"Chews Wisely"

How sensory properties can be used to influence eating behaviours and energy intake

Ciarán Forde[1,2]

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www.a-star.edu.sg/cnrc

Understanding why we eat what we eat…

Food based non-communicable diseases are largely **avoidable** and are the result of **food choices** and poor **dietary behaviours**

"…..The study of what is in food is extremely important, but all of this knowledge amounts to little if we cannot persuade people to eat what is good for them and to avoid what will harm them…"

Paul Rozin (1998),
"Towards a Psychology of food choice"

'Today we know much more about food and how it effects the body, than we do about what makes people eat certain foods and not others, and what makes us start and stop eating at particular moments'

John Blundell, *Nutrition Bulletin* (2017)

‘Sensory Science’ and ‘Ingestive Behaviour’

From Perception

…. to ingestion

Sensory Science; ‘Evoke Measure, Analyse and Interpret’
Control stimulus delivery/quantify perceptual response

Ingestive Behaviour; Quantifying intake, often controlling for sensory properties

Sensory Ingestive Behaviour;
Linking food perception and food choice to energy selection and intake

Sensory Influences; Often summarised as just "Liking"

TASTE PREFERENCES
AND FOOD INTAKE

A. Drewnowski
Human Nutrition Program, School of Public Health, The University of Michigan, Ann Arbor, MI 48109; e-mail: adamdrew@umich.edu

Energy intake and sensory properties of food[1,2]

Adam Drewnowski

REVIEW

Effect of sensory perception of foods on appetite and food intake: a review of studies on humans

LB Sørensen[1]*, P Møller[2], A Flint[1], M Martens[2] and A Raben[1]

The Journal of Nutrition
Supplement: Low-Calorie Sweeteners, Appetite and Weight Control—What the Science Tells Us

Sweetness and Food Preference[1–3]

Adam Drewnowski,[4]* Julie A. Mennella,[5] Susan L. Johnson,[6] and France Bellisle[7]

[4]The University of Washington, Nutritional Sciences Program, Seattle, WA; [5]Monell Chemical Senses Center, Philadelphia, PA; [6]University of Colorado, Anschutz Medical Campus, Denver, CO; and [7]Unité d'Epidémiologie Nutritionnelle, Université Paris 13, Bobigny, France90252012

Sensory Influences on Food Intake

David A. Booth, Ph.D., D.Sc. *1990*

TASTE VERSUS CALORIES: SENSORY AND METABOLIC SIGNALS IN THE CONTROL OF FOOD INTAKE*

Harry L. Jacobs
University of Illinois, Urbana, Ill. and U. S. Army Natick Laboratories, Natick, Mass.
and
Kamal N. Sharma
St. Johns Medical College, Bangalore, India

1969

Energy Density, Palatability, and Satiety: Implications for Weight Control

Adam Drewnowski, Ph.D.

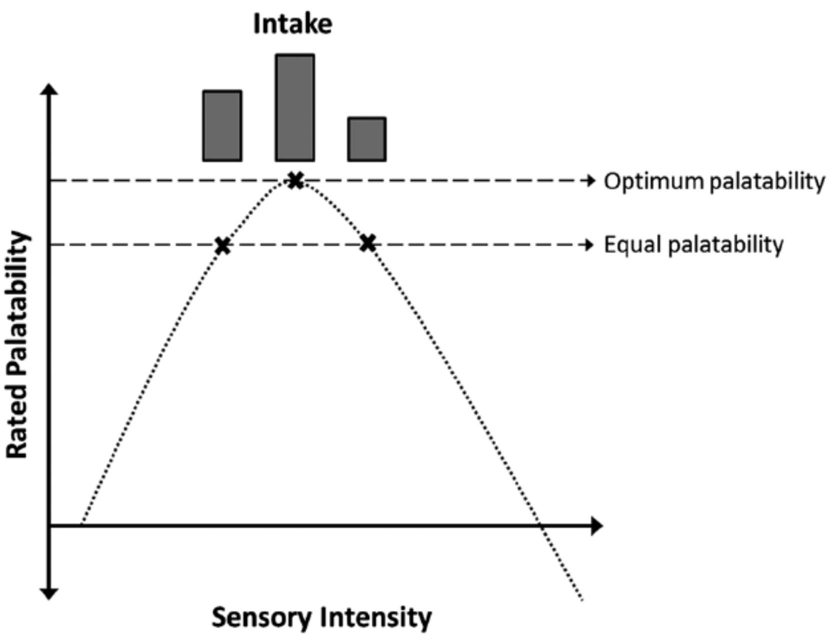
Physiology & Behavior, Vol. 45, pp. 177–183. Copyright © Pergamon Press plc, 1989. Printed in the U.S.A. 0031-9384/89 $3.00 + .00

Sugar and Fat: Sensory and Hedonic Evaluation of Liquid and Solid Foods

ADAM DREWNOWSKI[1]
Human Nutrition Program, School of Public Health and Department of Psychiatry Medical School, The University of Michigan, Ann Arbor, MI 48109
E. EILEEN SHRAGER, CAREN LIPSKY, ELIOT STELLAR
Obesity Research Group, University of Pennsylvania, Philadelphia, PA 19104
AND
M. R. C. GREENWOOD

Sensory cues play a **functional role** in food choice and intake

Sensory **quality** and **intensity** plays a role in moderating energy intake



obesityreviews

obesity reviews doi: 10.1111/obr.12340

Etiology and Pathophysiology

Sensory influences on food intake control: moving beyond palatability

K. McCrickerd[1,2] and C. G. Forde[1,2,3]

[1]Clinical Nutrition Research Centre, Centre for Translational Medicine, Yong Loo Lin School of Medicine, Singapore; [2]Singapore Institute for Clinical Sciences, Agency for Science, Technology and Research (A*STAR),

Summary

The sensory experience of eating is an important determinant of food intake control, often attributed to the positive hedonic response associated with certain sensory cues. However, palatability is just one aspect of the sensory experience. Sensory cues based on a food's sight, smell, taste and texture are operational before, during and

McCrickerd and Forde (2016) *Obesity Reviews* (Open access)

Sensory cues influence food choice and intake differently

Smell mainly plays a priming role in eating behavior, driving sensory specific appetites, influencing food choice and intake (↑) [1]

Taste plays a role in (macro)nutrient sensing during consumption and is more likely linked with the onset of satiation (↓)

Food texture informs the oral processing required to prepare food for swallowing [2]

Sensory influences on food choice and intake change over the course of the life-span [3]

Article

PERCEPTION

The Differential Role of Smell and Taste For Eating Behavior

Perception
2017, Vol. 46(3–4) 307–319
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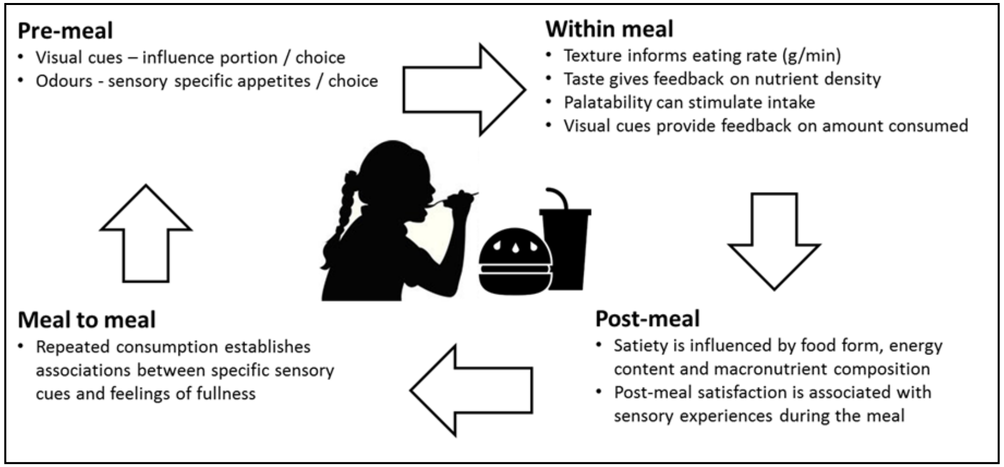
sagepub.co.uk/journalsPermissions.nav
DOI: 10.1177/0301006616685576
journals.sagepub.com/home/pec

SAGE

Sanne Boesveldt and Kees de Graaf
Division of Human Nutrition, Wageningen University, Wageningen, the Netherlands



[1] Boesveldt and DeGraaf (2017), *Perception*
[2] Forde (2018) *“From perception to ingestion” FQAP*
[3] Boesveldt , Bobowski, McCrickerd, Maitre, Sulmont and Forde (2018), *“Changing role of the senses” FQAP*

Todays talk

- Describe how oral processing behaviour influences energy intake and body composition
- Approaches to changing eating behaviours using sensory properties
- Opportunities to apply sensory approaches to moderate eating behaviours and dietary energy intake

The Sensory Ingestive Behaviour Team
Clinical Nutrition Research Center, Singapore

Our goal: understand how food perception, preference and intake behaviours, influence energy intake at key stages in the life-course

‘Something to Chew On’

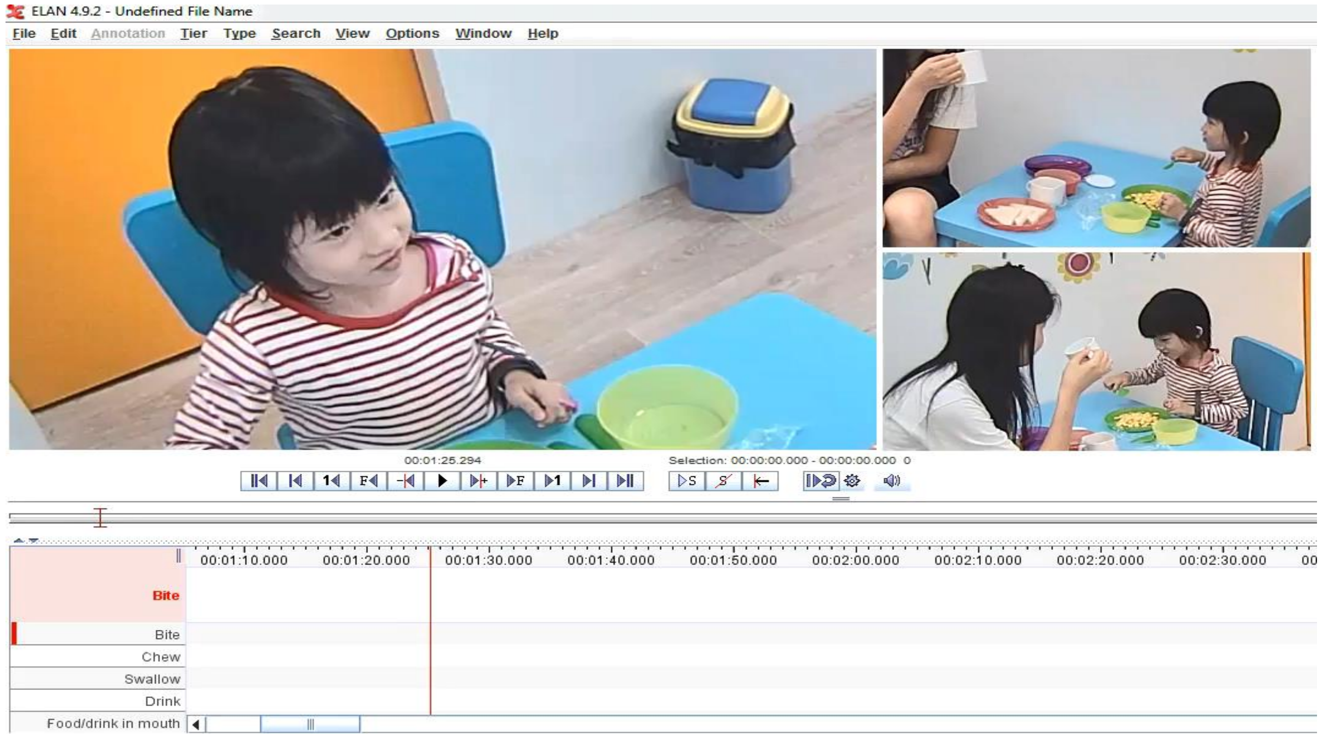
Eating rate, energy intake and body composition

Oral processing, Energy Intake & Body Composition in Children

Energy Intake:

4.5 years: (Buffet meal)

6 years: (Fried rice)



Body composition measures:

BMI, skinfold anthropometry,

MRI scan of abdominal adiposity

Coding scheme from Forde *et al* (2013)

Derived Measures

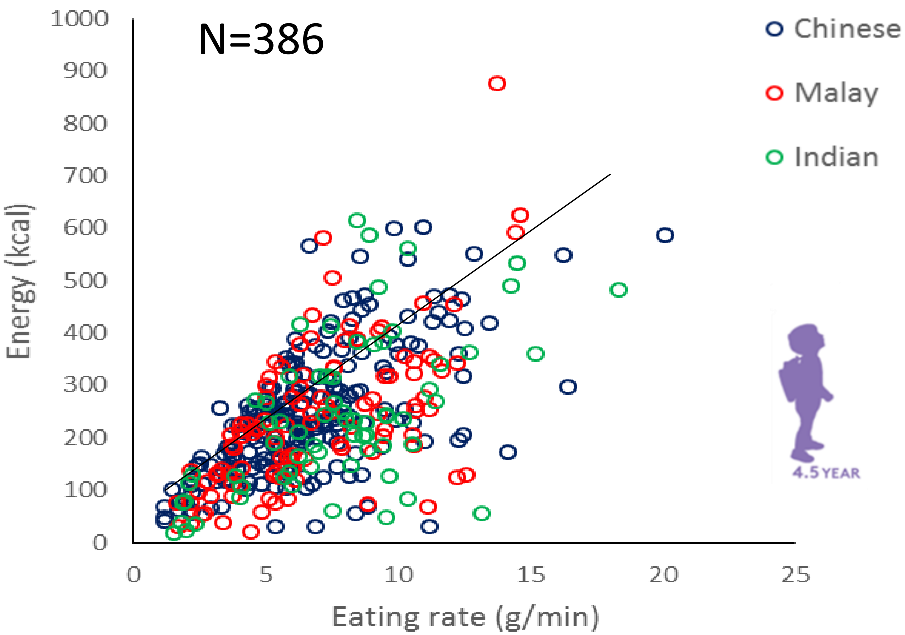
- Eating rate (g/min)
- Average bite size (g/bite)
- Chews per gram
- Oral exposure per bite

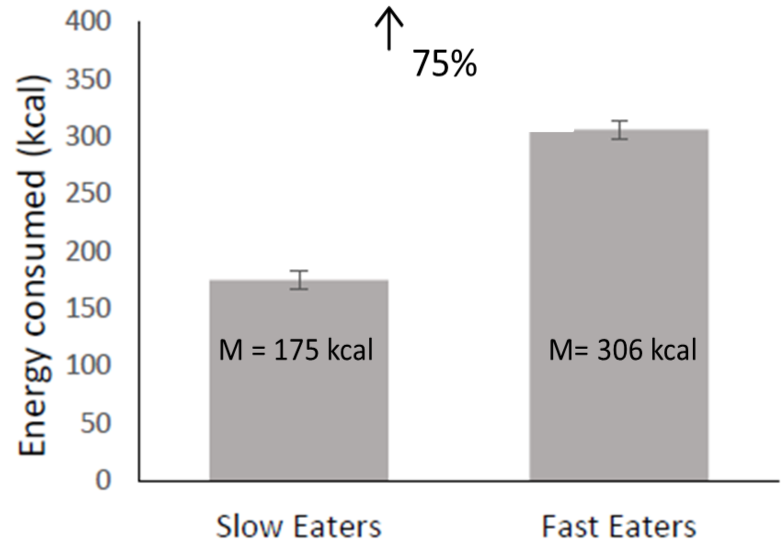
Ai Ting Goh

GUSTO
GROWING UP IN SINGAPORE TOWARDS HEALTHY OUTCOMES

Eating Rate and Energy Intake

- Children who ate the fastest consumed more, especially if they ate for longer[1,2]
- This behaviour is stable within child over time[3] and is associated with stronger appetitive traits[4]



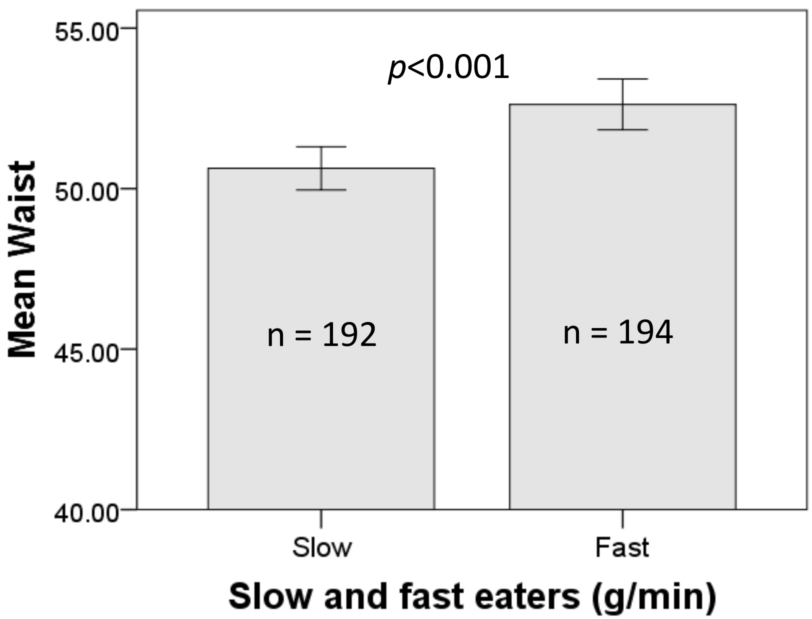


[1]Fogel, *et al* (2017a). Eating rate, energy intake and body comp. - *British Journal of Nutrition*
[2]Fogel *et al* (2017b), *'Obesogenic Eating Style' - Physiology and Behaviour*
[3]McCrickerd *et al* (2018a). *In preparation – Continuity of eating rate*
[4]Fogel *et al* (2018a), 'Eating rate and Child Appetitive traits' - *Appetite*

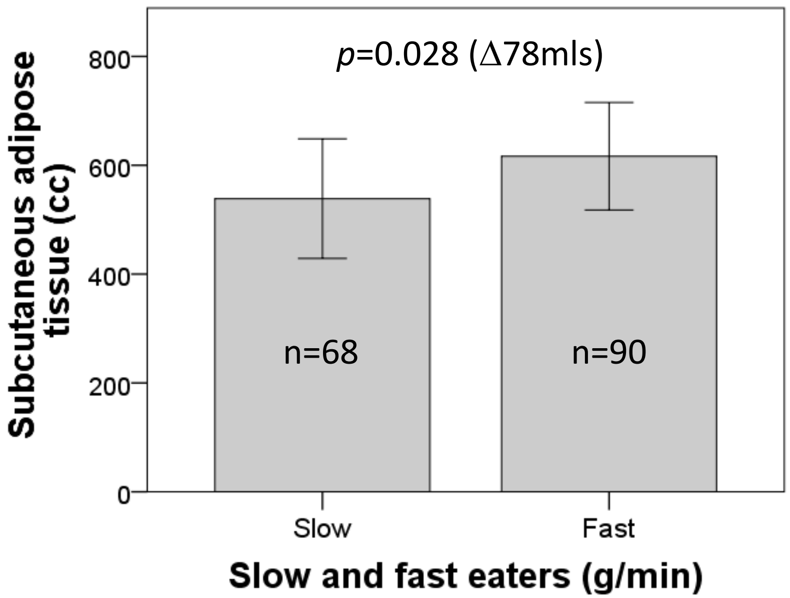
GUSTO
GROWING UP IN SINGAPORE TOWARDS HEALTHY OUTCOMES

Eating Rate is associated with greater BMI & Adiposity

Waist circumference (N=386)



MRI-Scan of subcutaneous abdominal adiposity (N=158)



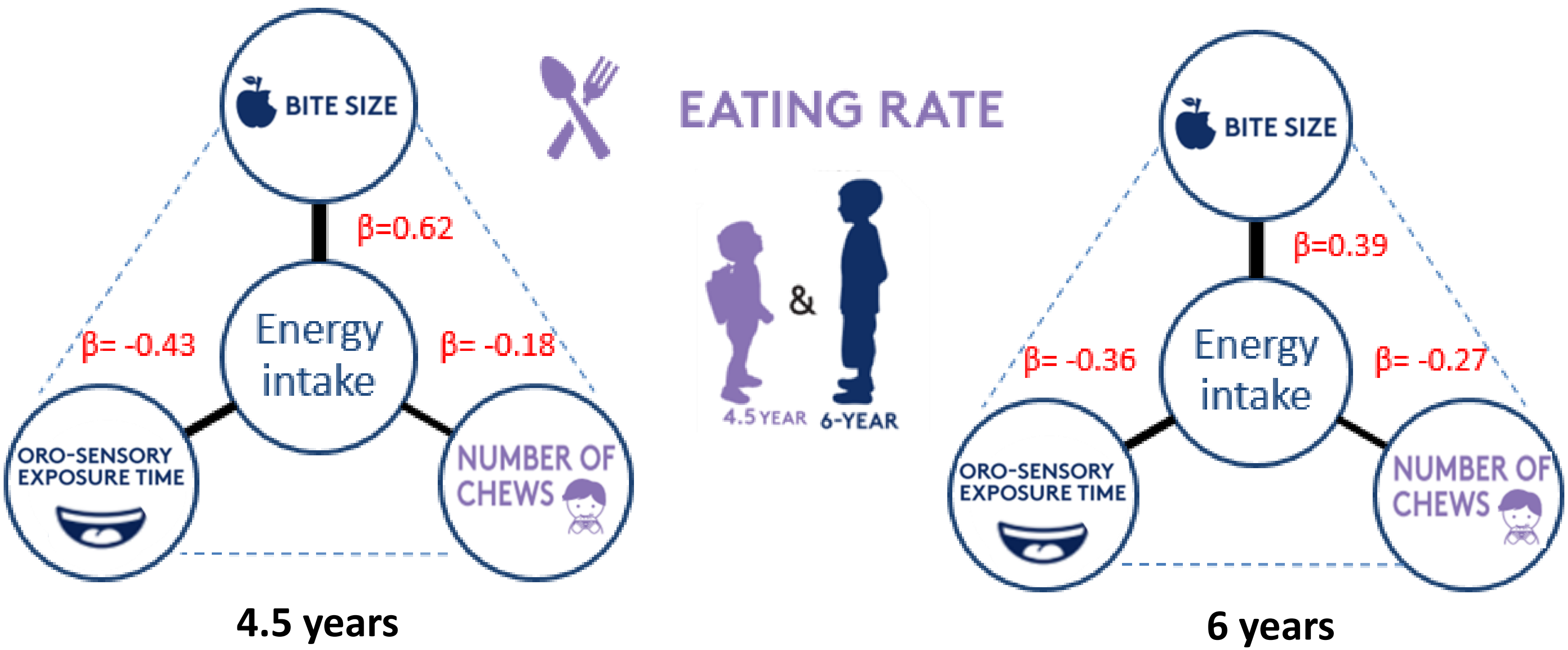
Positive association between faster eating rates and all anthropometric skinfold estimates of adiposity

Fogel, *et al* (2017a). *British Journal of Nutrition*

Stability of the "Obesogenic" Eating Style Over time

Eating behaviours that promote faster eating & increased energy intake are stable over time[1]

Faster eating rate at 4.5 years predicted larger BMI_z and skinfold adiposity at 6 years[2]

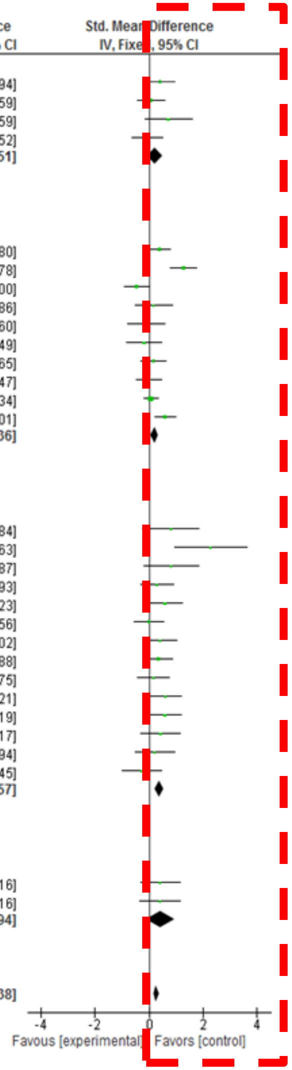


[1]Fogel, *et al* (2017b). "Describing an Obesogenic eating style" *Physiology and Behaviour*

[2]McCrickerd, *et al* (2018) "Continuity in eating rates & links to adiposity" *(In Preparation)*

Faster Eating Rate is linked to higher ad-libitum energy intake

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
1.1.1 Eating rate verbal instructions								
Andrade 08	645.7	155.9	30	579	154.7	30	3.9%	0.42 [-0.09, 0.94]
Andrade 12	707.9	142.4	30	694	178.6	30	4.0%	0.08 [-0.42, 0.59]
Smit 11	358	63	11	313	56.4	11	1.3%	0.72 [-0.14, 1.59]
Weijzen 08 C	38.4	29.2	24	39.8	28.4	24	3.2%	-0.05 [-0.61, 0.52]
Subtotal (95% CI)			**95**			**95**	**12.4%**	**0.23 [-0.06, 0.51]**
Heterogeneity: Chi² = 3.03, df = 3 (P = 0.39); I² = 1%								
Test for overall effect: Z = 1.55 (P = 0.12)								
1.1.2 Eating rate food form								
Bolhuis 13	3,082	866.1	50	2,694.2	1,025.2	50	6.5%	0.41 [0.01, 0.80]
Forde 13 A	606.5	28.4	39	569.3	28.6	41	4.3%	1.29 [0.81, 1.78]
Forde13 B	569.2	29.9	37	582.9	30.4	40	5.0%	-0.45 [-0.90, 0.00]
Kissileff 80 A	706.8	601.4	16	621.9	353.6	16	2.1%	0.17 [-0.53, 0.86]
Kissileff 80 B	848.4	420.3	16	894.9	524.5	16	2.1%	-0.10 [-0.79, 0.60]
Spiegel 93	268.3	20.1	18	271.9	21.4	18	2.4%	-0.17 [-0.82, 0.49]
Weijzen 08 A	43.6	30	59	38.4	29.2	24	4.5%	0.17 [-0.30, 0.65]
Weijzen 08 B	39.7	26.9	59	39.8	28.4	24	4.5%	-0.00 [-0.48, 0.47]
Zijlstra 10	157	125	106	148	121	106	14.0%	0.07 [-0.20, 0.34]
Ziljstra 08	319	176	49	226	122	49	6.2%	0.61 [0.20, 1.01]
Subtotal (95% CI)			**449**			**384**	**51.5%**	**0.22 [0.08, 0.36]**
Heterogeneity: Chi² = 35.85, df = 9 (P < 0.0001); I² = 75%								
Test for overall effect: Z = 3.06 (P = 0.002)								
1.1.3 Eating rate computerized task								
Ioakimidis 09 A	390.2	76.3	8	310.2	107.6	8	1.0%	0.81 [-0.22, 1.84]
Ioakimidis 09 B	390.2	76.3	8	237.1	46.5	8	0.6%	2.29 [0.95, 3.63]
Ioakimidis 09 C	310.2	107.6	8	237.1	46.5	8	0.9%	0.83 [-0.20, 1.87]
Karl 13 A	697	336	20	601	283	20	2.6%	0.30 [-0.32, 0.93]
Karl 13 B	999	459	20	733	419	20	2.5%	0.59 [-0.04, 1.23]
Martin 07 A	588	212	26	585	216	26	3.4%	0.01 [-0.53, 0.56]
Martin 07 B	1,020	248	22	918	225	22	2.8%	0.42 [-0.18, 1.02]
Scisco 11	428.2	201.4	30	357.8	176.8	30	3.9%	0.37 [-0.14, 0.88]
Zandian 09 A	305	97	23	291	64	23	3.0%	0.17 [-0.41, 0.75]
Zandian 09 B	305	97	23	258	42	23	2.9%	0.62 [0.03, 1.21]
Zandian 09 C	291	64	23	258	42	23	2.9%	0.60 [0.01, 1.19]
Zandian 12 A	303	87.8	15	271.4	44.8	15	1.9%	0.44 [-0.28, 1.17]
Zandian 12 B	303	87.8	15	285.6	58.8	15	2.0%	0.23 [-0.49, 0.94]
Zandian 12 C	271.4	44.8	15	285.6	58.8	15	2.0%	-0.26 [-0.98, 0.45]
Subtotal (95% CI)			**256**			**256**	**32.5%**	**0.39 [0.21, 0.57]**
Heterogeneity: Chi² = 16.41, df = 13 (P = 0.23); I² = 21%								
Test for overall effect: Z = 4.31 (P < 0.0001)								
1.1.4 Eating rate food delivery								
Hogenkamp 10	575	260	16	475	192	13	1.9%	0.42 [-0.32, 1.16]
Kissileff 08	824	398.4	14	655.3	398.4	14	1.8%	0.41 [-0.34, 1.16]
Subtotal (95% CI)			**30**			**27**	**3.7%**	**0.41 [-0.11, 0.94]**
Heterogeneity: Chi² = 0.00, df = 1 (P = 0.99); I² = 0%								
Test for overall effect: Z = 1.54 (P = 0.12)								
Total (95% CI)			**830**			**762**	**100.0%**	**0.28 [0.18, 0.38]**
Heterogeneity: Chi² = 57.86, df = 29 (P = 0.001); I² = 50%								
Test for overall effect: Z = 5.49 (P < 0.00001)								
Test for subgroup differences: Chi² = 2.57, df = 3 (P = 0.46), I² = 0%								



The American Journal of
CLINICAL NUTRITION

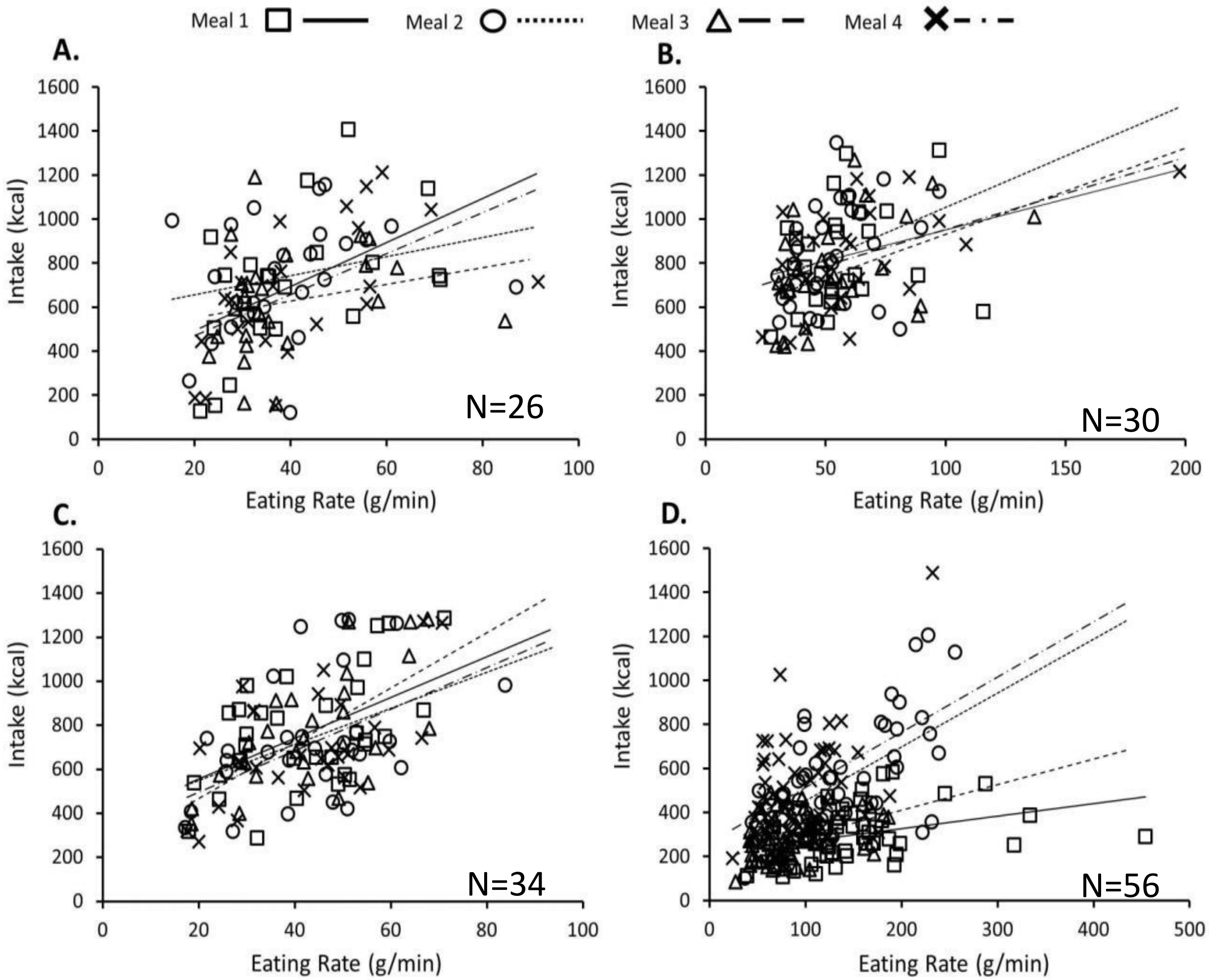
Positive Relationship between eating rate & energy intake

Robinson, Almorin-Roig, Rutters, DeGraaf, Forde, Smith, Nolan and Jebb (2014) *Am. J. Clin. Nutr. (2014)*

Eating Rate: Consistent & predictive of energy intake across meals

Study 1
Meals 1-4

Study 2
Meals 1-4



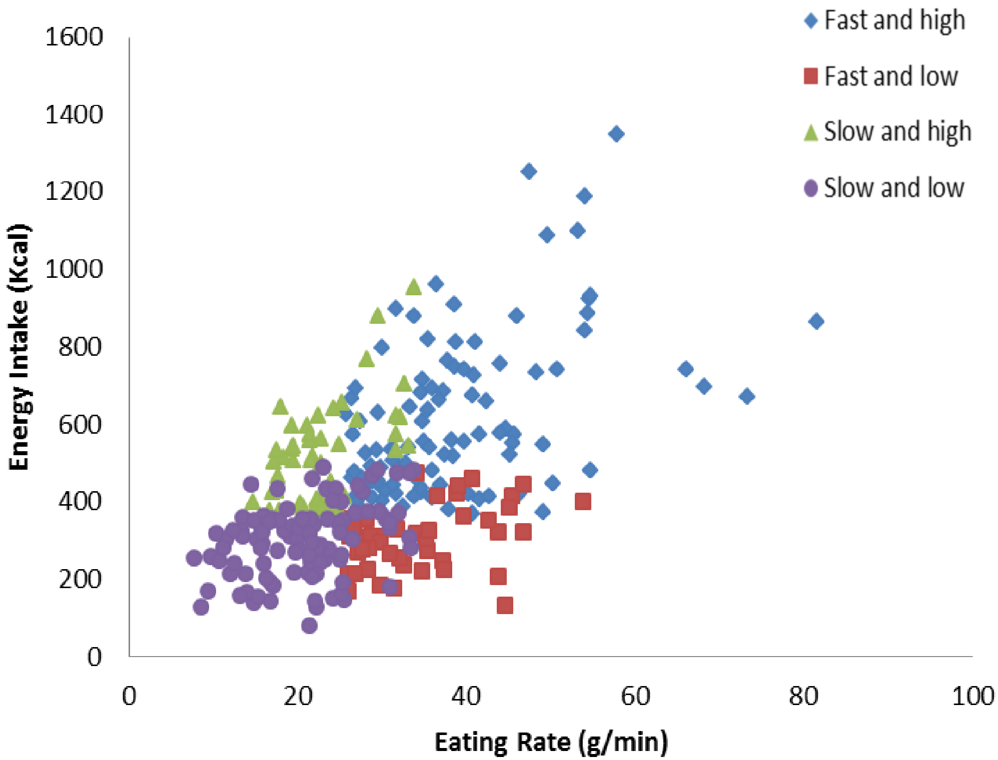
Study 3
Meals 1-4

Study 4
Meals 1-4

McCrickerd and Forde (2017) *Nutrients*

‘Eating rate’ can be viewed as an interaction between the persons drive to eat, and their chosen food environment

Singapore Body Composition Survey



Eating Rate; an interaction between an individuals drive to eat, and the eating properties of their food environment

Food Factors

Food texture (hard / firm)
Lubrication (moist / dry)
Portion Sizes
Utensils
Eating context

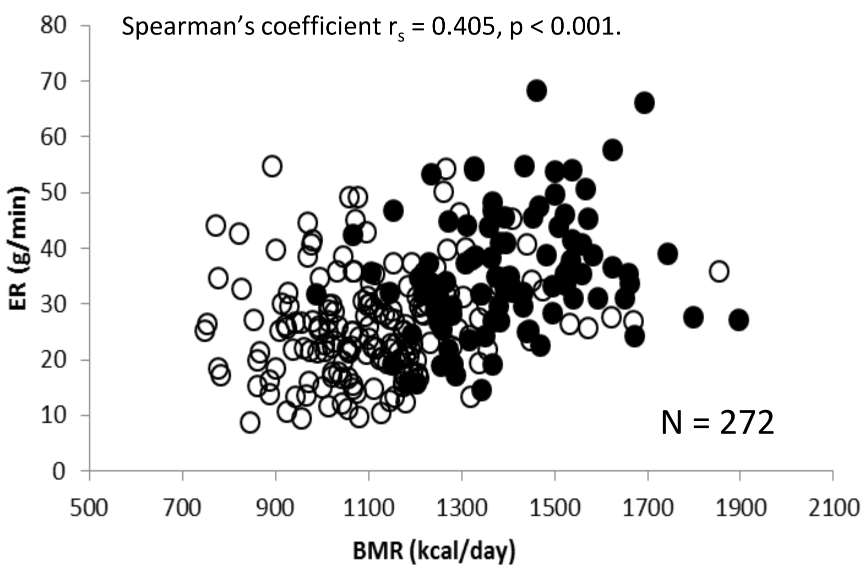
Human Factors

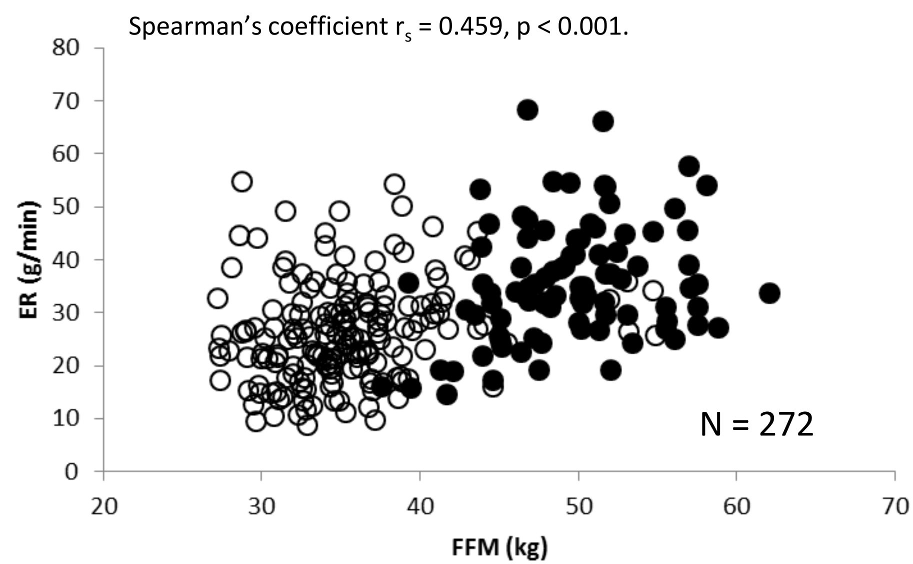
Appetitive traits
Sensitivity to hunger/fullness
Food responsivity
Psychological traits
Energy requirements

Goh, McCrickerd, Henry and Forde *(In Preparation)*

Faster Eating Rates as a behavioural expression of higher energy requirements

The largest contribution to Energy Expenditure is BMR (largest contribution to BMR is FFM)
Differences in Basal Metabolic Rate explain about 15% of the variation in Eating Rate





N=272 participants. Males (n = 91) were represented
by the solid circles and females (n = 181)

Henry, Ponnalagu, Bi and Forde (2018) *Physiology and Behaviour*

Singapore Body Composition Survey

‘Chews Wisely’

Understanding the Impact of food texture on oral processing behaviours and energy intake

(i) Reducing Eating Rate and Energy Intake: **Target the Person**

"reduce eating speed to control energy intake" Mechanick, Kushner, Sugerman, *et al*. *Obesity* (2009)

Eat slowly.
Lose weight.
Feel great!

SPLENDID

SEVENTH FRAMEWORK PROGRAMME

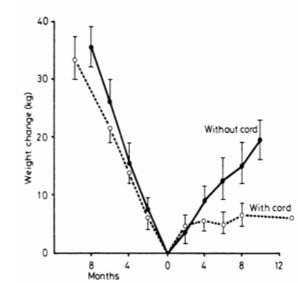
The work leading to these results has received funding from the European Community's ICT Programme under Grant Agreement No. 610746, 01/10/2013 – 30/09/2016.

The consortium of SPLENDID comprises 7 partners originated from Sweden (3), Switzerland (1), Spain (1), the Netherlands (1), and Greece (1).

858 BRITISH MEDICAL JOURNAL VOLUME 282 14 MARCH 1981

Maintenance of weight loss in obese patients after jaw wiring

J S GARROW, G T GARDINER



Weight change (mean ± SEM) before and after jaw wiring in seven women fitted with a waist cord after the wires were removed (open circles) and in nine women who did not have a waist cord fitted (closed circles).

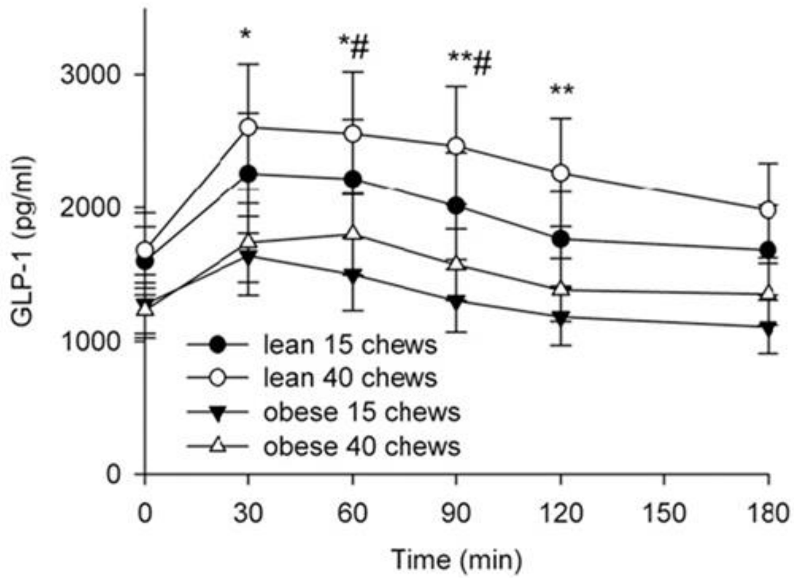
"Fun Feeder ™"

Specially designed plate to slow eating rate in Obese dogs

SMARTBYTE

(Some) Physiological Correlates of Mastication

- **Satiety hormone responses; GLP-1, PYY, Ghrelin** (Li *et al* (2010), Kokkinos *et al* (2011), Zhu & Hollis (2013))



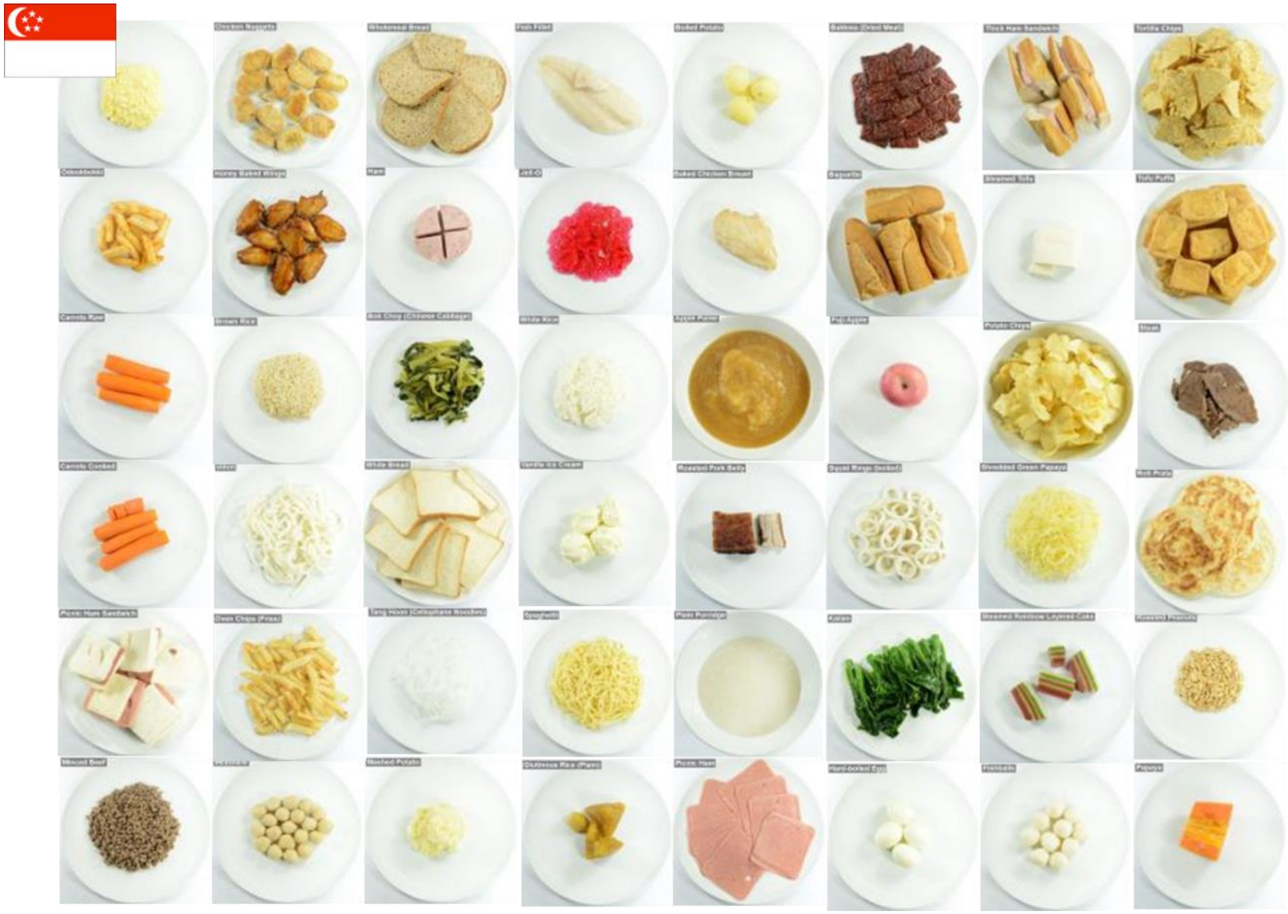
Li et al (2011) *AJCN*

- **Dietary induced thermogenesis** / body temperature / Sphlanic blood flow (Hamada et al 2014)

- **Cephalic Phase Response** (Lasschuijt *et al* (2018) *Appetite*)

- **White adipose tissue accretion** (Oka et al (2003), Fuijise et al (1993, 1998), Sakata et al (2003))

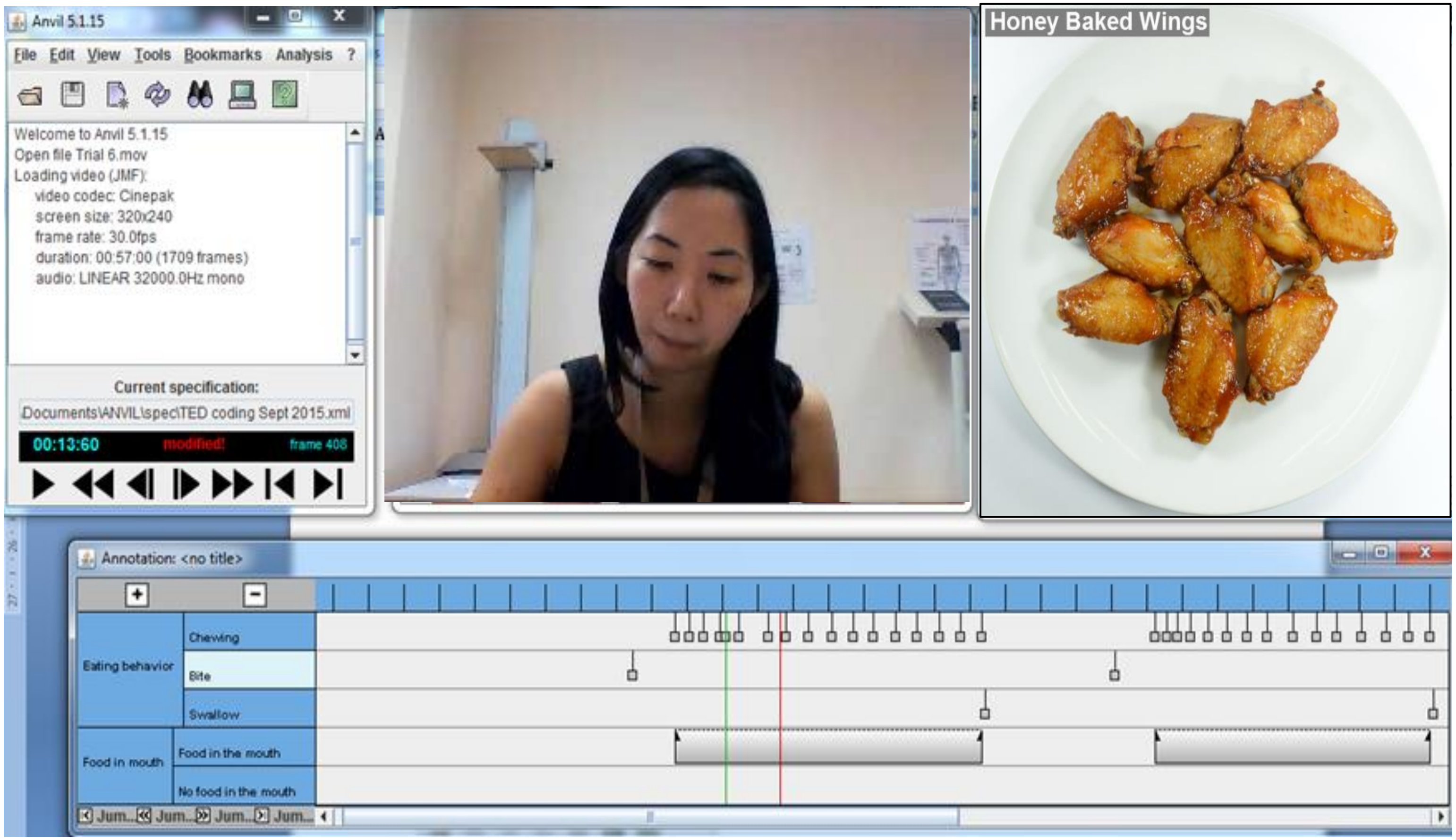
(ii) Enhancing, rather than restricting the contribution of chewing to fullness



Forde, Leong, Chia-Ming, and McCrickerd (2017). *Food and Function*

Application of a ‘Sensory Approach’ to Study Eating Behaviours

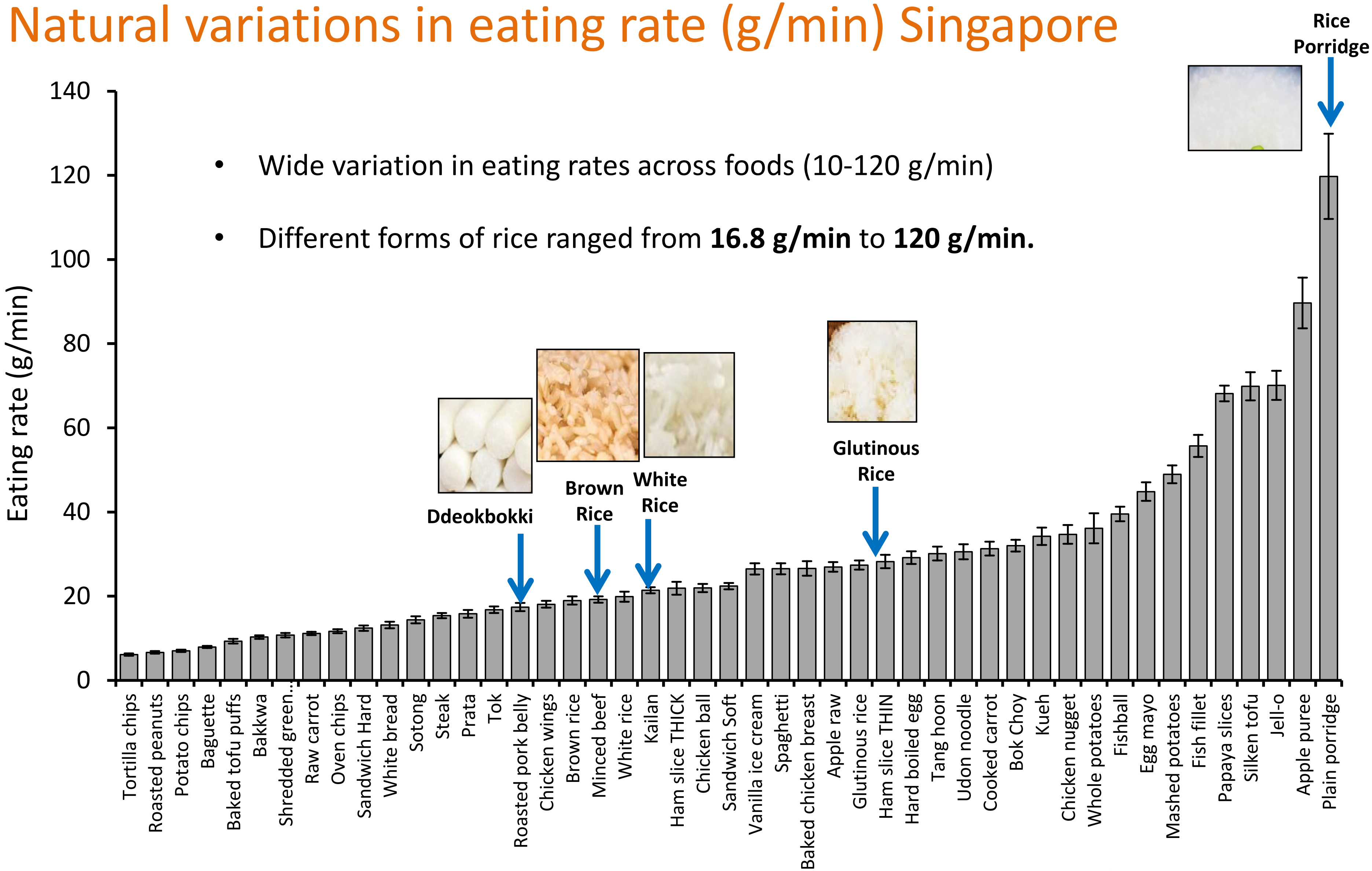
‘Evoke, Measure, Analyse and Interpret’



Forde *et al* (2013a), *Appetite “*Oral processing behaviours of savoury meal components”
Forde *et al* (2013b), *Appetite* “Texture and Taste influences on food intake for a realistic lunchtime meal”

Natural variations in eating rate (g/min) Singapore

- Wide variation in eating rates across foods (10-120 g/min)
- Different forms of rice ranged from **16.8 g/min** to **120 g/min.**



Forde, Leong, Chia-Ming, and McCrickerd (2017). *Food and Function*

Using Food Texture to reduce Eating Rate and Energy Intake

Contents lists available at SciVerse ScienceDirect
Appetite
journal homepage: www.elsevier.com/locate/appet

Research report

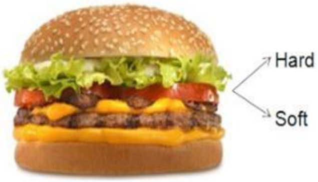
Texture and savoury taste influences on food intake in a realistic hot lunch time meal

C.G. Forde[a,*], N. van Kuijk[b], T. Thaler[a], C. de Graaf[b], N. Martin[a]

OPEN ACCESS Freely available online
PLOS ONE

Slow Food: Sustained Impact of Harder Foods on the Reduction in Energy Intake over the Course of the Day

Dieuwerke P. Bolhuis[1*], Ciarán G. Forde[2], Yuejiao Cheng[1], Haohuan Xu[1], Nathalie Martin[2], Cees de Graaf[1]



Texture-Based Differences in Eating Rate Reduce the Impact of Increased Energy Density and Large Portions on Meal Size in Adults[1–3]

Keri McCrickerd, Charlotte MH Lim, Claudia Leong, Edwin M Chia, and Ciaran G Forde*

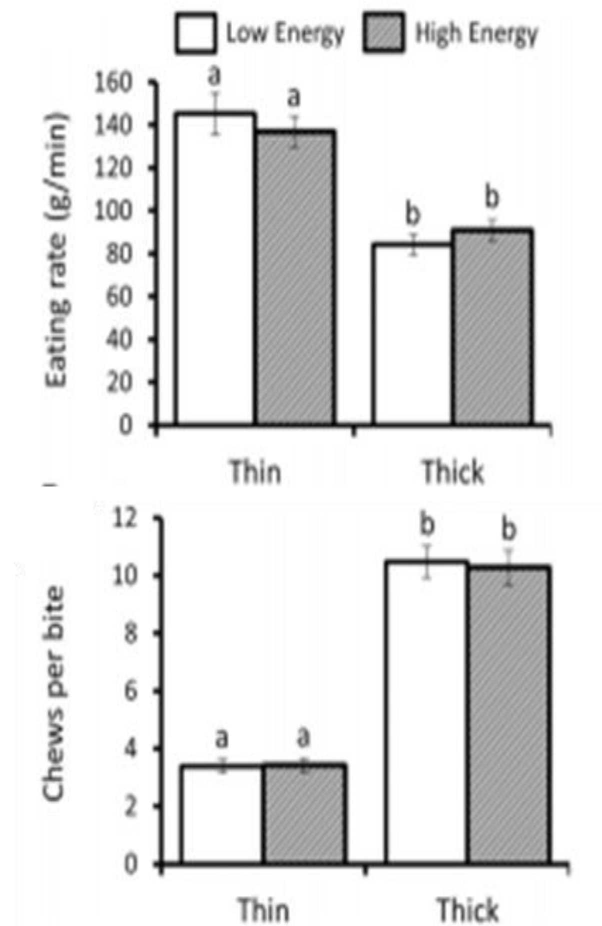
Reducing Eating Rate, Energy Density and Portion Size

The Journal of Nutrition
Ingestive Behavior and Neurosciences

Texture-Based Differences in Eating Rate Reduce the Impact of Increased Energy Density and Large Portions on Meal Size in Adults[1–3]

Keri McCrickerd, Charlotte MH Lim, Claudia Leong, Edwin M Chia, and Ciaran G Forde*

Clinical Nutrition Research Centre, Singapore Institute for Clinical Sciences, Agency for Science, Technology, and Research, and National University Health System, Singapore, Singapore



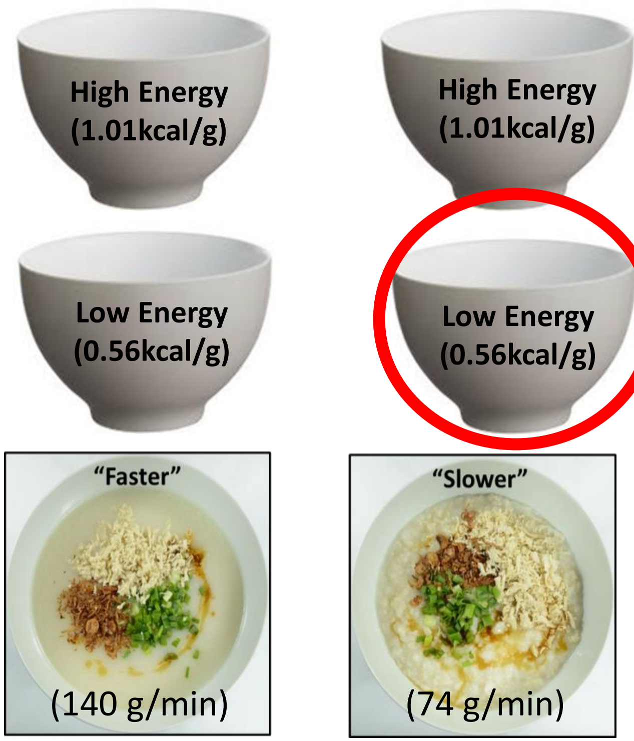
McCrickerd, Lim, Leong, Chia and Forde (2017) *Journal of Nutrition*

Impact of Reduced Eating Rate, Energy Density & Portion Size

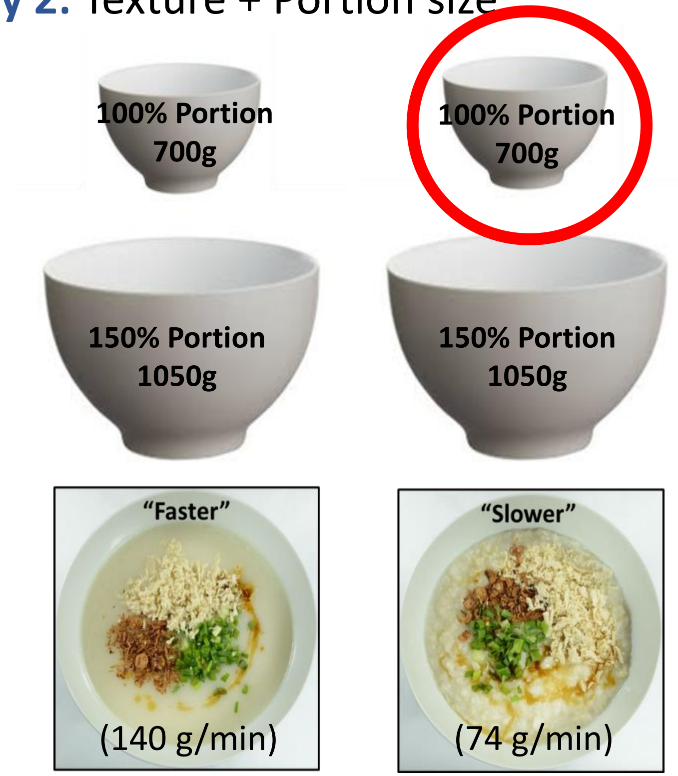
Texture intervention resulted in 11-15 % reduction in kcal intake

Reducing energy intakes but no reduction in meal liking or post-meal fullness

Study 1: Texture + Energy density



Study 2: Texture + Portion size



McCrickerd, Lim, Leong, Chia and Forde (2017) *Journal of Nutrition*

See Also: *Bolhuis et al* (2014) *PLoS One, Forde et al* (2013b) *Appetite,* Lasschuijt *et al* (2017) *Physiology & Behaviour*

The Opportunity: Food Texture to slow eating rate & reduce energy intake

- We adapt our eating style to the food textures served, and can use hedonically equivalent textures to slow eating rate and reduce energy intake

- Slowing eating rate by approximately 20% can produce on average a 15% reduction in *ad-libitum* intake

- Reductions are further enhanced when combined with ↓energy density & ↓portion

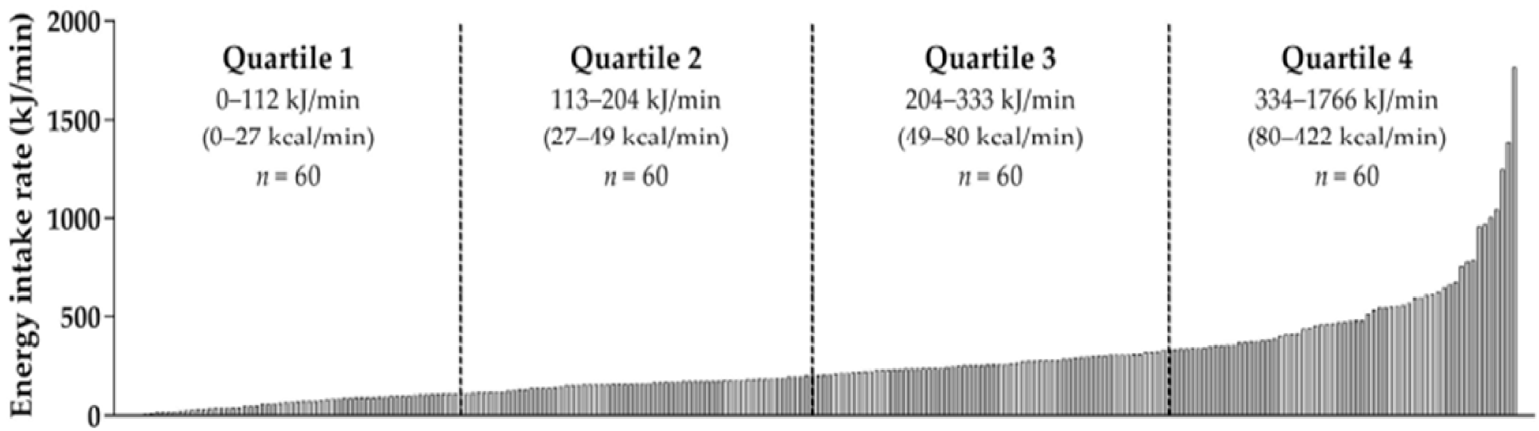
Better Living through Sensory

Future opportunities & challenges

From acute *ad-libitum* feeding trials to a whole diet approach

Low calorie velocity
(kcal/g/min)

High calorie velocity
(kcal/g/min)



N=240 foods

Energy Intake Rate = Eating Rate (g/min) x Food Energy Density (Kcal/g)

*"….it is possible to choose alternatives with a lower **energy intake rate**, from the same or another food group….*

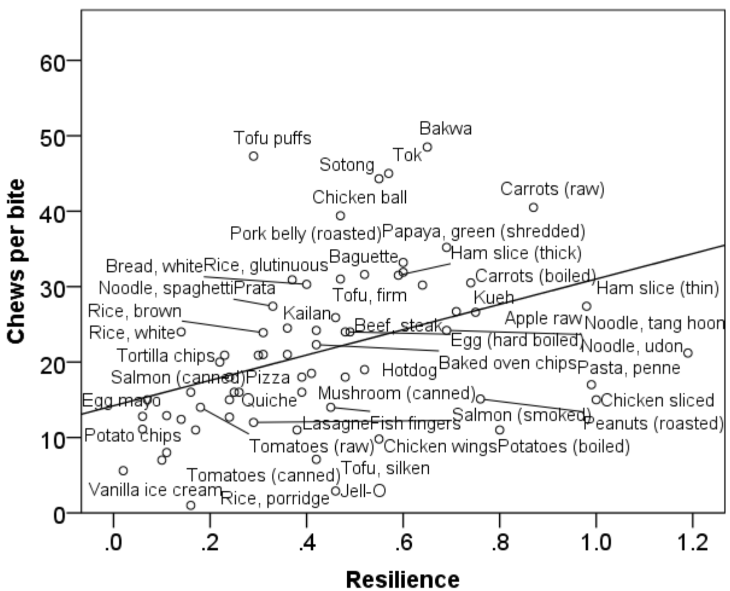
Janet Van Den Boer

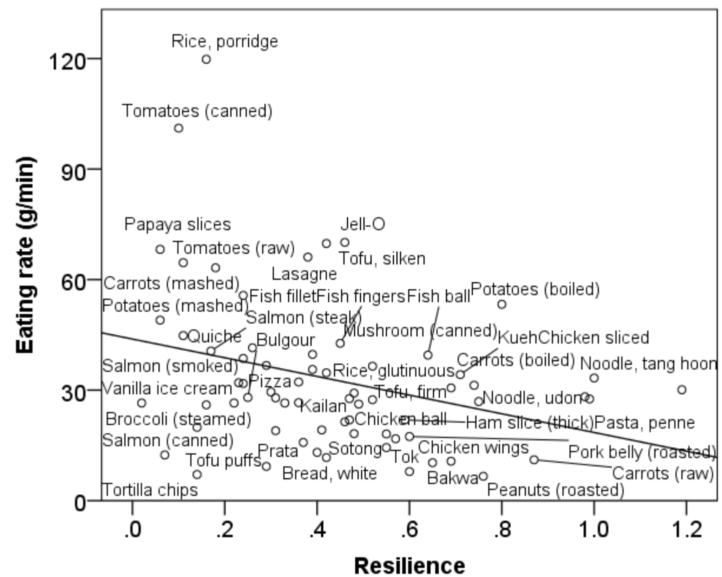
Van den Boer *et al* (2017) *Foods*

Understanding how food structure influences eating behaviours

Modelling oral processing from instrumental / mechanical properties of foods

- Relationship between oral processing, food structure and lubrication properties
- Identify changes required to food structure and lubrication to reduce eating rate





Currently being used to screen foods for a feeding intervention

May Wee Sui Mei

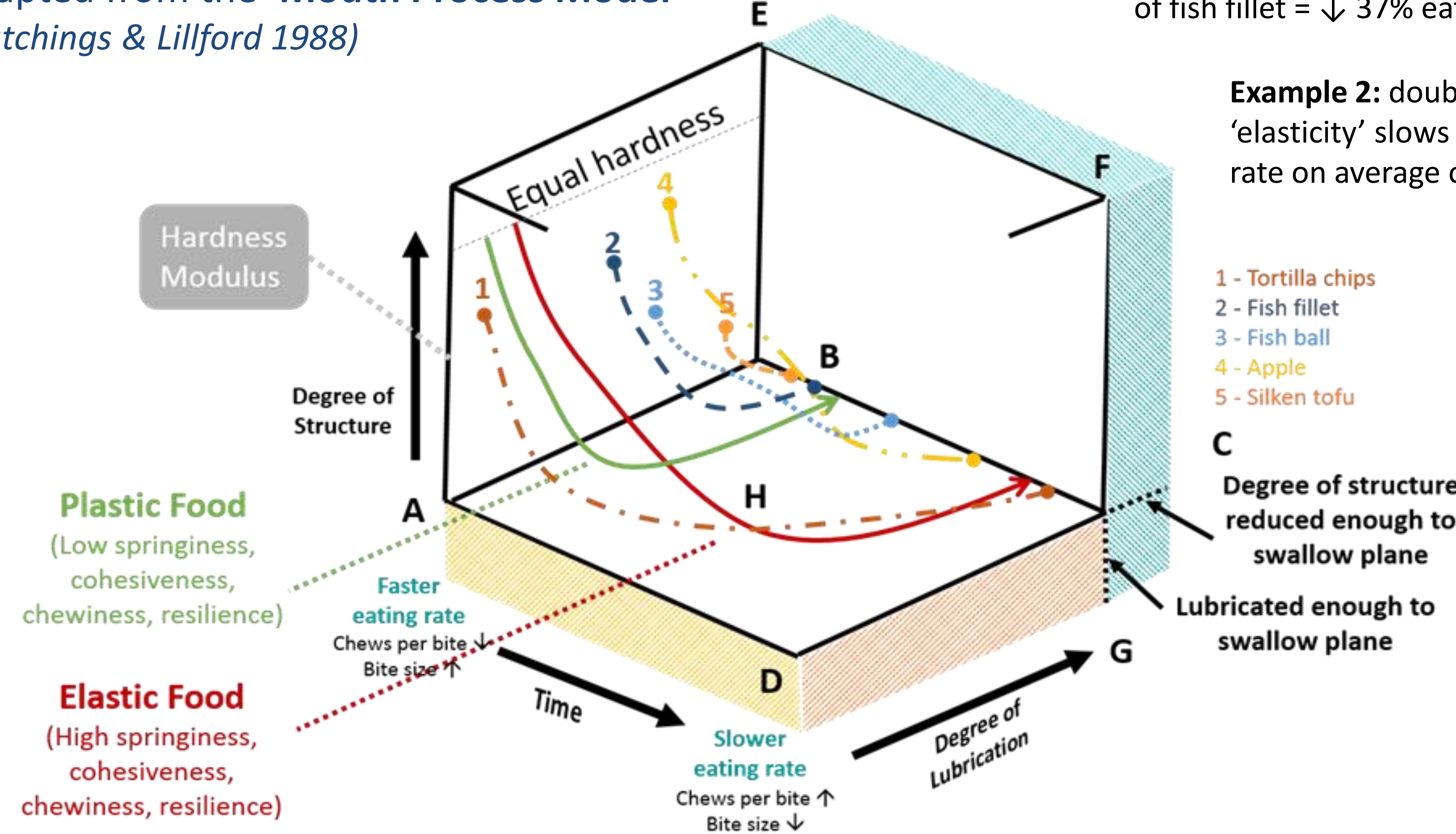
Wee, Goh, Stieger and Forde (Under Review)

Developing 'design principals' from Food Structure-Oral Processing relationships

Adapted from the **'Mouth Process Model'**
(Hutchings & Lillford 1988)

Example1 : Fish ball has twice the *springiness*, *chewiness* & *resilience* of fish fillet = ↓ 37% eating rate

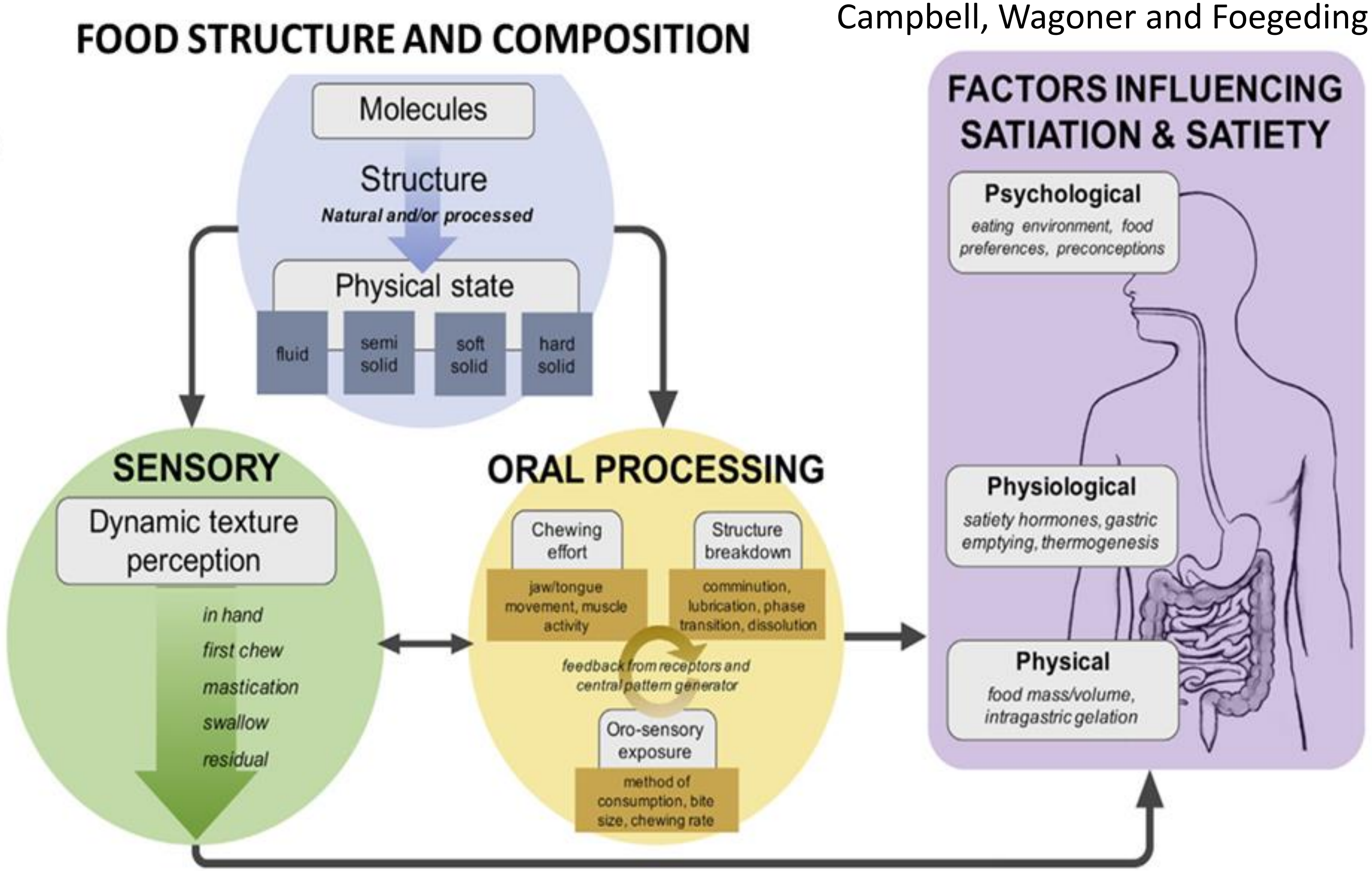
Example 2: doubling the 'elasticity' slows eating rate on average of 10%



Wee, Goh, Stieger and Forde (*Under Review*)

Re-structure & Re-formulate to produce a ‘Leanogenic’ food environment

Campbell, Wagoner and Foegeding (2016)



Wee, Tan and Forde (Under review) (2018)
Campbell, Wagoner and Foegeding (2016)
Forde, Leong, Chia, and McCrickerd (2017)

Forde, *“Flavour Perception & Satiation”* (2016)
Chambers, McCrickerd and Yeomans (2015)
McCrickerd and Forde (2016) *Obesity Reviews*

Conclusions

Sensory & Ingestive Behaviour Team

Sensory Properties play a 'function role' in driving energy intake;

Kcals have odours, tastes and textures that influence food choice and intake

How a food is eaten influences energy intake and satiety, and is a modifiable food property

Oral processing can be considered a measure of the interaction between an individuals drive to eat and the properties of their food environment;

We need to understanding the food and "human" factors that increase energy intake acutely within meals, and at a whole diet level

Sensory quality and intensity can moderate what and how much we eat

Understanding how a foods sensory properties influence energy intake will create new opportunities to use sensory cues to moderate the flow of energy through a persons diet

Thank You

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