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Consumer perception of salt-reduced potato chips: Sensory strategies, effect of labeling and individual health orientation

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ABSTRACT

Lowering dietary intake of sodium is currently an important public health goal, and a major driver of food product development. Reducing the salt content of food while maintaining the same structure and sensory quality is, however, no easy feat. While several strategies for reformulation exist, the available literature indicates that their effectiveness is highly product-dependent. The present research focused on different salt reduction strategies for potato chips (crisps), drawing on two studies focusing on young (18–30) consumers.

In Study 1 (N = 200), the effect of simple salt reduction and two salt replacers (KCl and MSG) on consumer perception was investigated, using a reference product as basis for systematic reformulation. Study 1 also addressed the issue of how information labeling affects consumer perception by comparing results in blind and informed conditions (N = 100 each). The results indicated that sodium can be reduced up to 30% while maintaining the same palatability, and that replacement (up to 30%) by either KCl and MSG even increased liking in the blind condition. A strong labelling effect was found, however, whereby consumers significantly preferred the reference product than any of the reformulation when informed of its content, whereas the opposite was observed (reference was least liked) when tested in blind.

Study 2 (N = 100) extended the range of experimental conditions by focusing on how salt reduction is affected by texture and seasoning type. The main result of Study 1 – that sodium can be reduced up to 30% while maintaining the same palatability (in blind) – was confirmed across different seasoning types, thus enabling a more robust basis for generalization. Contrary to expectations, the presence of a wavy (vs. smooth) texture increased liking only for a single seasoning type, and the effect was not dependent on salt content.

1. Introduction

High levels of sodium intake in the diet are known to increase the risk of cardiovascular diseases and hypertension, which is diagnosed in more than 26% of the adult population worldwide (Kearny et al., 2005). This issue is particularly pressing in western countries, in many of which the sodium intake is between 3600 and 4800 mg/day (compared to a physiological need of around 180–230 mg). The main source of sodium is sodium chloride (NaCl) and is primarily obtained through consumption of processed foods, which accounts for at least 75% of the sodium intake in the industrialized diet (Mattes & Donnelly, 1991).

Since the general consumer population is often not aware of the recommendations on daily intake of sodium, and/or may not even be interested in reducing it (Hoppu et al., 2017), notable stakeholders such as the World Health Organization have called for a higher engagement of the food industry to implement a gradual reduction of sodium in foods (WHO, 2007). By changing the dietary behavior of the consumers, the incidences of lifestyle-related diseases can be reduced. Enabling the consumers to make healthier choice by offering low-salt options in the market is currently of major interest to the food industry, and is part of a general trend that sees consumers becoming more aware of how their dietary habits contribute to their health and well-being (Giacalone, 2018a, 2018b; Hoppu et al., 2017; Lacey, Clark, Frewer, & Kuznesof, 2016; Lähteenmäki, 2013).

From a product development perspective, reducing or replacing sodium content in food presents several challenges, both technical (for example, salt reduces water activity values and thus helps maintain microbiological stability and structure) and economic (salt is generally cheaper than any replacers). The greatest challenge is however related to sensory aspects: salt increases palatability and suppresses bitterness (Breslin & Beauchamp, 1997; Liem, Miremadi, & Keast, 2011; Mojet, Heidema, & Christ-Hazelhof, 2004), so any substantial reduction in sodium content is likely to result in lower acceptance. Therefore, effective salt reduction in food remains a challenge for the food industry.

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1.1. Sensory strategies for salt reduction in foods

Sensory strategies to reduce salt content in food traditionally have included salt reduction, salt replacement and physical modifications to increase sodium availability in the mouth (Busch, Yong, & Goh, 2013; Dötsch et al., 2009; Kuo & Lee, 2014).

With respect to simple salt reduction, several studies have looked at the changes occurring in the sensory profile of food products and how they affect consumer acceptability. The results show that removal of sodium is associated with reduced saltiness but also with other sensory changes, such as increased bitterness and reduced sourness, due to altered taste-taste interactions (Mojet et al., 2004; Keast & Breslin, 2003). Accordingly, the reduction in salt concentration that can be achieved before consumers notice a change, or before the change is so large that it negatively affects acceptability, has been found to vary substantially from one study to another (Liem, Miremadi, Zandstra, & Keast, 2012). Previous research indicated that consumers do not notice NaCl reductions of up to 20%, depending on the specific food matrix (Jaenke, Barzi, McMahon, Webster, & Brimblecombe, 2017; La Croix et al., 2015; Levings, Cogswell, & Gunn, 2014). However, cases of successful reduction even beyond that upper limit have been reported in the literature. For instance, studies in meat products have shown that a reduction of 25% could be achieved without significant impact on either taste intensity or acceptability for ham and frankfurter sausages (Aaslyng, Vestergaard, & Koch, 2014). Ganesan and collaborators showed that consumers could only distinguish between two reference dairy products (cheddar and mozzarella) and their salt-reduced reformulations when NaCl reduction hit the 30% mark (Ganesan, Brown, Irish, Brothersen, & McMahon, 2014), and Torrico and collaborators showed that it was possible to reduce NaCl up to 40% in potato chips without affecting consumer acceptability (Torrico et al., 2019).

Generally, reducing salt content in food without accounting for the associated reduction in saltiness is risky as it may lead consumers to switch to alternative products with a higher sodium content and/or to compensatory strategies such as re-adding salt themselves (Liem et al., 2012; Torrico et al., 2019). Therefore, a more practical strategy is to replace (totally or, more often, partially) NaCl with salt replacers that can impart saltiness to foods. These generally include other mineral salts such as potassium chloride (KCl) or with flavor enhancers such as monosodium glutamate (MSG), yeast extracts, and 5′ nucleotides.

Partial replacement with KCl has been extensively studied and is expected to increase in the near future (van Buren, Dötsch-Klerk, Seewi, & Newson, 2016). According to previous studies, the range of replacement by potassium chloride in which the impact on the flavour will not be noticed by consumers is 10–40%, depending on the type of food considered. Higher values are generally unfeasible because KCl, in addition to saltiness, at increasing concentrations also contributes with undesirable taste qualities such as bitter and metallic (Armenteros, Aristoy, Barat, & Toldrá, 2012; Grummer, Karalus, Zhang, Vickers, & Schoenfuss, 2012; van Buren et al., 2016; Sinopoli & Lawless, 2012; Torrico et al., 2019).

Replacement with MSG has also been applied with positive results. Natural sources of umami – such as mushrooms, tomato, onion, soy sauces and cheese – are often used in salt-reduced products (Jinap & Hajeb, 2010; Jinap et al., 2016) due to their saltiness enhancing properties and positive effect on acceptability. Accordingly, research on salt replacement by MSG have found that a substantial decrease in sodium chloride (up to 50% in some cases) can be achieved without leading to significant loss of either taste intensity or acceptability (Kremer, Mojet, & Shimojo, 2009; Roininen, Lähteenmäki, & Tuorila, 1996).

A common (perceived) problem with saltiness enhancers is that they need to be declared as food additives on the packaging (e.g., within the European Union KCl and MSG they would be reported by the e numbers E508 and E631, respectively), which may limit their use as many manufacturers worry about consumers' general aversion towards food additives (Asioli et al., 2017; Bearth, Cousin, & Siegrist, 2014).

Therefore, alternative strategies to enhance saltiness perception are sought after. Among others, these include modifying the size and shape of the salt crystals and modifying the texture of the food to enhance sodium release from the matrix (Busch et al., 2013; Kuo & Lee, 2014). The former works mostly in the context of surface-salted food such as potato chips, where studies have shown that smaller crystal size fractions dissolve faster in the tongue saliva and are therefore associated with higher saltiness (Rama et al., 2013). The second strategy, which has not yet drawn much attention, is based on the fact that a large fraction of sodium in food – up to 95% according to some studies – still remains in the food and thus gets swallowed but does not contribute to the perception of saltiness (Phan et al., 2008).

Several studies have been conducted in order to understand the role the food matrix plays on sodium release and saltiness perception. For example, increased dry matter and protein content have been found to correlate negatively with saltiness due to the fact that they effectively slow down the release of sodium from the matrix (Colmenero, Ayo, Carballo, 2005; Panouillé, Saint-Eve, De Loubens, Déléris, & Souchon, 2011). Nevertheless, the relationships among the properties of matrix, sodium release, and saltiness perception are still not well understood, also because the highest availability of sodium does not always correspond to the highest saltiness (Kuo & Lee, 2014).

In this context, modifying food texture is also particularly interesting as it can enhance saltiness perception through cross-modal interactions whereby a rough (vs smooth) texture has been found to be associated to higher saltiness (Biggs, Juravle, & Spence, 2016), and because a more discontinuous stimulation has been hypothesized to slow down the process of sensory adaptation (Busch et al., 2013; Stieger & van de Velde, 2013). Some support for an effect of texture on saltiness perception can be found in the literature. For example, Pfaum and collaborators showed that saltiness of bread can be affected by crumb texture, so that a coarse-pored bread tasted significantly saltier compared to fine-pored version with the same sodium content (Pflaum, Konitzer, Hofmann, & Koehler, 2013). Nevertheless, research on texture-taste interactions with specific focus on saltiness is scant and somewhat contradictory (Kuo & Lee, 2014), with other studies failing to find significant correlations between texture and saltiness (Saint-Eve, Lauverjat, Magnan, Déléris, & Souchon, 2009).

1.2. Consumer acceptance of salt-reduced products

Besides product-related challenges, the complexity of successful salt reduction also relates to the inherent variability in consumers' perception and preference for saltiness (see e.g. Antúnez et al., 2019). These are, to a significant extent, a function of their dietary sodium intake: research has shown that repeated exposure to high level of sodium in foods cause a decrease in sensitivity for saltiness; conversely, consumers on a low-sodium diet are more sensitive to salt and tend to prefer lower salt levels (Bertino, Beauchamp, & Engelman, 1982, 1986; Dötsch et al., 2009; Methven, Langreney, & Prescott, 2012). Therefore, higher exposure to foods with high contents of salt, which are mainly found in industrial processed foods or restaurant foods, increases the liking for saltiness. Consumers are often not attentive to the salt content in processed foods and they are unaware of their daily intake of salt (Dötsch et al., 2009). Therefore, for an ordinary consumer it can be challenging to reduce their salt intake, since food choices are primarily driven by sensory preferences and consumers tend to prefer foods that are familiar (Bearth et al., 2014). Accordingly, a gradual salt-reduction with incremental changes to the existing product may be the most successful approach to maintain consumer acceptance (Zandstra, Lion, & Newson, 2016).

Socio-demographics characteristics such as age and gender have been found to affect salt perception and preferences. Ageing in general is associated with a decrease in NaCl sensitivity (Mojet, Heidema, & Christ-Hazelhof, 2003), although whether this translates to a preference for higher sodium content in real foods remains unclear (Song, Giacalone, Johansen, Frøst, & Bredie, 2016). Regarding gender, women have been found to be more sensitive than men for NaCl concentrations commonly encountered in food (Hayes, Sullivan, & Duffy, 2010) and, accordingly, men tend to have slightly higher preference for saltiness than women (Lampuré et al., 2015). Smoking status is also known to be a factor, with smokers reportedly having a higher liking for saltiness, which may be due to taste impairment and/or because smokers generally tend to consume more fatty-salted foods (Lampuré et al., 2015).

Finally, consumers' variability in response towards salt-reduced products may also relate to attitudinal aspects such as health orientation, both general and salt-specific (Antúnez et al., 2019), which may influence their willingness to compromise on taste for a health gain. Consumers are reported to be increasingly aware of the negative effect of sodium on health (Liem et al., 2012; Newson et al., 2013), however, whether this translates into an actual acceptance for salt-reduced products is not known, with some authors noting that a substantial attitude-behavior gap is likely to exist on this matter (e.g., Zandstra et al., 2016).

Given the current interest in health and wellness amongst consumers, it is somewhat surprising that very few studies have investigated whether the effect of salt reduction on consumer perception can be influenced by the presence of nutritional information and health claims. Generally, product-oriented studies (e.g., those reviewed in § 1.1.) have strictly focused on consumer acceptance in blind conditions, whereas consumer-oriented studies have typically focused on consumer understanding and use of salt-labeling on food products prior to actual consumption (e.g., Grunert, Wills, & Fernandez-Celemin, 2010; Newson et al., 2013; Sacks, Rayner, & Swinburn, 2009; Van Kleef, Van Trijp, Paeps, & Fernandez-Celemin, 2008).

The (very few) studies that did combine these two aspects have reported inconsistent results. Some studies suggest that informing consumers about a salt-reduction negatively affect taste expectations regarding saltiness which, through contrast effects (see Cardello, 2007), may enhance the perceived difference and lower acceptability compared to reference (*i.e.*, non NaCl-reduced) products (Liem et al., 2011; Liem et al., 2012). One thing to notice here is that, at least within the EU, a salt-reduction can only be claimed if the sodium content is at least 25% less than similar products within the category (Danish Veterinary and Food Administration, 2018). As argued in the previous section, this means that a substantial decrease in sodium content (above or close to the difference threshold in many cases) must be implemented in order to use "salt-reduced" as a health claim.

By contrast, Torrico and collaborators reported that, using a within-subject design, acceptance of salt-reduced products could be increased by disclosing information on salt reduction (Torrico et al., 2019). Yet other studies reported no effect of nutritional information on consumer perception of salt-reduced products (Czarnacka-Szymani & Jezewska-Zychowicz, 2015). These inconsistencies are likely related to differences in the type of claim, type of product, experimental design, etc., and still leave open the question of whether labeling information has a positive or negative effect on consumer preferences. Again, a narrow focus on averaged data is also likely part of the problem (Antúnez et al., 2019): for labeling to be effective, it is necessary that consumers effectively ascribe a health benefit to the message, and therefore it is also likely that nutritional information on salt reduction is processed differently by consumers with different degree of health orientation and dietary habits.

1.3. Aims of the present research

To summarize, while several strategies for salt-reduction in foods are available, the exisiting literature indicate that their effectiveness is highly product-dependent. Additionally, continued reliance on blind test results in previous research leaves open the question of whether consumer liking for salt-reduced products can be modified by information labeling.

Situated within this context, the present research focused on different salt reduction strategies for potato chips (crisps), drawing on two consumer studies, and had three overall aims:

1. evaluate consumer preferences for salt-reduced chips in blind and informed conditions;
2. understand the effectiveness of different salt reduction strategies on consumer acceptability and sensory perception of salt-reduced chips.
3. relate the results to consumers' background characteristics, with particular focus on consumers' health orientation.

2. Materials and methods

2.1. Research overview

The research draws on two studies, which consisted of consumer tests in a central location testing (CLT) facility.

Study 1 ($N = 200$) focused on the effect of simple salt reduction and salt replacers (KCl and MSG) on consumer perception, using a reference product as basis for systematic reformulation. Study 1 also addressed the issue of how information labeling affects consumer perception by comparing results in blind and informed conditions ($N = 100$ each).

Study 2 ($N = 100$) aimed at replicating the results from Study 1 and extended the range of experimental conditions by focusing on how salt reduction is affected by texture and seasoning, thus enabling a more robust basis for generalization.

Results from both studies were related to individual consumer characteristics.

2.2. Study 1

2.2.1. Experimental design

Study 1 focused on an existing product (Kim's Sour Cream and Onion, Orkla C&S Aps, Denmark) which is very familiar to the majority of Danish consumers as it has been market leader for many years. It is a wavy snack chip made of potatoes (63%), sunflower oil (30%) and a seasoning mix (7%, incl. sugar, salt, powdered onion, whey powder, milk powder, lactose, MSG, parsley, yeast extract, malic acid, natural aromas). The reference product was compared to nine reformulations developed according to an experimental design where sodium content reduction (3 levels: −10%, −20%, −30%) and salt replacer (3 levels: No replacer, KCl, MSG) were systematically varied. The specific levels for the design factor were determined based on a mix of scientific and practical considerations. For sodium content, the 30% reduction was included because it represents the normal range after which acceptability generally decreases based on literature (reviewed in § 1.1), but also because of its commercial relevance with respect to the aforementioned EU regulation for salt-reduction claims. The inclusion of the −10% sample was due to expectation that a gradual reduction in NaCl content can be achieved without affecting acceptability. Finally, −20% samples were included due to expectations that the roughly 15% mark would represent the Weber ratio after which salt reduction in chips becomes noticeable. The three levels for salt replacement were chosen based on the vast literature supporting the effectiveness of KCl and MSG as salt replacers in food applications, while the "no replacer" level provided a benchmark to evaluate their relative performance. A complete overview of the samples used in the study, including sodium content and abbreviations used in tables and figures, is given in Table 1.

2.2.2. Consumers

Two-hundred consumers participated in Study 1. They were selected from an internal database to be in the 18–30 age range, which represents the main target segment for the category. Besides age, the only inclusion criterion was that they should like and consume potato

Table 1
Samples used in Study 1.

Sample Id	NaCl (g/100 g)	KCl (g/100 g)	MSG (g/100 g)
Reference (Kim's SC&O)	1.6	0	0
−10% NaCl	1.4	0	0
−20% NaCl	1.3	0	0
−30% NaCl	1.1	0	0
−10/+10% KCl	1.4	0.2	0
−20/+20% KCl	1.3	0.3	0
−30/+30% KCl	1.1	0.5	0
−10/+10% MSG	1.4	0	0.2
−20/+20% MSG	1.3	0	0.3
−30/+30% MSG	1.1	0	0.5

Table 2
Samples used in Study 2.

Sample Id	Seasoning	Texture	NaCl (g/100 g)
Sea Salt Ref.	Sea Salt	Wavy	1.6
Sea Salt −30%	Sea Salt	Wavy	1.1
Sea Salt Ref.	Sea Salt	Smooth	1.6
Sea Salt −30%	Sea Salt	Smooth	1.1
BBQ Ref.	BBQ	Wavy	1.5
BBQ −30%	BBQ	Wavy	1.1
BBQ Ref.	BBQ	Smooth	1.5
BBQ −30%	BBQ	Smooth	1.1
SC.O. Ref.	Sour Cream & Onion	Wavy	1.6
SC.O. −30%	Sour Cream & Onion	Wavy	1.1
SC.O. Ref.	Sour Cream & Onion	Smooth	1.6
SC.O. −30%	Sour Cream & Onion	Smooth	1.1

chips. Conversely, self-reported food allergies or intolerances were the only reason for exclusion. Consumers in Study 1 were randomly assigned to two conditions, "Blind" (N = 100, Gender: 28% women/72% men, Age: 74% 18–24 and 26% 25–30) and "Informed" (N = 100, Gender: 31% women, Age: 73% 18–24 and 27% 25–30). We refer to these as Study 1A and Study 1B in the remainder of the paper. Consumers in the two conditions were balanced with respect to gender ($\chi^2_{(1)}$ = 0.21, p = 0.64) and age ($\chi^2_{(1)}$ = 0.02, p = 0.87). Detailed information on the participants' background can be found in the Supplementary material (Appendix A). Consumers participated in the study on a voluntary basis and received no compensation for their time.

2.2.3. Procedures

The study was conducted at CLT at the University of Southern Denmark, Odense, Denmark. Consumers tasted all 10 products monadically with individual serving orders, obtained following a Latin square design (MacFie, Bratchell, Greenhoff, & Vallis, 1989) to minimize order and carry-over effects.

Consumers in the blind condition (Study 1A) received the samples (3–4 pcs, ≈ 6–8 g, depending on the size of the chips) in 80 cc aluminum cups blind-labeled with a random three-digit codes. Consumers in the informed condition (Study 1B) evaluated the same samples as in the previous condition but also received a description of each product, matching the information contained in Table 1. For example, the information sheet for the reference sample was "Kims Sour & Cream and Onion", whereas the information for the reformulated samples were Kims SC&O "with/[−x%] sodium" or "with/[−x%] sodium replaced by KCl" or "with/[−x%] sodium replaced by MSG". This information was placed on top of each individual ballot (whereas in Study 1A the same place would instead only show the three-digit code).

For each sample, consumers had to rate the following (in order of appearance in the ballot):

1. degree of liking using a 9-pt hedonic scale ranging from 1 = Not at all to 9 = Very much;
2. perceived healthiness ("to which degree do you experience this as a healthy potato chip"), again on 9-pt scale ranging from 1 = Not at all to 9 = Very much;
3. appropriateness of five sensory properties (saltiness, sourness, bitterness, sweetness, spice intensity) using 5-pt JAR scales (Way too little, Too little, Just about right, Too Much, Way too much);
4. perceived familiarity ("taste-wise, how close is this sample to the chips you normally eat?"), on a 5-pt scale ranging from 1 = Not at all to 5 = Very close.

Water was provided as palate cleanser and consumers were encouraged to drink water and take a break before moving on to the next sample. After they had completed the sample evaluation, consumers answered an extensive survey regarding their demographics (age, gender, education, income), attitudes and habits towards chips (frequency of chips consumption, perceived healthiness of chips, interest in salt-reduced chips) and salt generally (perceived salt intake, interest in reducing dietary intake of salt, frequency of adding salt to food, frequency of eating processed food).

The ballot and the full protocol were pilot tested with a group of consumers (N = 20) similar to the main consumer group, in order to ensure that the questions were understandable and also to ensure that the task was not too cumbersome for the participant. Average completion time in the main study was ≈20 min. The study was not found to require formal ethical approval by the Danish National Committee on Health Research Ethics.

2.3. Study 2

2.3.1. Experimental design

Study 2 used a full experimental design with systematic variation in the following three factors: sodium content (2 levels: Reference vs −30%), texture (2 levels: Wavy vs Smooth), and seasoning (3 levels: Sea salt, BBQ, and Sour Cream & Onion). A complete overview of the samples used in the study, including sodium content and abbreviations used in tables and figures, is given in Table 2. Regarding seasoning, all three levels represent well established products in the Danish market. The BBQ seasoning was included because of its umami character, mainly associated from the tomato used in the seasoning. The sea-salt was included as it provides a relatively blander flavor matrix where the only seasoning is salt itself, thus providing an opportunity whether the same level of salt reduction can be achieved without a complex seasoning. The SC&O, already described earlier in the paper, was included in order to check the robustness of the results obtained in Study 1, as two of the SC&O samples (those with wavy texture) were present in both studies.

2.3.2. Consumers

One-hundred consumers (Gender: 68% women/32% men, Age: 67% 18–24 and 33% 25–30) participated in Study 2. Recruitment strategy, inclusion criteria, etc. were identical to Study 1. Detailed information on the participants' background can be found in the Supplementary material (Appendix A).

2.3.3. Procedures

Experimental procedures in Study 2 were equivalent to those used for the blind condition in Study 1. The ballot was slightly shorter as perceived healthiness ratings were not included (since expected to be mostly related to labeling). Nevertheless, since consumers evaluated 2 additional samples in this study, completion time was similar to that of Study 1 (≈20 min). The same set of background information (demographics, attitudinal, etc.) as in Study 1 was collected on this consumer sample as well.

2.4. Data analysis

A similar set of data analyses – informed by the three objectives – were performed on data form both studies. Analysis of variance (ANOVA) was used to uncover the effect of the experimental factors on liking, healthiness and familiarity. In Study 1, this was done with a 4-way ANOVA using test condition (blind vs. informed), NaCl content (Ref, −10, −20, −30), Reformulation strategy (None, Salt reduction, KCl, MSG), samples, and their two-way interactions as main effects. Consumers (within each test condition) were included as random source of variation in the model. A corresponding model was used in Study 2, this time using texture (smooth vs. wavy), NaCl content (Ref, −30), recipe (SCO, Sea Salt and BBQ), samples and their interactions as main effects, and, again, consumers as random effect. Where significant main effects were found, pairwise comparisons by Tukey's Honestly Significant Difference (HSD) test were carried out to uncover differences between means.

Results from the JAR scales were mainly explored visually using histograms showing the frequency of response of the JAR points for each sample by test condition (Study 1) and by texture (Study 2). Additionally, a penalty analysis was conducted to identify how deviations from the JAR point affected liking on a sample by sample basis. Specifically, mean liking for consumers who ticked the JAR point was compared to the mean liking for consumers who ticked the non-JAR scale points to identify significant differences. Note that the original 5-point scale was reduced to 3 for this analysis (accordingly, in figures in tables pertaining to the JAR data, the "not salty enough" category represents both "Too little" and "way to little", and the "too salty" represents both "too much" and "way too much"), in order to improve presentation clarity and because there were too few data points (N < 10) in the extreme points (for complete results refer to Appendix B).

In both studies, the effect of individual traits on liking and perceived healthiness of the samples was also evaluated. For discrete variables (e.g., gender, smoking status) liking and healthiness means were compared using ANOVA. For quantitative variables (e.g. age, consumption frequency) correlation analysis (Pearson's correlation coefficient) was used to elucidate their relationship with the two focal variables as well as within each other.

All analyses were performed using R (R Core Team, 2017), using native functions as well as functions from the `ggplot2` (Wickham, 2009) and `corrplot` (Wei & Simko, 2017) packages. Statistical significance was set at α = 5%.

3. Results

3.1. Study 1

3.1.1. Effect of labeling

We start by presenting results concerning differences due to test conditions (blind vs informed) on liking, perceived healthiness and familiarity of the samples.

With respect to liking, the ANOVA revealed a marginally significant main effect of test condition ($F_{(1,1979)} = 3.6$, $p = 0.057$), a significant effect of NaCl content ($F_{(3,1979)} = 2.9$, $p = 0.034$), salt replacement strategy ($F_{(2,1979)} = 3.1$, $p = 0.043$), as well as a significant two-way interaction between test condition and NaCl content ($F_{(3,1979)} = 15.2$, $p < 0.001$). All other effects were not significant. Mean liking was slightly higher in the informed condition than in the blind condition ($\text{Mean}_{(\text{Blind})} = 6.0$, $\text{Mean}_{(\text{Informed})} = 6.3$); however, the presence of a significant interaction with NaCl content, and visual inspection of results on sample by sample basis clearly indicated that the difference was almost exclusively due to the reference sample: as shown in Fig. 1, this sample was liked significantly more (1.9 on a 9-pt scale) when consumers were aware that it was the standard version of this product, and was the most liked sample overall in the informed conditions whereas, remarkably, it was the least liked in the blind test. Liking for all other NaCl level did not differ across test conditions according to the Tukey's test.

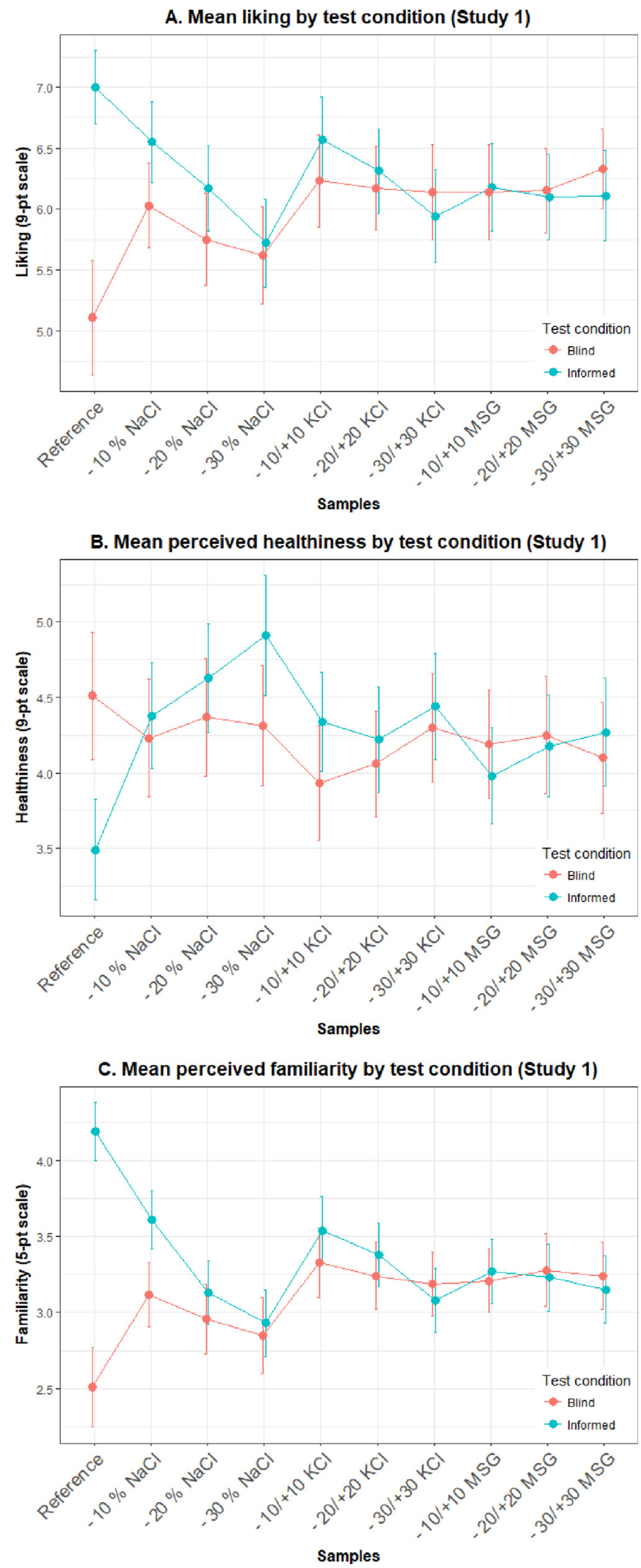

Fig. 1. Study 1: Mean liking (A), perceived healthiness (B) and familiarity (C) for each sample by test condition (blind vs. informed). The error bars represent 95% confidence intervals around the means.

With respect to perceived healthiness, the four-way ANOVA revealed a significant main effect of test condition ($F_{(1,1979)} = 24.1$, $p < 0.001$), NaCl content ($F_{(3,1979)} = 2.8$, $p = 0.038$), reformulation strategy ($F_{(2,1979)} = 4.9$, $p = 0.007$), as well as a significant two-way interaction between test condition and NaCl content ($F_{(3,1979)} = 6.1$, $p < 0.001$). Mean healthiness ratings of the samples spanned a larger range in the informed condition than they did in blind (Range $_{(Blind)}$ = 3.9 – 4.5; Range $_{(Informed)}$ = 3.5 – 4.9). However, as shown in Fig. 1, the real difference between the test conditions pertained, again, to the reference sample, which was perceived as significantly less healthy in the informed condition compared to all salt-reduced samples, consistent with the fact that the two-way interaction term was significant.

With regards to familiarity, the main effects of NaCl content ($F_{(3,1979)} = 7.0$, $p < 0.001$), reformulation strategy ($F_{(1,1979} = 4.7$, $p = 0.009$) were significant. Unlike for liking and healthiness, test condition did not affect familiarity directly ($F_{(1,1979)} = 0.03$, $p = 0.869$) but only through an interaction with NaCl content ($F_{(3,1979)} = 32.0$, $p < 0.001$), which again related to the reference sample which was perceived as much more familiar in the informed condition than in blind, whereas all other samples received similar ratings across the two conditions (Fig. 1c). Observing Fig. 1a and 1c side-by-side shows that sample ranking across the two test conditions is very similar. Accordingly, liking and familiarity were found to be quite highly correlated in both conditions (Blind: $r_{(998)} = 0.68$, $p < 0.001$; Informed: $r_{(998)} = 0.67$, $p < 0.001$).

3.1.2. Salt-reduction strategies

As reported in the previous section, the main effect for NaCl content on liking was significant in the ANOVA. However, mean liking for the different NaCl levels were very close. Accordingly, pairwise comparisons for the different NaCl levels following ANOVA revealed that only significant difference was between the −10% and −30% levels, with the former being liked slightly more (0.3 on a 9-pt scale) than the latter (Tukey $p = 0.021$).

Regarding the reformulation strategies for reducing salt, replacement by KCl was the most liked strategy whereas simple salt reduction was the least liked. This was the only difference that was significant, though, again, the difference was extremely small (Mean $_{(KCl)}$ = 6.2, Mean $_{(No\ replacer)}$ = 6.0), and after adjusting for multiple comparisons it appeared to be only marginally significant (Tukey $p = 0.08$). Replacement with MSG (Mean $_{(MSG)}$ = 6.2) and the reference (Mean $_{(Reference)}$ = 6.1) could not be differentiated from the other strategies.

Concerning the main effects of reformulation strategy on healthiness ratings, simple salt reduction (Mean $_{(-NaCl)}$ = 4.5) was perceived as significantly healthier than both KCl replacement (Mean $_{(KCl)}$ = 4.2, Tukey $p = 0.074$), and MSG replacement (Mean $_{(MSG)}$ = 4.2, Tukey $p = 0.018$).

All in all, the range of difference pertaining to sensory reduction strategies was modest (< 1 on a 9-pt scale), indicating that all samples were similarly liked.

To get insights into the sensory consequences of salt-reduced reformulations, Fig. 2 shows the results for the saltiness JAR scales in the form of histograms showing response frequencies for each of the JAR point. Fig. 2 also presents the results by test condition (blind and informed), as it was expected that the presence of information may make consumers more sensitive to differences in saltiness.

The biggest difference pertained to, again, the reference sample (Fig. 2a), where many more consumers ticked the JAR point in the informed (60%) than in the blind condition (40%). The opposite was observed for the 30% KCl sample (Fig. 2g) and the 30% MSG sample (Fig. 2j): for these two samples, consumers in the blind condition more frequently reported that their saltiness was optimal (JAR), whereas consumers in the informed condition to a much higher degree perceived them as being not salty enough.

In general, however, the JAR results seemed more dependent on the samples than on the test protocol. As expected, reduction in NaCl resulted in a more left-skewed distribution of JAR responses. This is especially evident for the reformulation consisting of simple salt reduction (Fig. 2b, 2c, 2d) as the loss of saltiness in these samples is not compensated by any replacers. Reduction of 10% NaCl across all three reformulation strategies (Fig. 2b, 2e, 2 h) resulted in frequencies of JAR responses very close to that of the reference sample (Fig. 2a). By contrast, the response distribution in the −30% samples were the most different from the reference as these samples tended to be much more skewed to the left (Fig. 2d, 2 g, 2j). However, the −30% samples were also the ones most different across the two conditions, as generally the JAR responses appear more normally distributed in the blind condition, and more left-skewed in the informed condition.

Results of the penalty analysis are shown in Table 3. The penalty analysis demonstrated that lack of saltiness was associated to a decrease in liking of up to 1.5–2 points on a 9-pt scale. Consumers in the informed condition reported more often that the samples lacked saltiness (except for the reference) compared to those in blind condition, however the associated drop in liking was generally lower.

JAR results for the other basic tastes showed much less sample-to-sample variability than saltiness (as one would expect). For brevity, these results are not shown here but are given as Supplementary material (Appendix B).

3.2. Study 2

With regards to Study 2, we first report on the effect of texture on the acceptability of the chips. Across all samples, the mean liking for textured (wavy) and non-textured (smooth) samples were virtually identical (5.6 and 5.5 on a 9-pt scale, respectively). Accordingly, the ANOVA on liking data revealed no significant effect of texture ($F_{(1,1187)} = 0.9$, $p = 0.35$). Conversely, we found a significant main effect of NaCl content ($F_{(1,1187)} = 5.5$, $p = 0.018$), a significant effect of recipe ($F_{(2,1187)} = 13.8$, $p < 0.001$), and a significant interaction between recipe and texture ($F_{(2,1187)} = 3.7$, $p = 0.025$). The interaction was primarily due to the SCO formulation, where the wavy samples were significantly preferred to the smooth sample in both the reference and the salt-reduced version (Fig. 3). Nevertheless, this result appeared more likely related to familiarity (the wavy SCO sample correspond to the texture of the market version of this product) than to an actual effect of texture, and familiarity ratings (not shown here) confirmed this interpretation.

With respect to differences due to NaCl content, Fig. 3 suggest that all sodium-reduced formulations were slightly less liked than their reference product. While the effect of NaCl content was significant in the ANOVA model, it should be noted that the magnitude of the difference was small – 0.3 on a 9-pt hedonic scale (Mean $_{(Ref)}$ = 5.7; Mean $_{(-30\%\ NaCl)}$ = 5.4, Tukey $p = 0.018$) – thus confirming the findings of Study 1. Actual differences between individual samples due to NaCl content were modest (ranging between 0.1 and 0.6 on a 9-pt scale).

The effect of recipe was instead due to the SCO samples being liked significantly more than the other two recipes (Mean $_{(SCO)}$ = 6.0; Mean $_{(SeaSalt)}$ = 5.4; Mean $_{(BBQ)}$ = 5.3). As in Study 1, liking appeared very driven by familiarity, with the textured SCO sample scoring highest in both variables. Again, correlation analysis revealed a clear positive correlation between the two ($r_{(1198)} = 0.75$, $p < 0.001$). This correlation coefficient was slightly, but significantly,[2] higher than those obtained in first study, likely because the sensory differences between the test products in Study 2 were larger than those in Study 1.

The JAR results (Fig. 4) to a large degree confirmed these indications as we can see that the stacked histograms for both texture and non-textured samples are very similar. As expected, sodium reduced

[2] Study 2 vs. Study 1 (Blind): z = −3.35, $p < 0.001$; Study 2 vs. Study 1 (Informed): z = −3.78, $p < 0.001$).

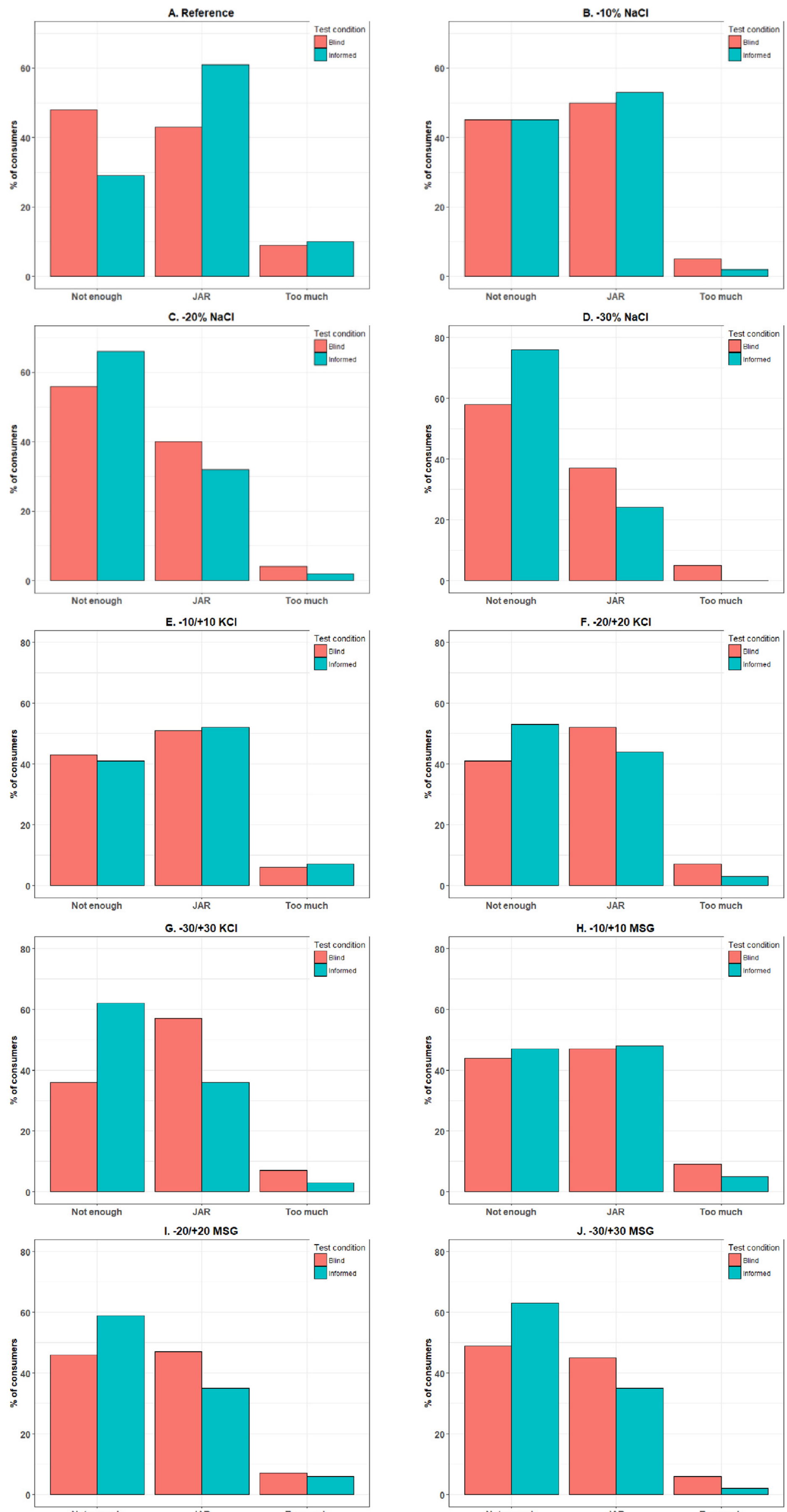

Fig. 2. Study 1: Histograms showing the frequency of mention of each point on the saltiness JAR scale by test condition (blind vs. informed).

Table 3
Penalty analysis showing mean drop associated with deviations from the JAR point on a sample by sample basis and across test conditions (Study 1).

Sample	JAR point	Test condition					
		Blind			Informed		
		Mean	Drop	%	Mean	Drop	%
Reference	Too Salty	4.6	−1.4	9%	7.3	−0.2	10%
	Just About Right	5.9		43%	7.5		61%
	Not Salty Enough	4.5	−1.4	48%	5.8	−1.7	29%
−10% NaCl	Too Salty	5.0	−1.8	5%	6.0	−1.3	2%
	Just About Right	6.8		50%	7.3		53%
	Not Salty Enough	5.3	−1.5	45%	5.7	−1.6	45%
−20% NaCl	Too Salty	5.2	−1.3	4%	7.0	0.0	2%
	Just About Right	6.5		40%	7.0		32%
	Not Salty Enough	5.2	−1.3	56%	5.7	−1.3	66%
−30% NaCl	Too Salty	5.6	−1.2	5%	0.0	−6.6	0%
	Just About Right	6.8		37%	6.6		24%
	Not Salty Enough	4.9	−1.9	58%	5.4	−1.2	76%
−10/+10% KCl	Too Salty	7.0	0.3	6%	6.1	−1.1	7%
	Just About Right	6.7		51%	7.2		52%
	Not Salty Enough	5.6	−1.1	43%	5.8	−1.4	41%
−20/+20% KCl	Too Salty	6.6	−0.3	7%	5.0	−2.1	3%
	Just About Right	6.9		52%	7.1		44%
	Not Salty Enough	5.2	−1.6	41%	5.7	−1.3	53%
−30/+30% KCl	Too Salty	5.3	−1.7	7%	8.0	1.1	3%
	Just About Right	7.0		57%	6.9		36%
	Not Salty Enough	4.9	−2.1	36%	5.2	−1.7	61%
−10/+10% MSG	Too Salty	5.0	−2.1	9%	6.6	−0.3	5%
	Just About Right	7.1		47%	6.9		48%
	Not Salty Enough	5.4	−1.7	44%	5.4	−1.5	47%
−20/+20% MSG	Too Salty	6.9	−0.1	7%	6.0	−1.0	6%
	Just About Right	7.0		47%	7.0		35%
	Not Salty Enough	5.2	−1.8	46%	5.6	−1.4	59%
−30/+30% MSG	Too Salty	6.0	−1.0	6%	5.5	−1.6	2%
	Just About Right	7.0		45%	7.1		35%
	Not Salty Enough	5.8	−1.2	49%	5.6	−1.6	63%

samples exhibited more left-skewed distributions. The penalty analysis (Table 4) showed that NaCl reduction caused a deviation from the JAR point, with the sodium reduced samples having between 6% and 22% fewer consumers evaluating them as being JAR with respect to saltiness. The drop in mean liking associated with lack of saltiness ranged from 0.6 to 2.4. Lack of saltiness was associated to a larger liking drop in the Sea-Salt samples (Max: −2.4; Min: −1.2), whereas it was less impactful in the BBQ samples (Max: −1.5; Min: −0.6). The range of mean drops for the SCO samples (Max: −1.9, Min: −1.4) was similar to Study 1 (as expected since this recipe was the basis for the samples used in that study).

3.3. Individual differences (both studies)

The last set of data collected concerned consumers' demographics, behavioral and attitudes.

Table 5 reports the effect of discrete variables (gender and smoker status) on the two outcome measures (liking and perceived healthiness) across all studies. A significant effect of gender on liking was found in Study 1B, with overall liking for women being 0.5 higher than for men on a 9-pt scale. This suggests that liking in women may have been affected by nutritional information, since no significant effect of gender was found in Study 1A. A significant effect of gender was also found in Study 2, this time in the opposite direction with men obtaining a higher mean liking than women (Table 5). Further analyses revealed that this result was due to a significant interaction effect between gender and sample, where men liked significantly more all samples with BBQ seasoning than women did (results not shown here). Concerning smoker status, the expectation that smokers would like salt-reduced chips was only marginally supported in Study 1A, where this group had a lower liking than non-smokers did, whereas no differences were found in Study 1B and Study 2 (Table 5). No instances where perceived healthiness was affected by either gender or smoker status were observed.

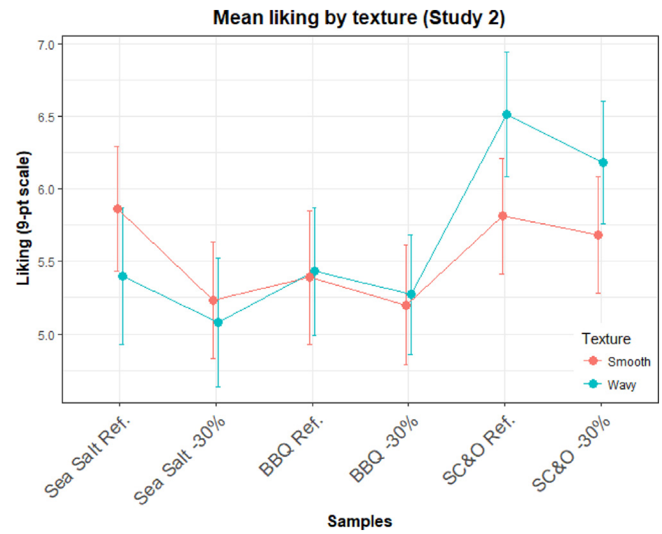

Fig. 3. Study 2: Mean liking for each sample by texture type (wavy vs. smooth). The error bars represent 95% confidence intervals around the means.

Fig. 5 shows the correlation between all quantitative variables (refer to figure captions for full variable explanation and to Appendix A for a full breakdown of this data) on a study by study basis. As the substantial number of "Xs" and light shades indicate, the majority of these correlation coefficients were either non-significant or very close to 0. The strongest and most consistent correlations found, besides the previously discussed one between liking and familiarity, pertained to general health orientation (variable "healthy lifestyle" in Fig. 5) which was found to be positively associated to physical exercise frequency ("Exercise") and negatively correlated to consumption of processed foods (Fig. 5). By contrast, correlations pertaining to behavioral and attitudinal statements about chips were mostly weak and/or transient. It should also be noted that in all studies liking was either completely uncorrelated or very weakly correlated to both consumption frequency for chips and willingness to buy (WTB) for salt-reduced chips.

Perceived healthiness ratings and self-reported motivation to reduce dietary salt intake ("SaltReduction" in Fig. 5) were the only two variables to consistently correlate with WTB across all studies. Remarkably, WTB for salt-reduced chips was relatively good as a sizeable percentage of consumers (Study 1A: 36%; Study 1B: 51%, Study 2: 43%) reported that they were "likely" or "very likely" to buy one or more of the samples after having been informed that they contained less salt than normal chips.

4. Discussion

This research focused on consumer perception of salt-reduced potato chips. The first aim was to evaluate consumer preferences for salt-

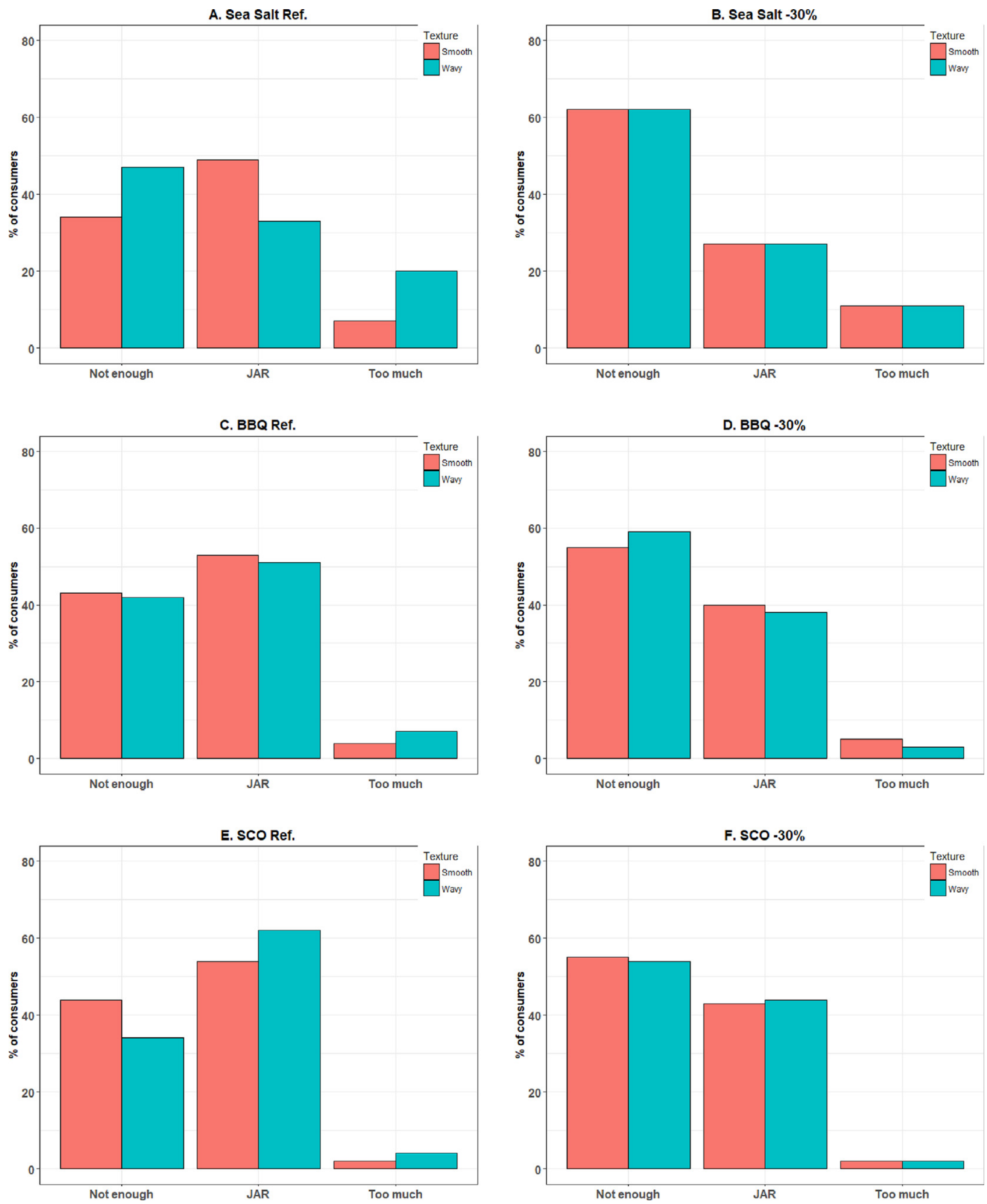

Fig. 4. Study 2: Histograms showing the frequency of mention of each point on the saltiness JAR scale by texture type (wavy vs. smooth).

reduced chips in blind and informed conditions. As discussed in the introduction, nutritional information has been found to affect consumer perception of salt-reduced products in previous literature, but the presence and direction of such effect has not been consistent across product categories. In Study 1, consumer liking in the informed condition was found to be higher only for the reference sample (corresponding to the market version of this product), indicating that this difference was more likely due to product/brand familiarity rather than to any negative effect of the nutritional information on salt content. Taken overall, we found no evidence of either assimilation or contrast effect (as e.g., in Liem et al., 2012); rather, our results indicated that nutritional information did not have a large effect on consumer liking for salt-reduced chips. These results are consistent with findings reported by Czarnacka-Szymani and Jezewska-Zychowicz (2015) in a different product category (dairy products), and suggest that claiming salt reduction in potato chips can be done without adverse effects on consumer acceptability.

One caveat here is that a strong effect of product familiarity (worth almost 2-pt of a 9-pt hedonic scale for the reference formulation) was observed, whereby consumers in the informed condition preferred the reference product when they knew that it corresponded to the usual formulation. This could be an instance of a status quo bias often observed for very familiar products (Giacalone & Jaeger, 2016). On that premise, the use of positively valenced communication (e.g. "*same great taste, less salt*" or something to that effect) – as opposed to the neutral phrasing used in this research – could be beneficial to counter this effect (Willems, van Hout, Zijlstra, & Zandstra, 2014). It is also likely that a more positive phrasing would also mitigate the loss of perceived saltiness (as highlighted by the JAR results) to some degree, since which previous studies indicate as an effective strategy in maintaining taste intensity; Zandstra et al., 2016).

Aside from sensory preferences, however, labeling did improve

Table 4
Penalty analysis showing mean drop associated with deviations from the JAR point on a sample by sample basis and across texture type (Study 2).

Sample	JAR point	Wavy (Textured) Mean	Wavy (Textured) Drop	Wavy (Textured) %	Smooth (Non-textured) Mean	Smooth (Non-textured) Drop	Smooth (Non-textured) %
Sea-Salt – Ref.	Too Salty	4.2	−2.9	20%	5.2	−1.3	7%
	Just About Right	7.1		33%	6.5		49%
	Not Salty Enough	4.7	−2.4	47%	5.2	−1.3	34%
Sea-Salt – −30%	Too Salty	4.5	−1.6	11%	4.5	−1.5	11%
	Just About Right	6.1		27%	6.0		27%
	Not Salty Enough	4.7	−1.4	62%	4.8	−1.2	62%
BBQ – Ref.	Too Salty	4.9	−0.9	7%	3.0	−3.0	4%
	Just About Right	5.8		51%	6.0		53%
	Not Salty Enough	5.1	−0.6	42%	4.9	−1.1	43%
BBQ – −30%	Too Salty	4.0	−2.2	3%	4.8	−1.0	5%
	Just About Right	6.2		38%	5.8		40%
	Not Salty Enough	4.7	−1.5	59%	4.8	−1.1	55%
SCO – Ref.	Too Salty	6.7	−0.4	4%	5.5	−1.0	2%
	Just About Right	7.1		62%	6.5		54%
	Not Salty Enough	5.3	−1.8	34%	5.0	−1.4	44%
SCO – −30%	Too Salty	6.5	−0.7	2%	6.0	−0.5	2%
	Just About Right	7.2		44%	6.5		43%
	Not Salty Enough	5.3	−1.9	54%	5.0	−1.5	55%

Table 5
Mean liking and perceived healthiness by gender and smoking status across all studies. *F* and *p* values from ANOVA associated with these mean differences are also reported.

	Gender: Female	Male	$F_{(1,998)}$	p	Smoker status: Yes	No	$F_{(1,998)}$	p
Study 1A (Blind)								
Liking	6.1	5.9	1.8	0.186	6.4	5.9	3.6	0.057
Healthiness	4.1	4.3	1.8	0.174	4.2	4.3	0.0	0.855
Study 1B (Informed)	Female	Male	$F_{(1,998)}$	p	Yes	No	$F_{(1,998)}$	p
Liking	6.6	6.1	13.2	< 0.001	6.3	6.2	0.1	0.742
Healthiness	4.4	4.2	2.4	0.118	4.2	4.3	0.2	0.683
Study 2	Female	Male	$F_{(1,1198)}$	p	Yes	No	$F_{(1,1198)}$	p
Liking	5.2	5.7	13.4	< 0.001	5.3	5.6	1.0	0.310

consumer attitudes towards the reformulations, as consumers consistently reported that they were more likely to purchase the tasted samples after being informed that they contained less salt, thus confirming previous findings that purchase intent of chips is affected by information on sodium reduction (Torrico et al., 2019). This finding is undoubtedly due to a perceived health gain associated to NaCl reduction and, accordingly, we found that consumers in the blind condition found harder to differentiate between the samples on the basis of healthiness than consumers in the informed condition. Interestingly, while nutritional knowledge regarding salt is reportedly more prominent in older consumers (Sarmugam, Worlsey, & Wang, 2013; Webster, Li, Dunford, Nowson, & Neal, 2010), the fact that nutritional information affected perceived healthiness in our studies indicate that young (millennials) consumers are also aware of nutritional risks related to a high sodium diet.

The magnitude of the effect of nutritional information on the perceived healthiness of the chips was contingent on the salt-reduction strategy. Simple NaCl reduction was perceived as being a healthier strategy than replacement by both KCl and MSG, possibly due to the unfamiliarity and/or perceived risks associated with these compounds (Asioli et al., 2017; Bearth et al., 2014). Importantly, however, all salt-reduced samples in the informed conditions were perceived as being healthier than the reference product, meaning that communication on sodium reduction overall is effective in increasing perceived healthiness. Interestingly, consumers rated in the informed condition rated the −30% NaCl samples as the healthiest. The −30% level was the only NaCl content that was perceived as significantly healthier than the reference samples, meaning that the information was most effective at about the same reduction level needed to meet current legal requirements (25%), although this is probably a coincidence as it is unlikely that many consumers knew this beforehand.

With respect to the effectiveness of different reformulation strategies – the second objective of this research – findings of both studies indicated that salt reduction was associated with lower acceptability. While the differences in terms of NaCl content were significant, their size was extremely modest. For instance, Study 2 showed that for all recipes after a 30% NaCl reduction the acceptability compared to the reference product only decreased, on average, by 0.3 on a 9-pt hedonic scale. This finding could be robustly replicated across both studies and held true even in a formulation where salt was the only seasoning, such as the sea salt formulation in Study 2. A somewhat unexpected finding from Study 1 was that the reference sample, in the blind condition, was actually liked less than the reduced salt formulations (cf. Fig. 1a), even in absence of replacers. This seem to be related to the relative higher sourness in this sample, possibly due to binary interactions between NaCl and the sour agent used in the seasoning (malic acid). Taste-taste interactions between saltiness and sourness have been reported in the literature. For instance, Mojet, Heidema and Christ-Hazeldof (2004) reported an increase in sourness associated with increasing NaCl concentration in tomato soups. Keast and Breslin (2003) note that the effect of salt on sourness are both concentration- and compound specific. In Study 1, we speculate that that NaCl enhanced sourness at the

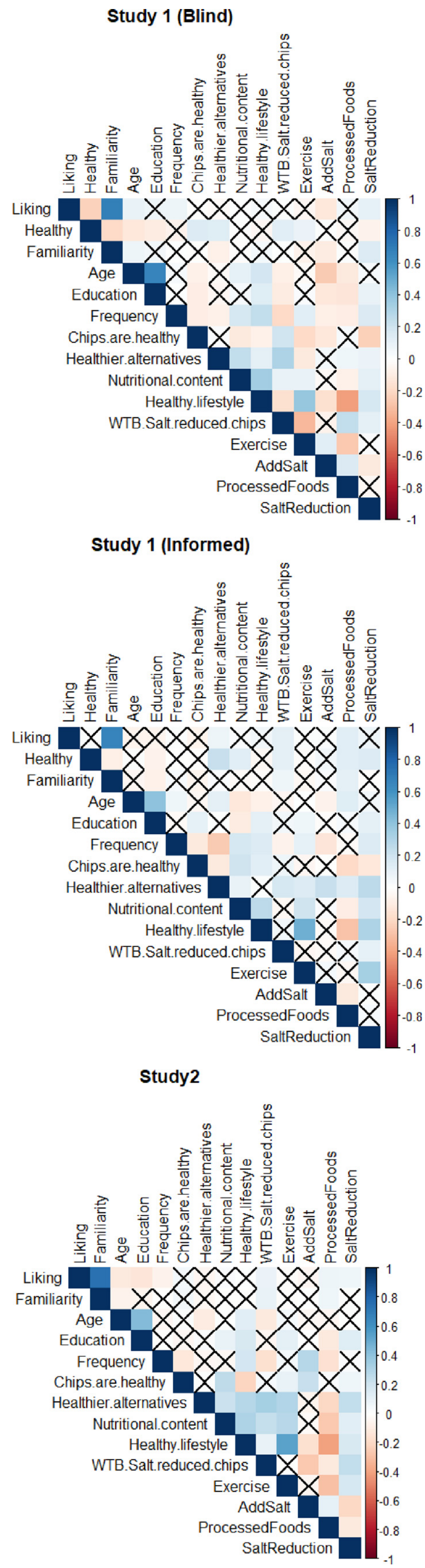

Fig. 5. Correlograms visualizing correlations between liking, familiarity and consumer background information for Study 1A (top), Study 1B (middle) and Study 2 (bottom). Blue and red shaded denote, respectively, positive and negative correlations, whereas "X" denotes not significant correlations ($p > 0.05$). Variables: "Liking" (Liking, 9-pt hedonic scale), "Healthy" (Perceived healthiness, 9-pt scale), "Familiarity" (Perceived familiarity, 5-pt scale), "Age", (Age in years), "Education" (Education level, ordinal scale), "Frequency" (Consumption frequency for potato chips, ordinal scale), "Chips are healthy" (agreement with statement "I think chips are a healthy snack", 7-pt Likert scale), "Healthier alternatives" (agreement with statement "I would eat chips more often if healthier alternatives with less salt were available", 7-pt Likert scale), "Nutritional content" (agreement with statement "When I buy chips and snacks I pay attention to the nutritional content", 7-pt Likert scale), "Healthy lifestyle" (agreement with statement "Generally, I try to lead a healthy lifestyle", 7-pt Likert scale), "WTB" (Willingness to buy salt-reduced chips, 5-pt scale), "Exercise" (Physical activity level, ordinal scale), "AddSalt" (Self-reported frequency of adding salt to dishes, ordinal scale), "ProcessedFoods" (Self-reported frequency of consumption of processed foods, ordinal scale), "SaltReduction" (Interest in reducing salt intake, 5-pt scale). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

concentration used in the reference sample, but less so (or not at all) at the lower concentrations. This interpretation is supported by the JAR results for sourness (reported in the Supplementary material) which show that more than 20% of consumers found the reference sample to be "too sour", whereas this percentage dropped to about 10% the salt-reduced versions. Also, deviation in sourness in the reference sample were associated with a larger drop in liking (-1.6 vs −1 in the other three samples). The relative higher sourness of this sample could also explain why consumers in the blind condition rated it as most healthy, due to the association between sour taste and health from both drugs and fermented foods that are very common in Denmark (e.g. sourdough bread).

Replacement with both KCl and MSG was effective in maintaining consumer acceptability. Additionally, the acceptability of formulations where NaCl was replaced with MSG was not dependent on sodium content (in blind, all three MSG samples were liked more than the reference). This finding is consistent with extant literature on taste-taste interactions showing an enhancement effect of umami on saltiness (Kremer et al., 2009; Roininen et al., 1996), and is further supported by Study 2 in which a seasoning high in umami (BBQ) effectively masked up to a 30% NaCl reduction. However, while there were no differences in mean liking ratings in both cases (the 30% MSG sample in Study 1 and the BBQ −30% NaCl in Study 2) more consumers perceived the chips as being not salty enough (about 10%-20% more than the reference), indicating that for a sizeable minority of consumers this level of NaCl reduction would result in a lower acceptability.

Replacement with KCl was very effective at the 10% level (this sample was liked on par with or better than the reference sample in, respectively, the informed and blind conditions) but in the informed condition was liked less at the 20% and 30% levels. The JAR results, however, suggest that this decrease in liking has a cognitive – rather than sensory – basis, as the frequencies of JAR responses between the reference and the 30% KCl sample in the blind condition were similar.

Furthermore, in Study 2, we considered the effect of texture as a way to potentially enhance saltiness through cross-modal interactions. As explained in the introduction, the rationale for looking into this aspect was informed by previous research suggesting that a less-homogeneous distribution of NaCl on the surface may slow down taste adaptation compared to a more uniform one (Busch et al., 2013; Pflaum et al., 2013; Stieger & van de Velde, 2013). In this case, the results did not align with expectations: neither did texture exert an effect on consumer acceptability, nor did it cause a shift in saltiness as JAR results for wavy and smooth samples were nearly identical. Nevertheless, we found relevant to report these negative results given the paucity of literature on the effect of texture on saltiness. A possible explanation for this lack of effect is that we failed to span a sufficiently large range of textural differences to elicit a differential release of tastants. Consumers' familiarity with the products may have further contributed to masking differences due to textural variation, as previous research has shown that when consumers have prior experience with a product, they may hold perceptual expectations that affect the intensity of specific sensory attributes (Dijksterhuis, Boucon, & Le Berre, 2014). Simply put, this means that since the chips had the same taste, smell and look as the products consumers are used to, small differences in texture may have gone unnoticed.

Finally, we considered the effect to which consumer background affected the results. Based on existing literature (Lampuré et al., 2015), it was expected that a significant effect of gender and smoker status on liking would be found, the idea being that men and smokers should like the samples less due to their reduced sensitivity to salt (compared to women and non-smokers, respectively). Only transient evidence in this direction was found, however. Smoker status affected liking in the hypothesized direction in one study, but not in the rest. Gender affected liking in Study 1, but only in the informed condition. The fact that liking in blind did not differ between genders suggests a cognitive, rather than perceptual, basis for this result. It might have been the case that women were more receptive to the nutritional information presented, in line with earlier reports indicating that women have a more favorable attitude towards salt reduction (Grimes, Riddell, & Nowson, 2009; Nasreddine, Akl, Al-Shaar, Almedawar, & Isma'eel, 2014).

Regarding consumer attitudes towards salt-reduced chips, perhaps the most noteworthy result was that consumers' stated WTB salt-reduced chips was overall high, in accordance with results reported by Torrico et al. (2019). Since liking was uncorrelated to WTB, this result too has likely a cognitive basis: accordingly, we found that perceived healthiness of the chips, as well as consumers' self-assessed motivation to reduce dietary intake of sodium, were consistent predictors of consumers' WTB for salt-reduced chips. Heterogeneity in motivation to reduce salt intake has been reported in the literature as a possible barrier to acceptance of salt-reduced foods (Bobowski, Rendahl, & Vickers, 2015). Our results support this view and suggest that targeted efforts, rather than "one size fits all" approaches, may be needed to successfully target consumers who have less intrinsic motivation and/or awareness of the potential health risks associated with high sodium diet.

4.1. Limitations and directions for future research

We acknowledge some important limitations which should provide relevant avenues for continuing this line of work. First, additional research is needed on compensatory strategies not considered in this research, such as controlling the rate of dissolution of salt crystals by modifying their size and shape (Busch et al., 2013), a strategy that has been shown to have some potential for reducing sodium content in similar snack products (Kilcast & Den Ridder, 2007). As already mentioned, the idea of modifying texture to provide taste contrasts and reduces adaptation could also be revisited in future research, by spanning a wider range of texture variation between the products than we did in this research.

Secondly, with respect to consumer segmentation, we did not find many relationships between background variables and acceptance of salt-reduced chips. It would be relevant to explore whether other variables could be relevant to explain acceptance in this product category. We would point to measures of oral sensitivity (e.g., PROP taster status was implicated in saltiness perception by Bartoshuk, Duffy, Lucchina, Prutkin, & Fast, 1998) and "hedonic sensitivity to salt" as defined by Bobowski et al. (2015),[3] as promising candidates for inclusion in future research. It is also worth emphasizing that this research focused exclusively on young consumers (18–30). As explained, this was part of the research strategy, since this segment is identified as the primary target for snack chips. Nevertheless, it is unclear that results would readily extend to other age groups, especially as e.g. health orientation and nutritional knowledge about salt are reportedly higher in older consumers (Sarmugam et al., 2013; Webster et al., 2010).

Finally, two methodological notes. The first is that the finding that all results are based on consumer self-reports. Given the topic of this research, some degree of social desirability bias in consumer responses, particularly with regards to the informed condition in Study 1, could be expected (for example, this consumer group reported higher WTB for salt-reduced chips than the other two, though not by much). The second methodological limitation is that we only present data relative at one time point, whereas it is quite well established in the literature that repeated exposure to reduced sodium formulation generally alters initial preferences (Bertino, Beauchamp, & Engelman, 1982; Bobowski et al., 2015; Methven et al., 2012). The direction of the effect is generally that of a reduction in liking for the reference product and an increase in liking for the salt-reduced reformulation. In future efforts it would be relevant to assess whether even larger sodium reductions can be achieved for this product category by employing a method requiring extended exposure (for example, home-use testing as demonstrated by Kremer, Shimojo, Holthuysen, Köster, & Mojet, 2013).

5. Conclusion

This research has focused on salt-reduction strategies for potato chips (crisps) and presented data from two consumer studies focusing on young consumers (18–30).

The main findings are as follows: first, we found that salt replacement of up to 30% NaCl with KCl or MSG is achievable with no or minimal loss of acceptability for most consumers, and – in blind conditions – even a 30% reduction of NaCl with no replacement performed as well as the reference in terms of liking.

Secondly, textural variation was anticipated as potentially interesting to enhance saltiness through cross-modal interactions, however, results did not conform to expectations as no or very marginal differences between chips with wavy and smooth texture were observed.

Thirdly, we found some differences in consumer test results obtained in blind and informed conditions, indicating a cognitive component in consumer acceptability of salt-reduced chips. In particular, consumers in the informed condition liked the reference sample (the market version of a widely popular product) significantly more than those in the blind condition, suggesting that product development efforts, besides optimizing the sensory performance of salt-reduced products, should consider ways to override brand attachment. Additionally, nutritional information allowed consumers to effectively discriminate the samples on the basis of perceived healthiness: salt-reduced formulations were perceived as healthier than the reference, though the magnitude of the effect of information was contingent on the salt-reduction strategy, with simple NaCl reduction generally perceived as healthier than NaCl replacement with either KCl or MSG.

Finally, consumer attitudes towards salt-reduced chips were positive, with many consumers reporting high purchase intent for the reformulations (especially in the informed condition). Consumer ratings of perceived healthiness of the test products, as well as their general motivation in reducing dietary intake of NaCl were found to be the strongest predictors of purchase intention for salt-reduced chips.

CRediT authorship contribution statement

Sara Kongstad: Conceptualization, Methodology, Formal analysis, Resources, Investigation, Writing - original draft. **Davide Giacalone:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Visualization, Supervision.

[3] Difference in liking between the test product with the highest and lowest salt concentration.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2019.103856.

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