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# Mechanical tasting: sensory science and the flavorization of food production

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## 1. Texturometers: introduction

The indisputable star of this story is the *Strain Gage Denture Tenderometer*, an instrument for food texture experiments constructed at MIT in the 1950s. The basic machinery was developed by the engineers B.E. Proctor, S. Davidson, G.J. Malecki and M. Welch, but the making of the tenderometer into an elaborate instrument for food experiments was essentially the work of the doctoral student Aaron L. Brody who finished his dissertation in 1957. Brody described the machine as a replica of human physiology, a mediator of knowledge of how humans experience food texture supposedly of great significance for food producers. The design of the instrument was eye-catching. The Strain Gage Denture Tenderometer was a sophisticated construction with metal frameworks, electrical wiring, sensors and interfaces. The centerpiece of the instrument was a "jaw" of acrylic teeth mounted on a pre-fabricated dental articulator (an odontological device for the fabrication of dentures). A plastic inset simulating cheeks, tongue and lips was placed at the mandible to hold food samples in place. The articulator was attached to electronic strain gauges connected to a cathode-ray oscilloscope displayed by a camera. To use the machine the food scientist placed a piece of food – Brody's experiments included materials such as cheese, beef, candy and jelly – in the denture and turned on the electric motor. The instrument would then chew the material and the gauges would provide the oscilloscope with signals, causing it to display points registered by the photographic film in the camera. Developed, the film would show a curve indicating the combination of strain and time needed to bite through the food. Hence, different foods were given signatures, called "bite curves", displaying their tenderness (Brody 1957, 25–56; Schultz 1957, 20).

[Fig. 1. The masticating mechanism of the Strain Gage Denture Tenderometer.  
Source: Brody 1957, 31.]

The Strain Gage Denture Tenderometer was not the first of its kind. In the literature of texturometry, the German so-called Lehmann Dexometer, presented in 1907, is often referred to as the first "biting" tool (Szczesniak and Torgeson 1976, 86–87). The main inspiration for Brody and the team at MIT, however, was a device constructed by the German food scientist N.N. Volodkevich at the University of Karlsruhe's Institute of Refrigeration in the 1930s, an instrument called "The apparatus for measurement of chewing resistance or tenderness of foodstuffs". Crucial in the design was the attempt to make the machine work according to the functions of the human jaw. The chewing part itself was constructed by using two wedges with rounded edges, a design chosen after experimenting with artificial teeth provided by a dentist. Movement of the machine was propelled by human force through a handle. In action, the apparatus squeezed different foodstuffs (meat in the cited experiments) between the wedges whereas the "tenderness" – technically defined as the relation of penetration in millimeter and

pressure in kilograms – was recorded as curves by a pencil on a piece of paper (Volodkevich 1938).

[Fig. 2. Volodkevich's machine. The "jaw" is placed on the left side, below "T". Artificial teeth were used in early experiments, but here mastication is performed by metal wedges. Source: Volodkevich 1938, 222.]

By following the traces of Volodkevich's apparatus we find other attempts to build replicas of the human jaw for food experiments, a technoscientific venture I here refer to as "mechanical tasting". An instrument important in this context is the *General Foods Texturometer* constructed by the MIT engineer Alina Szczesniak in the early 1960s. Szczesniak modelled the "texturometer" (I will use this term for all instruments of this paper) on Brody's. It also used a dental articulator, but the eye-catching denture was replaced by a plunger pushing against a platform, instead of an oscilloscope a strip chart recorder was used, and it did not perform a sideways masticatory movement like its MIT predecessor did. Testing of different materials was facilitated by a set of replaceable plunges of various sizes and shapes. An important novelty of the General Foods Texturometer was that it performed two biting sequences, a function assumed to give more compound and realistic data on food texture (Szczesniak 1973, 88; Szczesniak and Torgeson 1976, 93; Herring 1976, 17).

[Fig. 3. The General Foods Texturometer. The strain sensors are attached to the plate, not on the moving upper part of the instrument, a technical adjustment that counteracted the impact of gravity. Source: Szczesniak 1973, 89.]

How shall we interpret these instruments? For what reasons was it important to make machines that simulated bodily functions of humans? What historical insights can laboratory devices for measurements of food texture provide us with? As the paper argues, a story of texturometers is also a story of food industries of the twentieth century, their increasing interest in the sensory qualities of the goods produced, and their interest in "hard" knowledge of flavors. By studying these instruments, in terms of design, usage, outcomes and applications, I argue that we may discern crucial linkages between the industrialization of food in the twentieth century, the cultures and behaviors of consumers, and the expansion of sciences of the senses of that era. The paper is structured as follows: In *section 2*, I attempt to place the developments of mechanical texturometry in the broader context of food production through the concept of flavorization; a course of change characterized by a growing interest of the sensory qualities of food. The section suggests that the instruments indicate the emergence of a "sensory-industrial complex". *Section 3*, discusses the different techniques in sensory science and the different ways in which they are supposed to mediate sensory experiences scientifically. Machines like the Strain Gage Denture Tenderometer belong to an experimental mode of sensory science I refer to as biomimetics. *Section 4* relates this biomimicry to the concept of objectivity and a core argument is that the designs of the instruments reflect an extreme form of objectivity, here referred to as mechanized objectivity. *Section 5* moves that discussion into the types of data produced by the texturometers and shows how it responded to ideas and demands of standardized definitions of texture qualities such as "toughness", "cohesiveness" and "crisp", and how the machines was utilized to produce a systematic terminology for texture properties.

*Section 6* gives some concluding remarks on the scientific and social significances of the instruments.

## **2. The complex of senses, science and production**

As an overall concept to capture the technoscientific context in which the texturometers were constructed, I suggest "flavorization". Its meaning is straightforward; flavorization refers to the processes through which flavor qualities of foods became more important for producers and consumers, processes essential for illuminating why sensory sciences developed so rapidly in twentieth century. From the perspective of food producers, and from the flavor scientists' point of view, it was common to interpret this as a shift in consumer cultures – a refinement of "taste" and a higher level of consciousness concerning flavor. The American flavor chemists Ernest C. Crocker and Washing Platt, pioneers in the field of food sensory sciences, commented on this change in their review of food flavor research of 1937 and drew a parallel to a rising level of knowledge: "Again, the public takes it for granted that variety should come in flavor. This is perhaps not so much because the public is fickle as that it is becoming educated, and with education comes appreciation and demand for more and better things." (Crocker and Platt 1937, 184)

As a salient phenomenon in the raise of mass consumption, the process of flavorization resided in a broader pattern of industrialization and sociocultural change through which sensory impression of commerce multiplied – think for instance of the sounds and moving pictures of movie theaters, the synthetic soundscapes of electronic music, the superurban visions of neon lights, and the kinesthetic sensation of playing with Slime and Play-Doh. This sensorial boost is a manifest phenomenon in the wake of the second wave of industrialization historians of industry and economy have started to gain interest in. The synthetic dye industries of the second industrial breakthrough of the late nineteenth and early twentieth centuries, for instance, provide an illustrative example by their production of a range of bright and inexpensive colors on textiles and other consumer goods; a part of a "color revolution" (Blaszcsyk 2012) in industrial societies. Food and food industries obviously played key parts in this sensory expansion in business and consumption and flavor management and "sensory design" (Petrick 2010) in food industries from the late nineteenth century and onward has been documented in a range of historical studies, showing for instance how crispness of lettuce (see Petrick 2006), tenderness of meat (see Horowitz 2006), butter aroma and taste, and the colors of fruit (see Hisano 2016) became key aspects of product development. "Flavorization", I hope, may provide a conceptual frame for this course of change.

In describing the increasing commercial attention to pleasure and experiences in the twentieth century and the role of sensory sciences therein, Steven Shapin talks about the emergence of an "aesthetic-industrial complex" (Shapin 2011a, 179). Using an alternative term – highlighting the same overall phenomenon but pinpointing perhaps more directly the modes of experimentation in sensory science – one can also think of a "*sensory-industrial complex*" of interlinkages between business operations and the

human senses. From this analytical standpoint, all methods and instruments of sensory science fulfil, at least ostensibly, share a common function: all of them aim to connect human senses with commercial activities. Or put differently: the ultimate purpose of those laboratory techniques was to master the human senses for commercial profits. By studying them closely, I believe we can gain a better understanding of the historical connections of sensory sciences and the dramatic economic, social and cultural changes taking place after the second wave of industrialization.

### **3. Sensory science: calibration, supplementation, imitation**

Sensory science, alternatively called "sensory analysis" or "sensory evaluation", can be defined as a cohort of methods and technologies for measurement of how humans respond to food and other types products with important sensory implications (see e.g. Lawless and Heymann 2010, 1). For clarity, there are good reasons to use "flavor" instead of "taste" in this context. In modern scientific framing, flavor refers to the complex of sensory reactions caused in the meeting of the senses and the physical and chemical properties of food and drink. In a 1960s article on flavor research, Lewis J. Minor, American flavor scientist and businessman, defined flavor as the three-tiered property of taste, odor, and kinesthetic factors including texture and qualities mediated by eyesight, touch, and of hearing (Minor 1966, 70). Food sensory research, due to this complexity of flavor, is therefore an example of a "synscientific" (see Root-Bernstein 1996) project; it does, and must, involve techniques and methods that capture the full range of sensoric stimuli and even account for the ways in which the consumer evaluate and think of the food.

Considering the close connection of sensory science to the every-day practice of eating, not to mention the impact on industrial food commodities, it is somewhat surprising that the field has received quite limited attention from historians of science and technology. Most previous work has been done by renowned sensory scientists that have given fruitful accounts on the origins of their field (e.g. Pangborn 1964; Peryam 1990; Schutz 1998; Bourne 2002, 26–30; Meiselman and Schutz 2003; Roudot 2004; Lawless and Heymann 2010, 4–10). In recent years, however, an expanding group of scholars has started to examine the histories of sensory science and produced a number of original and systematical texts on the matter (e.g. Howes 2015; Shapin 2016; Phillips 2016; Berenstein forthcoming). Nevertheless, and particularly outside of the American context, there are still significant lacunas in the history of sensory sciences. A likely explanation for this lack of historical work on sensory science is found in its amorphous character; historically, sensory science emerged out of several contexts and is characterized by the adoption of methods and procedures from other areas and disciplines, making it a highly diversified and "hybrid" technoscientific field. Important for understanding the establishment of food sensory science, hence, is to look at it not so much as a distinguished field or discipline but rather as a cohort of technical and scientific practices centered around sensory aspects in food production.

Thus, a history of food sensory sciences should depart in industrial rather than scientific contexts. As a proto-scientific practice, organoleptic evaluation emerged in

trades where it became important with more calibrated practices for evaluating food products. Familiar examples would be "tasters" of coffee, tea, wine, and dairy products such as cheese and butter. Experts of this kind became important in the nineteenth century as the distance between producer and consumer increased and the level of trust and tacit understanding decreased (Cohen 2011). The rise of industrial food production in late nineteenth and early twentieth century meant that those taste experts were challenged by an emerging mode of sensory assessment, based not so much on social or professional authority but on methodology and instrumentation. Characteristic of this new venture was the emphasis on elaborate tasting procedures; whereas older practices put trust in personal expertise, modern sensory evaluation produced trust by rigorous methodology and instruments (see Berenstein forthcoming, chap. 3). Importantly, it is difficult to point to any specific origin of these practices; development of controlled sensory evaluation and analysis was incremental and seemingly spontaneous, starting as local practices in laboratories of food producers (see Owens 2004). Sensory evaluation somewhat distinct field surfaced in the 1930s, particularly in the U.S. with Crocker and Platt as leading personalities. The key role played by chemist does however not mean that other scientific areas were insignificant. On the contrary; characteristic also of the 1930s was the articulated effort of bringing together practices from varying contexts into one somewhat well-defined field. In a 1937 special issue of *Food Research* devoted to flavor, papers came from areas as home economy, agriculture and chemistry.

I suggest that the practices of sensory science can be divided into three main categories, based on how modes of experimentation relate to the human senses: *calibration*, *enhancement*, and *imitation*. In a first category of *calibration* is the range of techniques referred to within sensory science as "organoleptic" – basically tasting, analyzing and judging purely through the human senses. Calibration implies the pursuit of stable knowledge and quantitative data by placing the human sensory subject in a highly controlled environment, essentially turning her or him into a biological laboratory instrument. This is no doubt the dominant mode of sensory science carried out through a plethora of techniques. The second category of *enhancement* is defined by the use of technical instruments that supposedly give more exact results. A key type of technique for supplementation is chemical tests, notably gas chromatography but also devices for measurement of taste qualities as salinity, sweetness or acidity. Instruments as Brody's and the other texturometers of this paper belong, I suggest, to a category of sensory *imitation*. In this category, we can also place advanced machinery such as electronic noses. Those techniques are, in other words, "biomimetic" devices designed to imitate substantial mechanisms of human physiology. From the historians point of view, looking at sensory sciences as a larger historical endeavor of the twentieth century, the interdependency of these different experimental traditions shows clearly. When organoleptic methods have failed to produce stable results, mechanical devices or chemical tests have been brought in. And vice versa; when those modes of evaluation and experimentation have dominated, they have been criticized for not detecting the true stuff, and thus organoleptic testing has been introduced. Hence, in flavor research, there is a constant circulation of sensory calibration, enhancement and biomimicry as modes of experimentation. Devices like texturometers were for instance always used together with organoleptic tests, and it was a shared assumption of texture analysts working with mechanical methods that without human sensory impressions, purely

mechanical testing would be empty of meaning – as Szczesniak (1973, 71–72) pointed out: "in the true sense, none of the instrumental devices measures texture per se, only physical properties which can be related (directly or indirectly) to textural attributes sensed organoleptically."

The texturometers of this study stand out in the field of sensory sciences due to the explicit ideas of mimicking human physiology to gain knowledge of sensory reaction on food qualities. In an article of 1976 on meat tenderness, co-authored with her colleague Kathryn W. Torgeson, Szczesniak noted that they witnessed a new phase in the evolution of instruments for food texture measurement. These new instruments, to which the General Foods Texturometer obviously belonged, were distinguished by "a detailed study of the physical, chemical, histological, and sensory characteristics of meat" (Szczesniak and Torgeson 1976, 34). Actually, this drift toward a more complex understanding had a linguistic side similar to the concept of flavor; by using "texture" instead of the previously more common concept of "tenderness", Szczesniak and Torgeson made a deliberate point: "Since the structural properties of food cannot be separated from its eating quality, it is preferable [...] to use the more inclusive term 'texture' in discussing the general class of characteristics" (Szczesniak and Torgeson 1976, 35). This notion of more immense knowledge of human sensory functions was essential for the instruments described in this paper. Biomimicry was thought to render more comprehensive measurement of texture. Volodkevich, for instance, emphasized that his machine imitated "real" tasting: "We suppose that the values obtained in this way may reproduce the real chewing resistance of foodstuffs and may serve as a measure of their tenderness" (Volodkevich 1938, 221). Brody underscored imitation in his work on the Strain Gage Denture Tenderometer:

It is now apparent that existing instruments use the simple mechanical operations of Shearing, crushing, puncturing, or cutting. These single operations are very different from the complex operations, which occur in the human mouth during the chewing process and therefore, accurate objective measures could not be expected. An instrument which can duplicate actual conditions of mastication would yield highly meaningful data. (Brody 1957, 19)

Indicative of how important human physiology was for the Strain Gage Denture Tenderometer was the knowledge on human mastication gathered from odontology in the construction process. Proctor, Davidson, Malecki and Brody used data from studies conducted at the dental school of Tufts University in which a gnathodynamometer was used to record the biting force on a series of individuals. That data paired with studies of how the jaw moved when chewing gave the MIT team knowledge of average human mastication that could be replicated mechanically by their instrument (Brody 1957, 21–25).

#### 4. Mechanized objectivity and performance

Experiments with biomimetic texturometers may seem distant to the organoleptic modes of flavor analysis where human panels are employed for testing food. Direct sensory perception on the one hand, techniques seemingly close to material science and instruments as the Brinell Test for hardness of materials on the other. A closer look on the historical development of sensory science, however, will show that a mechanical device like the Strain Gage Denture Tenderometer has much in common with conventional organoleptic sensory analysis of food. The concepts of subjectivity and objectivity play a salient part here. The field of sensory science is characterized by continuous struggles of the meanings of objectivity and subjectivity. In Brody's dissertation for instance, all methods for food quality measurement based on human senses were labelled "subjective" in contrast to "objective" measurement using chemical tests or mechanical devices as tenderometers and "maturometers" (Brody 1957, 3–18). The organoleptic tradition is however, as previous historical studies show, marked by a tendency to draw the boundary between objective and subjective between controlled organoleptic analysis and consumer preference tests on the other (see Phillips 2016, 463). Thus, the attempts within sensory sciences to distinguish between "objective" and "subjective" methodology should in most cases be understood rather from a sociological point of view than epistemological; they represent subfields equipped with different tools for gaining credibility and producing knowledge packaged as hard and stable – but essentially they are chasing the same epistemic enigma: the elusive quality of flavor. In sensory science subjectivity has not been "noise" or bias; it has been the key object.

Furthermore, in a longer historical perspective on sciences of the senses, we have reasons to challenge the late modern understanding of the subjective/objective polarity. Instrumental for the emerging modern devaluation of the human senses as sources of true knowledge is the philosophical bifurcation of primary and secondary qualities, made famous not least by John Locke's philosophy in which he used the taste of a pineapple as an example of an entity impossible to grasp empirically without its actual meaning dissolves in endless meaningless descriptions (see e.g. Silver 2008; Shapin 2011b, 24–30). The long-term consequences of this split of knowledge are as obvious as substantial; on the one hand "hard" and highly valued knowledge preferably mediated by non-human instruments – on the other hand "soft" elusive knowledge filtered through human perception. In its most extreme form the virtues surrounding hard primary knowledge have resulted in what previous studies have coined "mechanical objectivity" (Porter 1995, 4–5; Daston and Galison 2007, 121ff). The term is illustrative for sensory science by pinpointing the epistemic interrelatedness of organoleptic vis-à-vis "physical" and "chemical" methods. The organoleptical tradition is characterized by the removal of human irregularity by rigorous training, strict routinization, and control of the body, and by the application of supportive sensory enhancement such as gas chromatography. To use the analogy of Christopher J. Phillips' (2016) study of sensory analysis in wine making, the ultimate goal was to turn humans into a "taste machine". A key to my argument here, put forth also by Bruno Latour (2004), is that sensory sciences operate in an epistemic realm where the distinctions of primary and secondary qualities are blurred. But there are still reasons to distinguish the constructions and uses of biomimetic instruments from organoleptic practices. The constructions of instruments

like the Strain Gage Tenderometer and Szczesniak's texturometer reflect a notion that truly objective knowledge of texture can be obtained by building replicas. This preference for machines as mediators of knowledge implies something more than just mechanical objectivity; it carries a vision of extra-human knowledge gathering. Thus, as a historical phenomenon, the inventions of the texturometers reflect a process of epistemic mechanization. I suggest we call this *mechanized objectivity* and its ethos was substantiated in Brody's thesis: "The most significant conclusion which may be drawn from this paper is that techniques have been developed for the Strain Gage Denture Tenderometer which have converted this apparatus into a fine instrument for the objective measurement of some previously intangible and unmeasurable subjective masticatory properties of foods" (Brody 1957, 249).

There is one important question concerning mechanized objectivity and the biomimetic texturometers – Brody's instrument specifically – which needs further discussion here: why the teeth? The greyscale images presented here does not show it, but the denture was in fact highly realistic and equipped with clear white teeth and pink gums. As a consequence of the eye-catching looks of the apparatus, Brody's experiments actually reached the realm of popular culture. In 1956, the Strain Gage Denture Tenderometer was featured in an issue of *Life Magazine* (October 29, 1956), presented in pictures showing the instrument chewing a piece of mozzarella cheese. Its appearance was commented with fascination in the magazine: "Baring its fangs like a starved wolf, the fearsome-looking robot at left is about to do its job as a precision-testing apparatus."

[Fig. 4. The Strain Gage Denture Tenderometer ready to bite into a sample of mozzarella cheese. Source: *Life Magazine*, October 29, 1956.

I believe this act of show-off reflects more than exhibitionism and a sense of humor. In fact, the spectacular design can be related to an important element in science; that of demonstration as a means for experiments to gain relevance and legitimacy. For the Strain Gage Denture Tenderometer, the element of demonstration worked in two main ways. One is rather obvious; by designing the instrument in a bizarre fashion it gained a buzz and placed Brody, at least momentarily, in the public limelight. More important, at least in the context of this paper, is the claim for epistemic legitimacy embedded in the biomimetic construction of the tool. As an alleged hybrid of biological and mechanical sensory capabilities it bridged, symbolically, the gap between primary and secondary qualities and gave an illusion of epistemic truthfulness. Similar examples of this performative objectivity are found among other instruments constructed in the field of sensory science, notably early prototypes of electronic noses: Robert W. Moncrieff's (1961) "Instrument for measuring and classifying odors" which was designed with a "nose", "lungs", and a "brain" – and Krishna Persaud's and George Dodd's (1982) more successful "Model nose" that explicitly imitated the mammalian olfactory system. Although Volodkevich apparatus and the General Foods Texturometer did not share the apparent biomimicry of Brody's and Proctor's machine, their technical designs were just as clearly influenced by an idea of obtaining true knowledge on texture by imitation of human sensory capacities.

## 5. Standardization of methods and properties

Design was not only about purely scientific matters; the constructions of the texturometers also give clear examples of how they were configured to close connections of business and senses. This section deals with standardization of texture characteristics, but before that I should bring up another, perhaps less exciting but crucial, pair of functions of the instruments: saving money and time for scientists and their patrons. One important task of the texturometers was simply to satisfy a need of becoming less dependent on the time consuming and expensive practice of organoleptic evaluation. It was about automation of sensory control. Automation in industry and agriculture was important in this context as mechanic devices that replace tactile assessment and other forms of sensory control of food products could give substantial benefits in terms of labor costs. In Brody's dissertation, this trace from production to sensory science shows clearly and he mentioned a plethora of such tools: "succulometers" for corn kernels, "fibrometers" for asparagus, the Warner-Bratzler Shear for meat, the Baker Compressimeter for bread, the Shortometer for cookies and crackers, the Bloom Gelometer for gelatinous products such as jam, and the Canco Tenderometer for peas (Brody 1957, 6–18). An additional benefit with the biomimetic texturometers was their wide area of application. Brody, for instance, argued that the Strain Gage Denture Tenderometer could be applied to a range of materials that previously had to be evaluated with different tools designated for one single product (Brody 1957, 257–258). Szczesniak made a similar observation when she looked back on the development of texture studies in a 2002 article; a problem with early instruments was that they were commodity oriented and had very limited interaction with each other (Szczesniak 2002, 215). Hence, instruments that could deal with a wide range of materials and products satisfied an important economic need.

The biomimetic texturometers had another perhaps more profound purpose as they, according to their inventors, rendered more standardized results than human subjects. This sensory standardization is related to automation, but highlights more directly the epistemic aspects and how the instruments were constructed to mediate flavor mechanically. Volodkevich substantiated the function of his machine by underscoring the complicated and elusive nature of tenderness: "The conception of tenderness is highly complicated since it includes physical, chemical, and physiological elements. It is not possible at present to express tenderness as clearly and simply as, for example, viscosity is determined in physics" (Volodkevich 1938, 224–225). Brody emphasized how his instrument could produce standardized knowledge on texture by replicate human mastication: "The Strain Gage Denture Tenderometer has thereby simulated the human system for commercial purposes by averaging the human masticating mechanism, standardizing its nervous system, and then applying a many-brain interpretation to the data obtained" (Brody 1957, 119). These ambitions implied in the construction of texturometers show clearly in the type of data generated by the machines. A key function of Volodkevich's apparatus was the recording part using a pencil pointed at a piece of paper. When put in motion, the instrument made the pencil move in different directions depending on the pressure needed to pierce the food sample. The data, thus, was a curve meant to give the specific signature of the foodstuff in question. In the published experiment, the data from four runs on boiled meat were

presented. The upper curves in fig. 5 show tests on beef, the lower tests on veal. The most valuable information of those curves is the peak indicating under what pressure the wedges penetrated the tissue of the meat.

[Fig. 5. Source: Volodkevich 1938, 224.]

According to Volodkevich, the experiments thus gave instrumental knowledge on tenderness and explained why veal is tenderer than beef, a common observation about meat Volodkevich first confirmed by organoleptic tests, then analyzed with his apparatus. He concluded that the feeling of tenderness in veal is caused by the absence of strong fibers that remains intact after the meat has been compressed:

The structure of meat consists of fibers of different resistance. In the beginning all the fibers resist, but having reached a squeezing force of 11 kg., the more tender fibers are torn one by one. The second increase of the curves may be due then to resistance of the stronger fibers. One can imagine that the remainder of stronger, tougher, unbroken fibers being chewed considerably influences the subjective judgment of tenderness. [...] Veal and beef were boiled; both types of meat were found to be tender by subjective tests, but in any case the impression was gained that beef was not so tender as veal. Probably this impression may be principally due to the remainder of stronger fibers which the upper five curves show. (Volodkevich 224–225)

These results by Volodkevich's instrument must have impressed the team at MIT. In his PhD thesis, Brody (1957, 21) claimed that the German instrument "laid the foundation" for the construction of the Strain Gage Denture Tenderometer. The novelty of the MIT instrument was about systematically engineered biomimicry. Instead of only biting the food sample, the new instrument performed a circular jaw movement displayed by oscillograms. The benefit of that mechanism was, allegedly, more realistic and comprehensive graphical data.

[Fig. 6. Data produced by the Strain gage denture tenderometer. The curves should be interpreted thusly: The machine chewed clockwise, and a free run would give an almost flat curve. When the teeth touched a food sample its resistance was measured by the strain sensors, generating an upward curve. The peak indicates maximum tension. The downward curve shows tension as the jaw opens. Source: Proctor, Davidson, and Brody 1956, 330.]

Whereas Volodkevich' experiments were limited to tenderness, tests with the Strain Gage Denture Tenderometer took on a much wider range of qualities. From the conclusion of Brody's (1957, 249) dissertation: "Those characteristics which have been definitely measured are toughness, tenderness, hardness, elasticity, plasticity, crispness, and brittleness. Two other properties have also been objectively measured, but not conclusively: crumbliness and cohesiveness." Indeed, the curves in Fig. 6 illustrate those properties graphically; the hard and crispy almonds, the hard but slightly elastic celery, the tender candy bar, and the plasticity of the cheese.

Although the General Foods Texturometer lacked the striking biomimicry of its predecessor it was based on observations of human chewing and did, according to Szczesniak, provide a more realistic reading of mastication due to the double compression performed by the machine. This basic principle of the instrument rested on observations that a key component of people's experiences and appreciations of texture is how food breaks down through repeated chewing. An important advantage of the machine, thus, was that it enabled the texture analyst to define formally a range of properties previous texturometers had failed to register (see Friedman, Whitney, and Szczesniak 1963). As shown in fig. 7, the curves produced by the General Food Texturometer gave clear indications of hardness, cohesiveness, elasticity, and chewiness through a set of formulas.

[Fig. 7. The basic measurement of the General Foods Texturometer. Source: Herring, 1976, 18.]

The abilities of the General Foods Texturometer laid ground for a wider project of texture analysis, the General Foods Texture Profile Method, often called Texture Profile Analysis. To understand the basic idea of this project one need to go back to earlier work on flavor chemistry dealing with the issue of semantic standardization of flavor properties. One notable example in this context is Ernest C. Crocker's and L.F. Hendersson's "Crocker-Henderson system" for odors developed at Arthur D. Little in the 1920s, a scheme using "fragrance", "acidity", "burntness and "caprylic character" as basic descriptors for odor properties (Crocker 1945, 10–14, 43–44). The direct inspiration for the Texture Profile Method came from the Flavor Profile Method, a procedure for flavor analysis invented by Loren B. Sjöström and S.E. Cairncross in the 1940s, employed also at Arthur D. Little. The Flavor Profile Method prescribed small panels of trained flavorists and its purpose was to give organoleptic testing a tool for systematic, and objective as the inventors claimed, description of flavors by sniffing and tasting and meticulously noting on certain templates how different flavor compounds appeared during the procedure. Importantly, the method rested on a standardized language of those flavor compounds, using a set of pre-defined expressions such as "horsy" and "metallic-bitter" (see Sjöström 1953, 65–74; Berenstein forthcoming, chap. 5). The Texture Profile Method shared the same rationale as Sjöström's and Cairncross' invention and aimed to define a range of texture properties scientifically. What distinguishes it from Volodkevich's and Brody's previous attempts of texture analysis is the ambition of creating a comprehensive system, a methodological package to be used in food industries. The method was developed in the early 1960, partly by Szczesniak, but notably by Margaret A. Brandt, Elaine Z. Skinner and John A. Coleman who published a seminal paper of 1963 in which they outlined how a combination of data from the texturometer, analysis by trained organoleptic panels, and a classification of texture properties provided the bases of the Texture Profile Method.

## 6. Conclusions

The outcomes of Szczesniaks work indicate what a main rationale of her machine and its precursors was. A crucial component of the Texture Profile Method was

systematic correlation between "physical" properties measured by the instrument and "sensory" properties. *Adhesiveness*, for instance, was mechanically defined as "Work necessary to overcome the attractive forces between the surface of the food and the surface of the other materials with which the food comes in contact" and sensory defined as "Force required to remove the material that adhere to the mouth (generally the palate) during the normal eating process". These parameters were related to popular terms, in this case "stickiness" and "gooeyness". Similar translations between mechanical, sensory and popular were made for other texture properties: The mechanical description of *chewiness* was "Energy required to masticate a solid food to a state ready for swallowing" and corresponded with the sensory description "Length of time (in sec) required to masticate the sample, at a constant rate of force application, to reduce it to a consistency suitable for swallowing." Popular terms were for instance "tenderness" and "toughness". *Springiness*, to bring up another example, was technically described as "Rate at which a deformed material goes back to its undeformed condition after the deforming force is removed", and was defined in sensory terms as the degree to which a product returns to its original shape after being compressed by the teeth (Szczesniak 2002, 216–217). In other words, these were bidirectional translations between popular understandings of how elastic or plastic food felt when chewed and the realm of hard mechanically defined data.

By shedding light on this type of translations between culture and mechanics, the paper says something crucial about the experimental practices evolving in sensory science in the twentieth century. The projects behind Volodkevich apparatus, Brody's tenderometer and Szczesniak's texturometer all reflect rather extreme epistemological ambitions; they materialized, strikingly, an urge for objectivity. They are thus, in some key aspects, typical of the technoscientific field in which they were constructed. Sensory sciences, as they developed in the twentieth century, are characterized by a "workmanship of certainty" (Lahne 2016) closely connected to the industrial mode of food production. That is: techniques for sensory experiments responded to strong industrial preferences for standardization and codification – and, notably, aversion to idiosyncrasy and irregularity. The tools for biomimetic texturometry described here obviously exemplify this scramble for certainty, but illustrate something even more intriguing this text has intended to capture by the notion of a "sensory-industrial complex"; these instruments connected, ostensibly, the subjective sensory domain with the logics of industrial manufacturing by replicating human sensory functions.

Moreover, the instruments and the act of "mechanizing" objectivity say something crucial about the time in which they were constructed and used. "Flavorization" as a conceptualization of a historical process could perhaps give a bright and positive image of food production in the twentieth century, alluding that foods were packed with flavors and designed to produce pleasure through the noses, mouths and taste buds of the consumers. But the notion of flavorization allows for less vivid images, and we may pose the same question Siegfried Giedion (1948, 6) once did: "What happens when mechanization meets an organic substance?". The implications of the project of obtaining standardized definitions of texture go beyond the scope of this study, but undoubtedly the formalized definitions of for instance gooeyness and tenderness must have affected the flavors of the food produced by industries. Important here is that the

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devices described here were not odd instruments constructed by ambitious scientists in confined laboratory settings. Volodkevich apparatus, for instance, was a key model not only for the Strain Gage Denture Tenderometer; other modifications were developed, and today the machine, particularly the "biting" wedges, is a common device for food texture experiments, and is known commercially under the name "Volodkevich Bite Jaws". The General Foods Texturometer was sold commercially already in the 1960s, and as explained above, the machine played an important part in Szczesniak's development of a standardized nomenclature for food texture properties that still plays a significant role in sensory sciences (see Lawless and Heymann 2010, 270–272). Hence, although the detailed connections are not brought to the surface in this study, these instruments are certainly important historical artefacts through which we gain understanding not only of the interactions of economies and sensoria in late modern times, but also about the food we eat.

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