

Hedonic taste shifts: Saltiness and sweetness

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Sugar
Sweet



Salt
Salty

Chemosensory Superstimuli

1. Can we manipulate human perception and preference for salty and sweet tastes by modifying exposure to these taste qualities?
2. More specifically, by reducing exposure to high salty and high sweet foods, can we adapt individuals - and by extension populations - to lowered salty and sweet environments?
3. Will this result in a healthier population by reducing disease burden (e.g. hypertension, heart disease, obesity, diabetes etc)?

Presumed functional significance of salty and sweet taste

Salty: Identification of Na which is necessary for life and often in short supply particularly for animals that eat mainly or exclusively plants

Sweet: Identification of energy mainly in plants

Salty

U.S. recommendations to reduce salt intake

1969: The first statement from the U.S. government:

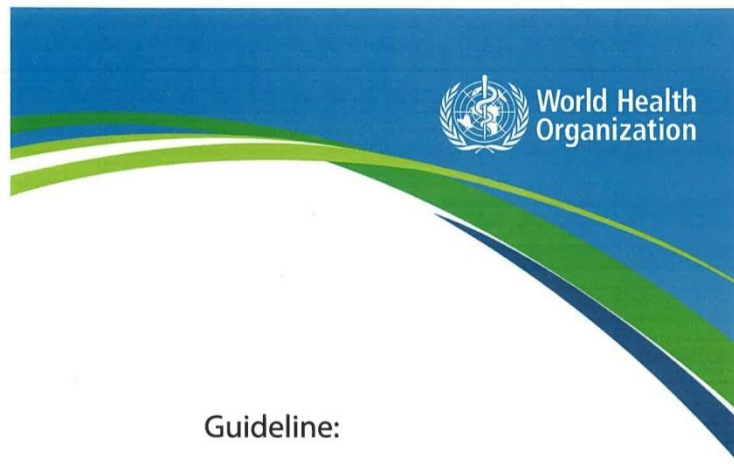
First: at risk populations

Later: all U.S. population

Since 1968, more than 18 national and international government and medical bodies have concurred.

Results to date: NO EFFECT!

World Health Organization: Salt intake recommendations



Guideline:

**Sodium intake
for adults and
children**

2012

WHO recommends a reduction in sodium intake to reduce blood pressure and cardiovascular disease, stroke and coronary heart disease in adults. WHO recommends a reduction to $<2\text{g/day}$ sodium or 2000mg/day (5g/day salt) in adults

WHO recommends a reduction in sodium intake to control blood pressure in children. The recommended maximum level of intake of 2g/day sodium in adults should be adjusted downward based on energy requirements of children relative to those of adults

Dietary salt promotes cognitive impairment through tau phosphorylation*

* In mice.

“Avoidance of excessive salt intake and maintenance of vascular health may help to stave off the vascular and neurodegenerative pathologies that underlie dementia in the elderly.”

Jonathan Swift

Gulliver's Travels

CHAPTER II.

The author conducted by a Houyhnhnm to his house. The house described. The author's reception. The food of the Houyhnhnms. The author in distress for want of meat. Is at last relieved. His manner of feeding in this country.

I was at first at a great loss for Salt; but Custom soon reconciled the Want of it; and I am confident that the frequent use of Salt among us is an Effect of Luxury, and was first introduced only as a Provocative to Drink; except where it is necessary for preserving of Flesh in long Voyages, or in Places remote from great Markets. For we observe no Animal to be fond of it but Man: **And as to myself, when I left this Country, it was a great while before I could endure the Taste of it in anything that I eat.**

Vilhjalmur Stefansson



The lions, tigers, and buffaloes are distinctly inferior to the Nineveh hunting scenes described in the previous article.

MR. V. STEFANSSON describes his successful method of Arctic exploration in an interesting article entitled "Living Off the Country" in the May issue of the *Geographical Review* (vol. vii., No. 5). Mr. Stefansson's well-known adoption of Eskimo habits and diet have enabled him to travel with very light loads and to penetrate far into the unknown for long periods without any anxiety. He contends that from experience he has found that a diet of flesh or fish is quite sufficient to sustain a person in good physical and mental condition, and that salt is not necessary for health. White men whom he has known to have lived for a year or more on an exclusive meat diet have shown no desire to return to the varied and elaborate diet of civilisation. So convinced is Mr. Stefansson of the abundance of food in the Arctic lands and seas he knows that he asserts that any man conversant with the ways of wild animals and the hunting and living methods of the Eskimo can load on one dog-team all the equipment he needs for a journey of several years. Where previous explorers had carried food and fuel, Mr. Stefansson carried neither, choosing to adapt himself to his environment rather than fight it. Instead of taking food and fuel he carried merely the instruments for obtaining them. By economy in the use of ammunition one can obtain as much as two tons of food for a pound of ammunition, or, in other words, ammunition is several thousand times as economical to carry as the most condensed kind of food. The paper deals at length

of racial contact will find food for thought and subjects for observation in Dr. Flint's presidential address.

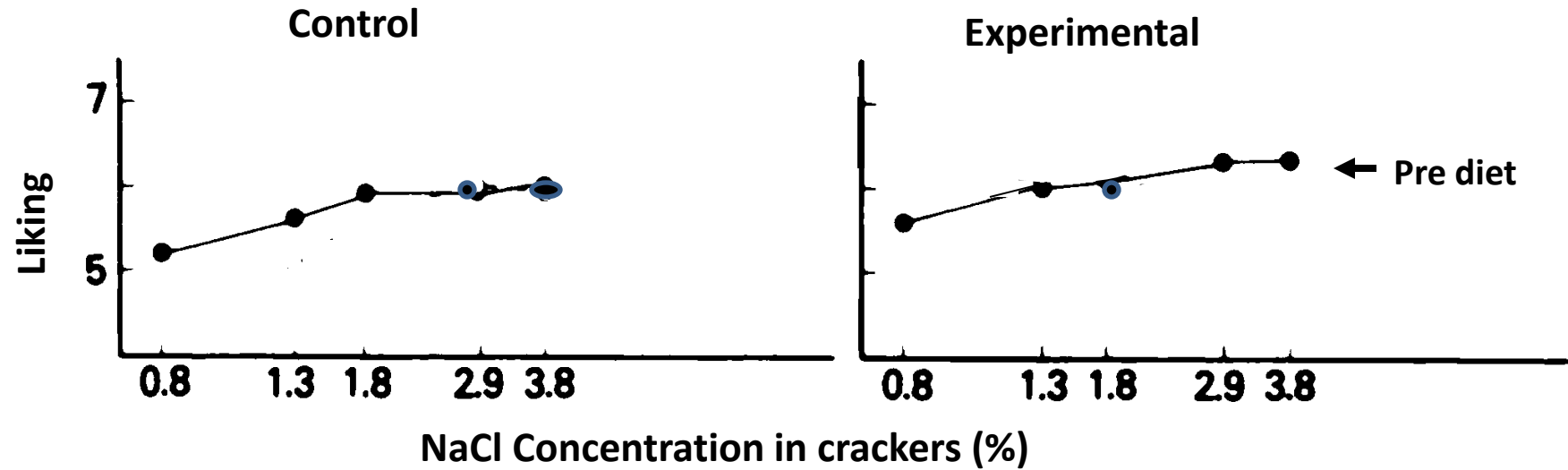
THE Board of Agriculture has received the following information from the International Agricultural Institute at Rome:—The yield of wheat in Spain, Scotland, Italy, Canada, the United States, India, Japan, and Tunis is estimated at 929,525,000 cwt., or 5.6 per cent. below the 1918 crop, and 1.1 per cent. below the average yield of the five years 1913-17. The estimated production of rye for Italy, Canada, and the United States is given as 48,274,000 cwt., or 7.1 per cent. below last year's production, but 67.3 per cent. above the average crop for the years 1913-17. The barley crop for Scotland, Italy, Canada, the United States, Japan, and Tunis is estimated at 159,397,000 cwt., or 15.1 per cent. below last year's production, and 4.1 per cent. above the average production of the years 1913-17. The estimated production of oats in Scotland, Italy, Canada, the United States, Japan, and Tunis is 491,933,000 cwt., or 18.4 per cent. below the 1918 yield, and 7.2 per cent. below the average yield of the five years 1913-17. The maize crop in Italy, Canada, and the United States is estimated at 1,473,592,000 cwt., or 10.2 per cent. above the 1918 production, and 3 per cent. above the average yield of the years 1913-17.

THE flora of Aldabra and other small islands of the western Indian Ocean is the subject of an article by Dr. Hemsley in the *Kew Bulletin* (No. 3, 1919). Aldabra is an atoll, similar in size to the Isle of Wight, 200 miles north-west of Madagascar, and about

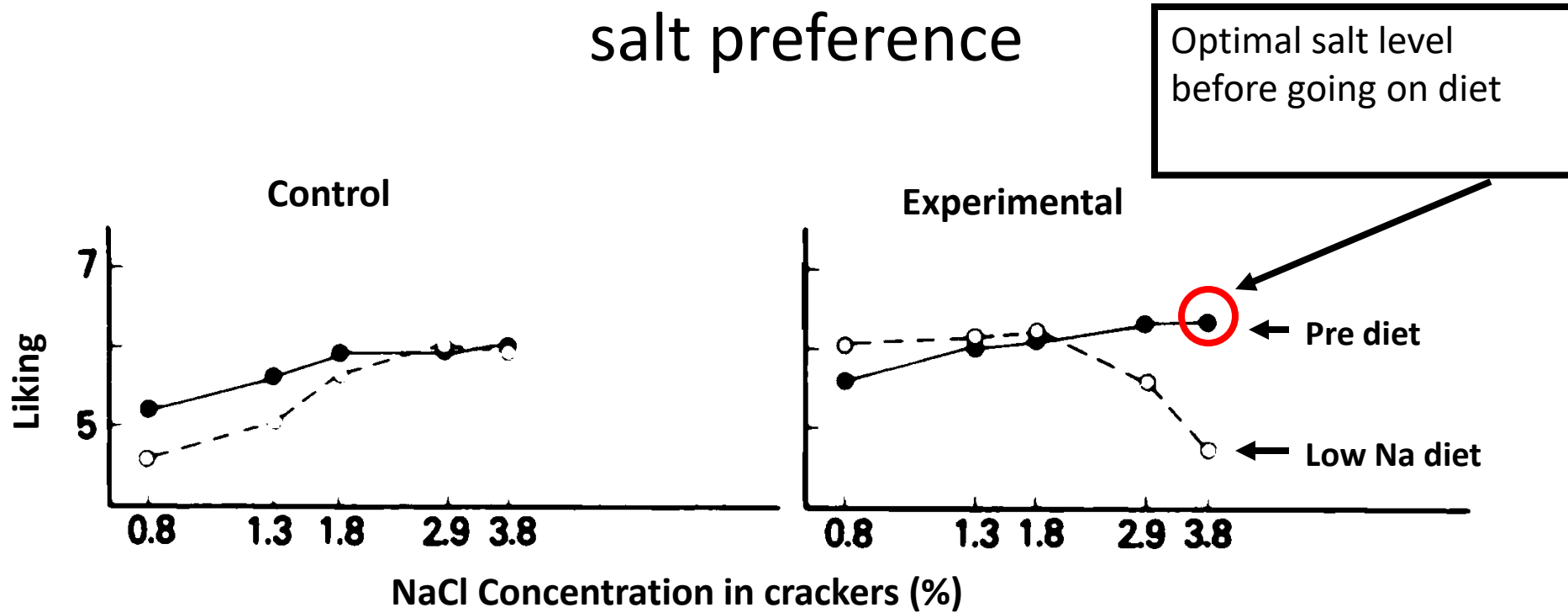
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Experimental studies on salt reduction and taste

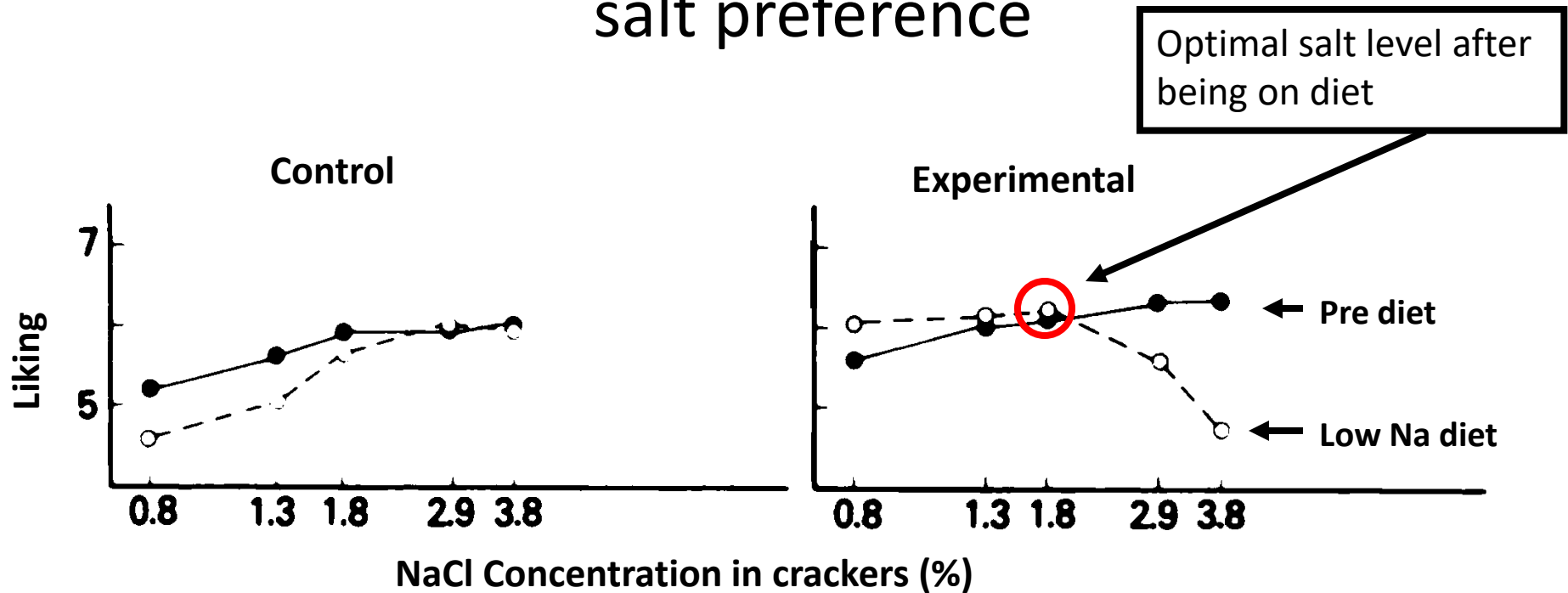
Decreasing Na intake is followed by decreased salt preference



Decreasing Na intake is followed by decreased salt preference

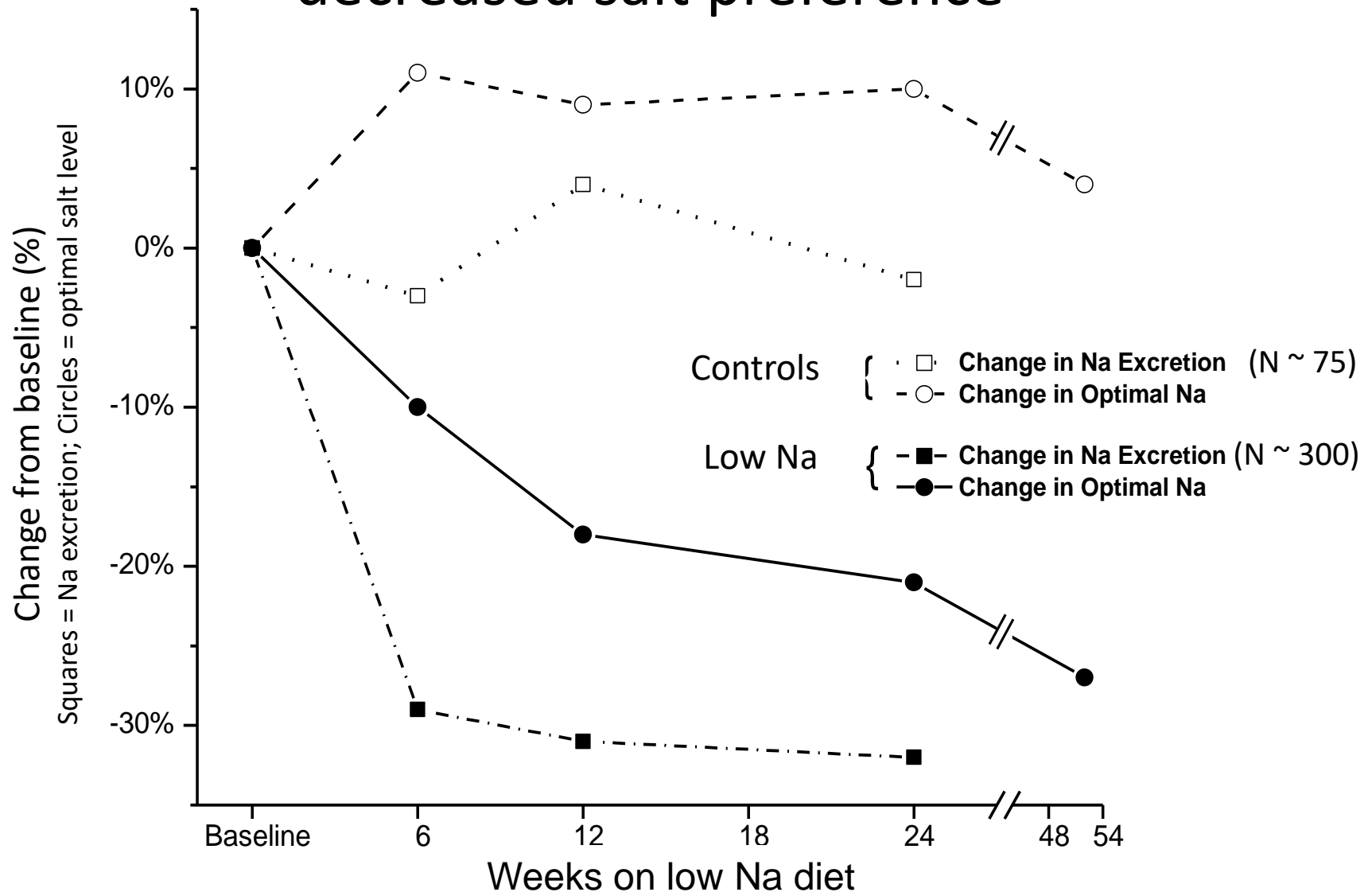


Decreasing Na intake is followed by decreased salt preference



After 3 months on a lowered sodium diet

Decreasing Na intake is followed by decreased salt preference



A change in salt intake is followed by a change in salt perception/preference

Lowered salt intake reduces high salt preference

- Bertino, Beauchamp & Engelman. AJCN 36: 1134-1144, 1982.
- Blais, Pangborn, Borhani, Ferrell, Prineas & Lang. AJCN 44: 232-243, 1986
- Elmer. Unpublished PhD thesis, University of MI, 1988
- Mattes. AJCN 65(Supplement): 692S-7S, 1997.

Increased salt intake increases high salt preference

- Bertino, Beauchamp & Engelman. Physiol Behav 38: 203-213, 1986
- Teo, DiNicolantonio & Morgan. Clin Exp – Theory and Practice, 1986.

Systematic review:
Change in salt taste with reduced
sodium intake

None available

Strategies to Reduce Sodium Intake in the United States

IOM Committee on Strategies to Reduce Sodium Intake



INSTITUTE OF MEDICINE

OF THE NATIONAL ACADEMIES

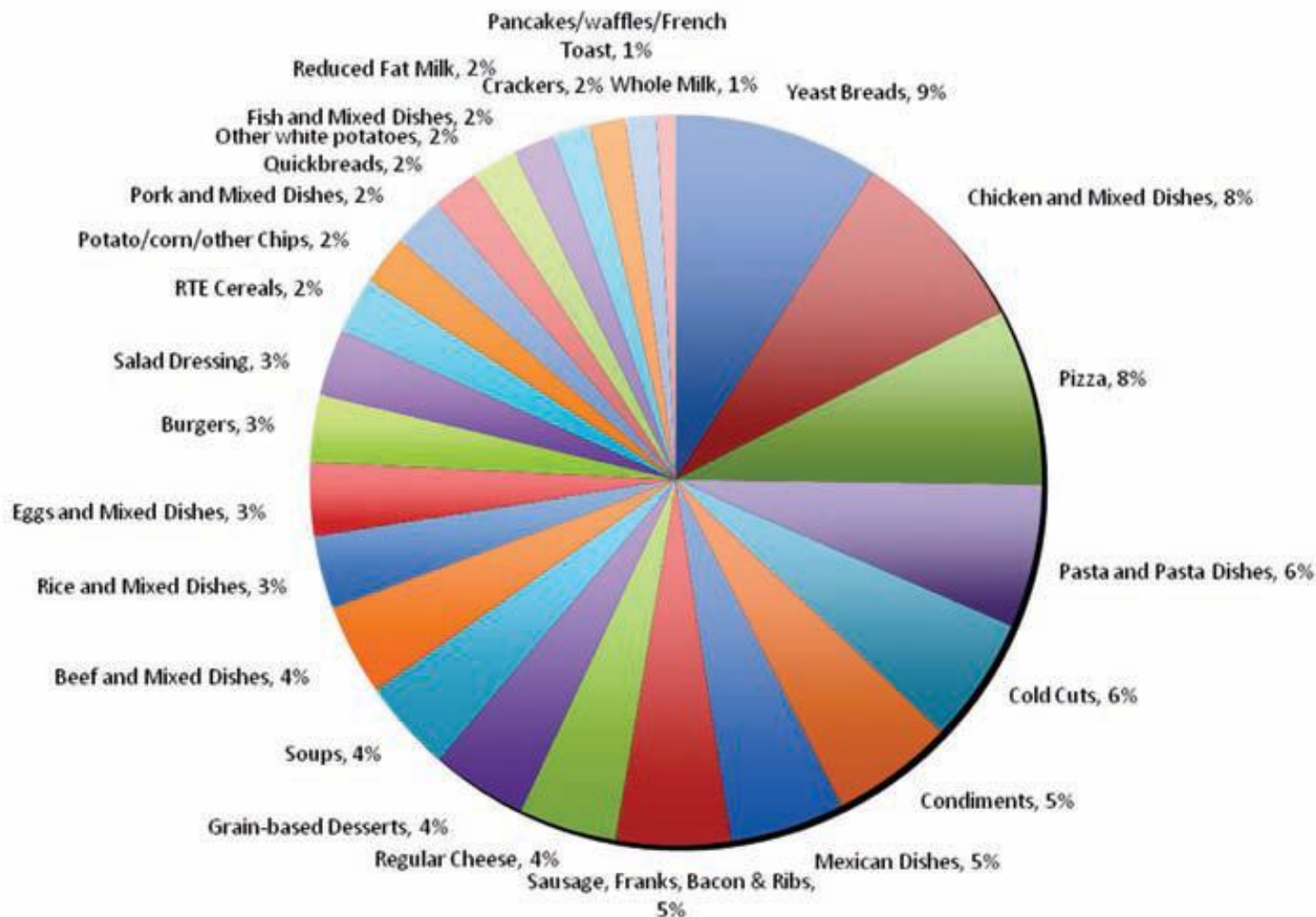
Advising the nation/Improving health

Major Recommendation of the U.S. Institute of Medicine Committee on Strategies to Reduce Sodium Intake

“FDA set mandatory standards to require food and restaurant industries to gradually reduce the salt content of their products.”

This will include a coordinated approach to set standards for safe levels of sodium added to foods using existing FDA authorities to modify the Generally Recognized as Safe (GRAS) status of salt and other sodium-containing compounds

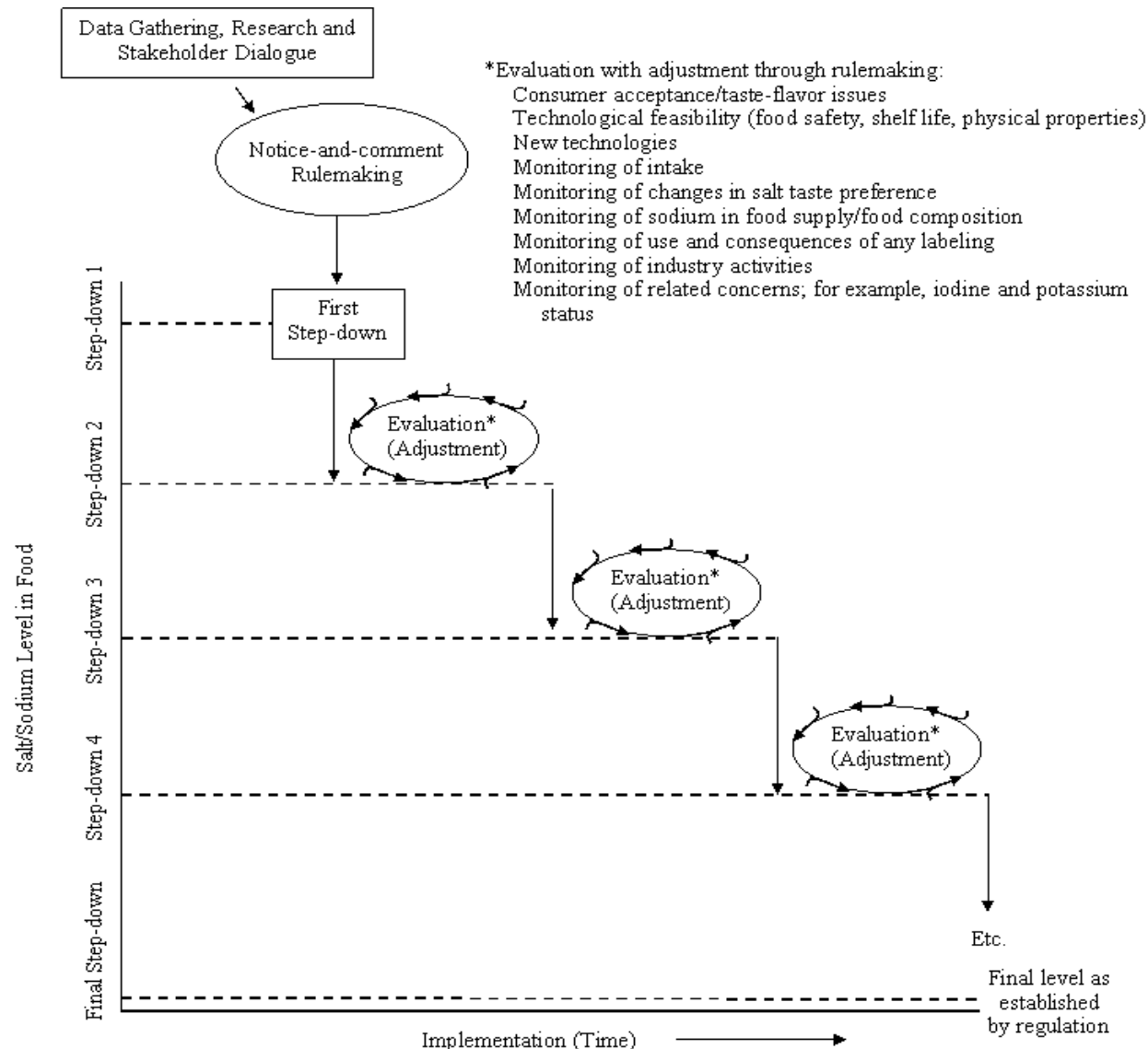
Dietary sources of sodium in the U.S.



Source: 2010 DGAC draft Report

After Richard Mattes

Stepwise process for achieving final standards for the addition of salt to foods



Open sensory questions in salt reduction.

-Gradual reduction vrs. abrupt reduction. All published studies have used abrupt but the IOM and CDC recommendations are for gradual. Does a gradual reduction have the same consequences as an abrupt one?

-Compensation. Will people just add more salt to compensate for reductions in the food supply? One published paper says no but this was small study in hospital. Is there some drive to reach a level of salt intake? Similarity of intake across cultures is consistent with this idea.

-Development. All experimental studies to date have manipulated intake of adults. Would reductions in children's intake have particularly salutary effects on perception, preference and food choice? Will these reductions during development have effects that persist into adulthood?

-Real world monitoring. Presuming that reductions by manufacturers actually reduce intake – does this change perception and preference levels as predicted by small experimental studies?

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FDA: Sodium Reduction, 2018

Frequently Asked Questions on FDA's Sodium Reduction Strategy

9. Won't foods with less sodium taste bad?

The sodium in your diet comes from a lot of different types of foods—especially mixed dishes that have a lot of components and sauces. Our approach is to encourage reductions in a variety of products—not just ones that are really high in sodium. This way, we aren't recommending drastic reductions that will significantly affect the taste of food, and you won't have to give up your favorites. We carefully studied the range of popular foods in today's marketplace to see what reductions are possible based on what some companies are already doing.

We also know that people usually don't notice small reductions (about 10 to 15 percent) in sodium. **Over time, taste buds get used to even larger changes, especially if they are made gradually.** In addition, there are other ways companies can reformulate, or change, certain foods while still making them tasty to consumers. Examples include adding savory herbs and spices, salt blends, or other flavorings and innovations that enable salt reduction.

Sweet

U.S. Dietary Guidelines 2015 - 2020

Consume less than 10 percent of calories per day from added sugars.

Food and flavor addiction?



Does exposure to sweet tastes mold sweet taste perception and/or preference?

Anecdotal evidence is not as strong as it is for salty.

But there is a general belief that this is true!

Public Health England, 2017

“PHE can see advantages in businesses not adding [low calorie] sweeteners to their products and gradually reducing the overall sweetness of their products **because this allows for people’s palates to gradually adjust to less sugary foods.** “

“

Pan American Health Organization, 2016

This (habitual use of sweet flavors) outcome is particularly important in young children **because consumption at an early age defines lifelong consumption patterns (28, 29)."**

WHO EMRO | Policy statement

“The need to help the population adapt to less sweetened foods also means that the use of [non-nutritive] sweeteners, while successful in reducing calories, does not help this adaptive process in people’s sense of appropriate sweetness.”

“

Science Advisory from the American Heart Association, 2018

A clinical report from the AAP [American Academy of Pediatrics] Committee on Nutrition, published in July 2015, described the use of LCS [low calorie sweetened] beverages as controversial for children and adolescents and an area of ongoing research and debate because they **could (1) lead to taste preferences for and habitual consumption of sweetened beverages ...**

“

How Children Get Hooked on Sugary Drinks

The New York Times

Andrew Jacobs

Oct. 22, 2019

“If your children get used to sweetness, it’s going to be almost impossible to get them to drink milk or plain water.”

Correlational and experimental studies on sweet reduction and taste

Published correlational studies of sugar intake and sweetness perception

- More sweet intake (sugars or NNS) **is associated** with a preference for higher levels of sugar
 - Mahar and Duizer, J Food Science 2007;72:S714-S718
 - Mattes and Mela, Chem Senses 1986;11:523-539
 - Holt et al., Food Qual Pref. 2000;11:299-312
- More sweet intake **has little or no association** with a preference for higher levels of sugar
 - Stone and Pangborn, Appetite 1990;15:63-79
 - Pangborn and Giovanni, Appetite 1984;5:317-327
 - Low et al., Nutrients 2016;8:241

Past experimental studies

Wise et al

Meta-analysis

Will a diet lower in sugar change perception of sweet taste?

	Month 1	Month 2	Month 3	Month 4	Month 5
Low sugar group (target of 40% reduction of simple sugars in the diet)	Normal diet	Low sugar diet	Low sugar diet	Low sugar diet	Diet of choice
Control (no diet manipulation)	Normal diet	Normal diet	Normal diet	Normal diet	Diet of choice

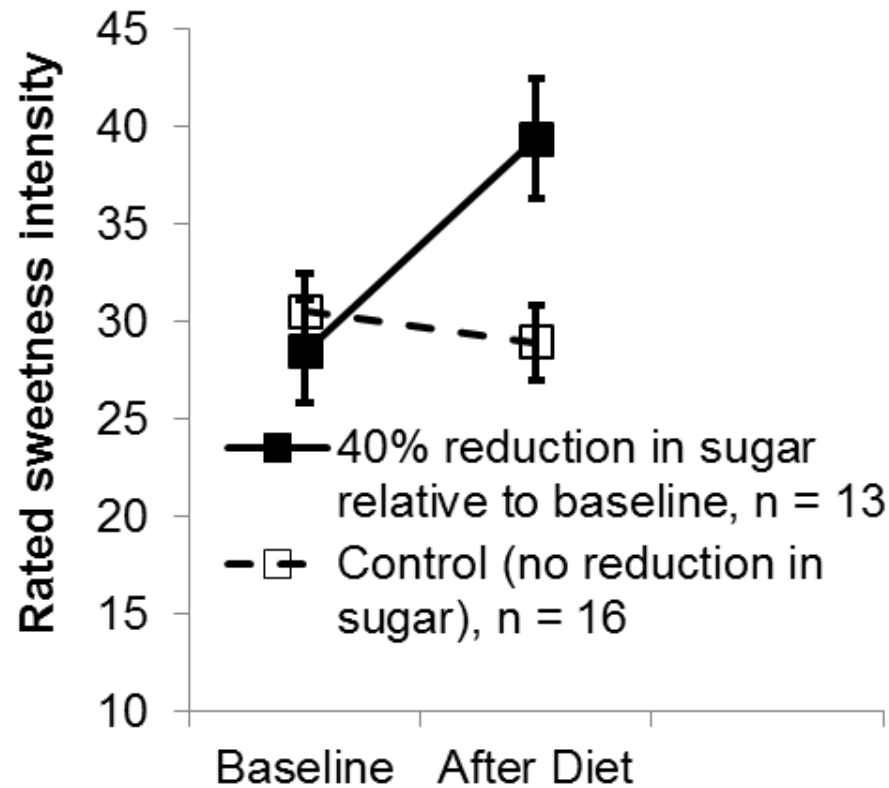
n = 16 for controls, n = 13 for the low sugar group

Measures

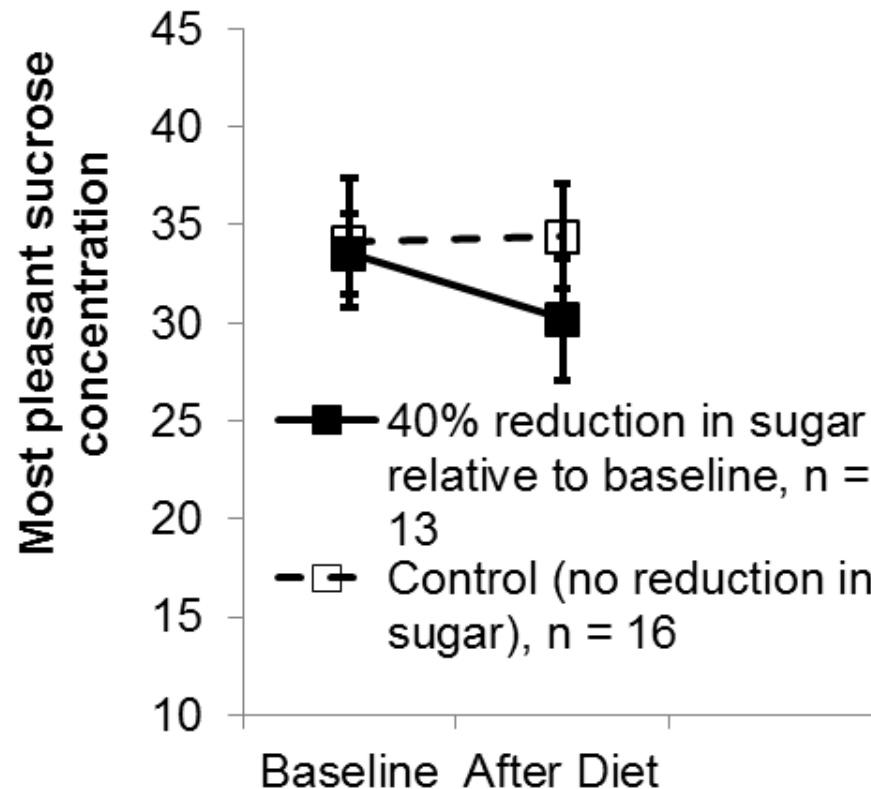
Sweetness intensity and pleasantness each month

- Vanilla puddings
- Raspberry beverages, 0 to 25% sucrose by weight

By diet month 3 (study month 4), rated sweetness intensity increased by about 40%



By diet month 3 (study month 4), mean rated sweetness pleasantness decreased but the difference was not significant.



Methodological Issues

- Small number of subjects
- Dietary control difficult
- No biomarker for sugar intake
- All sweetness reduced – no distinction between nutritive and non-nutritive sweeteners
- Planned more extensive study: addressing all these issues

Impacts of In Utero and Early Infant Taste Experiences on Later Taste Acceptance: **A Systematic Review***

“Our systematic review clearly shows programming of the acceptance of bitter and specific tastes. **For other tastes [sweet, salty, sour] the results were either equivocal or confined to a few number of studies that precluded us to draw conclusions.**”

*I Nehring, T Kostka, R von Kries, EA Rehfuss. Journal of Nutrition, 2015

Sweet taste exposure and the subsequent acceptance
and preference for sweet taste in the diet:
Systematic review of the published literature*

“Our findings reveal a very limited, highly heterogeneous evidence base that addresses the impact of dietary exposure to sweet tasting foods or beverages on the subsequent generalized acceptance, preference, or choice of these foods and beverages in the diet. The available evidence suggests possible reduced preferences for sweet taste following exposure in the shorter term, but **limited and equivocal effects in the longer term**. Given the public health and commercial relevance of the question, **further research in the form of adequately powered clinical trials with well characterized taste exposures is clearly required.**”

*KM Appleton, H Tuorila, EJ Bertenshaw, C de Graaf, and DJ Mela. *AJCN*, 2018

Planned and ongoing studies

1. G. Beauchamp & P. Wise (in collaboration with D. Baer, J. Novotney & M. Kramer, all of USDA), Monell Center, Funded by NIDCD U01

2. C (Kees) de Graaf et al, Wageningen University, The Netherlands

Others?

1. Beauchamp & Wise

Study Objectives

- 1) Determine how reduced sugar diet affects **perceived sweetness** intensity of model foods/beverages. Outcome measure: general labeled magnitude scale (gLMS).
- 2) Determine how reduced sugar diet affects **most preferred concentration of sugar** in model foods/beverages. Outcome measure: paired-comparison preference tracking.

Clinical Trial Design

NIH-funded (2018 – 2023) Cooperative Agreement (U01)

	Month 1	Month 2	Month 3	Month 4	Month 6
1) Low sugar, low sweet	Baseline (normal diet)	37% sugar reduction ^a , no NNS ^b	37% sugar reduction, no NNS	37% sugar reduction, no NNS	Follow-up, after diet of choice ^c
2) Gradual reduction	Baseline (normal diet)	12.3% sugar reduction, no NNS	24.7% sugar reduction, no NNS	37% sugar reduction, no NNS	Follow-up, after diet of choice
3) Low sugar, with sweet	Baseline (normal diet)	37% sugar reduction, w/ NNS	37% sugar reduction, w/ NNS	37% sugar reduction, w/ NNS	Follow-up, after diet of choice
4) Control	Baseline (normal diet)	No sugar reduction	No sugar reduction	No sugar reduction	Follow-up, after diet of choice

Participants

- 128 adults (32 per study group), assuming about 112 (28 per study group) finish diet
 - 25 to 75 years of age
 - Good general health
 - > 10% of total energy intake from simple sugars
- Tested in four cohorts of 32
 - One cohort per study years 1 through 4
 - May adjust cohort size based on interim analysis



Study flow

- Baseline measures
- Randomly assigned to study group
- Feeding period (study months 2-4)
 - Breakfast and dinner, M-F
 - Boxed meals for lunch and weekends
 - Collect primary measures near end of each month
- Follow-up, no feeding or dietary instructions (study months 5-6)
 - Collect primary measures toward the end of study month 6



Core Predictions

- There will be an increase in perceived sweetness between the baseline month and the third diet month for sugar reduction groups, with no change in the control group.
- There will be a decrease in most preferred sugar concentration between the baseline month and third diet month for sugar reduction groups, with no change in the control group.

Secondary (exploratory) analyses

- Fecal samples will be collected a times throughout the protocol for **microbiome** analyses
- Selected blood-based metaboic **hormones** will be evaluated to determine changes in metabolism in different treatment groups
- A large number of **questionnaires** will be used to develop testable hypotheses on food cravings, food satisfaction etc as a function in changes in sweetener intake
- Targeted investigations of the relationships between selected sweet **taste receptors** and variations in dietary sweetness effects will be undertaken

2. C (Kees) de Graaf et al

Sweet Tooth: nature or nurture?

The statement 'less sweetness exposure induces a lower sweetness preference, leading to lower sugar and energy intake, which could result in a lower body weight' is simple, attractive and powerful. However, scientific evidence that supports this reasoning is currently lacking.

Objective

- To determine the long term (6 months) effects of a lower (and higher) level of sweetness exposure in the overall diet on;
 - Changes in perceptions of and preferences for sweetness, saltiness in familiar and unfamiliar products
 - Changes in ad libitum intakes/choices,
 - Changes in glucose metabolism, body weight
 - Compliance measures

Outcome measures

- Changes in perceived intensity and liking of sweetness in 3 sweet and 2 savoury foods; Familiar and novel foods ; through psychophysical/psychohedonic functions
- Changes in food choice/taste patterns/energy intake during observational in home days.
- Well-being, quality of life, appetite, glucose metabolism, body weight etc..

Experimental Procedures

Months:											
0	1	2	3	4	5	6 (End)	1	2	3	4	
Baseline	Intervention diet						Follow-up				
N = 150 Participant's diet	N = 50 regular sweetness exposure diet (control) (RSE)						N = 150 Participant's diet				
	N = 50 low sweetness exposure diet (LSE)										
	N = 50 high sweetness exposure diet (HSE)										

Primary outcome measures:

Sweetness preferences	x	x					x	x			x
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Secondary outcome measures:

Sweetness intensity perception	x	x					x	x			x
Food choices and intake	x	x					x	x			x
Sweet liker status	x	x					x	x			x
Dietary taste patterns	x	x					x	x			x
Taste preferences	x	x					x	x			x
Food cravings	x	x					x	x			x

Body weight	x						x				x
Body composition	x						x				x
Glucose homeostasis	x						x				x
Plasma, serum & whole blood biomarkers	x			x			x				x

Compliance measures:

Dietary assessment (24h recall)	x		x		x		x	x			x
Urine biomarkers	x		x		x		x	x			x

Adverse events:

Self-report diary				Throughout the intervention							
Consults with dietician		x	x	x	x	x	x				

Public Health England, 2017

“One of the most important of these actions [to reduce sugar intake] was the introduction of a broad, structured and transparently monitored programme of gradual sugar reduction in everyday food and drink across all sectors of the food industry (retailers, manufacturers and the out of home sector including cafes, coffee shops, family and quick service restaurants). **This was modelled on the UK’s salt reduction programme, which has been successful in driving down population intakes of salt by 11%...**”

“

Potential differences: salty and sweet

Salty:

- Anecdotal evidence for salty taste change as a function of intake
- Experimental evidence that this is the case
- Much human and animal model data implicating experience in modulating salty taste perception and preference
- Moderate and conflicting evidence that need free salt taste liking is innate
- Mechanisms determining intake closely related to need

Sweet:

- Little anecdotal evidence for sweet taste change as a function of intake
- Little experimental evidence that this is the case
- Few animal model studies supporting these purported changes
- Strong evidence that sweet taste liking is innate
- Mechanisms determining intake less closely related to need

Open sensory questions in salt reduction.

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Open sensory questions in sweet reduction.

Many of the same ones for salt reduction:

-Gradual reduction vrs. abrupt reduction?
Compensation? Development? Real world
monitoring? Mechanism?

-Additionally and most significant: Does sweet taste perception and preference change with sweetness exposure reduction in adult humans?

