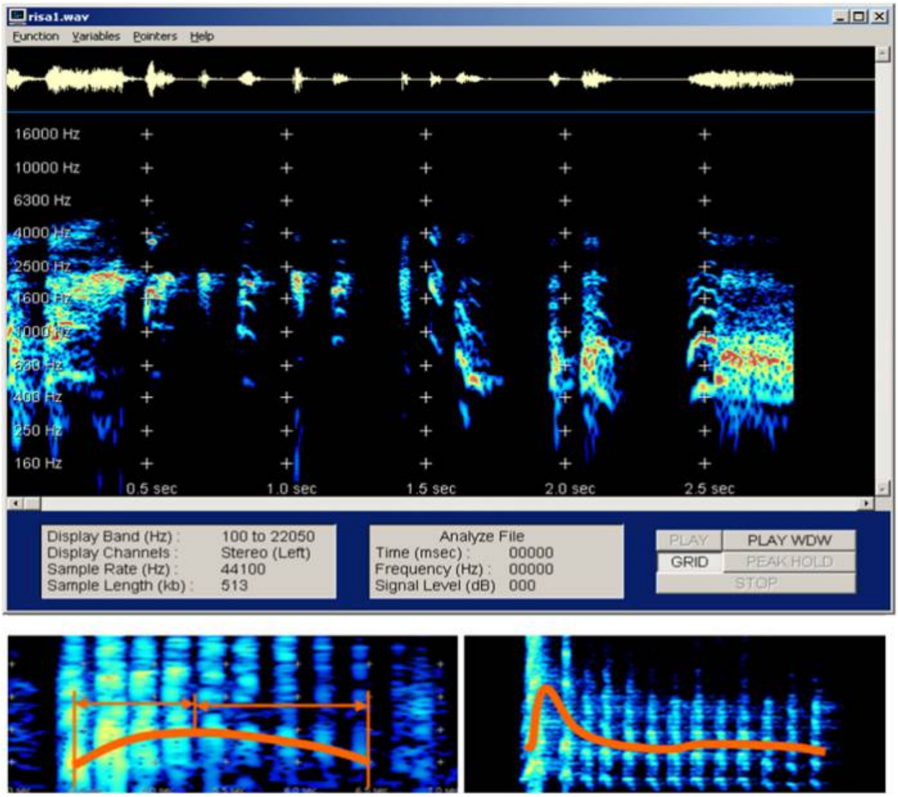


Figure 3.
Sonogram of a "well-formed" laughter recorded during the joyful play of a toddler (recorded by PCM)

Notes: In around 10-11 plosives it shows a crescendo, a plateau, and a decrease of the *Fo* values, the colours of which are graded from blue to red (from lowest to highest values); a hypothetical "arch" corresponding to the golden mean could be drawn (like in below); after this episode, a few further plosives are composing another sentic form, probably showing "excitation". Below, two sonograms are shown comprising two different sentic curves superimposed; at the left, the golden mean is appearing again; at the right, a "surprise" form is showing up, followed by a soft episode of well-formed laughter

(2) Laughter is incorporated in the neuromolecular recompenses of the linguistic virtual grooming, but augmented, as it now comprises a heavy physical massage (absent in languaging) and a new form of cognitive reward throughout its "automatic" problem-solving minimization.

(3) The behavioural consequence of both the real massage and the extra endorphin reward is that the laugh signal becomes eagerly looked upon in social interactions – mainly in those where some bonding strength or positive memory outcome is desirable.

(4) The bonds of laughter, presumably more robust as more laughter episodes accumulate upon them, will accompany the individual all along his/her life cycle: babies, toddlers, playing children, adolescent groups, courtship, parenthood, grandparents, social coalitions, small-talk partners, social sharing of food, etc.

(5) Individuals laugh abstractly: when a significant neurodynamic constellation coding for some problematic circumstance suddenly vanishes, i.e., when a relatively relevant behavioural or sensorimotor problem becomes unexpectedly channeled in a positive way and vanishes as such problem. Laughter is then spontaneously produced by the subject, always to be displayed to others, instinctively showing the own behavioural competence.

(6) The sounds of laughter "encode" the main neural processes participating in the variational energy minimization and entropy optimization of the occasion, leaving a signature of the sentic/emotional state of the individual to be projected to others.

(7) Neural entropy, which is generated in the mental flux by the sudden conceptual disorder of the occasion, and the subsequent optimizing solution found, would allow for a new organization of experience and/or new premises for the codification of thoughts – concurring thus with Bateson (1953), but emphasizing that the essential, unconscious target of laughing subjects in the reorganization of their experiences are the social bonds around.

An intriguing consequence associated to the essential bonding function of laughter is the conveyance of individual identity. That's what the bonding is about: a shared cortical memory about positive interactions between specific individuals. In the noisy environment of the talkative human groups, the cracking sound of a highly differentiated laugh may be far more recognizable at a distance than any voiced exclamations of the same individual. Besides, it is a social signal of wellness, of bonds in the making – and exhibiting a very conspicuous signature can be interesting and advantageous in group contexts of cooperation/competition and in different stages of the individual's life cycle (e.g. specificity of materno-filial attachments). Thus, in the extent to which laugh would contain emotional signs, as well as individual cues to easily identify each subject – resembling Clynes' "personal pulse"? – a tempting speculation addressed to cyberneticians and theoretical science researchers is that all of this could be done by tuning up on parameters of chaotic attractors in phase space.

Another promising research direction about social consequences of laughter concerns its potential use as an indicator of well-being and mental health (Hasan and Hasan, 2009), and as a diagnostic tool in neuropsychiatric pathologies, when the bonding capability of the individual is close to collapse (Marijuán and del Moral, 2008). An ad hoc research proposal elaborated by the authors (Marijuán, 2009) has matured into a biomedical project about laughter as a diagnostic tool in depression and other pathologies, with highly interesting results (Navarro *et al.*, 2014, 2016).

Of course, that this whole social and neurodynamic scheme becomes acceptable as a heuristic device is a highly debatable matter, even more in connection with the neural entropy and the sentic forms hypotheses. But the commonality between these two views is remarkable: the global/local entropic variable comprises the evolution of brute excitation/inhibition coupling, which is shared by the different motor expression capabilities and easily recognizable by all sensory modalities. Clynes (1979) himself wrote about laughter as "another sentic form", or as a composite of sentic forms – as we would mean here […]. Beyond these particulars of laughter, a number of illustrious voices in contemporary neuroscience could be enlisted in support of the need of new synthetic theories about human information processing, which should be capable of a meaningful connection with natural behaviour, perhaps not too distant from these argumentary lines.

Maybe another of the consequences of laughter, of its strategic placement right in the middle of human emotional-cognitive-social processes, as a safety valve of sorts, is that it shall force us to discuss on the contemporary absence of a central neurodynamic theory, so to speak dealing with the "thermodynamic workings" (Tozzi and Peters, 2016) of the whole cerebral cauldron.

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