Brain Evolution Resulting from Cooking

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Synonyms

Encephalization; Thermal processing of food

Definition

Cooking as a potential explanation for the evolution of the disproportionately large human brain.

Introduction

The disproportionately big human brain is a conundrum – it is larger than would be expected for a primate of our size, and it is a very energetically expensive organ. Since human basal metabolic rate (BMR) is not elevated to match such a big brain, the extra energy needed to sustain it suggests a dietary explanation. Feeding the large brain would likely require a shift to a high-quality diet: one comprised of energy-rich, easily digestible foods. This hypothesis is supported by a number of anatomical features: smaller teeth, jaws, stomachs, and a shorter large intestine. Two key elements of human subsistence – cooking and meat eating – have been proposed as a possible means of achieving this high-quality diet.

Encephalization and Trade-Off Theories

The human line has experienced a remarkable increase in brain size during the last couple of million years: the first major expansion occurred around 2 million years ago (MYA) with the second one following around 800,000 years ago (YA), when the brain increased to its modern level. A modern human's average brain is 4.6 times larger than expected for our body mass and takes up to 20 % of our body's resting metabolic rate (RMR) in comparison to only 9 % for other primates (RMR is conceptually related to the basal metabolic rate, though BMR is more accurately measured). This substantial energetic cost to the body, however, is not accompanied by a corresponding increase in BMR to supply the extra energy, as a mature human's BMR is quite typical of primates. How, then, do humans feed the expanded energy needs of the large brain when the basal metabolic rate remains fixed?

Various theories have been proposed to explain how the expansion of such a costly brain occurred in the human lineage. Aiello and Wheeler's expensive-tissue hypothesis (Aiello and Wheeler 1995) suggests that a size reduction in the gastrointestinal tract (only 60 % of what is expected for a primate our size) energetically balances increases

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in brain size. The metabolically expensive tissue of the brain is thus offset by a smaller gut – another metabolically costly organ. Such decreased gastrointestinal tract points to diet as a major determinant, with less bulk and higher digestibility of energy-packed foods (e.g., low-fiber plants, fruits, meats) requiring relatively smaller guts. In humans, the colon is only 20 % of the total volume of the digestive tract, compared to 50 % in apes. Since big colons permit fermentation of fibrous low-quality plant foods, humans are relatively poor at utilizing uncooked plant fiber. Aiello and Wheeler propose that cooking – a way to externalize part of the digestive process – might have been an important factor in attaining such a high-quality diet. The authors' hypothesis of the gut-brain trade-off, however, is challenged by Navarrete et al. (2011), who failed to find the negative correlation between relative brain size and digestive tract for 100 mammal species.

Another theory has been proposed by Fonseca-Azevedo and Herculano-Houzel (2012), who suggest a trade-off between brain size and body size, with larger primates having smaller brains due to caloric restraints that cannot fuel both the brain and body to be large. These caloric restraints are a result of the limited number of hours available for feeding per day and the low caloric yield of raw foods. Their calculations show that, with a raw food diet similar to that of extant nonhuman primates (e.g., great apes), the *Homo* species would have to feed for more than 9 h a day to afford their total body mass and brain size (Cornélio et al. (2016) challenges these calculations, concluding that only 5–6 h of daily foraging would have provided enough energy to sustain a large brain). With this theory of the brain versus body growth trade-off, Fonseca-Azevedo and Herculano-Houzel also point to a high-quality diet as early humans' strategy to circumvent the caloric restraint, with cooking specifically as a way to provide more calories in less feeding time.

Cooking: The Human Universal

The significance of cooking for our biological evolution was not widely discussed until the twentieth century. Because fire was considered to be first controlled by Homo sapiens, the origins of cooking were placed only recently- less than 200,000 YA. The shift to a high-quality diet was thus popularly attributed to eating more animal foods. Later archeological evidence gave rise to other approaches, placing cooking as early as 1.8 MYA (around the emergence of *H. erectus*) and increasing academic interest in its role in human evolution. Wrangham's book, *Catching Fire: How Cooking Made Us Human* (2009), supports the earlier adoption of cooking (1.8 MYA) with plenty of time to allow for a larger brain.

Cooking is both a unique and universal human feature: every human culture cooks, while no other species does. The hypothesis that *Homo erectus* already cooked food by 1.8 MYA is mainly supported by the fact that specific features of *H. erectus* (small mouth, small blunt molars, and smaller gut) are difficult to explain unless a diet of soft easily digested foods was available year-round. In terms of archeological record, there is sparse evidence of fire use as far back as 1 MYA, but it is reasonable to accept its use specifically for cooking after about 800,000 YA. With these timelines we can expect cooking to produce genetic change, considering that other examples of dietary modifications causing genetic adaptations occurred in much less time – such as with dairying and lactase enzyme persistence into adulthood. Indeed, there appears to be genetic evidence for our adaptation to cooked foods (Carmody et al. 2016).

Cooked Starches, Large Brain

Cooking can increase energy gained from food by improving nutrient digestibility, reducing body's costs of digestion, and decreasing the energy spent on immune defenses (by eliminating foodborne pathogens). For humans, the most consistent evidence for cooking's ability to increase net energy gain of food is for starchy vegetables, though there is evidence for meat and nuts as well ("▶ Increased Energy/Reduced Digestion").

Starchy foods in particular could have been important in the evolution of a large brain and particularly in cooked form. The brain tissue is characterized by high glucose demands (the human brain uses up to 60 % of the body's glucose in a resting state), and a consistent diet of cooked starchy plants – the richest form of dietary glucose – can meet such demands quite well. Cooking starches gelatinizes them, allowing the digestive enzyme in our saliva (salivary amylase or AMY1) to begin digesting it. Humans are in fact unusual in the high number of AMY1 genes (six copies, in comparison to only two in other primates), which makes starch digestion more efficient. Hardy et al. (2015) propose that the rapid increase in brain size from the Middle Pleistocene (about 800,000 YA) was energetically affordable due to the coevolution of cooking and increases in expression of AMY1, as raw starches are poorly digested by this enzyme. While nonthermal methods of food processing, like grinding and blending, can also improve starch digestibility, they cannot achieve the same effectiveness as gelatinization through heat.

Coevolution of cooking and salivary amylase AMY1 would have resulted in higher availability of glucose necessary for the enlarging brain. This is important, because even when the brain uses ketones (by-products of high levels of fat oxidation) during long periods of fasting, its normal functioning still absolutely requires 30–50 g of dietary glycemic carbohydrate per day. One would have to generate large stores of glycogen during periods of sustained fasting, requiring a diet that provides a caloric surplus consistently. The energy expenditure necessary to obtain starchy tubers and roots would have been far lower than that to obtain animal foods for a reliable food source (Carmody et al. 2011).

A Case for Cooking: The Modern Raw Foodist

Some unexpected evidence for the importance of cooking comes from studies with raw food communities. "Raw foodists" are groups living in industrialized societies that avoid cooked foods for perceived health benefits. Studies consistently show insufficient energy on such diets for maintaining body weight (Carmody and Wrangham 2009; Koebnick et al. 1999). In Koebnick et al. (1999), this energy deficiency resulted in 50 % of the female respondents experiencing amenorrhea or the absence of menstruation. These outcomes are surprising, considering that modern raw foodists enjoy access to a rich variety of high-energy foods free of seasonality constraints. In addition, they process their diets quite extensively through dehydration, blending, sprouting, and pickling, which can increase the food's caloric value. Adding cold smoked meats to the raw plant diet did not improve the odds of becoming underweight, so the lack of meat does not appear to hinder reproductive function or one's energy status. The energy deficiency seen with long-term modern raw foodists, even with the addition of meat, suggests that the diet to which humans are adapted evolutionarily has to include cooked foods.

Nonthermal Processing: An Alternative Hypothesis

Cornelio and colleagues (2016) challenge the hypothesis that cooking is a prerequisite to our brain expansion: they propose that it is the use of tools that helped early hominins increase their daily energetic intake, as well as the inclusion of new food sources – meat and seeds. The author's work with mice indicated no weight gain on a cooked meat diet, suggesting that cooking was not necessary for increasing caloric intake of foods. Not including cooked starches limits the study's conclusions, however, since cooking would be applied to both meat and plants. Carmody et al. (2011) include both foods in their cooked versus raw design and find that mice on cooked meat and plants retain weight, while mice on the raw versions lose it, contrasting Cornelio and colleagues' results. Carmody et al. (2011) also challenge the tool use hypothesis by testing the effect of both cooking and non-thermal food processing methods, such as pounding. They demonstrate that with starches, mice lose weight on the raw diet whether the starchy food is whole or pounded, yet retain weight on the cooked version. With meat, mice lose weight from all versions of the diet but they lose less of it with the cooked meats, again showing higher caloric gain with thermal processing. Therefore, processing methods involving tool use do not appear to match cooking in their ability to increase the net energy value of foods.

Conclusion

According to the archeological record available so far, cooking does not appear to predate the first rapid brain expansion around 1.8 MYA. However, for the second main period of hominin brain expansion (around 800,000 YA), cooking could have been the crucial element for brain size acceleration by enhancing energy gain from raw foods.

Thermal processing would increase the energy gained from foods, providing the extra calories for an expanding brain. In addition, cooking starchy foods and evolving the extra copies of salivary amylase to efficiently digest them would supply the brain with glucose – its main source of fuel. Nonthermal food processing, such as tool use, could alternatively allow this shift to a high-quality diet. Studies with raw foodists are one challenge to this approach, as even the addition of meat and various processing methods does not improve odds of becoming underweight on an uncooked diet. Another challenge are mice studies that show higher net energy gain from cooked versions of meats and starches than those processed nonthermally. Cooking, thus, is not paralleled by other processing methods and remains an important factor in theories of encephalization.

Cross-References

▶ Increased Energy/Reduced Digestion

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