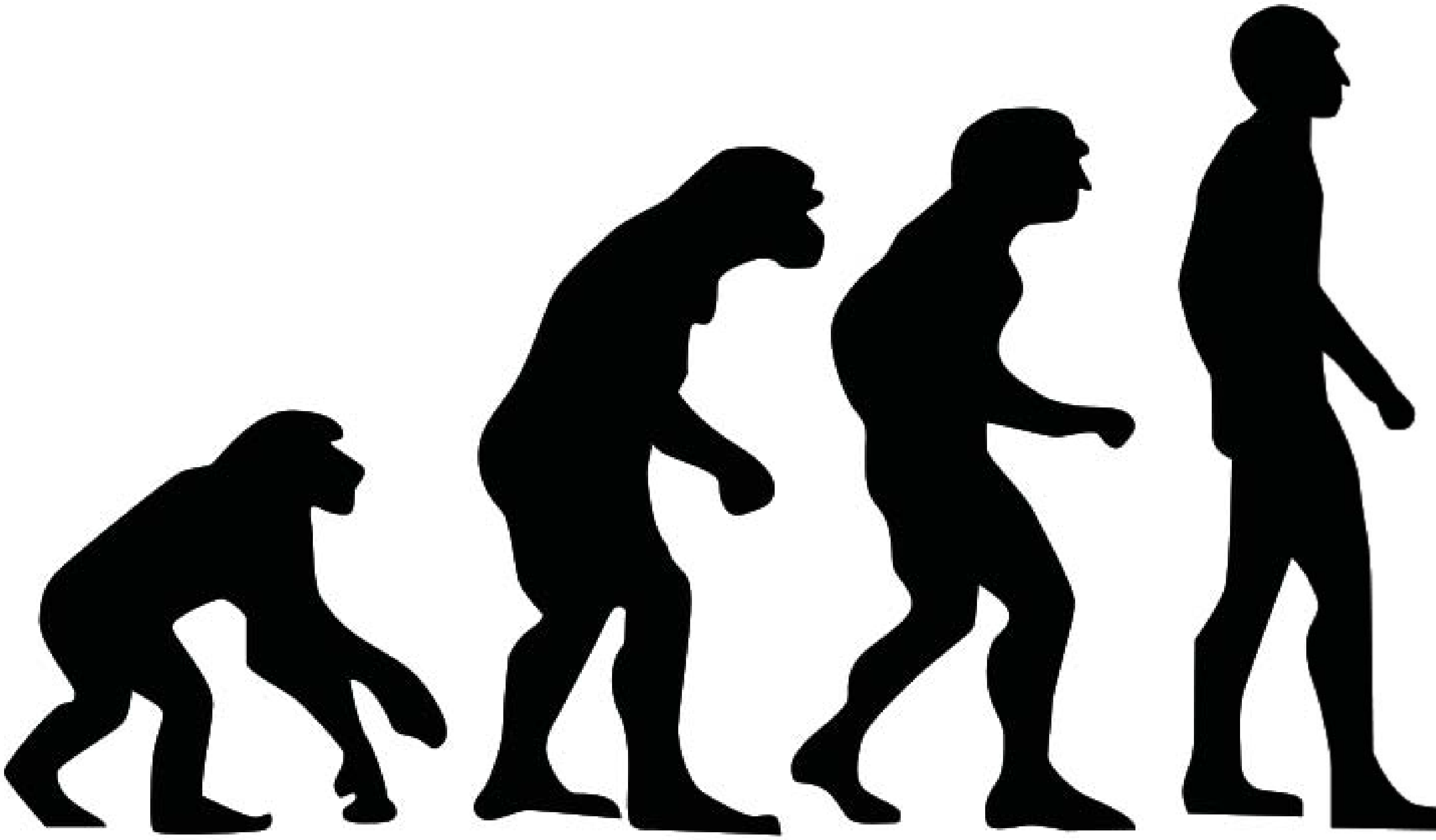
EDIBLE EVOLUTION

A Review of the Cooking Hypothesis

BY EMILY GROOPMAN



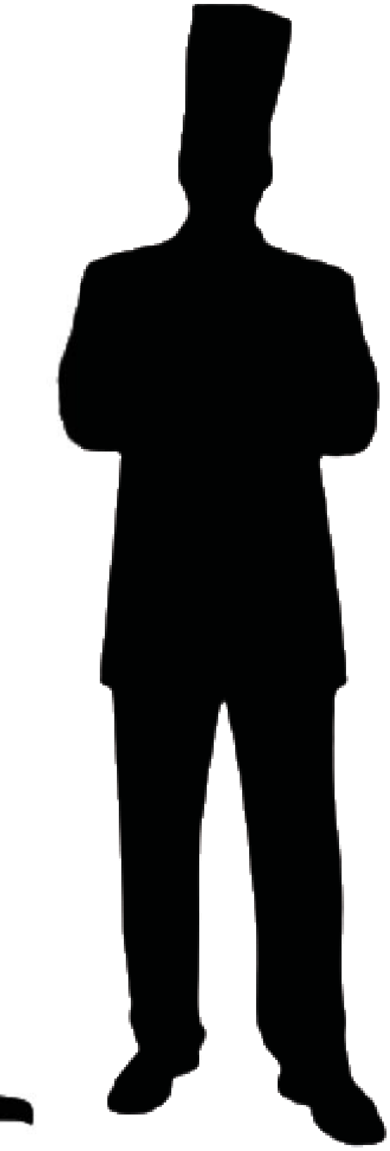
While humans have accomplished much over our race's existence, our most compelling triumphs is perhaps our ability to exist at all. Our uniquely large brains, 4.6 times the size of that predicted for a similarly-sized mammal, demand 16% of our basal metabolic rate, regardless of cognitive effort (1). This high degree of encephalization (brain: body size ratio) carries further metabolic costs. Large, complex brains require a long time to grow, resulting in extended gestation, lactation, and juvenile periods, during which a mother must provide not only for herself, but also for the hungry brain (and body) of her offspring (2). Yet, despite these costs, humans are profligate energy spenders. Inter-birth intervals tend to be short, saddling mothers with the metabolic burdens of multiple dependents; meanwhile, our high calorie needs necessitate considerable effort to be spent on obtaining food (2). So, how did our ancestors not only survive, but thrive into the populous species Homo sapiens of today? According to scientists such as Harvard University's Richard Wrangham, the answer may lie at the hearth.

The Road to the Cooking Hypothesis

Intrigued by this paradox, evolutionary biologists have long attempted to explain what could have enabled ancestral humans to prosper within the energetic unpredictability of a hunter-gatherer lifestyle. For the past 2 million years, humans have experienced an exceptional increase in cranial capacity (1; Fig. 1a). Meanwhile, female body size has grown, despite the high energetic sensitivity of ovarian function (3). Yet, we simultaneously show adaptations limiting the amount of food we can ingest. Humans possess smaller mouths, jaws, and teeth, and lack the expansive guts that allow other primates, such as the closely-related chimpanzee, to extract the maximum energy out of their diet (4). Together, these changes suggest that ancestral Homo somehow gained steady access to soft, readily absorbable, and energetically-dense foods over evolutionary time (2).

A Meaty Matter?

For over forty years, scientists have said meat accounts for this phenomenon. Unlike the undomesticated plant foods available to early humans, animal products such as fat, organ, muscle, and marrow are rich in calories, fat, and protein (1). Furthermore, stone tools and cut-marked animal bones provide ample evidence towards man's early adoption of hunting (5). However, this carnivorous approach is questionable. Obtaining animal foods has high energetic costs and fitness risks, especially given ancestral Homo's rudimentary weaponry: a chase might not only be unsuccessful, but result in serious injury or even death (6). Wild game is also very lean, resulting in the risk of "rabbit starvation," weight loss resulting from the prohibitively high digestive costs of protein-based diet (2). Left unchecked, this progressive weight loss can be fatal (4). Finally, humans' blunt molars make them inefficient consumers of all but the softest animal tissues (2). Given these considerations, the "hunting hypothesis" left many biologists unsatisfied. Citing both the above criticisms and the detrimental health consequences observed in individuals consuming a raw diet, Wrangham and colleagues claimed the "human spark" came from the flames of a campfire.



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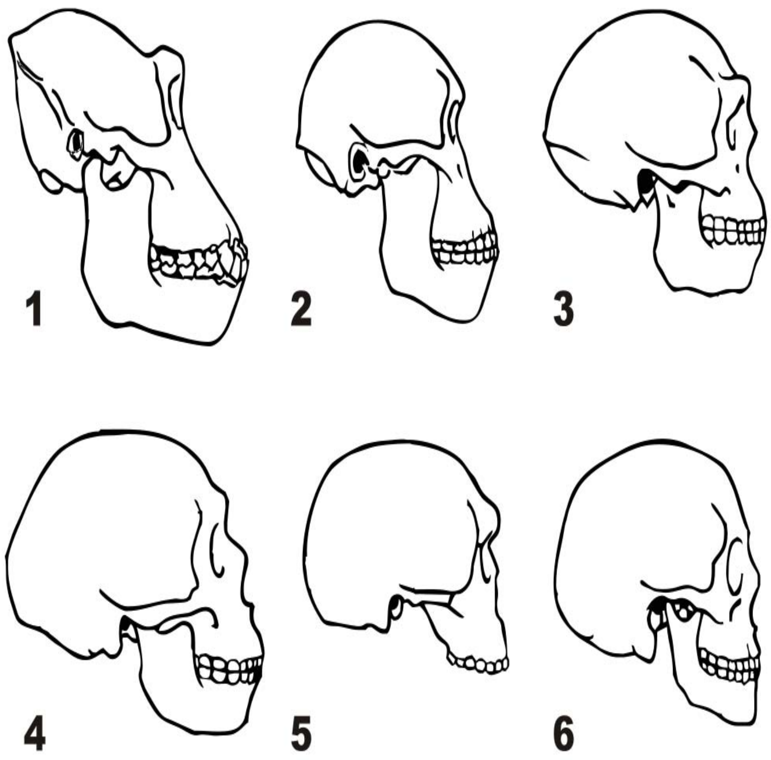

Fig. 1a: A dramatic spike in cranial capacity beginning at approximately 2 million years ago. ***Image from Wikimedia Commons.***

Something to Chew (Less) On

According to the USDA, preparation method has no effect on a food's energy content (10). These reports suggest that cooking does nothing more than remove water (4). In fact, heating breaks down food, both macro and microscopically, such that it consistently provides more calories. In plant items, heat weakens the polysaccharides (sugar polymers) that hold cells together, lessening structural integrity (7; Fig 2a). This softening reduces the chewing force needed to compress the food into an ingestible ball (2). Heat also gelatinizes intracellular starch. Plant cells contain hundreds of small sacs, or granules, each of which contains the simple sugar glucose. These granules are too minute to be disrupted by mechanical processes, such as chewing, and, if left alone, will simply pass through, unabsorbed, to the colon (4). However, if raised to a temperature of at least 90˚C (i.e. slightly below boiling), they will rupture: heat splits the hydrogen bonds holding glucose molecules together, fragmenting the polysaccharide chain. This process, known as gelatinization, exposes individual glucose molecules to the carbohydrate-digesting enzyme amylase, allowing more sugar to be absorbed (8). As a result, cooked starches are both more mechanically and chemically digestible than uncooked ones.

While the advantages of thermal processing for meat are more ambiguous, clear benefits exist. Common methods of cooking meat, such as roasting, broiling, and sautéing, result in some fat loss due to dripping (8). Since fat is the most energy-dense macronutrient, dripping causes some calorie loss. However, the fat left may be easier to absorb. The "pre-heating" of lipids to temperatures equal or higher to internal body temperature could decrease the energy normally expended in doing so (8). Additionally, heat's liquefaction of fats could increase fat molecules' surface area, making them more accessible to bile acids in the small intestine (8). This, like the gelatinization of starch, would facilitate absorption. No consensus has been reached about the net impact of the above processes.

Cooking has similarly murky effects on bioavailable protein content. Heating animal protein represents a molecular tradeoff: (muscle) proteins begin to unfold and toughen at 40˚C, but the tough, rope-like collagen fibers surrounding them only start to be broken down at 60-70˚C (8; Fig. 2b). Uncooked, collagen is too tough to chew; however, rupturing it increases the bite force needed to ingest the nearby muscle fibers. Nevertheless, cooking meat seems to have an overall positive effect on its energy density. Though unfolded, or denatured, proteins are indeed more difficult to chew, they are also more accessible to protein-cleaving enzymes, increasing energy absorption (2). Heating meat also drastically improves its smell and flavor, promoting ingestion, and thus greater calorie intake (4). Finally, cooking may lower the immune risks of meat consumption (8). Raw meat is a major source of dangerous food-borne pathogens, including E. coli, Salmonella, and Listeria. To combat these microbes, humans must engage in energetically expensive warfare, such as increasing body temperature (i.e. fever) and manufacturing cells needed to mount a counterattack. Thermal processing would prevent this costly – and potentially fatal – process. While further research is needed to fully understand the physiological consequences of these phenomena, available evidence strongly supports cooking to promote overall energy gain.

Rodent Models

Proving a hypothesis, scientific or otherwise, requires empirical investigation. Yet, until recently, no studies had attempted to quantify the biological impact of cooking. Noting this knowledge gap, Dr. Rachel Carmody, a colleague of Wrangham's, investigated the effects of both thermal (cooking) and non-thermal (pounding) processing using rodent models. In a 2011 paper, co-authored with Wrangham and Gil Weintraub (Harvard '10), Carmody evaluated net energy gain, as indicated by changes in body mass, of mice reared on raw/unpounded, raw/pounded, cooked/unpounded, or cooked/pounded diets of meat or tubers (2). Changes in body mass were directly related to the degree of dietary processing: mice fed the cooked/pounded tuber diets gained the most weight, while those reared on the raw/unpounded diets exhibited the most dramatic weight loss (2). (Mice on the meat diets all lost weight due to the high costs of protein digestion (noted in "A Meaty Matter?"); however, degree of processing again had a positive effect on energy balance (2)).

Though pounding did increase dietary energy gain, heating had a much stronger impact: mice fed raw/pounded tubers lost weight, while those on cooked/unpounded diets gained (2). These results substantiated both the hypothesized energetic advantages of cooking and the unsustainability of a raw diet. Residing in a sterile, insulated barrier facility, rodents did not have to spend calories on costly activities such as thermoregulation, immune activity, or obtaining food. Thus, the weight loss observed among raw-fed subjects would have been higher, and potentially even fatal, in natural settings – such as those inhabited by ancestral humans.

A subsequent investigation by Carmody, Wrangham, and University of Alabama biologist Steven Secor, found processing to not only increase calorie intake, but also lower the associated metabolic output. Ingesting, digesting, and absorbing food all require energy, the sum of which is termed diet-induced thermogenesis (DIT). While DIT burns fewer calories than other physical activities, such as exercise, it nevertheless consistently impacts energy balance: absorbing food energy requires expendi-

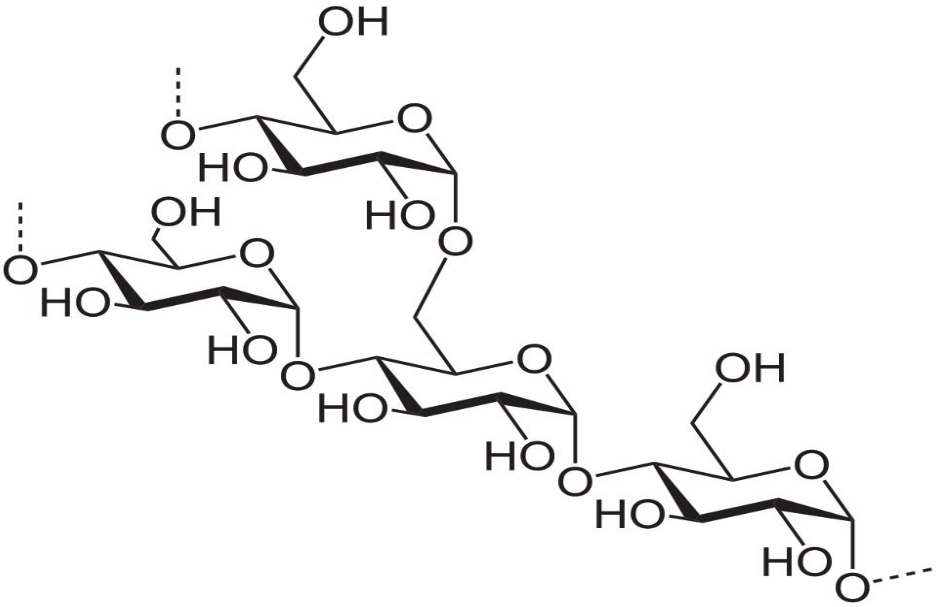

Fig 2a: Chemical structure of a starch molecule. Heat helps disrupt this ordered structure, facilitating digestion by the enzyme amylase. ***Image from Wikimedia Commons.***

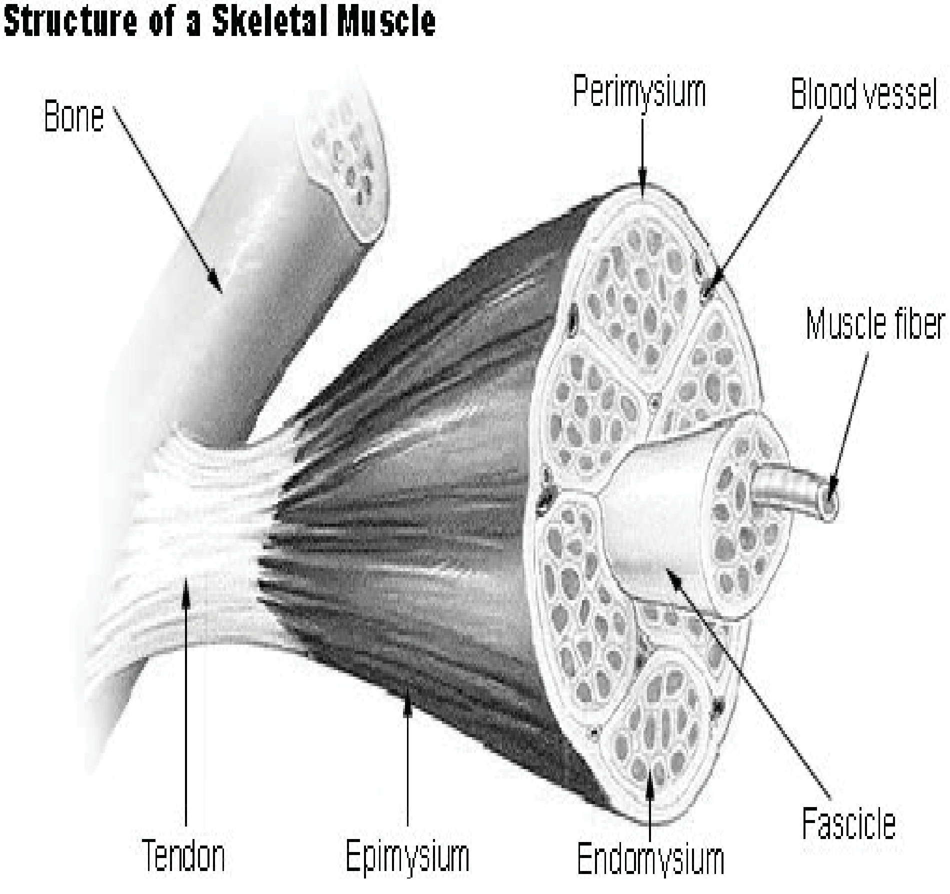

Fig 2b: Physical structure of meat. Proteins, organized into muscle fibers, are surrounded by a collagen matrix. ***Image from Wikimedia Commons.***

ture, so some loss is required for a net accrual. Over time, these small losses add up; thus, decreased DIT could result in increased energetic gains. To investigate this, Carmody, Wrangham, and Secor fed rats raw/unpounded, raw/pounded, cooked/unpounded, or cooked/pounded meat or tubers, and monitored DIT through respirometry (2). Values were then divided by the calories consumed to reflect how much of the ingested food energy was lost via DIT. Results paralleled those found in the 2011 study: rats fed cooked/pounded diets displayed the lowest DIT response, while those on the raw/unpounded regimen showed the highest values. While pounding did decrease DIT, cooking had a larger effect for both meat and tuber diets (2). Together, Carmody's studies demonstrate that processing items, especially through thermal methods, has significant physiological impact. Cooking food enables us to not only ingest more (bioavailable) calories per mouthful, but lose less of it while absorbing it. The result is an increase in net energy balance – which has biological consequences of its own.

MORE THAN CALORIES: THE NON-ENERGETIC CONSEQUENCES OF COOKING

In nature, food is synonymous with evolutionary fitness. Individuals must take in sufficient energy to survive, grow, and reproduce, making inadequate intake a threat to life itself. As a result, diet drives behavior: organisms act such that they obtain and maintain steady access to appropriate foodstuffs, shaping features such as group size, interpersonal relationships, and activity patterns (4). According to Wrangham and colleagues, these biological truths caused food processing to not only impact ancestral anatomy, but also shape social interactions (11). As shown by observations of the non-human great apes, chimpanzees, bonobos, gorillas, and orangutans, the low energy density and high digestive effort of a raw food diet require over eight hours for feeding, chewing, and digesting (4). Given that most hunter-gatherers spend at least eight hours sleeping, this would result in individuals spending at least half of their (sixteen) waking hours on these activities, leaving little room for anything other than repeated eating and resting (4). Cooking drastically reduces the required amount of food and the effort needed to ingest it: cross-culturally, modern humans spend no more than thirteen percent of the day chewing their food (4). Freed from these burdens, our ancestors could have pursued other activities.

In "The Raw and the Stolen," Wrangham and colleagues suggest that these changes could have created our modern social system. Female fertility is exceptionally sensitive to energy balance: inadequate intake and/or excessive activity cause ovulatory failure (3). Thus, women tend to gather more available plant foods, rather than incurring the high caloric costs of hunting (8). The advent of cooking not only increased the value of these everyday staples, but also encouraged theft: ancestral culinary methods, such as roasting, demanded a lengthy stay at a glowing fire, making a cook easily visible. To protect themselves and their vital food resources from scroungers, women were forced to enter domestic partnerships with physically dominant individuals – in other words, males (11). While females gained a certain degree of security, males received the bulk of the benefits: guaranteed a steady supply of cooked, energy-rich (plant) items, they could freely engage in physically costly activities, whether chasing game or competing for dominance (8). The net energetic gains of this system increased its participants' reproductive success, resulting in the cross-cultural patterns of sexually-divided labor we see today (8). Though more archaeological evidence is needed to evaluate Wrangham and colleagues' claims, the hypothesis is nonetheless viable – and provides a compelling explanation for the gender norms that persist today.

BUT CAN IT TAKE THE HEAT?

Despite this evidence, the Cooking Hypothesis remains controversial. Having empirically demonstrated the energetic benefits of cooking in the present, biologists now face the challenge of proving the significance of these gains in the evolutionary past. The observed increase in high-energy features, such as cranial capacity and female body size, and simultaneous decrease in digestive capacity is dated at approximately 2 million years ago (mya); however, the earliest accepted evidence for controlled fire, at Wonderwerk Cave, South Africa, is only 1 mya (9; Fig 3). This presents a problem: if the "jump" to our modern physiology was fueled by a food-filled hearth, then why do the consequences precede the cause? While some supporters of the Cooking Hypothesis note that fire leaves few lasting traces as a potential explanation for this discrepancy, and others suggest that the earliest gains may have resulted from non-thermal processing (e.g., pounding), this issue remains unresolved (2). Future archaeological inquiry will hopefully offer a more thorough understanding of the role of cooking, as well as other modes of food processing, in human evolution.

FUTURE DIRECTIONS

Though cooking has been traditionally studied as a cultural phenomenon, it is and will likely continue to be examined for its biological relevance. Thermal food processing both increases bioavailable energy intake

Fig. 3: Wonderwerk Cave, South Africa, the earliest recorded site of the control of fire. ***Image from Wikimedia Commons.***

and lowers the costs of food consumption, resulting in significant positive effect on overall energy balance. Given the centrality of energy to life, it is clear that the effects of cooking extend far beyond the kitchen. As the Cooking Hypothesis proposes, thermal food processing spawned many features we consider uniquely ours. The energetic gains from heating items enabled our ancestors to acquire costly features, such as larger brains, longer childhoods, and more rapid reproductive rates, while simultaneously losing structures needed to survive on a less calorie-dense diet. The result was modern human morphology. However, the combination of fire and food not only altered anatomy, but also shaped behavior. Steady access to energy-rich items liberated Homo from a perpetual cycle of eating and resting, allowing him to engage in other pursuits. It may have even birthed our modern social pattern: the vulnerability of female cooks to male scavengers could have spurred them to form exclusive alliances for protection, resulting in an enduring system of monogamous pair bonds. But the Hypothesis, and its associated findings, is not only relevant to the past. A deeper understanding of the consequences of food processing, both physiological and societal, enables us to solve the problems that plague us today. Whether attempting to remedy imbalances of energy, such as obesity, or of gender, such as current gendered labor divisions, knowing their history offers us the opportunity to transform the present. Cooking may help us not only comprehend our origins, but improve our future.

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