THE ROLE OF AUDITORY CUES IN MODULATING THE PERCEIVED CRISPNESS AND STALENESS OF POTATO CHIPS

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ABSTRACT

We investigated whether the perception of the crispness and staleness of potato chips can be affected by modifying the sounds produced during the biting action. Participants in our study bit into potato chips with their front teeth while rating either their crispness or freshness using a computer-based visual analog scale. The results demonstrate that the perception of both the crispness and staleness was systematically altered by varying the loudness and/or frequency composition of the auditory feedback elicited during the biting action. The potato chips were perceived as being both crisper and fresher when either the overall sound level was increased, or when just the high frequency sounds (in the range of 2 kHz–20 kHz) were selectively amplified. These results highlight the significant role that auditory cues can play in modulating the perception and evaluation of foodstuffs (despite the fact that consumers are often unaware of the influence of such auditory cues). The paradigm reported here also provides a novel empiric methodology for assessing such multisensory contributions to food perception.

INTRODUCTION

Our evaluation of the objects and events that fill the world in which we live depends on the information reaching several of our senses simultaneously (Neisser 1976; Driver and Spence 2000). For example, auditory cues are often elicited when we touch or interact with everyday objects, and these sounds

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frequently convey potentially useful information regarding the nature of these objects' properties (Foster 1956; Gaver 1993; Norman 1998; Miskiewicz and Letowski 1999), including their surface texture (Lederman 1979; Katz 1989; Guest *et al*. 2002).

Our perception of the food we eat is also derived from the integration of multisensory cues. Not only is it important what a food looks, smells and tastes like, but also what it feels like (i.e., oral texture) and sounds like in the mouth (think of the tactile/auditory sensation associated with eating potato chips or celery; Amerine *et al*. 1965; Vickers and Bourne 1976a,b; Vickers 1980; Dacremont and Colas 1993). For example, people can use the sound produced when they bite into an apple together with any visual, olfactory and gustatory cues to determine its ripeness.

Many foodstuffs elicit particular sounds when we bite into them. In one of the first studies to be published in this area, Drake (1963) demonstrated that the sounds produced by chewing or crushing a variety of different foods varied in their amplitude, frequency and temporal characteristics. Several subsequent studies have also shown that our perception of the pleasantness of many foods is dependent not only on their flavor in the mouth, but also on the sounds produced by crunching them, and/or by the oral tactile sensations produced by the action of chewing (Drake 1970; Vickers and Bourne 1976a; Vickers 1981, 1983). For instance, Vickers (1983) showed that when participants in their study evaluated biting and chewing sounds using nine auditory descriptors, crispness was the most closely associated with pleasantness. Vickers and Bourne (1976a) suggested that auditory cues were essential for the accurate judgment of crispness. Interestingly, Vickers (1981) reported that a person's estimation of a food's crispness as determined by biting and chewing sounds alone is no different from the estimation of crispness, achieved using both oral–tactile and auditory cues. Taken together, results such as these suggest that our perception of certain foodstuffs, such as the crispness of potato chips, can be determined by the vibratory and/or acoustic cues produced by biting or chewing. It is worth noting here though that Christensen and Vickers (1981) have shown that the perception of crispness can, under certain conditions, be unaffected by masking the sound of the biting action with loud noise.

Crispness is one of the most important food qualities (Yoshikawa *et al*. 1970; Szczesniak and Kahn 1971; Szczesniak 1971). Moreover, preference for food texture has been shown to increase with increasing crispness (Iles and Elson 1972). Crispness is a textural descriptor of foods that is characterized by tactile, mechanical, kinaesthetic and auditory properties (Vickers 1987). Analysis of the sound properties of foods has revealed that crispy foods are typically higher in pitch than crunchy foods (Vickers

1979). Furthermore, Moskowitz and Kapsalis (1974) have reported that crispness is positively related with crunchiness and negatively related with cohesiveness.

To the best of our knowledge, all of the previous research in this area has used different kinds of foodstuffs, often with different levels of freshness, to investigate the role of auditory cues in judgments of food quality, particularly those concerning crispness (Drake 1963; Vickers and Bourne 1976a; Sherman and Deghaidy 1978; Vickers and Wasserman 1979; Christensen and Vickers 1981; Vickers 1984, 1987; Seymour and Hamann 1988; Florian-Rohde *et al*. 1993). In fact, the majority of previous research has tended to focus on the auditory analysis of food-crushing sounds in order to determine both the sensory attributes of food texture, such as crispness and crunchiness, and also to compare subjective and instrumental measures of these food attributes (Drake 1965; Brennan *et al*. 1974; Jowitt and Mohamed 1980; Mohamed *et al*. 1982a,b; Edmister and Vickers 1985; Vickers 1988a,b).

In the present study, we attempted to show that it is possible to modify the perceived textural attributes of potato chips simply by modifying the airborne sounds associated with biting into them. Our research was motivated by the publication of several recent studies that have shown that the perception of a variety of surface textures, and other (nonfood related) object properties, can also be changed simply by manipulating the auditory cues associated with them, while leaving the physical characteristics of the stimulus unchanged, i.e., without manipulating the underlying physical substrate (Jousmäki and Hari 1998; Guest *et al*. 2002). Here, we investigated the nature of any crossmodal (or multisensory) interactions between auditory, oral tactile, mechanical and kinaesthetic information in the rating of the perception of the "crispness" and "freshness" of potato chips (more typically known as crisps in the United Kingdom), a product that most people think of as being a good example of a crispy food (Szczesniak 1988). Participants were required to bite into potato chips (without chewing them) and to rate either their crispness or freshness using a computer-presented visual-analog scale. The potato chips were all selected from the same package and had the same shape and a homogenous texture. The participants were also encouraged to adopt a stereotypical biting action. If auditory cues affect the perception and evaluation of foodstuffs (as previous work suggests), then one would predict that participants would perceive the freshness and crispness of the potato chips as varying when the sounds made by the biting action were manipulated, even for stimuli that are actually physically identical. Indeed, robust effects were expected given that the definition of the "tactile" and "mechanical" qualities of crispness often seems to be described in specifically auditory terms (Vickers 1981, 1987).

METHODS

Participants

Twenty participants (6 males and 14 females, with ages ranging from 18 to 34 years and an average age of 28 years) took part in this experiment as paid volunteers. The experiment lasted approximately 30 min. All participants were naïve as to the purpose of the study, and varied in their previous experience of psychophysical testing procedures. All participants reported normal hearing and normal, or corrected-to-normal, vision. The experiment was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Participants were paid £5 for taking part in the study.

Apparatus and Stimuli

Participants were seated comfortably in a small sound-attenuated booth (see Fig. 1 for a schematic representation of the experimental setup), and received one potato chip (Pringles Original, Procter & Gamble, Cincinnati, OH) on each trial during the experiment. A microphone (Sennheiser ME66/K6 supercardioid, Wedemark, Germany), powered by a Spirit Folio Notepad mixer, was placed such that when participants were seated in the booth, the microphone was positioned directly in front of their mouths. The output from the mixer was then fed through one of three attenuators (Advance Instruments step-attenuator, model A64A, Bethel Park, PA) situated outside the booth, and subsequently through one of three 1/3 octave graphic equalizers (Phonic, model PEQ3300, Tampa, FL) before being fed back to the participant in the booth, via a pair of headphones (Ross RCB200) powered by the output from the mixer. The amplification level was set so that the loudest sounds were presented to the participants at approximately 75 dB(A), which corresponds to a "comfortable" listening level.

Food sounds normally consist of both air- and bone-conducted components, with the relative contribution of the former being greater when the mouth is open rather than closed (Lee *et al*. 1990; Dacremont *et al*. 1991). Given that the only sounds that were modified in the present study were those picked up by the microphone situated outside the mouth, all of the effects reported here should be attributed to the modification of the airborne component of the biting sound (Lee *et al*. 1990). Nevertheless, it is worth noting that previous research has shown that air-conducted sounds are actually more important than bone conducted sounds for the determination of the crispness of foods (Dacremont 1995).

The response scale was presented on a computer monitor situated outside the experimental booth (approximately 50 cm from the participant) and visible through a window in the side wall of the booth. The response scale was 25 cm

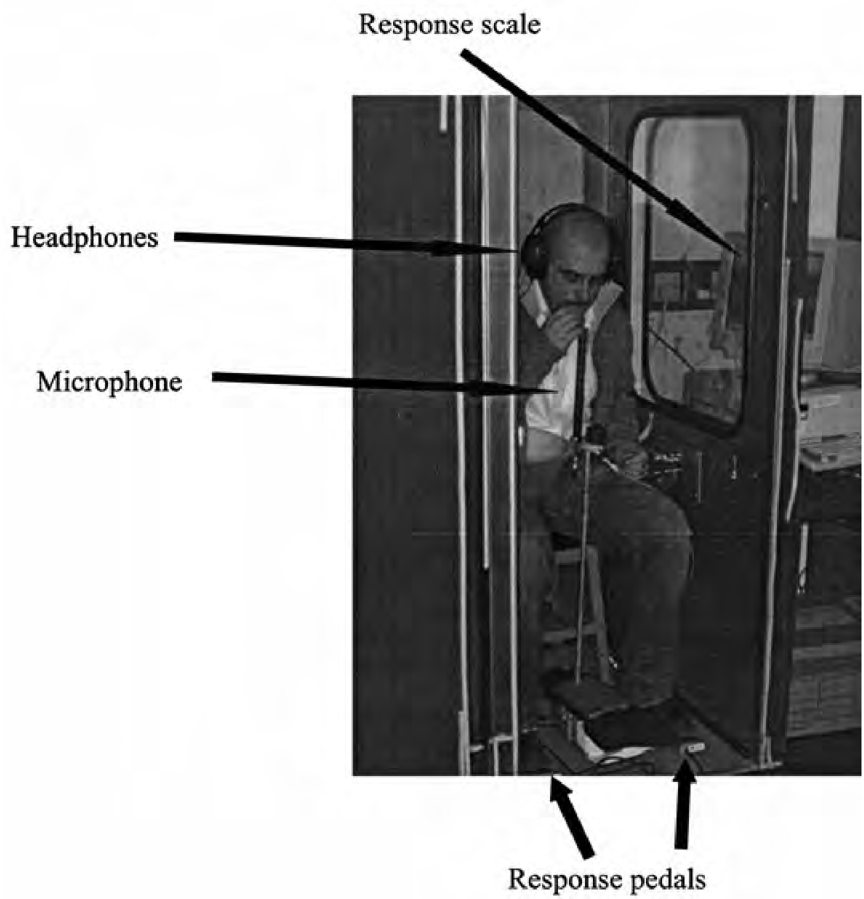

FIG. 1. SCHEMATIC VIEW OF THE APPARATUS AND PARTICIPANT
Note that during the experiment the door of the booth was closed. Participants viewed the response scales on the computer monitor through the window in the left-hand side wall of the booth.

wide, with 100 scale divisions, and semantic anchors at either end of the scale bar. For the soft–crisp scale, the "soft" anchor was placed on the left side of the scale, while for the fresh–stale scale the "fresh" anchor was placed on the left. For each scale, it was stressed to participants that the semantic anchor on one side was the opposite of the semantic anchor on the other side (i.e., "soft" was the opposite of "crisp" and "fresh" was the opposite of "stale"). Movement of the scale pointer was achieved using a pair of footpedals situated under the toes of the participant's feet. Participants normally kept both footpedals depressed, and moved the pointer to the left by lifting their left foot off the left foot-pedal, and to the right by lifting their other foot off the right foot-pedal. The participants were instructed to depress a button located next to the microphone once they were satisfied with their subjective rating on the response dimension presented for a given trial. This registered the participant's response and initiated the next trial. No time limits were imposed for the completion of a participant's responses on any individual trial.

Design

There were three within-participants factors: Auditory Frequency Manipulation (high-frequencies attenuated, veridical feedback or high-frequencies amplified), Overall Sound Attenuation (0 dB, 20 dB or 40 dB) and Response Scale (soft–crisp vs. fresh–stale). These factors were fully crossed resulting in 18 conditions, which were each presented 5 times within a block of 90 randomly ordered trials. On each trial, the participant's task was to rate either the perceived crispness or the perceived freshness of the crisp using a visual analogue scale.

In the veridical sound condition, the sounds made when participants bit into a crisp with their front teeth were fed back without any auditory frequency adjustment. In the high frequency amplified sound condition, sound frequencies in the range 2 kHz–20 kHz were amplified by 12 dB (according to the 1/3 octave resolution of the graphic equalizer). In the high frequency attenuation condition, sounds in this frequency range were attenuated by 12 dB. Furthermore, for each frequency manipulation, there was an attenuation of the overall volume of either 0 dB (i.e., no attenuation), 20 dB or 40 dB. These values were chosen on the basis of our previous research demonstrating audiotactile interactions in texture perception for sandpaper samples where the same standard set of sound manipulations were used (Guest *et al*. 2002). However, somewhat serendipitously, our use of 2 kHz as the lower boundary for frequency amplitude modulation happens to coincide well with Seymour and Hamann's (1988) finding that low-moisture crisp products (including Pringle's potato chips, as used here) tend to be characterized by being heavily influenced by frequencies above 1.9 kHz (Dacremont 1995).

Procedure

Participants were seated comfortably in the sound-attenuating booth with the microphone and response foot-pedals situated immediately in front of them. They were instructed to make a single bite (lasting about 1 s) with their front teeth into the crisp with their mouth positioned directly above the microphone and then to spit the crisp out (without swallowing) into a mixing bowl placed on their lap. There were several reasons for adopting the "single bite" approach in the present study. First, to try and maximize the uniformity of our participant's contact with each crisp, and so avoid any potential problems associated with the marked temporal changes in the auditory signals that occur during the chewing of potato chips (Lee *et al*. 1988). Second, previous research has shown that the perception of brittleness/crispness is largely determined by the auditory information present during the first bite (Sherman and Deghaidy 1978; Vickers 1987). In fact, according to a more recent paper by De Belie *et al*. (2000), crispness is specifically defined as “the amount and pitch of sound generated when the sample is first bitten with the front teeth”. Vickers (1984) reported that bite sounds are higher in pitch than chewing sounds because when participants bite into foods they perceive both airborne and bone-conducted sounds, while when they chew foods high-frequency sounds are reduced by the soft tissues in the mouth; Finally, by adopting a “single bite” approach, we also avoided any problems associated with the bone-conducted transfer of sound attributable to the use of the molars.

On each trial, the experimenter gave a potato chip to the participant who was instructed to bite into it after the booth door had been closed before looking at the dimension scale on the computer monitor. They were then instructed to rate the subjective sensation of the potato chip’s freshness or crispness according to the scale dimensions highlighted on the computer monitor for that particular trial. It was stressed to participants that the response dimension would vary from trial to trial, and that care should be taken to ensure that they responded along the correct dimension, which was displayed on the monitor for the duration of each trial. The participants were given no information regarding the source of the potato chips that they were presented with (i.e., about how one might vary from the next). An initial practice block of 18 trials (one trial per condition) was provided prior to the main experimental block in order to allow the participants time to familiarize themselves with the experimental setup and the task at hand.

RESULTS

The data from the soft–crisp response scale are presented in Fig. 2A. A two-way within-participants repeated-measures analysis of variance (ANOVA) performed on this data had the factors of Frequency Manipulation (attenuated, veridical or amplified) and Overall Sound Attenuation (0 dB, 20 dB or 40 dB). For all of the analyses reported here, posthoc comparisons used Bonferroni-corrected *t*-tests (where $P < 0.05$ prior to correction). The analysis revealed a significant main effect of Frequency Manipulation ($F_{2,38} = 39.91$, $P < 0.001$), reflecting the fact that participants judged the potato chips as being crisper when the high frequency sounds were amplified (mean score of 71) than when either veridical sounds were presented ($M = 62$), or when high frequency sounds were attenuated ($M = 58$; the comparison

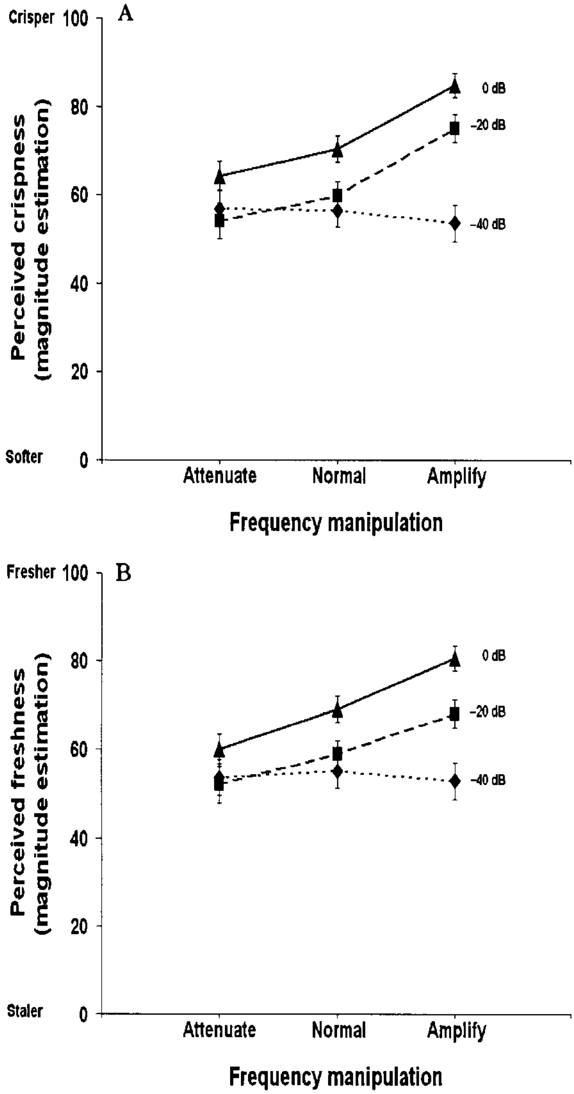

FIG. 2. MEAN RESPONSES FOR THE SOFT–CRISP (A) AND FRESH–STALE (B) RESPONSE SCALES FOR THE THREE OVERALL ATTENUATION LEVELS (0 dB, −20 dB, OR −40 dB) AGAINST THE THREE FREQUENCY MANIPULATIONS (HIGH FREQUENCIES ATTENUATED, VERIDICAL AUDITORY FEEDBACK OR HIGH FREQUENCIES AMPLIFIED)
Error bars represent the between-participants standard errors of the means.

between these latter two conditions also reached statistical significance). The main effect of Sound Attenuation was significant ($F_{2,38} = 43.26$, $P < 0.001$), attributable to the fact that participants reported the potato chips to be crisper at 0 dB attenuation ($M = 73$) than at either 20 dB attenuation ($M = 63$), or at 40 dB attenuation ($M = 55$; all pairwise comparisons were significant).

The interaction between Frequency Manipulation and Overall Sound Attenuation also reached significance ($F_{4,76} = 19.92$, $P < 0.001$), reflecting the fact that the effect of frequency manipulation had a greater influence on crispness ratings at the two lower attenuation levels (i.e., at 0 dB and 20 dB attenuation) than at the 40 dB attenuation level (Fig. 2A). At the 0 dB overall attenuation level, participants rated the potato chips as being significantly crisper when the high frequency sounds were amplified ($M = 85$) than when veridical feedback was presented ($M = 71$), or when the high frequencies were attenuated ($M = 64$; the comparison between these latter two conditions failed to reach significance, $P = 0.10$). At the 20 dB attenuation level, the most crisp sensations were reported when the high frequency sounds were attenuated ($M = 75$) as compared with the veridical feedback ($M = 60$), or high frequency amplification conditions ($M = 54$; all pairwise comparisons were significant). Manipulation of the frequency factor had no significant effect on crispness ratings at the 40 dB attenuation level (i.e., no pairwise differences reached significance at this level of overall attenuation), presumably because the overall sound level was close to threshold.

A similar ANOVA performed on the fresh–stale response scale data (Fig. 2B) also revealed a significant main effect of Frequency Manipulation ($F_{2,38} = 34.57$, $P < 0.001$). This result reflects the fact that the high frequency amplification and veridical sound conditions ($M = 67$ and 61, respectively) both led to potato chip judgments that were significantly fresher than the high frequency attenuation condition ($M = 55$; the difference between the high frequency amplification and veridical sound conditions was also significant). The main effect of Overall Sound Attenuation level was also significant ($F_{2,38} = 29.24$, $P < 0.001$). A comparison of the three overall sound levels indicated that the 40 dB attenuation condition resulted in participants judging the potato chips as being staler ($M = 54$) than at 20 dB attenuation ($M = 60$) or at 0 dB attenuation levels ($M = 70$; all pairwise comparisons were significant).

The significant interaction between Frequency Manipulation and Overall Sound Attenuation level ($F_{4,76} = 11.47$, $P < 0.001$), illustrated in Fig. 2B, reflects the fact that, at 0 dB attenuation, participants judged the potato chips as being fresher on high frequency attenuation levels ($M = 81$) when compared with the veridical sound condition ($M = 69$), or with the high frequency amplification condition ($M = 60$; the difference between the latter two conditions was also significant). Meanwhile, at the 20 dB attenuation level, the potato chips were judged to be fresher when the high frequency sounds were amplified ($M = 68$) as compared with veridical sound ($M = 59$) or when the high frequencies were attenuated ($M = 52$; the comparison between these latter two conditions was also statistically significant). Once again, no differences were found between the frequency manipulation conditions at the 40 dB attenuation level, presumably due to a floor effect.

Finally, we tested whether participants distinguished between the two scales when making their responses in the present study, given the link between crispness and freshness (Szczesniak and Kahn 1971). We compared the data from the crispness and freshness scales to investigate whether there was any difference between responses on the two scales. A two-way within-participants repeated-measures ANOVA performed on this data had the factors of Scale (crispness, freshness), Frequency Manipulation (attenuated, veridical or amplified) and Overall Sound Attenuation (0 dB, 20 dB or 40 dB). There was a main effect of the Scale ($F_{1,19} = 8.24$, $P = 0.01$), showing that participants' responses on the crispness scale ($M = 64$) were somewhat higher than for freshness scale ($M = 61$) overall. This result supports the hypothesis that, at least to some extent, participants were able to distinguish between the two scales in our study. However, there were no other interactions between Scale and any of the other factors (all Fs < 1.5), showing that the pattern of auditorily induced changes in responding was indistinguishable for the two scales.

DISCUSSION

The analysis of the data reported here reveals that the perceived crispness and freshness of foods can be modified simply by changing the nature of the sounds produced during the biting action. In particular, our results show that the evaluation of the freshness and crispness of potato chips is influenced both by the overall intensity of the sounds elicited during the biting action, and by the frequency spectrum of the biting sounds that are heard. The potato chips were judged to be fresher and crisper when the overall sound level was increased and/or when the high frequency components (2 kHz–20 kHz) of the biting sound were amplified[1], while reducing the sound and attenuating the high frequency components resulted in participants judging the potato chips as both softer and staler.

[1] It is worth noting here that the perception of crispness and freshness are positively correlated, thus providing evidence for a connection between these two food qualities (Szczesniak and Kahn 1971).

Our finding that boosting the amplitude of frequencies over 2 kHz leads to an increase in the perceived crispness of potato chips is consistent with the results of a study by Seymour and Hamann (1988). They found that the sounds associated with a variety of different low-moisture crisp products were characterized by being heavily influenced by frequencies above 1.9 kHz. In a similar vein, Dacremont (1995) has reported that crispy foods generate high-pitched sounds with a pronounced contribution from frequencies above 5 kHz. Our results are also consistent with other previous claims that “crisper” sounds are typically both louder and higher in pitch (Drake 1965, 1970; Vickers and Bourne 1976a; Vickers 1979, 1985, 1987, 1988b; Christensen and Vickers 1981). However, what is particularly novel about the present study is that it provides a new methodology for assessing the effect of changing the sound of food of texture perception while keeping the physical substrate constant.

Lederman (1979) has suggested that in everyday life, the tactile examination of textured surfaces is based only on tactile information (i.e., ignoring the auditory information, which may be masked by other external noises). In our experimental situation, however, auditory cues played a significant role in modulating perception. Given that the crisps in the present study were very similar to each other (e.g., in terms of their shape, texture and flavor), the only information that varied during the task was the sound. Participants may have “felt” a different texture of the crisps guided by the sound since the other senses always received the same information. Interestingly though, the majority of the participants (15 out of 20) reported that they thought the crisps were selected from different packages after informal questioning at the end of the experiment.

It is well known that multisensory integration is stronger when the information reaching the various sensory receptors comes from the same, rather than from different, spatial locations (Stein and Meredith 1993). In our experiment, participants typically reported that the sounds, which were actually presented over headphones (and which if presented in isolation would themselves presumably have been localized within the head), appeared to emanate from their mouth during the biting action, due presumably to a form of audiotactile “ventriloquism” effect (von Békésy 1964; Caclin *et al.* 2002). Therefore, auditory and tactile information were actually perceived as originating from the same spatial location (i.e., the mouth), presumably making the influence of the auditory cues over tactile sensation stronger than might otherwise have been the case. One might, in fact, consider introducing a delay between the biting of the potato chips and receiving the audio feedback of the biting sounds over the headphones to confirm the genuinely perceptual nature of this effect (Jousmäki and Hari 1998; Caclin *et al.* 2002; Guest *et al.* 2002). In particular, any difference with the present results uncovered by adding a delay between the auditory and tactile inputs would support the view that they were being combined during the illusory sensation at a genuinely perceptual level. Additionally, the majority of the participants stated anecdotally on debriefing after the experiment that the auditory information had been more salient than oral tactile information, and this may also help to account for our effects. For many researchers believe that the extent to which information provided by one sense dominates, or modulates, perception in another sensory modality depends on the relative strength, reliability or amount of information presented in the two modalities (Welch and Warren 1980; Shimojo and Shams 2001; Ernst and Banks 2002).

It is important to note here that many other apparently “tactile” phenomena may also reflect the consequences of changes in auditory perception as well (Brown 1958; Gordon and Cooper 1975; Lederman 1979). For example, Brown reported that bread was judged as being fresher when wrapped in cellophane than when wrapped in wax paper. It may be that the sound produced when touching the different wrappers influenced the freshness judgment for the bread in this study (think also of the noisy packets in which crisps are typically presented; perhaps cuing people to the auditory attributes of the food inside). One might wonder whether the perception of the crispness of potato chips would also be modulated by variations in the auditory qualities of the packaging in which they are presented (i.e., silent or noisy; cf. Brown 1958). Importantly, though, these cues are often processed at a covert level, and so people are often unaware of their potential influence (i.e., we tend to introspect about the “feel” of surface, rather than about its sound; see Driver and Spence 2000).

Given that the present results show that participants judged the crisps they were biting into to be both crisper and fresher when we presented louder sound and/or higher frequency feedback, one might hypothesize that people would judge foods to be less crispy in noisy environments (such as in restaurants with loud music) than in quiet environments. However, preliminary evidence against this claim comes from a study by Christensen and Vickers (1981) who found no evidence for any effect of variations in the level of background noise on the perception of the crispness of foods (Vickers 1984). It is, however, worth noting that with loud background noise it isn’t necessarily the case that the food has no sound, rather people will presumably assume that the sound is still present but is simply masked by the background noise (and in certain situations people have even been shown to fill in missing sounds, as when, for example, part of a speech stream is masked by a cough, or some other arbitrary noise; see Samuel 1981, for a review). Therefore, the situation in which food sounds are masked might be very different from the situation in which foods really makes no sound (i.e., when the lack of auditory cues regarding the foodstuff are attributed to the food itself, rather then to the masking qualities of the environment in which the food is consumed). More research will be needed on this topic to assess the relative contributions to food perception of varying the sound of food, by changing the food itself vs. changing the background noise levels.

Given that the present results show a clear effect of our frequency manipulation on the participants' estimation of food qualities, it will be interesting in future studies to investigate whether it is possible to show a stronger effect for more specific frequency manipulations (i.e., rather than the relatively crude boosting or attenuation of all frequencies in range of 2 kHz–20 kHz). It will also be interesting to compare crisps that genuinely vary in their freshness/staleness, to get a quantitative estimation of just how much effect auditory manipulations of biting sounds can have on oral texture perception. Additionally, it will be of interest to investigate how the pitch-and-loudness-modulated aspects of crispness perception interact with variations in the unevenness of discontinuity of the eating sounds themselves, as these have also been shown to be an important factor modulating oral texture perception (Vickers and Wasserman 1979).

Finally, one possible application of these findings could be in the preparation of foodstuffs. For example, one might consider varying product microstructure to develop products with specific auditory response profiles that have been shown to modulate texture/pleasantness perception. Foods that are less dense, or stiffer, might be expected to produce higher-pitched sounds given that increasing stiffness or reducing mass contributes to augmenting the frequency of vibration (Rossing 1982). Developing foods that more effectively "stimulate our ears" may also become more important as the population ages, and so age-related declines in taste/flavor perception (mediated by a decline in olfactory and/or gustatory processing) become ever more prevalent, and thus important (Spence 2002). Our results may also have implications for the advertizing of foodstuffs, as crispness may be one of the few nonvisual attributes of a foodstuff that can be successfully conveyed via advertizing (Vickers 1977). The auditory enhancement of food texture perception may be especially important, given the high regard of the consumer for crispness in foods (Szczesniak and Kleyn 1963; Szczesniak and Kahn 1971).

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