# Possible limitations of perceptual studies for informing production networks - the case of laughter

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We welcome the commentary paper by Caruana (Caruana, 2021) and we would like to make a couple of qualifications to what is a very interesting theoretical perspective on the neural basis of laughter processing.

Within Caruana's commentary, he delineates laughter as falling into the categories of mirthful laughter and unemotional laughter. We think that this strict designation of networks and behaviours is not necessarily the case, and that this may be even less likely when laughter is perceived. As such, conversational laughter is associated with emotional experiences and expressions – Bryant has shown that conversational laughter varies in emotional tone depending on the relationships of the two people laughing together (Bryant et al., 2016). We also note that even completely faked laughter leads to an increased uptake of endorphins, and a consequent increased tolerance of painful stimuli (Dunbar et al., 2012), while shared positive expressions of emotion in a conversational context are effective ways of reducing physiological stress (Levenson et al., 1990; Yuan et al., 2010). This suggests that laughter does not need to be fully spontaneous and involuntary to have a positive emotional valence. The opposite case is also found: there are reports in the literature of laughter without positive emotion associated with neural damage. Pathological laughing and crying is seen in involuntary emotional expression disorder (IEED), where patients produce laughter and/or weeping that is not appropriate, and which are unrelated to mood (e.g. Wilson 1924). The lesions and neurodegenerative diseases associated with these disorders of emotional expression are highly variable, however, and we would suggest that this reflects how the production of laughter can interact with the emotional responses to the laughter, such that these may not be simple networks to distinguish. We suggest instead that we should refer to the two laughter types as spontaneous laughter, which processing could be processed by  “unmediated emotional mirroring”, and conversational laughter, or ‘laughspeak’, conversational laughter, or laughspeak, which is maybe experienced through “reverse motor stimulation” (Goldman & Sripada, 2005).

In our original paper we are not arguing that we can distinguish two separate systems for laughter: our results do not show that pre-SMA/anterior cingulate gyrus (ACC) controls the perception of spontaneous laughter, while the ventral premotor/motor regulate the perception of conversational laughter. Rather, we find differences in the degree that the pre-SMA was activated in response to the two laughter types. While there is a substantial amount of evidence that spontaneous and conversational laughter are produced by distinct networks, it is likely that in laughter perception these systems are overlapping. We can see that there is an interplay between the systems on a behavioural level -  involuntary, reactive vocalizations may be harder to suppress, but they are still to some degree controllable. Examples of spontaneous expressions that are able to be suppressed include pain shrieking, and the ability to reduce crying in situations where it might not be socially appropriate. Similarly, laughter has also been demonstrated to be influenced by social situations and relationships (Oveis et al., 2016). Our results show that the processing of both laughter types result in significant pre-SMA activity.

This suggests that the confluence between spontaneous and conversational emotional expressions happens in the pre-SMA, rather than exclusively associating it with spontaneous laughter, as Caruana suggests.

Recent work on descending projections by Gerbella confirms Jurgens' work that the pACC is the initiator for innate and emotional, while pre-SMA for learned/conversational (Gerbella et al., 2021). The pre-SMA receives information about the starting and stopping of speech commands from the pACC, and is involved in volitional mouth/face motor control (Errante et al., 2019; Jürgens, 2002). Croxon's cross-species comparison suggests that from monkey to human the white matter expanded from conserved limbic cortical and subcortical areas to later include higher-order functioning, in particular the pre-SMA. The authors also pointed out that higher variability exists in this network, potentially underlying differences in emotion communication and regulation (Croxson et al., 2018). The connection between the ACC to the pre-SMA that results in intentional vocalisations is evolutionarily recent. This is confirmed by work by Jürgen et al., who demonstrated that the pre-SMA produces vocalisations when stimulated in humans, but not in other mammals, and stimulating the ACC results in vocalisations for rhesus monkeys, squirrel monkeys, cats, and bats - but not humans (Jürgens, 2002).

The descending connections from the pre-SMA indicate its position as a controller of intentional vocalisations. Functional connectivity work demonstrates that the pre-SMA is most strongly connected to areas associated with language, such as the left inferior frontal gyrus, left supramarginal and angular gyri, Wernicke's area, the left mid-frontal gyrus, and the left frontal operculum(Gerbella et al., 2021; Jackson et al., 2020; Lou et al., 2017; Ruan et al., 2018). Lastly, information from the pre-SMA reaches the brainstem through the internal capsule similarly to the frontal operculum and primary motor, both regions being associated with voluntary vocalisations (Gerbella et al., 2021).

We suspect that the pre-SMA should not be considered the initiator for spontaneous laughter. Rather, we think that emotional detection might happen in ACC rather than pre-SMA for “emotional mirroring”, which has been previously demonstrated in rats(Carrillo et al., 2019). Caruana’s work on stimulating this network showed no effects on emotional response from the pre-SMA, but there was from the ACC and the frontal operculum(Caruana et al., 2016). Evidence for the pre-SMA being associated with higher-order processing rather than detection include the opioid release associated with hearing laughter in ACC, but not pre-SMA(Manninen et al., 2017).

Our theory is that this increase in pre-SMA activity for both laughter types is related to its role as a selector, as it acts as an inhibitor of a reflexive response and an initiator of an intentional response for spontaneous and volitional laughter, respectively. On a basic anatomical level, the pre-SMA is a part of the frontal region, and related to cognition, rather than the motor or pre-motor regions. The role of the pre-SMA as a selector is evidenced in primate studies, which demonstrate the pre-SMA’s involvement in preparing and initiating one action, while simultaneously inhibiting unintended actions(G. E. Alexander & Crutcher, 1990; Catani et al., 2012; Matsuzaka et al., 1992; Rizzolatti et al., 1990). Similarly, the pre-SMA has been implicated in the response-inhibition network in humans, as it both inhibits the reflexes and impulses and initiates learned behaviours (Forstmann et al., 2008; Obeso, Cho, et al., 2013; Obeso et al., 2017; Obeso, Robles, et al., 2013; Wolbers et al., 2006). Indeed, the application of TMS to the pre-SMA affects the processing of competing tendencies (Allen et al., 2018; Taylor et al., 2007).

The role of the pre-SMA as a selector is further evidenced by its functional connections. There are no known descending projections from the pre-SMA to the ACC, but there are projections from the pre-SMA to the frontal operculum, a region associated with the production of voluntary vocalisations (M. P. Alexander et al., 1990; Gerbella et al., 2021). The influence of the prefrontal cortex on the pre-SMA alludes to the integration of higher-order cognition on the production of an appropriate response to laughter within a social social situation (Johansen-Berg et al., 2004). Previous work on neural responses to spontaneous and conversational laughter demonstrate that the degree to which the pre-SMA is recruited is related to individual differences in accuracy of authenticity ratings (McGettigan et al., 2015). Similarly, the grey-matter density of the pre-SMA has been shown to predict individual differences for action selection during conflict (van Gaal et al., 2011).

We would like to thank Caruana for his kind review and the opportunity to discuss these theories further.  An important consideration when measuring the effect of laughter is that participants aren't simply hearing and decoding the sounds, but processing and reacting to them (Caruana, 2017; Caruana et al., 2020). Research aimed at detangling these processes would benefit immensely from combining the strengths of different methodologies in order to test the hypothesis of the neural correlates of processing and production of emotional vocalisations.

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