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Knowing the world through mouth: Aural aspect of food texture perception

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Abstract

A variety of ways have been studied in order to learn more about how humans perceive the world and are able to experience new sensations, as well as, to comprehend the way we sense and process the already discovered flavours or aromas. Throughout the years, many studies have also led to important discoveries about the way that sounds can affect, in a positive or negative manner, our own perception about food texture and taste. In this study, we managed to review the effect of auditory stimulation in correlation with how we can sense food texture in our mouth, ear and brain. To help us understand this process, we also included in our study a review of the different elements involved in mechanical stimulation and correlate our aforementioned objective with some other important factors, such as, sonic seasoning and the study of tribology. Our bibliographic research has also focused on the consumer behaviour and how can auditory stimulations have a direct or an indirect link towards our flavour or aroma perception, but also the way we can consume or buy that specific product. It was apparent that sounds with a direct link would have a significant effect on our behaviour, but the most important finding was that, sounds that have no direct link exert an immense amount of influence towards our gustatory or olfactory perception, but our consumer behaviour as well. With the information that was found, we have proposed a new definition about taste perception and also, included in our research, the ethical aspect of possible manipulation or taking advantage of the consumers behaviour. Finally, our study viewed possible limitations of previous researches and we proposed a collective study of measurements and techniques, in order to achieve more significant results and with a more representative aspect towards our world.

Resumen

Introducción

Se han estudiado diversas formas para que los humanos aprendan más sobre el mundo y puedan experimentar nuevas sensaciones, así como para comprender la forma en que sentimos y procesamos los sabores o aromas ya descubiertos. A lo largo de los años, muchos estudios han llevado a importantes descubrimientos sobre la forma en que los sonidos pueden afectar, de manera positiva o negativa, nuestra propia percepción sobre la textura y el sabor de los alimentos.

Objetivos

Revisar el efecto de la estimulación auditiva en correlación con cómo podemos sentir la textura de los alimentos en nuestra boca, oído y cerebro. Para ayudarnos a comprender este proceso, tenemos que incluir en nuestro estudio los diferentes elementos de estimulación mecánica y correlacionar nuestro objetivo antes mencionado con algunos otros factores importantes, como el condimento sónico y el estudio de la tribología.

Resultados

Nuestra investigación empírica también se ha centrado en el comportamiento del consumidor y en cómo las estimulaciones auditivas pueden tener un vínculo directo o indirecto con nuestra percepción de sabor o aroma, pero también la forma en que podemos consumir o comprar ese producto específico. Era evidente que los sonidos con un vínculo directo tendrían un efecto significativo en nuestro comportamiento, pero el hallazgo más importante fue que,

los sonidos que no tienen un vínculo directo ejercen una inmensa influencia en nuestra percepción gustativa u olfativa, pero nuestro comportamiento del consumidor también.

Conclusiones

Con la información encontrada, hemos propuesto una nueva definición sobre la percepción del gusto y también, incluido en nuestra investigación, el aspecto ético de una posible manipulación o aprovechamiento del comportamiento de los consumidores. Finalmente, nuestro estudio vislumbró posibles limitaciones de investigaciones previas y planteamos un estudio colectivo de medidas y técnicas, con el fin de lograr resultados más significativos y con un aspecto más representativo hacia nuestro mundo.

Contents

Introduction

Humans get to know the world through multiple senses but some senses predominate others in the earlier stages of life, as seen in the taste and touch sensation of neonates. Due to the fact that the sense in their fingertips is not yet fully developed, taste through their mouths is what allows humans even from the neonatal state to get to experience and learn about the different flavours and sensations that the world contains (1).

Food texture perception is a complex process that according to Burbidge et al. (2, p.11), ''is inherently a dynamical process with no obvious equilibrium state of adsorption of an agonist to a particular receptor, and the stimuli are therefore inherently dependent on the exact modes of deformation and the deformation history of the tested material''.

A big part of the biophysics of food texture perception includes also the structure of a given food or sample, as the structure is the ''implicit property of the material''(2, p.11).

Although, the texture perception of food is basically an individual's perception of a specific sample at a given time, for an example, an individual can sense a different stress field for the same sample given different stimuli or different periods of time.

Food texture perception includes 4 different senses: taste, touch, audition and olfaction.

From all of the other senses mentioned above taste has been researched studied the most as the receptors involved in taste are comparable to most living organisms.

Taste according to Liu et al. (3), in 2017; is a physical sense and a perception of our mind that relates to the ingesting of a substance mixed with saliva(3). In general, and more specific in the scientific field, taste is often referred to as the axis of the perceptive process of food. It is thought that from 1970 onwards, sufficient knowledge was collected about the Central

Nervous System pathways related to taste and the way taste is perceived (taste buds, signalling processes, etc.) with the use of advanced techniques. Just half a century ago, the only organ thought to be related to taste was the tongue, because up until then researches had found taste buds located solely in that area of the mouth, whereas during those 50 years, new structures of the body were also added to the contribution of flavours and taste, such as; the pharynx, the palate and the epiglottic larynx (laringopharinx). It also notable that only sweet, salt, bitter and sour flavour qualities were known. With these studies throughout the years researchers were able to realise that a receptor cell that is inside a taste bud can produce a nerve impulse which is transmitted through our brainstem and thalamus in order to reach the gustatory cortical area. This process is done with the aid of gustatory afferent terminals located in the taste buds (4).

More specific sweet, umami and bitter receptors are GPCRs or G-Protein Coupled Receptors. Salt receptors are ion channels for Na and sour receptors are hydrogen cations(2). According, to Han et al. (4), in 2019, a variety of techniques, such as molecular biology, optical and brain imaging and the use of electrophysiologic recordings have proven that depending on the quality of the flavour, the taste relay produced by that flavour has a specific topographic or chemotropic display in our brain. Furthermore, there were found more areas in the brain associated with food perception. The limbic system processes information in regards with the emotional or pleasurable aspect of taste and some parts of the cortex and nucleus accumbens are responsible for altering or enhancing taste behaviour whereas, the hypothalamus although important it mainly processes information in relation with the regulation of feeding. The brain can integrate data that is received through the process of eating but it can also amass an enormous library of previous experiences to reach conclusions (4).

However, from 1920 until now, mechanical aspects of food perception have been studied and integrated in the food perception map. Those aspects include **mechanoreception**, the study of friction or also known in the scientific field as, **tribology**, and last but not least **sonic seasoning**.

Mechanoreception is a relevant part of our review as the mouth is a constant control medium where these mechanoreceptors are always active and provide feedback to the brain about multiple processes that may or may not include food intake, such as swallowing, phonation and others (2). But taste as can be clearly seen in Figure 1 is not the only factor that can influence our oral perception. Aroma, as well as, texture and thermal perception have an important role in our overall food perception.

Moreover, there has been a link of extra-oral sensations and perceptions with our food perception. There is no doubt that the way of how food or drinks are perceived can be affected by sounds, vibrations, or even with the different environment and feelings that can be associated through the experience of eating/drinking in our mouth; these catalysts affect the way we perceive what we taste even if we are unaware of their effects, which according to Zellner et al. (5), 2017, we mostly are oblivious to them(6).

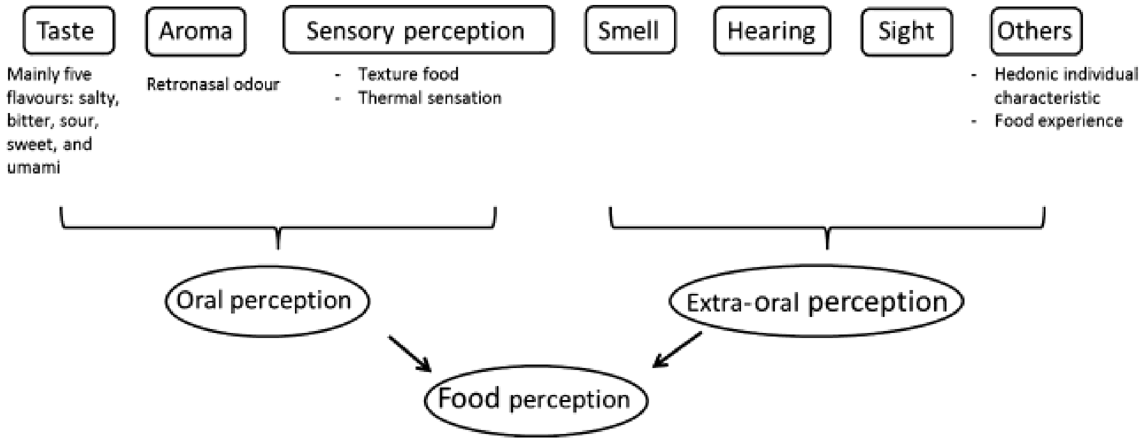


Figure 1. Catalysts related to food perception. Retrieved from Batisse et al. (7)

Before further investigation of the different ways that alter our perception of food texture, a basic overview of our acoustic and stomatognathic system will be presented and also the way they work during mastication and occlusion.

According to Stenfelt et al. (8), in 2003, when the external acoustic meatus is open the occlusion has almost no factor towards the process of hearing and Stenfelt et al. (9), in 2011, stated that, during occlusion the sound emitted by the movement of the external auditory meatus parts is trapped and is then transmitted to the tympanic membrane .

The processes of mastication and swallowing are complex where food, brain as well as its physiology are closely intertwined. As seen in Figure 2 all of the components play an important and vital role in the food texture perception (3).

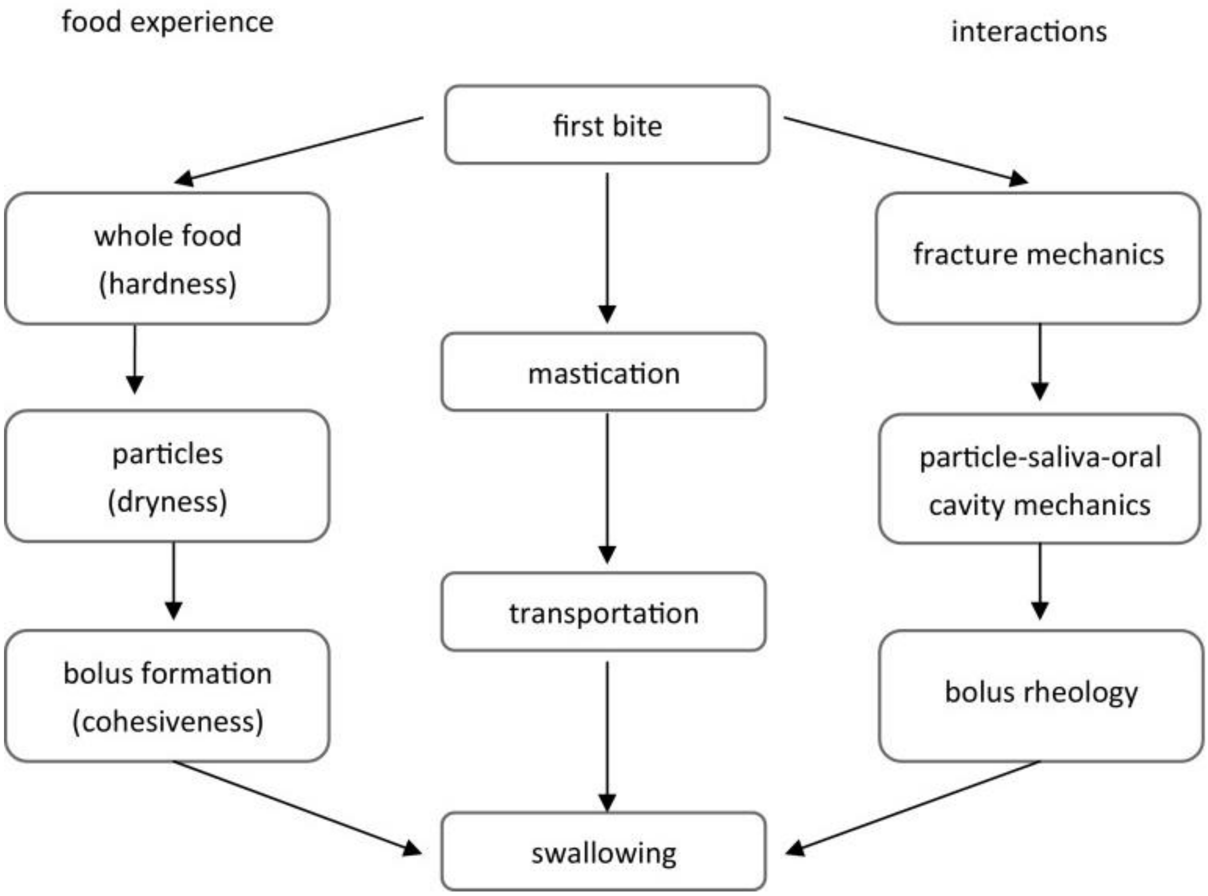


Figure 2. Oral Processing Framework. Modified from Liu et al. (3).

A different way that humans can sense texture perception is through sound. Sound is a mechanical vibration that propagates through a material medium that can be a gas, a liquid or a solid. Usually, we refer sound as those vibrations travelling through the air, but how can we perceive sound through more solid materials like tissue and bone?

In the case of the human body, we can differentiate three types of sound conduction: air conduction, bone conduction and soft tissue conduction. The soft tissue conduction, which until recently was only referred as non-osseous bone conduction, was rarely researched but it has proven to have great applications in sound energy transmission especially when compared to bone conduction.(10) Here we see the first ''appearance'' of the term dentaural hearing. The famous musician Beethoven used a bony apparatus, that had one end attached to his piano and the other end to his teeth, in order to compensate for his hearing loss and to be able to perceive the sound in his inner ear.

Beethoven seemed that he had found a niche in his disability and treated the bone conducting sounds in his skull as a gift, rather than an annoyance such as Obrebowski who thought that bone conducting sounds in physiological state should be hindered rather than accentuated (10).

More studies were made in the aspect of dentaural hearing throughout the years that lead to some interesting results. According to Brown (11), in 1969, teeth in the maxilla can conduct sound energy better than the teeth in the mandible which shows that bone conduction has better results comparing to soft tissue conduction in regards to sound energy transmission. Another noteworthy fact, was the examination applied for bone conduction, where a tuning fork is placed on the mastoid bone. Bone conduction allows the vibrations or sounds to be transmitted to the inner ear, whereas air conduction uses the ear as an apparatus to direct and amplify different vibrations or sounds. There is also, a reduced volume transmitted by the skull bones to the opposite ear, that has little but nonetheless some effect to sound transmission (10).

More recent findings of dentaural hearing can be seen in 2007 where Hasbro the famous toy company produced a unique toothbrush called Tooth Tunes. This toothbrush could generate vibrations that translated into sounds in the user’s head, making the trivial act of toothbrushing into a fun activity(10).

Many studies have lately focused on the term called **sonic seasoning**, where different sounds and locations have an alternate effect on the way we can perceive food, according to Spence and collaborators (6,12,13). An important role is seen in the variable characteristics of music, such as pitch, tempo, frequency and others. There is also a link with the term ‘’sensation transference’’, where the background music can affect the process of eating or drinking and vice versa. For example, Kantono et al. (14), in 2016, stated that the ice cream was perceived as sweet or sour was directly linked with whether the music played in the background was like or disliked.

Over the last half century there has been a vast amount of studies (15, 16,17), that have focused on and shown that background music and sounds played in public areas such as restaurants, bars and stores can affect the customers in regards to taste experience or enjoyment. Even affect the way of choosing what to order or consume and what would be the amount of money they are willing to spend .

An interesting theory by Muniz et al. (18), in 2017 describes how people can be influenced by the combination of music and food and the effects of that. On the other hand, Hauck and Hecht (19), in 2019 describe how food and beverages that are consumed in silence affect our mental behaviour as well as our consuming behaviour.

Furthermore, a study made by Fiegel et al. (20) , describes how the tempo, pitch, volume or different auditory stimuli can affect the way we can enjoy food or drinks. Without a surprise people who were stimulated while eating or drinking experienced a higher quality of enjoyment or pleasure.

A similar effect can be seen by people associating memories with food; either that being a landscape or a sound or whether this is related to brand recognition such as the study made by Speed, Peters, and Croijmans (21) ,where the participants have associated themselves with familiar brands easier and faster than brands that were unknown or hardly used.

Tribology is the study of friction, lubrication and wear of the related surfaces in response to motion. These processes take place in our tongue, palatal mucosa and teeth and more specifically, when the surfaces aforementioned are moving or contacting other features of the oral cavity (20). This concept has been linked with the study of food oral processing and the perception of the different senses involved in that process. According to the study made by Joyner et al. (22), particles, fat, emulsifiers and hydrocolloids are important substances located in both mouth sensations and tribology that whether or not they are present in the mouth can affect tribology and structure perception (23).

Although known by its protective function, its assistance in swallowing, digestion and taste perception, saliva secretion arose as a key component of tribology and food texture perception. From the study made by Engellen and Van der Bilt (24), in 2008, the importance of saliva for the correct food oral processing and perception was shown, as well as, the effect of one of the critical functions of saliva; salivary flow. The study showed that salivary flow and composition of saliva through dilution, enzyme breakdown or even mixing of the food ingredients and saliva have an effect on lubrication and food texture perception.

More emphasis will be shown on our results and discussion part about the multifactorial stimuli and their effects that are involved in the complex process of food texture perception through the mouth and the ear.

This paper will mainly focus on the different stimuli that could affect our food perception that are caused from different textures and perceptions of food in the mouth and ear. Special interest will be shown towards the mechanical stimulation of taste and olfaction as well as to the terms; tribology and sonic seasoning and their effects on food texture perception.

Objectives

Main Objective

To understand and integrate the key features of aural aspect in food texture perception.

Secondary Objectives

- To review scientific studies related to the influence of mechanoreception, sonic seasoning and tribology in food perception.
- To provide a more accurate definition of taste, according to all the processes that influence our food texture perception.
-To analyse the social impact of the aural perception of food texture.
-To analyse the implications of the aural aspect of food texture perception in dental practice.

Materials and methods

The study targeted all empirical research, case studies, and systematic literature reviews written in English that correlated to the keywords mentioned below, as well as, towards our primary and secondary objectives. The main sources for our articles were Medline, PubMed and the university's Online Library (CRAI Dulce Chacón).

The keywords used for the research included: food texture perception, aural perception, auditory food perception, physiology of food perception, sonic seasoning and oral tribology.

All articles that were found when then put through an exclusion process until we reached our final bibliography. More precisely, the total number of articles found for the collection of the aforementioned keywords, were 9939, from which we instantly excluded just a bit over a quarter of our initial search and to be more specific 26,5%, for the fact that they were outside of our research date period of 2010-2021.

So, our total amount of articles was 7303, from which 36 articles were carefully selected that matched our criteria the best, as well as, a relation towards the dental field. Only, four out of these 36 articles appear to be outside of our designated timeframe, but their inclusion in our study was deemed necessary in order to for the reader to fully understand our study. The articles selected were subjected to a data analysis process. Data were captured on an Excel spreadsheet and reported in a comprehensive table seen below.

The Mendeley referencing application was used to organise the bibliographical part and simultaneously to cite our study, according to the requirements set from the department of Biomedical and Health Sciences, which required a Vancouver style citation method. All the pictures included in our study were, also cited by the Mendeley referencing system.

Total amount	9939	7303	36
Keyword	**N. of articles**	**N. of articles after exclusion**	**N. of articles of final selection**
food texture perception	2135	1630	5
aural perception	1400	970	6
auditory food perception	634	483	3
physiology of food perception	5467	3946	8
sonic seasoning	53	49	10
oral tribology	250	225	4

Table 1. Comprehensive table of the data representation of our bibliographic search and selection of articles.

Results

Dentaural anatomy and conducting pathways

In order for us to fully comprehend the link between a stimulus and the perception produced by it, we need to have a quick overview of the anatomical structures involved in the process of food texture perception. All the anatomic parts that will be mentioned are located in the head region and more precisely; in the oral cavity and ear, including the Temporo-Mandibular Joint (TMJ); which as the name indicates is the connection between the temporal bone and the jaw or also known as, the mandibular bone. Regarding the sound conducting pathways we will refer to the three different mechanisms already mentioned: soft tissue conduction, air conduction and bone conduction.

The TMJ is the only bilateral synovial joint that acts as a singular unit, but also the most relevant soft tissue sound conduction mechanism to our research, that humans have on their head. With soft tissue conduction the cerebrospinal fluid pathway is followed, that will eventually lead to the perilymph (10).

This mechanism is completely different from the other two ways of sound conduction; air conduction and bone conduction, as mentioned above, except from the fact that all the information is finally headed as well, towards the perilymph.

Regarding air conduction there are two pathways followed; the ossicular and the acoustic, with the ossicular pathway acting as the principal one, due to its greater effectiveness.

The conduction of sound through bone follows as well two pathways; the tympanic and the cochlear pathway (10).

Furthermore, the structures involved in these pathways can be divided in three parts of the ear; the **outer**, consisting of the auricle and the external acoustic meatus, the **middle** that includes the tympanic membrane and cavity, malleus, incus, stapes and the semi-circular canals and the **inner** ear, where the cochlea and vestibule are located, accompanied by the cochlear and vestibular nerve and as well the oval window and the Eustachian tube; which provides connection to the nasopharynx (10).

Finally, regarding the mouth, the structures involved in sound conduction and food perception involve the maxillary and mandibular teeth, the tongue and the maxillary and mandibular bones (10).

Texture perception and sensitivity

As mentioned above, food texture perception is a dynamical and complex process that depends on the receptor and the stimuli itself. The use of an individual technique renders the research results almost useless as in order for us to be able to understand completely the process of eating and subsequently of food texture perception, a variety of techniques and measurements have to be applied. Further studies were made throughout the decades about texture sensitivity and other physical properties of food, that has led to new measuring techniques like temporal dominance of sensations and time-intensity technique, as we can observe in the studies by Foster et al. (25), in 2011 and Koç et al. (26), in 2013.

More methods such as acoustic signal capture, where also introduced by Saeleaw & Schleining (27), in 2011, and measurements regarding the activity of the jaw seen by the study made by Koc et al. (28), in 2013.

These techniques allowed us to assess a more complex and dynamic food processing behaviour, rather than the widely researched static properties of food itself.

From these studies a claim was made, which stated that in order to measure and fully comprehend the connection between sensory perception and physical properties, ''in vitro'' experiments should be performed with the aim of clarifying the physics involved in our mouth(19).

According to Engelen (24), the physical properties of food are perceived by specific receptors found in the oral cavity, known as mechanoreceptors (mentioned above), that provide us with touch and proprioception elements .

Other receptors include; thermal receptors, that measure the temperature of foreign objects that come in contact with our oral cavity, as well as nociceptors, that provide the brain with a sensory input of pain perception. Finally, chemical receptors that contribute in the smell and taste sensations. More important is the fact that food texture perception is perceived not only from one or two of these receptors but from the totality of them (24).

That specific sensory input is translated into a perception inside our brain, as shown in the study made by Rolls (29) about the neural representation of oral texture including fat texture. Rolls mentioned in his study that in order to measure correctly the perception of the enjoyment of flavours and oral texture, we must assess taste, olfactory and texture elements all together. More specifically, the study aimed to show the specific areas in the brain where the aforementioned sensations took place. The subjects were presented with chocolate milk or tomato juice; one for stimulating the brain with a pleasant feeling and the other to decrease that sensation. The results of the study showed that the orbitofrontal cortex was the specific part of our brain that was responsible for perceiving the enjoyment food flavour and the sensory-specific phenomenon known as satiety (Figure 3).

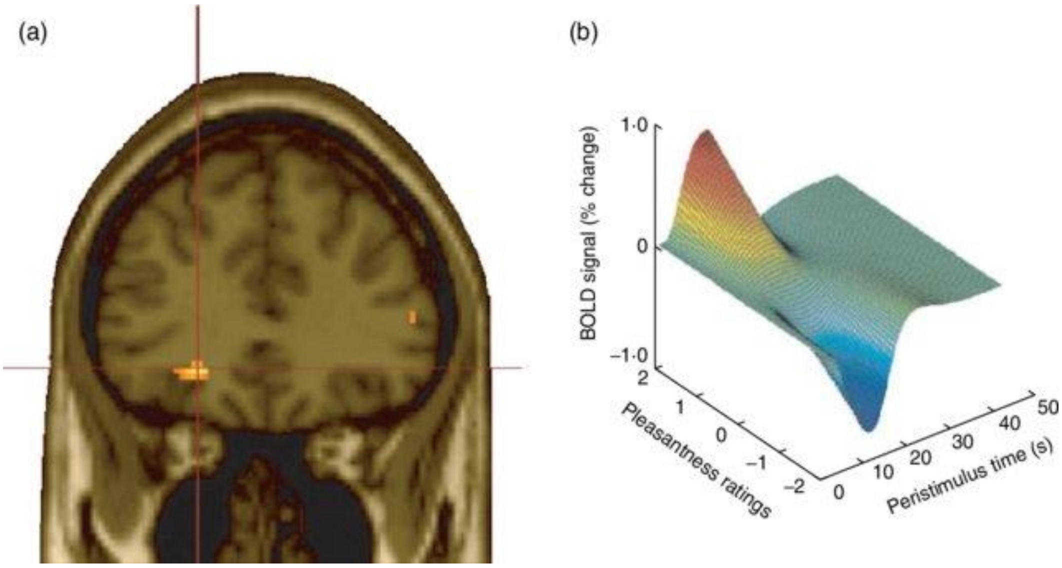


Figure 3: Areas of the brain with activations linking pleasantness with food in the mouth. (a) Coronal section of the orbitofrontal cortex showing in yellow the peak of pleasantness correlated with the foods given. The experiment consisted of subjects that were hungry and were fed to satiety, where after a period of time the pleasantness of the food was reduced to neutral or even to some extent unpleasant. The type of this experiment was a sensory-specific satiety design. b) Plot of the magnitude of the hemodynamic response from an individual against the pleasantness ratings (on a scale from -2 to +2) and peristimulus time measured in seconds.
Retrieved from Rolls (29).

Sonic Seasoning

As explained before, sonic seasoning is the term used to describe intrinsic and extrinsic aural stimuli that can affect an individual's perception and their costumer behaviour. The difference between the intrinsic and extrinsic stimuli is the direct link between the stimuli and the food or not, respectively. In an interdisciplinary review made by Spence et al. (12), in 2019, we can observe 4 different ways of how noise or music can influence what we taste. The first 3 ways explain the effects of background noise, background music and sensational transference, respectively. The fourth phenomenon described was sonic seasoning and its effects on human perception. An interesting study mentioned by Spence and Crisinel (30) in 2010, where the test subjects had to match a taste to a specific note with the aid of different musical instruments. The participants were given different aroma tastes, such as sweet and fruity or even bitter and smoky aromas. The results of this study were consistent to the extent of recording similar measurements between different participants for the same aromas. More precisely, the test subjects tend to associate sweet and fruity aromas to a higher note and higher pitched musical instrument such as a piano or wind instrument, whereas the bitter and sour aromas were recorded in low pitch musical instruments and low notes, such as brass instruments.

In a different study by Wang and Spence (16), it is stated that the participants had to listen to some melodies that were either pleasant to the ear or even annoying and distasteful and try to associate them with different flavoured foods. The results of the study did not surprise as most test subjects were associating sweet flavours with pleasant melodies and sour taste to distasteful or unpleasant music. But the interesting part was the feedback correlation that seems to be involved to music and flavourful food, whether that being pleasant or not. So, in this study for example we see that most participants also preferred to consume a specific pleasant drink under the influence of consonant music instead of an unpleasant melody, meaning higher pleasant ratings for flavour and music (16).

In a study performed by Jutras et al. (31), in 2019, the impact of external ear blockage in food perception was studied. Authors aimed to measure participants without any auditory or gustatory, including olfactory deficiencies and their external ear occlusion effect upon greater masticatory sounds produced during occlusion. Different sounds measures were recorded for soft or crispy food, with crispy food recording greater sound levels than soft foods. Especially when the subjects were instructed to use an earplug the same measurements of ''crispiness'' were even higher than without the use of an earplug. Also, there were different sounds measures documented for males and females, with males reaching greater sound levels of mastication, probably due to higher mastication forces used by the gnathic muscles of males or greater occlusal forces (27,31). Although, this study could not really prove their original hypothesis, they did reach a different finding in the end. Apparently, loud noises during eating are not directly related with food perception. Despite that, the study concluded that there were different results according to sex, where according to these results the assumption that male participants preferred loud noises during mastication was made.

Tribology

As mentioned above in the introduction, tribology is the study of friction on a surface in relation to motion. Important elements that are included in this study (22) are saliva and the salivary flow, as well as, the fact that, tribology when analysed has to follow some specific parameters, such as; surfaces (for example; soft or hard), lubricants (food) and different measuring systems.

Furthermore, Macakova et al. (32), in 2010, stated that the effects or changes caused by the mixing of food components and saliva can be due to alterations in the ionic strength or pH that in return change the composition and hydration of the salivary film. There has been a link proposed between oral processing techniques, the use of tribology and salivary interactions to be combined in a study in order to move forward with the understanding of the effect of oral processing in the food texture perception (33).

Discussion

In general, during our bibliographic overview, we tried to show the different ways that food perception can be comprehended or altered by different stimuli. More specifically we have prioritised our study towards the mechanical stimulation of food texture perception. This overview included also, sonic seasoning and tribology, which with the aid of recent studies, seem fundamental towards the concept of taste and its affect towards food texture perception. Socially, the definition of taste focuses on the concept of flavour. On the other hand, in scientific literature, taste has been defined as a,“ physical sense and a perception of our mind that relates to the ingesting of a substance mixed with saliva” (3). However, as has been shown in this paper, sensory experiences derived from mechanical stimulation in the process of eating as well as sound seasoning, decisively influence the perception of food, appearing as indissoluble to the concept of taste itself.

For this reason, I believe that such processes should be included in the definition of the concept and the following is proposed: Taste is a chemical or mechanical sensation, that can be perceived or altered in our mind, with the aid of gustatory, olfactory and also auditory stimuli. As seen below in our paper, this new concept also entitles some requirements in order to give sufficiently reliable results (34, ch.6).

Most of the authors that have based their work on sonic seasoning and its effects on human brains, have come to the conclusion that a specific pattern is made and followed by each individual during their own experience of flavours or textures of food. In mechanical terms, although those patterns may be different at first, their information is led always towards the same location; the perilymph (10). Following this concept of thought there should be a collective study including not just one of the factors that can alter our perception, but if possible, all of them; aroma, taste, textures and sounds. This view seems to be contradicted by Engmann et al. (35) in 2013, who believed that elements like taste or aroma should be eliminated, in order for their study to be successfully fulfilled. Despite this contradiction, most of the authors; including Engmann, have a common limitation agreement, which includes the fact that the number of participants in the study should be greatly extended, in order to be representative and precise towards our population in the world (22). The same views can been seen in Tribology, where in order to be able to obtain, significant results; a variety of factors need to be analysed, such as different surfaces or food types (lubricants) (22).

All these claims are leading towards our concept of unifying all of the different systems or properties into one combined study that could produce more realistic and representative, instead of the stochastic results that many authors had to rely up until now.

Also, after many studies researchers have understood that specific sounds can affect not only our pleasantness, but also, the way we would consume or buy products.

Correlations between the authors' views can be seen in the articles, mainly publised by Wang, Spence and by Reinoso-Carvalho between the years of 2018 and 2020 (6,12,13)(15-17). Some of the findings of these studies included the fact that, the external aural stimulation that is being used while consuming a product, has a significant effect in the way we could perceive the variety of flavours. This range of favours can be either, tasted or smelled.

This fact has been recorded not only during research studies with a chosen number of test subjects, but it is also observed in the behaviour of consumers in places like restaurants, bars and cafes, as well as, retails and shops (6,12). It is also believed that the customers and consumers remain oblivious to the fact that these sounds are influencing their behaviour, just because there is no direct link to the sound produced and the product itself (12).

Another interesting theory was shared by Wang (34, ch.6) in 2017, during his PhD thesis, which included the rational that in order for the participant to be able to experience any auditory stimulation towards his food perception, an actual gustatory or olfactory stimulus had to be introduced to the taster from the start. This could be explained by the notion that the participant while consuming the testing flavour, appears to be fixated to the auditory stimulation, which in return makes the flavour that was tasted more noticeable (6, 30, ch.6).

This could be the starting point for an interesting ethical analysis of capitalist methods of influencing consumer behaviour. There is a large volume of articles and books on theories of human rationality on which to base such ethical studies, as reviewed in Kahneman (36).

In this respect, several questions could be discussed: Is it ethical to influence consumers indirectly through direct experientiality such as taste? Is it possible to set a limit in this respect?

Continuing with the different ways we could enhance our further research into the auditory aspect of food texture perception and the way we use these elements to get to know and experience the world, some studies have suggested the replacement of loudspeakers for the production of auditory stimuli with headphones, which could provide higher isolation and therefore, attention towards that stimulus rather than drowning it out or even completely cancelling it out (15). Another important parameter that seems to be discussed in the study by Spence et al. (15), in 2019, is the idea that the participant of the study should be unaware to what they are about to taste. Also, the supply of a unique flavour seems to be more appropriate for acquiring comparable results, as for example if we were to supply our participants with a commonly used flavour, their results could be tainted by personal experience of that particular flavour.

This concept could be implemented towards the improvement of the perception of food in individuals with lack of taste integration due to old age or neurological problems that can affect the feeding process and in return the tasting experience as well.

Dentists are meant not only to treat but to prevent traumatisms and diseases. As stated from Batisse et al. (7), factors such as, the decline of dental status and insufficient oral hygiene can be a leading cause towards the alteration of the taste perception. Other causes also mentioned, where individuals who had a prosthetic treatment and people with dry mouth or also known as xerostomia. Mastication is important for oral processing and taste perception, so a proper oral hygiene and often visits to the dentist are necessary not only for aesthetics, but also for simple function, as mastication and taste sensation. Therefore, the dentist should be aware that interventions in the mouth can radically affect the psycho-physiological aspect of the individual where not only the physiological processes can be affected but also the perception of the world.

Conclusion

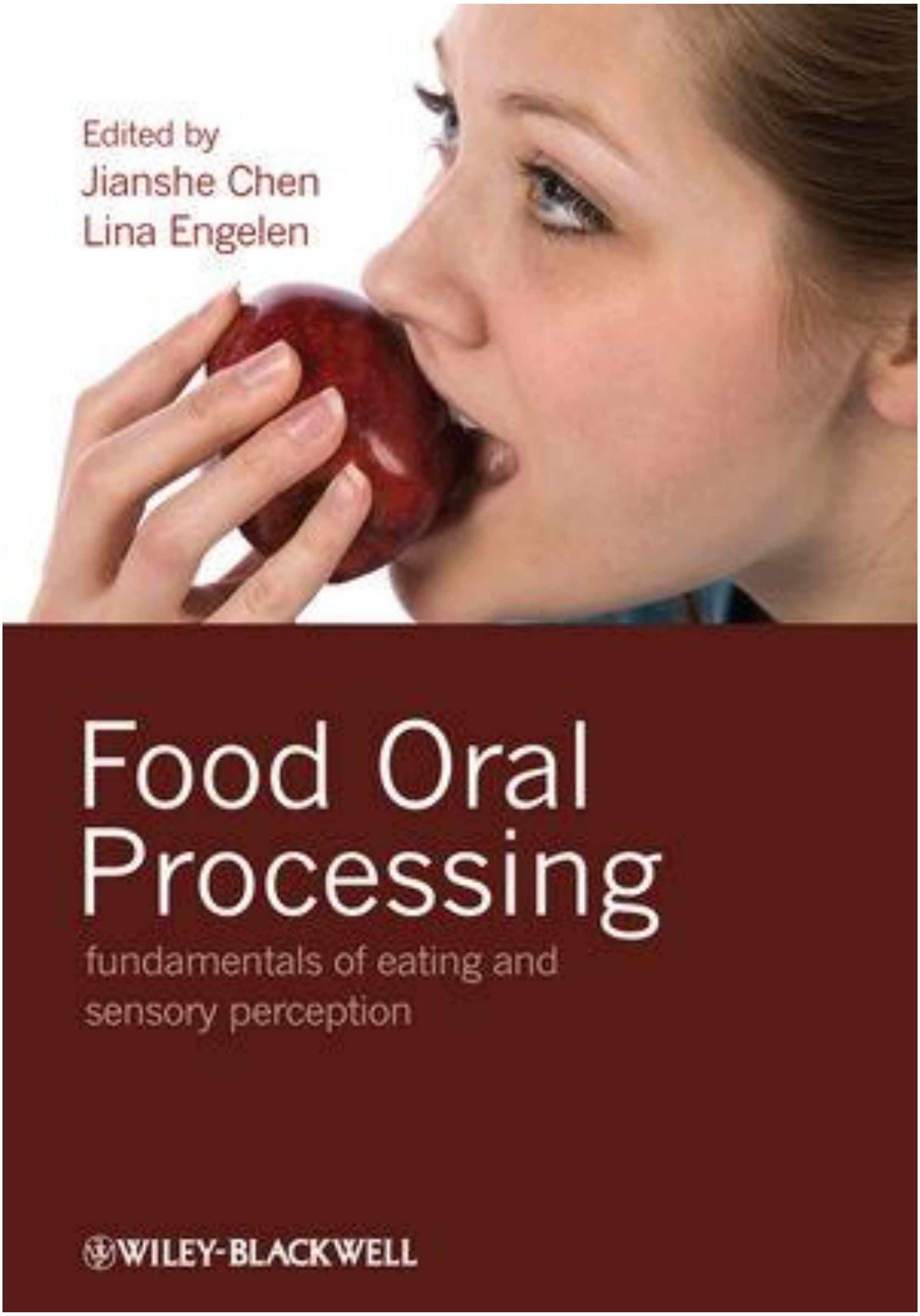
During our literature research we aimed to demonstrate the link between food texture perception and the auditory aspect of it. In relation to that, we have included some terminologies that have been linked to food texture perception, such as sonic seasoning and tribology. As, the result of the work the following conclusions have been reached:

- Mechanical stimulation affects the way we perceive food, including also, auditory stimulation. The auditory aspect of food texture perception and oral processing is a very important factor but nonetheless not the only contributing factor.
- As we have observed and discussed in our study the way we perceive food can be influenced by many stimuli; thermal, mechanical, chemical or even aural. Links between music or noise have been made with food texture perception and results showed that different flavours can be associated with various musical notes to represent a feeling or a sensation.
- One of the most interesting findings was that in reality music, noises or even areas associated with a pleasant feeling will affect our food experience and vice versa whether we are aware of it or not (5).
- A collective study was proposed after all these findings that proposed the combination of techniques and measurements, rather than the dampening of some senses. An overall representation and mapping of our brain is necessary to be made, relating the oral texture perception, tribology and sonic seasoning.
- Due to these findings, we have proposed a new definition to taste, which states that: Taste is a chemical or mechanical sensation, that can be perceived or altered in our mind, with the aid of gustatory, olfactory and also auditory stimuli.

- We have also observed the social responsibility of the consumers behaviour and how sonic seasoning can affect their decisions and acts. Moreover, we observed the possible implications that can correlate with Dentistry and the professional responsibilities towards the patients' health and comfort. Dentists can prevent and treat traumatisms and diseases and they are responsible for improving the tasting experience and quality of life of their patients.

Further research needs to be made in the aid of understanding the different kind of stimulations that can affect our food texture perception. As mentioned above, a complete mapping of the oral, aural and mechanical/chemical stimuli and their conducting pathways, which lead to the brain has to be performed. This new collective study could show a new approach towards fully comprehending the way we perceive food and in how many ways this feeling can be altered.

Annexes

1. 
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Food Oral Processing
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Biophysics of Food Perception

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Abstract.

In this article, we present food perception across a range of time and length scales as well as across disciplines between physics, chemistry and biology. We achieve this objective of the article by presenting food with a material science angle as well as the physiology of food perception that enables humans to probe materials in terms of aroma, taste and texture. We highlight that by using simple physical concepts, one can decipher also the mechanisms of transport that link the food structure with the perception physiology and define in which regime the physiology operates. Most importantly we emphasize the notion that food-consumer interaction operates across the interface biological fluids that can be grouped under the terminology of *mucus*, acting as a transfer fluid for taste, aroma and pressure between food and dedicated receptors.

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Keywords: Food, Physiology, Sensory, Perception, Biophysics, Transport Phenomena

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1. Introduction

Foods are essential as a source of nutrition to sustain the body from both and energetic and a structural repair perspective, but the experience of eating good food is a highly pleasurable sensory experience. In the current short article we offer a high level review of how the structural elements of food interact with the human oral biology and physiology to provide sensory stimuli for the brain. We attempt to provide a physically focused view and attempt to highlight aspects that seem, or have been demonstrated, to be amenable to a physics inspired technique or explanation in the hope that it might highlight potentially interesting research questions to researchers who are not already working on food or nutritional questions.

2.

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REVIEW ARTICLE

Impact of oral processing on texture attributes and taste perception

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Abstract Mastication is the first step of food digestion, where foods are broken down and simultaneously impregnated by saliva resulting in the formation of semi-fluids known as food boluses. This review focuses on the impact of oral processing on texture attributes and taste perception. The article describes the oral actions in which texture characteristic are measured for the critical conditions that trigger swallowing. Taste perception also plays a key role in oral processing and oral sensations. There are still challenges in terms of determining different oral physiological characteristics. These include individual chewing behavior regardless of the temporal aspects of dominant processes of comminution, insalivation, bolus formation and swallowing. A comprehensive approach is essential to process favorable foods with respect to the food properties of texture and taste.

Keywords Oral processing · Facture · Bolus formation · Swallow · Texture perception · Taste perception

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Introduction

Food processing is a rigorous and important means of structural adjustment. Food oral processing includes all muscle activities, jaw movements, and tongue movements that contribute to preparing food for swallowing. The processed foods which is not only support the enjoyment and pleasure of consumption but also provide energy and essential nutrients (Chen 2009). Typical food processing involves selecting a variety of raw materials and mixing with other food additives, forming a constant desirable structure which can be stored (Chen 2015). However, food oral processing is the reverse of this process. Figure 1 provides a conceptual framework of the dominant food physics, sensory and physiological parameters during oral processing of solid food. The whole food form is reduced to increasingly small and more numerous small particles (Salles et al. 2011; Selway and Stokes 2014). Food begins a structural degradation and disintegration leading to a special microstructure and texture suitable for swallowing. The fundamental properties of food oral consumption include mechanical fragmentation of teeth while using the extrusion of tongue–palate and combining with saliva formation (Harrison and Cleary 2013; Neyraud et al. 2003). Using research techniques, it is possible to follow the process of reducing the whole food to a swallowable bolus. As food oral processing occurs, rheological properties play an important role more so than the fracture characteristics depending on the matrix' transformation to a bolus (Selway and Stokes 2014). Both fracture characteristic and rheological properties of the food matrix make contribution to sensory perception, in particular texture perception which is likely to influence consumers' acceptance and preference (Foster et al. 2011).

3.

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COMPREHENSIVE REVIEW

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The sweet taste signalling pathways in the oral cavity and the gastrointestinal tract affect human appetite and food intake: a review

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ABSTRACT
Sweet taste is associated with food reward and energy source in the form of carbohydrate. Excessive sweet consumption is blamed for the prevalence of obesity. However, evidence for the potential of sweet taste to influence food intake and bodyweight regulation in humans remains unclear. The purpose of this review was to examine the physiological responses relevant to sweet taste mechanisms and the impact on appetite control. The literature was examined for studies that assessed the effects of non-nutritive sweeteners and natural sugars on hormonal secretions and neural activations via oral and gastrointestinal pathways. The findings indicated that a network of sweet taste signalling pathways in the oral cavity and the gut seem to mediate hormonal responses and some metabolism differences in neural circus that orchestrating the hunger-satiety cycle. Individual variations of sweet taste perception which is modulated by hormonal and genetic factors have been associated with dietary nutrient and sugar consumption.

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KEYWORDS
Sweet taste receptor; caloric sugars; non-nutritive sweeteners; food intake; hormone; brain activation

Introduction

Sweet taste has the potential to guide food or nutrients consumption and impact health, as the prevalence of overweight and obesity has been largely due to overconsumption of sugars. The mammalian gustatory system has evolved with the ability to detect nutritionally relevant and harmful substances in food and serve as a dominant regulator and driver for feeding behaviour (Yarmolinsky et al. 2009). In humans, taste is categorised into five modalities: sweet, bitter, salty, sour and umami (the taste of glutamate or amino acids), and strong evidence support fatty acid as a sixth taste modality (Besnard et al. 2016). Sweet taste has been associated with food reward and energy source in the form of carbohydrate. However, excessive sugar consumption is blamed for the prevalence of overweight and obesity. Although controversies exist as to whether the non-nutritive sweeteners (NNSs) are ideal substitutions to natural sugar (Burke and Small 2015; Rogers 2017), the NNSs have been widely applied in recent years as it could deliver hedonic sweet note and provide negligible energy. To expand our understanding of sweet agonists in appetite, satiety and food intake, it is important to understand the physiological and neural responses to sweet agonists-receptor bindings at various sites during food consumption, mainly the oral cavity and gastrointestinal tract (GIT), and the similarity and differences between the effect of caloric sugar and NNSs.

Thus, the present review aimed to provide an overview of key research findings on sweet agonists. First, hormonal response to oral and GIT perception of sweetness (cephalic phase responses) was reviewed; second, brain responses to sweetness via oral or GIT administration were summarised; finally, the relationship between sweet perception, satiety and food intake in humans were discussed, highlighting the importance of individual sweetness perceptual variations.

Methods

Peer-reviewed publications written in English were searched in PubMed, Google Scholar and Web of Science. Literatures covering the following topics were screened and reviewed: (1) hormonal and/or brain responses to sweet taste agonists presented in oral cavity or GIT (2) sweet taste perception, satiety and food intake. Studies on either caloric sugar or NNSs or both were included. According to the focus of current review, searched articles were included with the following

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4.

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Short Communication

Ethnic congruence of music and food affects food selection but not liking

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ABSTRACT

Research investigating whether hearing a particular type of ethnic music will influence people to choose food from that same culture has found mixed results. Some studies found that when given a selection of different ethnic foods subjects were more likely to choose the food that was typical of the culture whose music was playing. Other studies have found no effect. The present study investigated the effect of instrumental Italian or Spanish music played in a university dining hall on the selection of either an Italian (chicken parmesan) or a Spanish (seafood paella) entrée. On two different nights both the Italian and Spanish entrée were available and students could select from those two entrees or other food choices. Italian music was played on one night and Spanish on another. The number of people who chose the two entrees was recorded on both nights. In addition, the hedonic ratings of the two entrees were obtained when either congruent or incongruent music was being played during the meal. On both nights more people chose the chicken parmesan than chose the seafood paella. However, there was a significant effect of the music on food choice. A significantly greater proportion of diners selected the paella over the chicken parmesan on the night when the Spanish music was played (34%) than on the night when the Italian music was played (17%). There was no effect of the type of music on liking for the food, possibly because the music was not as loud where diners were eating as where they ordered.

1. Introduction

Music is a part of the "ambience" of a restaurant, along with the décor, lighting, temperature, and other environmental components. Recent research has found that the choice of music played in a restaurant might have a significant impact on the diners in a number of ways. For example, music has been found to affect speed of eating (Caldwell & Hibbert, 2002; Milliman, 1986; Roballey et al., 1985). In addition, classical music increases the amount of money diners spend on food (North & Hargreaves, 1998; North, Shilcock, & Hargreaves, 2003).

The perceived pleasantness of food can also be affected by music. In general, food is rated as more pleasant when it is consumed while listening to music the subject rates as pleasant and food is rated as less pleasant when consumed while listening to unpleasant music (Kantono et al., 2015, 2016). However, what music is considered pleasant might be context specific. Music that is pleasant in a nightclub might not be pleasant in a coffee house. In a similar vein, a certain type of music might be pleasant if it is appropriate for the restaurant in which it is played but unpleasant if it is inappropriate. Patrons might expect, and enjoy hearing, reggae music in a Jamaican restaurant but not in a French restaurant. These contextual preferences based on ethnicity might affect liking for the food consumed while listening to that music. Listening to Bob Marley might make jerk chicken taste better but coq au vin taste worse. That is, if the music in a restaurant is ethnically congruent with the food served, then liking for that food might be enhanced.

In addition to affecting how much a food is liked, hearing a particular kind of music prior to consumption of food in a restaurant might also affect food choice. Patrons might be predisposed to choose food that is congruent with the music being played. The findings that more expensive food and wine are chosen when classical music is being played (Areni & Kim, 1993; North & Hargreaves, 1998) might be examples of such an effect. Thinking that classical music is associated with having a lot of money might lead one to choose food that one imagines would be eaten by people who listen to such music (i.e., the more expensive things on the menu).

A similar predisposition might occur with ethnic music which might call to mind other aspects of that particular culture (i.e., priming of that culture would occur). In research (Bell, Meiselman, Pierson, & Reeve, 1994) conducted in a restaurant, environmental cues other than music (i.e., an Italian décor and Ital-

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5.

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Introduction to the Special Issue on Auditory Contributions to Food Perception and Consumer Behaviour

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1. Introduction

What we hear before and/or while we eat/drink affects our taste/flavour experiences, even if we don't realize it. While there has been a long history of sensory science research investigating the impact of food sounds during consumption (Zampini and Spence, 2004; see Spence, 2015, for a review), the focus of this special issue is rather on the product-extrinsic, or contextual/situational, cues such as music and ambient soundscapes, that have also been shown to influence what we expect, what we choose to buy/order in shops, restaurants, cafes, and bars, and how satisfied we are, as well as the perception we have of what we eat and drink (e.g., Biswas *et al.*, 2018; Feinstein *et al.*, 2002; Novak *et al.*, 2010; Septianto, 2016; Spence, 2012; Zellner *et al.*, 2017).

One area of particular interest for the present Special Issue relates to the recent emergence of a body of literature on the topic of 'sonic seasoning' (Spence, 2017): This is where music/soundscapes are especially chosen, or else designed/composed, in order to correspond to, and hence hopefully to modify, the associated taste/aroma/mouthfeel/flavour in food and beverages (e.g., Crisinel *et al.*, 2012; Reinoso Carvalho *et al.*, 2015; Wang and Spence, 2016). Sonic seasoning, then, represents one strand of research on crossmodal correspondences (see Spence, 2011, for a review). Interesting questions here

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6.

Journal of Oral Rehabilitation

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Review

The influence of oral health on patients' food perception: a systematic review

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SUMMARY **Oral food perception depends on somatosensory information that includes taste and can be modified by oral components and/or functions such as mastication. The purpose of this study was to describe the interplay between oral health, mastication and taste. A review according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist was conducted on 615 publications found by both PubMed and backward research. Thirty-one studies have been included. The results showed that the decline in taste ability observed during the healthy ageing process could be potentiated by the deterioration of oral health and poor oral hygiene. Prosthetic treatment could modify taste ability and oral food perception. A palatal covering with removable dentures can have an impact on taste perception which may depend on taste modality. During the mastication sequence, taste is apparently scattered throughout the oral cavity, probably through saliva. The deterioration of masticatory function modifies taste perception. Oral health and oral care should consider factors influencing patients' food perception and relations between taste and mastication. Therefore, dentists may modulate these factors to improve food perception and patients' eating pleasure and quality of life.**

KEYWORDS: taste, oral food perception, oral health, prosthodontic treatments, chewing, review

Accepted for publication 6 June 2017

Introduction

The goal of the dentist was to contribute towards maintaining good oral health and effective masticatory function. Some studies have shown a relationship between taste and oral health, between taste and prosthetic treatment and between taste and mastication. It is still difficult, however, to obtain clear understanding regarding these topics. A systematic review is needed. The objective of this study was to describe the interplay between oral health and care, mastication and food perception through taste and somatosensory sensibility. It focuses on the oral parameters influenced by dental care and suspected to interfere with food perception. The other factors shown in Fig. 1 are less likely to be influenced by dental work and have not been considered. Consequently, better understanding of the role of the dentist in maintaining taste and oral food perception is expected.

7.

Three approaches were determined according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (1). The first section explored the impact of oral health and oral hygiene on taste. The second section focused on the potential role of prostheses, especially palatal coverage, in taste, including the interplay between food perception and prosthesis. Finally, the third section explored the interactions between taste and masticatory function.

Materials and method

A thorough search of the literature was conducted using the MEDLINE database (via PubMed), and a systematic review according to the PRISMA checklist was applied.

Factors contributing to bone conduction: The outer ear

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(Received 2 May 2002; accepted for publication 4 November 2002)

The ear canal sound pressure and the malleus umbo velocity with bone conduction (BC) stimulation were measured in nine ears from five cadaver heads in the frequency range 0.1 to 10 kHz. The measurements were conducted with both open and occluded ear canals, before and after resection of the lower jaw, in a canal with the cartilage and soft tissues removed, and with the tympanic membrane (TM) removed. The sound pressure was about 10 dB greater in an intact ear canal than when the cartilage part of the canal had been removed. The occlusion effect was close to 20 dB for the low frequencies in an intact ear canal; this effect diminished with sectioning of the canal. At higher frequencies, the resonance properties of the ear canal determined the effect of occluding the ear canal. Sectioning of the lower jaw did not significantly alter the sound pressure in the ear canal. The sound radiated from the TM into the ear canal was investigated in four temporal bone specimens; this sound is significantly lower than the sound pressure in an intact ear canal with BC stimulation. The malleus umbo velocity with air conduction stimulation was investigated in nine temporal bone specimens and compared with the umbo velocity obtained with BC stimulation in the cadaver heads. The results show that for a normal open ear canal, the sound pressure in the ear canal with BC stimulation is not significant for BC hearing. At threshold levels and for frequencies below 2 kHz, the sound in the ear canal caused by BC stimulation is about 10 dB lower than air conduction hearing thresholds; this difference increases at higher frequencies. However, with the ear canal occluded, BC hearing is dominated by the sound pressure in the outer ear canal for frequencies between 0.4 and 1.2 kHz. © *2003 Acoustical Society of America.* [DOI: 10.1121/1.1534606]

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I. INTRODUCTION

Hearing by bone conduction as a physical phenomenon can be divided into three general routes (Tonndorf, 1966):

(1) the sound radiated into the external ear canal, termed the osseotympanic route,
(2) compression and expansion of the petrous bone, which results in displacement of fluid into the cochlea and, consequently, basilar membrane motion, and
(3) the inertial effect of the middle ear ossicles and the inner ear fluids.

It is the first route that is the scope of this investigation, in particular the different parts of the external ear (cartilage and soft tissue part of the canal, bony part of the canal, and the tympanic membrane) which contribute to the sound radiation into the external ear canal. Moreover, the influence of the sound radiated into the external ear canal on the total BC hearing is estimated.

When the head is subjected to a vibration, the vibration is transmitted to the temporal bone of the skull and causes a hearing sensation: this is termed BC sound or hearing by BC. The BC sound makes the skull vibrate relative to the surrounding air, which causes the surrounding air to be compressed and expanded, and an air-borne sound is radiated from the skull. Similarly, with BC stimulation, an air-borne sound is set up in the external ear canal. The slight difference between the sound radiated into the air surrounding the head and into the ear canal is that the ear canal itself is compressed and expanded from the skull vibrations; this distortion of the ear canal walls is the source of the radiated sound in the external ear canal.

Sound radiation into the ear canal with BC stimulation is well known and has been reported extensively in the literature. Berthold was one of the first to objectively present this phenomenon; he used a microphonic flame to show the alternating air pressure in the ear canal when a BC sound was presented to the skull (Bárány, 1938). Later, extensive investigations of ear canal sound pressure with BC stimulation were reported (Bárány, 1938; Huizing, 1960; Békésy, 1960; Elpern and Naunton, 1963; Tonndorf, 1966; Khanna *et al.*, 1976).

Conflicting theories and results on the influence of the ear canal sound pressure (ECSP) on hearing by BC have been reported. Wever and Lawrence (1954) describe the osseo-tympanic stimulation with BC as secondary to the inertial or compressional mode of BC stimulation. Kirikae (1959) stated that inertial effects dominate low-frequency BC hearing and compressional effects dominate high-

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8.

Kompis M, Caversaccio M-D (eds): Implantable Bone Conduction Hearing Aids.
Adv Otorhinolaryngol. Basel, Karger, 2011, vol 71, pp 10–21

Acoustic and Physiologic Aspects of Bone Conduction Hearing

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Abstract

Bone conduction (BC) is the way sound energy is transmitted by the skull bones to the cochlea causing a sound perception. Even if the BC sound transmission involves several pathways including sound pressure induced in the ear canal, inertial forces acting on the middle ear ossicles and cochlear fluids, alteration of the cochlear space, and pressure transmission through the 3rd window of the cochlea, the BC sound ultimately produces a wave motion on the basilar membrane similar to that of air-conducted sound. The efficiency of the BC stimulation is largely dependent on the skull bone where the skull acts as a rigid body at low frequencies and incorporates different types of wave transmission at higher frequencies. The interaural stimulation difference is determined by the difference between contralateral and ipsilateral BC sound transmission: the transcranial BC sound transmission. To benefit from binaural processing, the transcranial transmission should be low, while the same should be high when using BC hearing aids for unilateral deaf subjects. By appropriately positioning the stimulation, high or low transcranial transmission can be achieved.

The conventional way of auditory stimulation is by an airborne sound that is transmitted through the ear canal, where it induces mechanical vibrations in the eardrum that are transmitted via the middle ear ossicles and become a sound pressure in the cochlea (scala vestibuli). This sound pressure acts on the basilar membrane producing a traveling wave that excites the sensory cells in the organ of Corti causing an auditory sensation. Bone conduction hearing is when the sound is transmitted through the skull bone, cartilage, skin and soft tissue, and fluids in the body, ultimately resulting in a sound pressure in the cochlear scalae. This type of sound transmission is sometimes divided between body conduction and bone conduction, where the latter is only sounds transmitted in the skull bone. Here, for simplicity, both body and bone conduction will be referred to as bone conduction and abbreviated BC.

Clinical Measurements using Bone Conduction

Understanding the processes of BC sound was early driven by its use for differential diagnosis between conductive and sensorineural hearing loss. In the 19th century, the usage of the tuning fork provided tests as Weber test and Rinne test [1]. After the introduction of the audiometer and

9.

Hearing and stomatognathic system: Searching for a link

Stan układu stomatognatycznego a proces słyszenia

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A – research concept and design; B – collection and/or assembly of data; C – data analysis and interpretation;
D – writing the article; E – critical revision of the article; F – final approval of the article

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Abstract

Acoustic vibrations reach the inner ear fluids in 3 integral ways: through the air, bone, and soft tissue. The final stimulation of the hearing receptor is recognized as the result of various interactions appearing between them. Air conduction is best described as the most efficient mode of auditory stimulation. Soft tissue and bone conduction (including dentaural hearing), being frequently underestimated in the complicated process of hearing, are still less examined. Clinical observations prove that dental health may have a direct influence on hearing. Additionally, hearing improvement after dental treatment is of a permanent nature.

This review presents a hypothesis and supporting literature review that dental disorders may contribute to disturbances in the excitation and/or the transmission of vibrations through the bone to the hearing receptor. Dissociation in the relationship between stimuli reaching the cochlea simultaneously in 3 modes may have a negative impact on hearing acuity.

Key words: bone conduction, acoustic stimulation, dentition

Słowa kluczowe: przewodnictwo kostne, stymulacja akustyczna, uzębienie

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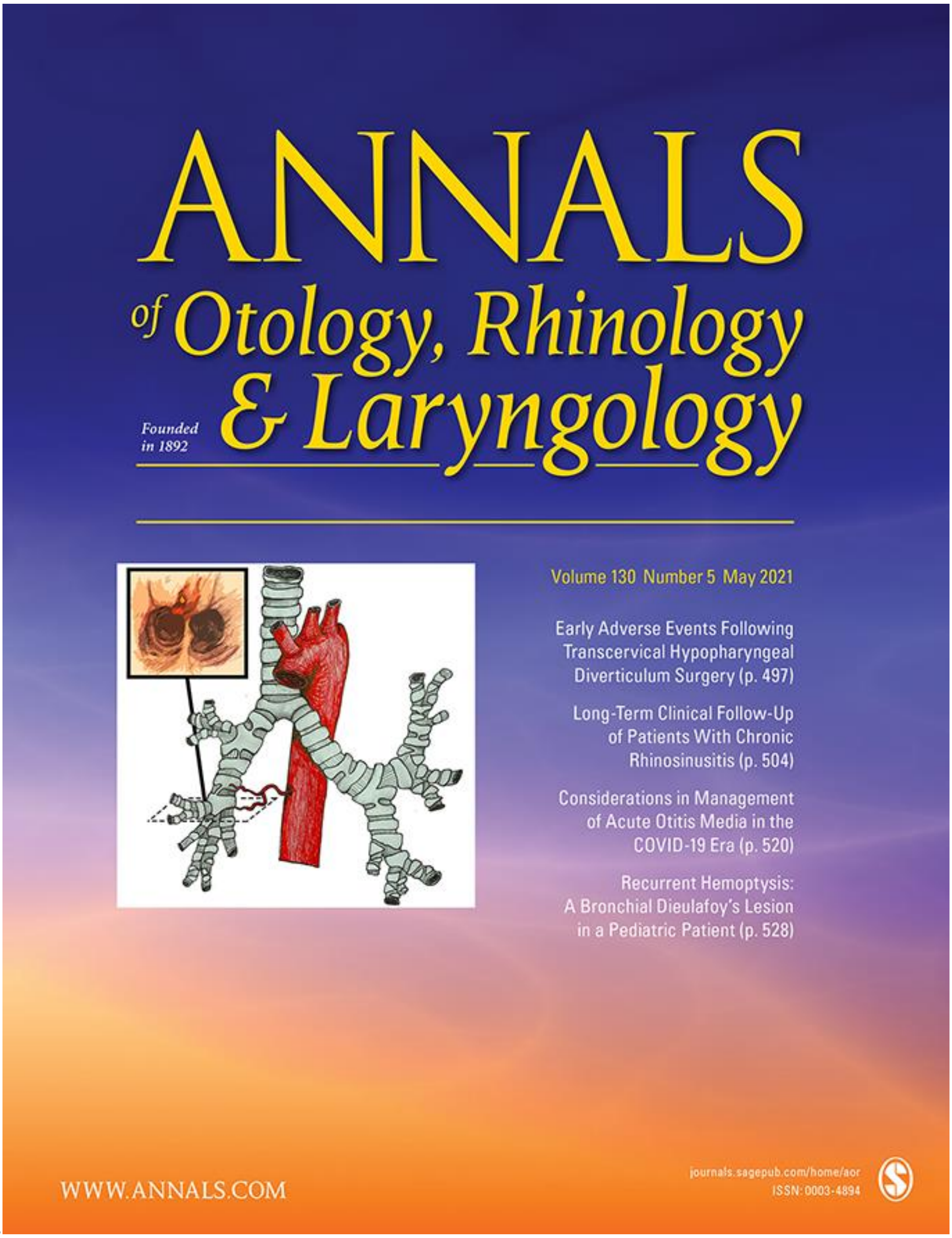
11. 
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Early Adverse Events Following Transcervical Hypopharyngeal Diverticulum Surgery (p. 497)
Long-Term Clinical Follow-Up of Patients With Chronic Rhinosinusitis (p. 504)
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Not Just Another Pint! The Role of Emotion Induced by Music on the Consumer's Tasting Experience

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Abstract

We introduce a novel methodology to assess the influence of the emotion induced by listening to music on the consumer's multisensory tasting experience. These crossmodal effects were analyzed when two contrasting music tracks (positive vs negative emotion) were presented to consumers while tasting beer. The results suggest that the emotional reactions triggered by the music influenced specific aspects of the multisensory tasting experience. Participants liked the beer more, and rated it as tasting sweeter, when listening to music associated with positive emotion. The same beer was rated as more bitter, with higher alcohol content, and as having more body, when the participants listened to music associated with negative emotion. Moreover, participants were willing to pay 7–8% more for the beer that was tasted while they listened to positive music. This novel methodology was subsequently replicated with two different styles of beer. These results are discussed along with practical implications concerning the way in which music can add significant value to how a consumer responds to a brand.

Keywords

Beer, flavor, music, crossmodal correspondences, sensory marketing, multisensory

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12.

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foods

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Article

Blending Emotions and Cross-Modality in Sonic Seasoning: Towards Greater Applicability in the Design of Multisensory Food Experiences

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Abstract: Sonic seasoning refers to the way in which music can influence multisensory tasting experiences. To date, the majority of the research on sonic seasoning has been conducted in Europe or the USA, typically in a within-participants experimental context. In the present study, we assessed the applicability of sonic seasoning in a large-scale between-participants setting in Asia. A sample of 1611 participants tasted one sample of chocolate while listening to a song that evoked a specific combination of cross-modal and emotional consequences. The results revealed that the music's emotional character had a more prominent effect than its cross-modally corresponding attributes on the multisensory tasting experience. Participants expressed a higher buying intention for the chocolate and rated it as having a softer texture when listening to mainly positive (as compared to mainly negative) music. The chocolates were rated as having a more intense flavor amongst those participants listening to 'softer' as compared to 'harder' music. Therefore, the present study demonstrates that music is capable of triggering a combination of specific cross-modal and emotional effects in the multisensory tasting experience of a chocolate.

Keywords: Bayesian; cross-modal; emotions; multisensory; sonic seasoning; tasting

1. Introduction

Sonic seasoning refers to music or soundscapes that have been selected, or else deliberately produced, in order to trigger specific effects on the multisensory tasting experience [1–4]. The approach derives from the framework of research on the cross-modal correspondences, which points to the majority of people tending to share systematic associations between features, attributes, or dimensions of experiences across the senses [5]. In this context, think, for example, of associating the high pitch of a sound with small size, or high elevation [6,7]. Music is, in fact, a rich production process involving a mix of specific auditory elements that are combined during composition (e.g., frequency ranges, pitch, tempo and loudness, amongst many other attributes). Thus, there may be several auditory features/dimensions that can be associated with elements from a wide range of possible tastes and flavors in a customized fashion. Such multisensory customization potentially allows for the modulation or modification of the consumers' experience of particular attributes of food and drink.

Musical tempo, for instance, has been shown to affect pleasure and arousal [8], while also affecting the tasting experience and shopping behavior [9]. Furthermore, the speed at which people eat and

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Listening to music can influence hedonic and sensory perceptions of gelati

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ABSTRACT

The dominant taste sensations of three different types of chocolate gelati (milk chocolate, dark chocolate, and bittersweet chocolate) were determined using forty five trained panellists exposed to a silent reference condition and three music samples differing in hedonic ratings. The temporal dominance of sensations (TDS) method was used to measure temporal taste perceptions. The emotional states of panellists were measured after each gelati-music pairing using a scale specifically developed for this study. The TDS difference curves showed significant differences between gelati samples and music conditions ($p < 0.05$). Sweetness was perceived more dominant when neutral and liked music were played, while bitterness was more dominant for disliked music. A joint Canonical Variate Analysis (CVA) further explained the variability in sensory and emotion data. The first and second dimensions explained 78% of the variance, with the first dimension separating liked and disliked music and the second dimension separating liked music and silence. Gelati samples consumed while listening to liked and neutral music had positive scores, and were separated from those consumed under the disliked music condition along the first dimension. Liked music and disliked music were further correlated with positive and negative emotions respectively. Findings indicate that listening to music influenced the hedonic and sensory impressions of the gelati.

1. Introduction

How people experience food is largely determined by the gustatory and olfactory senses (Ramírez, Martínez, Fernández, Corti Bielsa, & Farina, 2010). However, beyond the dominance of taste and smell there are other sensory systems contributing to food perception, including the trigeminal, visual, tactile, and auditory systems. This multisensory nature of food perception is an on-going area of enquiry, and while it has yet to be determined how diverse sensory dimensions integrate (Sester et al., 2013), studies on cross-modal sensory integration suggest that one sensory modality can enhance the response of another if both are active concurrently (Sagiv & Ward, 2006).

When considering cross-modal sensory interactions in the food sciences, the most often overlooked modality is audition (Spence & Shankar, 2010), which is unfortunate, as for most people food is rarely consumed in silence. Indeed, the sonic background in which we consume our food has been shown to influence our food choices (Stroebele & De Castro, 2004), as well as rate of consumption, identification, and hedonic experiences (Spence & Shankar, 2010). However, while a number of cross-modal interactions have been reported in the literature, including taste and odour; flavour and irritation, and; flavour and colour (Lawless & Heymann, 1999), comparatively less is known about the effect of the auditory modality on food perception. Of the few studies reported in the literature, interactions between pitch of musical instrument and five basic tastes of food names (Crisinel & Spence, 2009), flavours of chocolate milk with varying fat content (Crisinel & Spence, 2011), and pleasantness ratings of chocolate (Crisinel & Spence, 2012)

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Extrinsic Auditory Contributions to Food Perception & Consumer Behaviour: an Interdisciplinary Review

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Abstract

Food product-extrinsic sounds (i.e., those auditory stimuli that are not linked directly to a food or beverage product, or its packaging) have been shown to exert a significant influence over various aspects of food perception and consumer behaviour, often operating outside of conscious awareness. In this review, we summarise the latest evidence concerning the various ways in which what we hear can influence what we taste. According to one line of empirical research, background noise interferes with tasting, due to attentional distraction. A separate body of marketing-relevant research demonstrates that music can be used to bias consumers' food perception, judgments, and purchasing/consumption behaviour in various ways. Some of these effects appear to be driven by the arousal elicited by loud music as well as the entrainment of people's behaviour to the musical beat. However, semantic priming effects linked to the type and style of music are also relevant. Another route by which music influences food perception comes from the observation that our liking/preference for the music that we happen to be listening to carries over to influence our hedonic judgments of what we are tasting. A final route by which hearing influences tasting relates to the emerging field of 'sonic seasoning'. A developing body of research now demonstrates that people often rate tasting experiences differently when listening to soundtracks that have been designed to be (or are chosen because they are) congruent with specific flavour experiences (e.g., when compared to when listening to other soundtracks, or else when tasting in silence). Taken together, such results lead to the growing realization that the crossmodal influences of music and noise on food perception and consumer behaviour may have some important if, as yet, unrecognized implications for public health.

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'Striking a Sour Note': Assessing the Influence of Consonant and Dissonant Music on Taste Perception

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Abstract

We report two experiments designed to investigate the consequences of manipulating the harmonic content of background music on taste perception. The participants in the present study evaluated samples of mixed fruit juice whilst listening to soundtracks that had either been harmonised with consonant or dissonant musical intervals. Each sample of juice was rated on three computer-based scales: One scale was anchored with the words sour and sweet, while the other two scales involved hedonic ratings of the music and of the juice. The results of an internet-based pre-test revealed that participants reliably associated the consonant soundtracks with sweetness and the dissonant soundtracks with sourness. The results of the on-site experiments demonstrated that participants rated the juices as tasting significantly sweeter in the consonant than in the dissonant music condition, irrespective of the melody or instrumentation that were evaluated. These results therefore provide empirical support for the claim that the crossmodal correspondence between a higher level musical attribute (namely, harmony) and basic taste can be used to modify the evaluation of the taste of a drink.

Keywords

Crossmodal correspondences, harmony, taste, hedonic correspondences

1. Introduction

In recent years, a growing number of researchers have become increasingly interested in studying the role of the various crossmodal correspondences that exist between sound and taste/flavour in shaping our gustatory experiences. A large and still expanding list of correspondences have now been documented between specific sound and taste attributes — such as, for example, between high pitch and sweetness, or low pitch and bitterness (e.g., Bronner *et al.*,

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"A sweet smile": the modulatory role of emotion in how extrinsic factors influence taste evaluation

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ABSTRACT

It has recently been demonstrated that the reported tastes/flavours of food/beverages can be modulated by means of external visual and auditory stimuli such as typeface, shapes, and music. The present study was designed to assess the role of the emotional valence of the product-extrinsic stimuli in such crossmodal modulations of taste. Participants evaluated samples of mixed fruit juice whilst simultaneously being presented with auditory or visual stimuli having either positive or negative valence. The soundtracks had either been harmonised with consonant (positive valence) or dissonant (negative valence) musical intervals. The visual stimuli consisted of images of emotional faces from the International Affective Picture System (IAPS) with valence ratings matched to the soundtracks. Each juice sample was rated on two computer-based scales: One anchored with the words sour and sweet, while the other scale required hedonic ratings. Those participants who tasted the juice sample while presented with the positively-valenced stimuli rated the juice as tasting sweeter compared to negatively-valenced stimuli, regardless of whether the stimuli were visual or auditory. These results suggest that the emotional valence of food-extrinsic stimuli can play a role in shaping food flavour evaluation and liking.

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KEYWORDS
Crossmodal correspondences; facial emotions; harmony; taste; sensation transfer; hedonic correspondences

Recently, various studies have started to demonstrate robust associations between taste/flavour attributes and external visual (see Velasco, Salgado-Montejo, Marmolejo-Ramos, & Spence, 2014, for a review) as well as auditory stimuli (see Knöferle & Spence, 2012, for a review). For instance, sweetness and sweet-tasting foods tend to be associated with rounded typeface and packaging shapes, softer speech sounds, and harmonically consonant music; whereas sourness is associated with angular typeface and packaging shapes, sharper speech sounds, and harmonically dissonant music (Knoeferle, Woods, Käppler, & Spence, 2015; Mesz, Trevisan, & Sigman, 2011; Ngo et al., 2013; Salgado-Montejo et al., 2015a; Velasco et al., 2014; Velasco, Woods, Hyndman, & Spence, 2015). Beyond mere associations, looking at curved shapes has been demonstrated to enhance sweet sensitivity compared to angular shapes (Liang et al., 2016; Liang, Roy, Chen, & Zhang, 2013). Similarly, listening to soundtracks with auditory attributes that correspond to sweetness (Wang, Woods, & Spence, 2015) can alter the reported level of sweetness of the food itself (e.g. Crisinel et al., 2012; Reinoso Carvalho, Wang, van Ee, & Spence, 2016; Reinoso Carvalho, Wang, van Ee, Persoone, & Spence, 2017; Spence, Velasco, & Knoeferle, 2014; Wang, Keller, & Spence, 2017).

While the mechanism(s) underlying this taste modulation effect is(are) as yet unknown, one possibility is that the visual and auditory cues are somehow priming (or triggering) certain emotions in the mind of the participant. Consequently, the participants might then transfer these emotions to the food/drink that they happen to the tasting. For instance, we recently demonstrated that harmonic consonance was associated with sweetness whereas harmonic dissonance was associated with sourness instead (Wang & Spence, 2016). Furthermore, participants in that study rated the same juice mixture as sweeter or more sour (and also more or less liked) depending

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The Role of Sound Congruency on Ethnic Menu Item Selection and Price Expectations

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ABSTRACT
Earlier research considered ethnic congruent versus incongruent music; this study extended earlier research by comparing the impacts of ethnic congruent music, ethnic incongruent music and restaurant background sounds on the dining experience. Additionally, it extends earlier research considering the impact on menu item selection and price expectations based on the impact of music/sound. Findings indicated music congruence effects along with baseline sounds should be considered by practitioners and researchers. Italian folk music increased Italian item selections compared to restaurant background sounds. Thai folk music was equal to background sounds for Thai items. Higher expected prices were apparent when listening to both Italian music and background sounds.

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KEYWORDS
Congruency; ethnic food; ethnic music; Italian cuisine; menu selection; Thai cuisine

Introduction

The notion that restaurants strive to create an atmosphere that attracts customers through a process intended to meet and exceed customer expectations is not a new one. Earlier research has shown a connection among atmosphere and consumer behaviors such as customer satisfaction, customer loyalty, and positive word-of-mouth (Kristensen, Martensen, & Gronholdt, 1999; Robinson, Abbott, & Shoemaker, 2005). What is unclear are the specific strategies that should be implemented to create the right dining atmosphere to enhance the guest experience leading to beneficial outcomes such as more profitable menu item selection, increased sales, word-of-mouth and loyalty.

Music and sound are considered interior variables of the atmosphere that impact the dining experience (Edwards & Gustafsson, 2008). Earlier research has demonstrated numerous effects of music including its impact on perceptions of the restaurant's environment, consumer behavior, and spending patterns (Harrington, Ottenbacher, & Treuter, 2015). Further, it was determined that playing music had a positive impact on the restaurant patron's attitudes and

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Having a Drink with Tchaikovsky: The Crossmodal Influence of Background Music on the Taste of Beverages

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Abstract

Previous research has shown that auditory cues can influence the flavor of food and drink. For instance, wine tastes better when preferred music is played. We have investigated whether a music background can modify judgments of the specific flavor pattern of a beverage, as opposed to mere preference. This was indeed the case. We explored the nature of this crosstalk between auditory and gustatory perception, and hypothesized that the 'flavor' of the background music carries over to the perceived flavor (i.e., descriptive and evaluative aspects) of beverages. First, we collected ratings of the subjective flavor of different music pieces. Then we used a between-subjects design to cross the music backgrounds with taste evaluations of several beverages. Participants tasted four different samples of beverages under two contrasting audio conditions and rated their taste experiences. The emotional flavor of the music had the hypothesized effects on the flavor of the beverages. We also hypothesized that such an effect would be stronger for music novices than for music experts, and weaker for aqueous solutions than for wines. However, neither music expertise nor liquid type produced additional effects. We discuss implications of this audio-gustatory interaction.

Keywords

Crossmodal correspondences, multisensory perception, auditory-gustatory interaction, background music, wine, expertise

1. Introduction

When talking about the culinary delights we experienced on a vacation, we tend to describe not only the gustatory properties of food and drinks we consumed, but we likewise describe the romantic ambient light at sunset, the fantastic jazz combo that played in the background, and the heavy crystal

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Variations in Food Acceptability with Respect to Pitch, Tempo, and Volume Levels of Background Music

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Abstract

This study aimed to determine whether pitch, tempo, and volume levels of music stimuli affect sensory perception and acceptance of foods. A traditional music piece was arranged into versions at two pitches, two tempos, and two volumes. For each session, chocolate and bell peppers were presented for consumption under three sound conditions: 1) upper or 2) lower level with respect to each of the three music elements, and 3) silence. Over three sessions, participants evaluated flavor intensity, pleasantness of flavor, texture impression, and overall impression of food samples, in addition to the pleasantness and stimulation evoked by the music stimuli. Results showed that lower-pitched and louder music stimuli increased hedonic impressions of foods compared to their respective counterparts and/or the silent condition. While the effects of music element levels on hedonic impressions differed with the type of food consumed, the participants liked the foods more when music stimuli were perceived as more pleasant and stimulating. Flavor was perceived as more intense when participants were more stimulated by the music samples. Although a specific element of music stimuli was manipulated, perceptions of other elements also varied, leading to large variations in the music-evoked pleasantness and stimulation. In conclusion, the findings provide empirical evidence that hedonic impressions of foods may be influenced by emotions evoked by music selections varying in music element levels, but it should be also noted that the influences were food-dependent and not pronounced.

Keywords

Music, pitch, tempo, volume, acceptance, flavor, texture

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High-Tempo and Stinky: High Arousal Sound–Odor Congruence Affects Product Memory

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Abstract

The tendency to match different sensory modalities together can be beneficial for marketing. Here we assessed the effect of sound–odor congruence on people's attitude and memory for products of a familiar and unfamiliar brand. Participants smelled high- and low-arousal odors and then saw an advertisement for a product of a familiar or unfamiliar brand, paired with a high- or low-arousal jingle. Participants' attitude towards the advertisement, the advertised product, and the product's brand was measured, as well as memory for the product. In general, no sound–odor congruence effect was found on attitude, irrespective of brand familiarity. However, congruence was found to affect recognition: when a high-arousal odor and a high-arousal sound were combined, participants recognized products faster than in the other conditions. In addition, familiar brands were recognized faster than unfamiliar brands, but only when sound or odor arousal was high. This study provides insight into the possible applications of sound–odor congruence for marketing by demonstrating its potential to influence product memory.

Keywords

Crossmodal congruence, arousal, attitude, product memory, brand, sound, odor

1. Introduction

Whether it is a bottle of cola, a request for charity money, or a picture portraying the perfect car, we are exposed to various forms of advertising every day. Advertisements have become part of our daily lives (Dyer, 1982). Because of technological developments like the internet and social media, one

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INVITED REVIEW

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Tribology and its growing use toward the study of food oral processing and sensory perception

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Abstract

Here we provide a comprehensive review of the knowledge base of soft tribology, the study of friction, lubrication, and wear on deformable surfaces, with consideration for its application toward oral tribology and food lubrication. Studies on "soft-tribology" have emerged to provide knowledge and tools to predict oral behavior and assess the performance of foods and beverages. We have shown that there is a comprehensive set of fundamental literature, mainly based on soft contacts in the Mini-traction machine with rolling ball on disk configuration, which provides a baseline for interpreting tribological data from complex food systems. Tribology-sensory relationships do currently exist. However, they are restricted to the specific formulations and tribological configuration utilized, and cannot usually be applied more broadly. With a careful and rigorous formulation/experimental design, we envisage tribological tools to provide insights into the sensory perception of foods in combination with other in vitro technique such as rheology, particle sizing or characterization of surface interactions. This can only occur with the use of well characterized tribopairs and equipment; a careful characterization of simpler model foods before considering complex food products; the incorporation of saliva in tribological studies; the removal of confounding factors from the sensory study and a global approach that considers all regimes of lubrication.

KEYWORDS
food oral processing, friction, lubrication, saliva, sensory perception, soft tribology

1 | INTRODUCTION

Tribology is the study of lubrication, friction, and wear between surfaces in relative motion. These occur during motion of oral surfaces (tongue, palate, and teeth) and arise in the oral processing of food and beverages. Two of the seminal papers that considered lubrication as an important factor in food oral processing were published in the Journal of Texture Studies, namely Kokini, Kadane, and Cussler (1977) and Hutchings and Lillford (1988) making it fitting to review the progress of this topic in this 50th Anniversary edition. Both publications highlight the dynamic nature of food oral processing and demonstrate the need for more than one instrumental technique to evaluate food texture, with lubrication being a key component together with the need for methods to capture food breakdown and the influence of human saliva. Kokini et al. (1977) in particular postulated that sensory attributes of smoothness and slipperiness are assessed in-mouth when the tongue is in lubricated contact with the oral surfaces, and provided some evidence to support the notion that these are proportional to friction force (smoothness) or both viscous and friction forces (slipperiness), respectively, for simple fluids.

Since these two pioneering articles featured in the Journal of Texture Studies, studies on "soft-tribology" (i.e., tribology involving at least one compliant substrate) have emerged over the last decade or so to provide knowledge and tools to assess the lubrication behavior of foods and beverages, as well as model fluids and soft solids. Many

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ORIGINAL PAPER

Impact of Oil-in-Water Emulsion Composition and Preparation Method on Emulsion Physical Properties and Friction Behaviors

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Abstract Emulsions have been used as a model food system for many studies on food behavior, including tribological studies. Several studies have examined the effect of fat content and emulsifier on emulsion friction behavior; however, other emulsion parameters such as ionic strength, pH, and homogenization pressure have received little attention in the literature. Additionally, emulsion friction measurements are generally compared to sensory data rather than physical property data. Thus, the objective of this study was to investigate the effect of various emulsion parameters on emulsion physical properties and rheological and friction behavior. Emulsion salt content, pH, and homogenization pressure all affected friction behavior, with specific effects dependent on the emulsifying protein. All emulsions showed reduced friction coefficient with increased fat content. Emulsion rheological behavior was not strongly impacted by changes in the emulsion parameters. Changing emulsion pH had the strongest effect on emulsion physical properties. The results of this study suggest that tribology may be used to develop a "fingerprint" for emulsions prepared using different parameters, allowing improved differentiation of these emulsions compared to traditional rheometry.

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Keywords Soft tribology · Food · Emulsion · Physical properties

1 Introduction

Emulsions are used in many commercial food products. Developing emulsions with reduced fat but sensory texture similar to full-fat emulsions has been a major challenge for industry [1, 2] and is a subject that has received considerable attention in food research. Fat replacers can provide bulk, but often give undesirable sensory properties to the emulsion. Although lower-fat emulsions can be designed to have similar rheological behavior to their full-fat counterparts, they often differ in sensory texture [3]. Generally, a smooth, creamy mouthfeel is considered desirable for an emulsion; fat replacers may not provide this mouthfeel. It has been shown that traditional rheometry is insufficient to describe emulsion texture as measured by a sensory panel [2, 4]. Additional information is needed to fully describe emulsion texture and assist in the development of lower-fat emulsions with desirable textures.

Tribology has been suggested as a possible technique to provide additional information on emulsion, and other food, mechanical behaviors [5]. In the study of friction and lubrication, tribology has gained interest over the past decade as a method of measuring friction behavior of foods and model food systems. Several studies have related instrumental friction to sensory texture [5–8], and the relationship between various textural aspects and oral friction behavior has been noted [2, 5, 8]. Nevertheless, tribology is relatively new to food research, and additional study is needed to expand the general knowledge base of food friction behavior.

Tribological testing is performed on two sliding surfaces with a lubricant between them. Typical testing apparatus

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ORAL PHYSIOLOGY AND TEXTURE PERCEPTION OF SEMISOLIDS

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ABSTRACT

In the oral cavity, the food is subjected to several mechanical and chemical processes. It is fractured by the teeth, diluted and broken down by saliva, heated or cooled by the ambient temperature of the mouth, formed into a bolus and finally swallowed. Numerous receptors in the oral cavity and nose respond to the initially ingested food and monitor the changes during processing. This leads to central perceptions of taste, odor, irritation and texture of the food. Most sensations associated with food texture occur only when the food is manipulated, deformed or moved across the oral receptors. In addition, people assessing the same stimulus differ in their ratings of that stimulus and their oral physiological parameters also exhibit inter-individual variations.

This paper is based on the PhD thesis of one of the authors. It gives an overview of this study and includes related work of other authors. The aim of our research was to improve the understanding of oral texture perception, in particular to examine the role of oral physiological processes in oral texture perception of semisolids and to investigate whether individual differences in perception could be attributed to differences in oral physiology among subjects.

The results of our study demonstrate that oral physiological parameters such as oral sensitivity, tongue movements, temperature and saliva composition are of importance for texture perception of semisolids. Many parameters of oral physiology correlate with various perceived texture attributes. This

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24.

R: Concise Reviews in Food Science

The Role of Oral Processing in Dynamic Sensory Perception

Kylie D. Foster, John M.V. Grigor, Jean Ne Cheong, Michelle J.Y. Yoo, John E. Bronlund, and Marco P. Morgenstern

Abstract: Food oral processing is not only important for the ingestion and digestion of food, but also plays an important role in the perception of texture and flavor. This overall sensory perception is dynamic and occurs during all stages of oral processing. However, the relationships between oral operations and sensory perception are not yet fully understood. This article reviews recent progress and research findings on oral food processing, with a focus on the dynamic character of sensory perception of solid foods. The reviewed studies are discussed in terms of both physiology and food properties, and cover first bite, mastication, and swallowing. Little is known about the dynamics of texture and flavor perception during mastication and the importance on overall perception. Novel approaches use time intensity and temporal dominance techniques, and these will be valuable tools for future research on the dynamics of texture and flavor perception.

Keywords: flavor, food structure, mastication, sensory perception, texture

Introduction

The food industry has relied mostly on incremental innovation for its new product launches, but is becoming increasingly aware that breakthrough, "new to the world" innovations are needed to remain competitive (Business Insights 2009). The incorporation of bioactive ingredients and modification of food structure to generate novel flavor and texture sensations in products that provide consumers with unique eating experiences is increasing the importance of understanding the relationships among food structure, mastication, and sensory perception.

It is generally considered that the way food is broken down intraorally influences the perception of that food and that these perceptions vary between individuals for many reasons, including age, physiological state, and eating occasion (Braxton and others 1996; Agrawal and others 1998; Szczesniak 2002). For example, Braxton and others (1996) found tenderness perception to be related to chewing efficiency and patterns (chewing time, number of chews, and muscle activities), processes that are known to differ from person to person and among foods. Sensory perception occurs during the full duration of mastication and must therefore be understood in relation to time-dependent processes during mastication.

Some time ago, there was a call for an integrated approach to this research (for example, Lucas and others 2004; Nishinari 2004). Since then, only little progress has been made, most likely because of the complex nature of foods and the difficulty of investigating the effect of single structural attributes on mastication and sensory perception. Texture and flavor (olfaction, gustation, and trigeminal responses) are considered the 2 most important attributes in the palatability of foods (Szczesniak 1963). They are complex perceptions that require dynamic sensory methods for evaluation. This review focuses on the role of human oral processing in dynamic sensory perception, with particular emphasis on the structural properties and breakdown of solid foods.

Overview of Human Mastication

Mastication is a complex process involving rhythmical jaw movements whereby the sizes of particles in the bolus are reduced and lubrication is provided to produce a bolus suitable for swallowing. Oral processing mostly involves the upper (maxilla) and lower (mandible) jaw, the tongue and to a lesser extent the cheeks and lips (Hiiemae and others 1996). The brain stem central pattern generator (CPG) activates the motor programme, which coordinates the activities of the jaw, tongue, and facial muscles (Dellow and Lund 1971; Yamada and others 2005). Sensory feedback from different types of receptors (for example, muscle spindles of the elevator muscles, the periodontal receptors, the receptors within the temporomandibular joints, skin receptors, and taste receptors) allows the motor programme to adapt continuously throughout a chewing sequence to the properties of the bolus (Woda and others 2006).

Transport in the mouth has been divided into 3 stages (stages I to III), which are later followed by a clearance stage. Stage I transport is the preparatory phase, representing the transport from the front of the mouth to the (pre) molars and involves low amplitude simple jaw movements in which the teeth do not come into occlusion (Hiiemae and Palmer 1999). Stage II transport is the reduction phase, representing the reduction of particle size by chewing in cycles. The cycles include a closing phase, a phase when the teeth are close to full occlusion and an opening phase. In some cycles, food is only transported, involving opening and closing strokes, without occlusion (Wilkinson and others 2000). The number of chewing cycles required to prepare a bolus for swallowing is related to the bite volume and consistency of the food (Thexton and others 1980; Peyron and others 1997; Thexton and Hiiemae 1997). The tongue plays an important role during this stage, deciding whether particles are sufficiently small and moistened for swallowing or require more reduction between the

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Food Oral Processing: Conversion of Food Structure to Textural Perception

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Keywords

sensory texture, rheology, fracture, mastication, physical properties

Abstract

Food oral processing includes all muscle activities, jaw movements, and tongue movements that contribute to preparing food for swallowing. Simultaneously, during the transformation of food structure to a bolus, a cognitive representation of food texture is formed. These physiological signals detected during oral processing are highly complex and dynamic in nature because food structure changes continuously due to mechanical and biochemical breakdown coupled with the lubricating action of saliva. Multiple and different sensations are perceived at different stages of the process. Although much work has focused on factors that determine mechanical (e.g., rheological and fracture) and sensory properties of foods, far less attention has been paid to linking food transformations that occur during oral processing with sensory perception of texture. Understanding how food structure influences specific patterns of oral processing and how these patterns relate to specific textural properties and their cognitive representations facilitates the design of foods that are nutritious, healthy, and enjoyable.

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Review

A review: Crispness in dry foods and quality measurements based on acoustic–mechanical destructive techniques

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ABSTRACT

Research during the past years has focused on crispness because of the great interest of consumers towards crispy foods. Currently crispness is measured with sensory, mechanical and morphological variables. Recently, the analysis of acoustic recordings with mechanical testing results appears to be an interesting technique of crisp foods. The first part of this article reviews briefly the definition and the determination of crispness by different test methods. The second part summarizes the results of studies conducted worldwide on the crispness which use destructive acoustic–mechanical methods.

Contents

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ADAPTATION OF ORAL PROCESSING TO THE FRACTURE PROPERTIES OF SOFT SOLIDS

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ABSTRACT

Hardness and rubberiness are distinct textural properties that are associated with extended oral processing times and therefore of interest to designing food structure for specific textural properties. Model food gels were developed with (1) increasing strength/hardness and constant deformability or (2) increasing deformability/rubberiness within a limited range of strength. Gel structures were characterized based on mechanical properties and the muscle activity (electromyography) and mandibular movements (three-dimensional jaw tracking) required for oral processing. Increased strength or deformability required more chewing cycles and increased muscle activity to breakdown samples for swallowing. In contrast, jaw movement amplitude increased in all directions with increased strength and remained constant or decreased with increased deformability. Specific mechanical properties that were correlated with oral processing parameters changed as chewing progressed, possibly reflecting a change in dominate mechanical properties and sensory perception during oral processing.

PRACTICAL APPLICATIONS

A fundamental understanding of how food structure determines sensory texture is essential to designing foods that are healthy and desirable to consumers. Oral processing, from first bite through swallowing, is the main physiological element of texture evaluation. Model soft solid foods with increasing strength/hardness or deformability/rubberiness were developed and characterized by mechanical tests and oral processing. Mastication of harder or more deformable structures required different chewing movements in bolus preparation. The specific mechanical properties relating to oral processing may change during the chewing sequence.

INTRODUCTION

There is a continuous desire to reformulate foods with altered composition (e.g., decreased sugar, salt or fat; gluten free) without changing properties associated with hedonic quality such as texture. The goal is to produce the same texture but with a different mixture of molecules, and this requires understanding how food structure produces specific textural properties. Another area of interest is the relationship between food structure and satiety (Hogenkamp *et al.* 2011). Foods that require more oral processing time are generally associated with increased satiety (de Graaf and Kok 2010). Increased gel strength (fracture stress) and gel deformability (fracture strain) are associated with extended

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THE NEURAL REPRESENTATION OF ORAL TEXTURE INCLUDING FAT TEXTURE

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Fat texture, food texture, obesity, olfaction, sensory-specific satiety, taste, viscosity

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ABSTRACT

The brain areas that represent taste also provide a representation of oral texture. Fat texture is represented by neurons independently of viscosity: some neurons respond to fat independently of viscosity, and other neurons encode viscosity. The neurons that respond to fat also respond to silicone and paraffin oil, indicating that the sensing is texture- not chemo-specific. This fat sensing is not related to free fatty acids such as linoleic acid; a few other neurons with responses to free fatty acids typically do not respond to fat in the mouth. Fat texture-sensitive neurons are found in the primary taste cortex, the secondary taste cortex in the orbitofrontal cortex where the pleasantness of food is represented, and in the amygdala. Different neurons respond to different combinations of texture, taste, oral temperature, and in the orbitofrontal cortex to olfactory and visual properties of food. Complementary human functional neuroimaging studies are described.

PRACTICAL APPLICATIONS

This research has implications for understanding how fat in the mouth is sensed. It therefore has implications for the design of foods that may mimic the mouthfeel of fat, but not its energy content.

INTRODUCTION

The aims of this paper are to describe how oral texture, including fat, is represented in the brain. This is an important issue, for it is not yet clear how oral fat is sensed, and evidence from neuroscience is providing indications about this by showing what must have been transduced by receptors in the mouth, in order to produce the neuronal responses found in the brain. Moreover, fat in the diet may be pleasant, yet its intake must be controlled, and understanding the rules by which the pleasantness of fat is regulated is important. In addition, the brain's representation of oral fat is frequently in terms of particular combinations with other sensory aspects of food, including taste, texture and olfactory inputs, and these combinations are important for understanding the full impact of the fat in food in the mouth on the pleasantness of food.

Because the representation of oral texture in the mouth is closely linked to taste processing in the brain, we start with an overview of taste pathways and processing in the brain, before we consider how oral texture is represented in the same brain areas, and is represented frequently but not always in combination with taste. To make the results relevant to understanding the control of human food intake, complementary evidence is provided by neurophysiological studies in nonhuman primates in which the taste and related pathways are similar to those in humans (Norgren 1984; Rolls and Scott 2003; Rolls 2005; Rolls and Grabenhorst 2008; Small and Scott 2009), and by functional neuroimaging studies in humans. A broad perspective on brain processing involved in hedonic aspects of the control of food intake and in affective responses more generally is provided by Rolls (2005). By oral texture, I mean texture, somatosensory, signals produced by stimuli in the mouth. By oral fat texture I mean the oral texture stimulus produced by fat in the mouth. The perceptual qualities of these stimuli have been investigated by Kadohisa *et al.* (2005a).

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As bitter as a trombone: Synesthetic correspondences in nonsynesthetes between tastes/flavors and musical notes

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In parallel to studies of various cases of synesthesia, many cross-modal correspondences have also been documented in nonsynesthetes. Among these correspondences, implicit associations between taste and pitch have been reported recently (Crisinel & Spence, 2009, 2010). Here, we replicate and extend these findings through explicit matching of sounds of varying pitch to a range of tastes/flavors. In addition, participants in the experiment reported here also chose the type of musical instrument most appropriate for each taste/flavor. The association of sweet and sour tastes to high-pitched notes was confirmed. By contrast, umami and bitter tastes were preferentially matched to low-pitched notes. Flavors did not display such strong pitch associations. The choice of musical instrument seems to have been driven primarily by a matching of the hedonic value and familiarity of the two types of stimuli. Our results raise important questions about our representation of tastes and flavors and could also lead to applications in the marketing of food products.

Synesthesia is an intriguing condition. Although the first detailed scientific report on synesthesia dates from more than a century ago (Galton, 1880), its mechanisms are still unclear (Cytowic & Eagleman, 2009). More attention has been devoted by researchers recently to various cases of synesthesia (see Hochel & Milán, 2008, for a review; see also Harrison, 2001). But are the perceptual experiences of synesthetes so very different from those of nonsynesthetes? Our senses certainly do not work in isolation from each other. We live in a multisensory world, and our brains constantly combine information from different sensory modalities in order to make sense of our environment (see Calvert, Spence, & Stein, 2004). The senses of taste and smell are so tightly combined in the evaluation of flavor that it is sometimes considered a form of synesthesia that is common to us all (Auvray & Spence, 2008; Small & Prescott, 2005; Stevenson & Tomiczek, 2007; see also Djordjevic, Zatorre, & Jones-Gotman, 2004). Moreover, the evaluation of the sweetness (i.e., a gustatory property) of a novel odor can be modified simply by pairing it during training with a sweet taste (Stevenson, Boakes, & Prescott, 1998). A number of other cross-modal associations have now also been reported, such as between pitch and visual size (Evans & Treisman, 2010; Gallace & Spence, 2006; Parise & Spence, 2009), between brightness and the frequency of vibrotactile stimuli (Martino & Marks, 2000), or between colors and tastes (O'Mahony, 1983). The use of audiovisual metaphors for loudness, pitch, and brightness has also been reported (Marks, 1982). These associations are different from those present in synesthetes in that they are bidirectional (synesthesia is usually thought of as being unidirectional, but see Johnson, Jepma, & de Jong, 2007), and a stimulus presented in one sensory modality does not elicit a conscious experience in another modality. However, the existence of these cross-modal associations supports the hypothesis that synesthesia might originate in feedback connections from a point of convergence of the two sensory pathways (Grossenbacher & Lovelace, 2001). Several researchers have argued in recent years that cross-modal associations and synesthesia may be usefully compared in an effort to better understand both phenomena (e.g., Sagiv & Ward, 2006; Ward, Huckstep, & Tsakanikos, 2006).

Associations between tastes and particular pitches have been reported previously by Holt-Hansen (1968, 1976) in a comparison of different brands of beer. It has also recently been shown that basic tastes are associated to relative pitch (Crisinel & Spence, 2009, 2010): In implicit association tasks, participants tend to associate sweet and sour tastes with high-pitched sounds. In these studies, tastes were evoked via the names of food or drink items. This method could therefore not totally exclude the possibility that it was the names themselves that may have had an influence on the associations observed (see also Simner, Cuskley, & Kirby, 2010). Moreover, this method introduced variability between participants depending on their experience with the food/drink items that were used. For example, coffee, which was intended to represent a bitter taste, might have evoked a sweet taste in those participants who normally drank their coffee with sugar and milk.

Our goal in the present study was to replicate Crisinel and Spence's (2009, 2010) recent studies but using real tastants and flavors instead of merely the names of such

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MISCELLANEOUS

Influence of external ear occlusion on food perception

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Abstract

Purpose The present study aimed to explore if food perception can be influenced by sound mastication level when the external ear canal was occluded.

Methods Fifty-nine adults (38 women) with normal hearing, smell, and taste participated in the study. They tasted five crispy and five soft food items over two sessions: one with and one without an earplug inserted in the external ear canal. Participants were asked to rate freshness and taste of the food as well as their willingness to eat more of it and how much they usually like this kind of food. The sound pressure level related to the food mastication was recorded with a probe microphone placed in the external ear canal.

Results Compared to the open ear canal condition, levels of the mastication sounds were higher when the participants had their ears occluded, as well as for crispy than for soft food. Regarding food freshness, food appreciation, and willingness to eat more of the same food, there was no significant difference concerning food type, ear condition, and sex. For soft foods, men rated their usual liking of this food higher when they were wearing ear plugs compared to the opened condition.

Conclusion Plugging the ear canals led to increased mastication sound levels. Participants did not seem to consider these additional acoustic cues when they rated food freshness, food appreciation, and willingness of eating the specific food. Only men seemed to take these cues into account when they rated their habit consumption of soft food.

Keywords Taste perception · Auditory perception · Sound · Food appreciation · Food freshness

Introduction

The associative relation between sound and food was investigated decades ago. Drake [1] was within the first studies to record the parameters—frequency, intensity, and duration—associated with sounds produced during food mastication. He found the differences of sound intensity between types of food, such as crispy brown bread, peanuts, apples, and soft white bread, when a microphone was pressed against the cheek. The study revealed that food mastication sounds recorded with the cheek method were more on the low-frequency range than the sounds recorded with a microphone placed closed to the mouth. Drake [1] questioned the latter method, because the sounds could be dampened by the cheek and tongue tissues. Dacremont et al. [2] examined the contribution of bone and air conductions on perception of food mastication sounds according to the eating technique—biting or chewing. Results suggested that both air and bone conductions contributed for perception of sound mastication when biting, whereas air conduction seemed to have a better contribution than bone conduction when chewing food.

Hearing sounds made by food when eating can provide information on food quality [3]. Biting sounds are louder with a higher frequency spectrum for crispy fresh food, such as potato chips, than for the staler food [4]. Zampini et al. [3] showed that changing sound parameters (frequency or intensity) associated with food can modulate the crispy/soft

Benoît Jutras and Antonia Lüönd shared first authorship.

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Influence of ionic strength changes on the structure of pre-adsorbed salivary films. A response of a natural multi-component layer

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ABSTRACT

Salivary films coating oral surfaces are critically important for oral health. This study focuses on determining the underlying nature of this adsorbed film and how it responds to departures from physiological conditions due to changes in ionic strength. Under physiological conditions, it is found that pre-adsorbed in vitro salivary film on hydrophobic surfaces is present as a highly hydrated viscoelastic layer. We follow the evolution of this film in terms of its effective thickness, hydration and viscoelastic properties, as well as adsorbed mass of proteins, using complementary surface characterisation methods: a Surface Plasmon Resonance (SPR) and a Quartz Crystal Microbalance with Dissipation Monitoring (QCM-D). Our results support a heterogeneous model for the structure of the salivary film with an inner dense anchoring layer and an outer highly extended hydrated layer. Further swelling of the film was observed upon decreasing the salt concentration down to 1 mM NaCl. However, upon exposure to deionised water, a collapse of the film occurs that was associated with the loss of water contained within the adsorbed layer. We suggest that the collapse in deionised water is driven by an onset of electrostatic attraction between different parts of the multi-component salivary film. It is anticipated that such changes could also occur when the oral cavity is exposed to food, beverage, oral care and pharmaceutical formulations where drastic changes to the structural integrity of the film is likely to have implications on oral health, sensory perception and product performance.

1. Introduction

Saliva has a unique ability to adsorb onto substrates of practically any chemical nature in a form of a multi-component protein-rich film [1–3]. The presence of this film was clearly linked to an improvement in the boundary lubrication between sliding surfaces [3,4], which has implications for oral health and comfort [5] as well as in food perception [6]. People with impaired saliva production or quality (xerostomia, dry mouth syndrome) suffer from a variety of symptoms including problems with mastication, swallowing and speech as well as from more rapid wear of their teeth [5]. Currently available salivary substitutes (artificial saliva) offer only limited relief to this highly uncomfortable condition [7,8]. One of the reasons can be their failure to satisfactorily mimic both bulk and interfacial physical properties of natural saliva [9], which are still not fully characterised nor understood.

To begin unravelling the mechanisms behind salivary film functionality, we examine the structure of a salivary film adsorbed in vitro on model hydrophobic polydimethylsiloxane surfaces. It was suggested that the adsorbed salivary films are structurally heterogeneous [1,2], with a uniform thin 'inner layer' formed by small salivary proteins and non-glycosylated parts of salivary mucins as well as an irregular 'outer layer' of sparsely distributed mucin-rich aggregates. The structure of the salivary films was found to be similar to those formed by purified salivary mucin MUC5B [2,10] and therefore, this mucin was suggested to be an important structural component of salivary pellicle. In their natural form, mucins are found associated with small molecular weight proteins [11], which can affect their network forming ability [12] as well as viscoelasticity of the interfacial films [13]. It is currently unknown how the multi-component character of the saliva affects the functions of the salivary pellicle in the oral environment, for example its lubrication and mechanical barrier functions under different oral conditions to which these films are exposed during the day.

This paper demonstrates that under physiological conditions, saliva is adsorbed in the form of a highly viscoelastic solid-like film on hydrophobic surfaces. The study examines how key structural attributes of the pre-adsorbed salivary film alter dramatically upon

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DISCUSSION PAPER

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The role of saliva in oral processing: Reconsidering the breakdown path paradigm

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Abstract

We discuss food oral processing research over the last two decades and consider strategies for quantifying the food breakdown model, originally conceptualized by Hutchings and Lillford. The key innovation in their seminal 1988 paper was shifting the focus from intact food properties, measured in the lab, toward strategies to capture the dynamic nature of eating. This has stimulated great progress in the field, but a key aspect missing in oral processing research is the conversion of the Hutchings and Lillford breakdown path conceptual model into quantifiable parameters considered in the context of physiological factors such as saliva and oral movements. To address these shortcomings, we propose the following analysis: Hutchings's and Lillford's definitions of "Structure" and "Lubrication" are incomplete and they comprise many and varied physicochemical properties. We offer, here, a deeper analysis of each parameter, and propose strategies for researchers to consider in their quantification as an update of the Hutchings and Lillford Breakdown path.

KEYWORDS
oral processing, rheology, saliva, sensory, texture and mouthfeel, tribology

1 | INTRODUCTION

Several decades of research into food physical properties has led to good integration of texture measurements and sensory testing, integration that continues to provide insights about oral processing. For example, techniques like time-intensity and temporal dominance of sensations are moving our focus from measuring static properties—which texture measurements historically probed—to capturing dynamic behavior. But texture is our brain's description of interactions between food and our physiology, as Hutchings and Lillford (1988) argued in their statement that texture exists in the brain. As such, using correlations of instrumental measurements performed in vitro with sensory data collected in vivo will not help us fully explicate the causality tying sensory percepts to physical properties. To complete the link, we hypothesize, requires in vitro experiments aimed at elucidating the physics underlying the processes occurring in-mouth. Liu, Stieger, van Der Linden, and van de Velde (2015), for example, present a highly integrated study into the structure and breakdown of emulsion-filled gels by using in vitro and in vivo techniques. Eating comprises mechanical and chemical actions, interactions between food and receptors, signal transfer to the brain, cognition, and feedback. This complex system places rheology (i.e., flow), physiology, and psychology as foundational disciplines in oral processing research. These disciplines therefore provide a framework for elucidating the following relationships: (a) the interplay between deformations (e.g., bending and puncture [Castro-Prada, Meinders, Primo-Martin, Hamer, & van Vliet, 2012] or dilution [Chen & Lolivret, 2011]), and food physical properties (e.g., shear viscosity, fracture behavior, acoustic response), (b) how those properties are "detected" by receptors in the oral cavity (e.g., mechanoreceptors and nociceptors) to create a sensory input (Engelen, 2012), (c) how the input is processed by our brain, including the input's cortical representation (Eldeghaidy et al., 2011; Guest et al., 2007), and (d) the sensory input's transformation into a perception (Rolls, 2011). Stieger and van de Velde (2013) highlight the presence of a feedback system linking perception and oral movements. We direct the

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ASSESSING THE MECHANISMS BEHIND SOUND-TASTE CORRESPONDENCES AND THEIR IMPACT ON MULTISENSORY FLAVOUR PERCEPTION AND EVALUATION

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From a very simplistic viewpoint, the human digestive system can be regarded as a long tube (with dramatic variations in diameter, cross-section, wall properties, pumping mechanisms, regulating valves and in-line sensors). We single out a few fluid mechanical phenomena along the trajectory of a food bolus from the mouth to the small intestine and discuss how they influence sensorial perception, safe transport, and nutrient absorption from a bolus. The focus is on lubrication flows between the tongue and palate, the oropharyngeal stage of swallowing and effects of flow on absorption in the small intestine. Specific challenges and opportunities in this research area are highlighted.

Introduction

Most food products are "complex fluids" with an internal microstructure, leading to rich and diverse flow behavior even for rather "simple" and well-controlled boundary conditions (*e.g.* flow in cylindrical pipes, on flat surfaces, jetting or dripping from nozzles, *etc.*).[1,2] Flows inside the human body introduce additional levels of complexity because of the strongly asymmetric, time-varying boundary conditions in these flows and the progressively changing structure and rheology of a food bolus exposed to body temperature, effects of saliva and "mechanical treatment" during its "journey" through the digestive system.[3,4] This article discusses how fluid mechanics might enable a deeper understanding and consequently more efficient product design for selected stages during this journey.

In-mouth perception of liquid foods and beverages

The perception produced by a food or beverage while present in the mouth is affected by prior experience and expectations, sensory impressions before eating and the interplay of olfactory, mechanical and trigeminal sensations in the oral cavity.[5] Fluid mechanical and rheological concepts cannot be used in isolation to predict the perception of a food product, but may play an important role in establishing the limits and sensitivity of differentiating foods and beverages *via* mechanical sensations in the oral cavity.[6,7] Aspects of in-mouth perception such as "thickness", "smoothness" or "creaminess" are related to the flow behavior of liquid and semi-solid food products and it therefore seems worthwhile to develop a deeper understanding of the mechanical aspects of in-mouth perception.

"Thickness" of a fluid and its relation to flow properties

Efforts to understand how the subjectively perceived "thickness" of liquid and semi-solid food products is related to the rheological properties of these products[8–13] are mostly motivated by the prospect of more targeted product development and more efficient use of sensory analysis. A few key challenges emerge from previous studies: (a) a large enough number of subjects, representative of larger populations, to perform unbiased sensory assessments, (b) materials with a clearly defined, well-characterised and sufficiently wide range of rheological properties and (c) controlling or eliminating confounding factors such as taste and aroma. The pioneering work of Shama and Sherman[8] is still remarkable in terms of its clear methodological approach and careful interpretation of the results, as is the study by Cutler *et al.*[9]

Kokini, Kadane and Cussler[10] offered a mechanistic interpretation of the findings of Shama and Sherman in terms of a "squeeze and shear" model, where the distance between the tongue and palate during the evaluation of "thickness" is assumed to be set by the fluid's resistance to squeezing under a constant force for a specified period of time and the perceived viscosity is then assumed to be proportional to the force experienced by the tongue when shearing against the palate under these conditions. This model largely agreed with the findings of Shama and Sherman, though significant disagreement was found for low-viscosity materials (<100 mPa s), where Shama and Sherman concluded that in-mouth viscosity evaluation occurs at a constant stress of approximately 10 Pa.

In our opinion, two principal regimes of viscosity differentiation seem likely: a primarily "stress-controlled" mode of evaluation for low viscosities (<100 mPa s), which operates *via* assessing the speed at which a liquid flows on the tongue under

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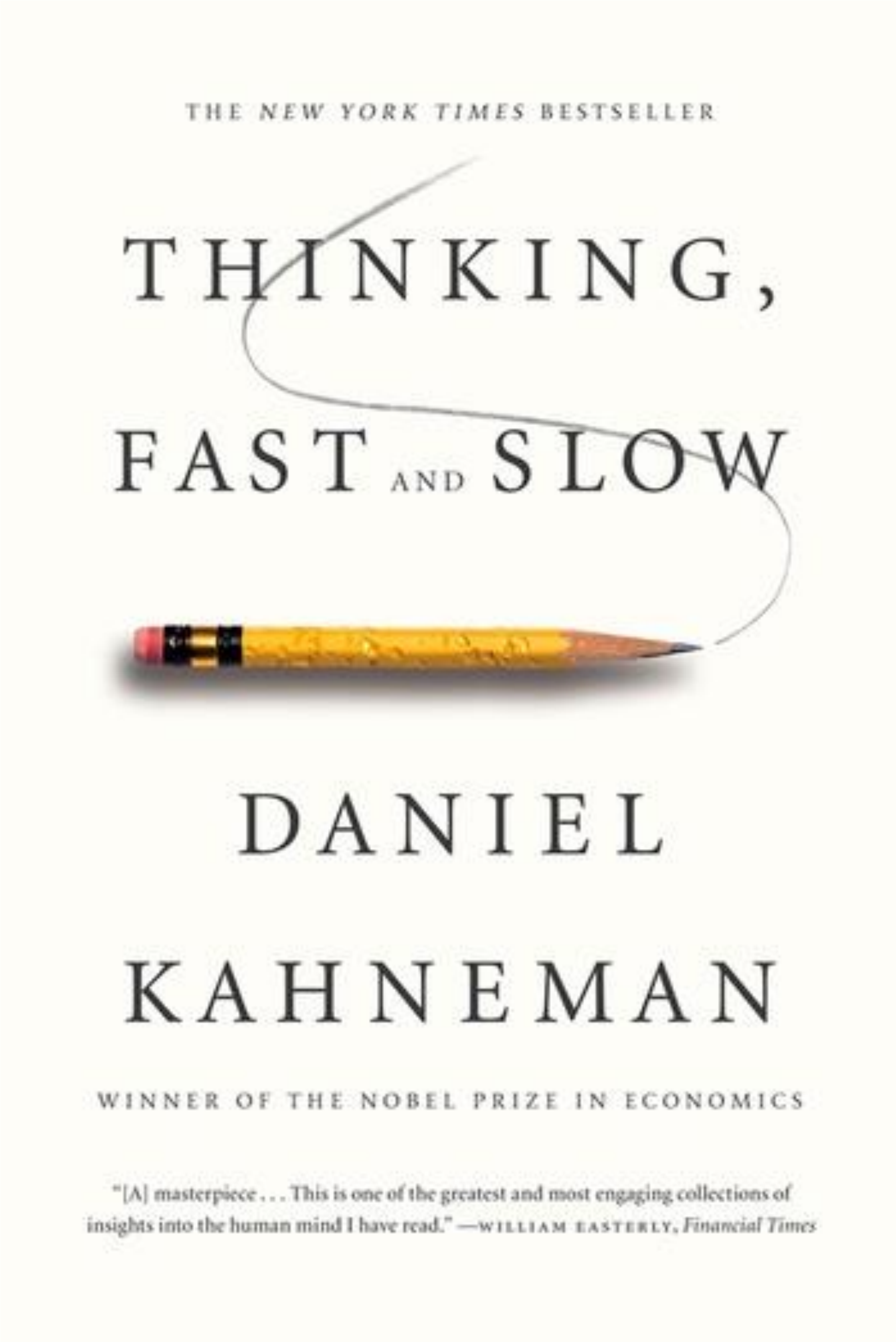
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