The Relationship between Sweet Taste Perception and Dietary Intake

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Abstract

Background: Since the late 20th century, a high sugar intake has been related to the increased prevalence of obesity and non-communicable diseases like Type-2 diabetes, and some forms of cancer. Therefore, there is an urgent call to reduce sugar intake worldwide. Many studies have suggested that sweet taste perception plays an important role in the dietary intake of sugar. However, limited studies investigate this and conflicting results are found.

Aim: To better understand the link between sweet taste perception and dietary intake in healthy women

Methods: The current study included 44 healthy New Zealand European women aged 20 to 40 years. Their sweet taste intensity and hedonic liking were assessed via general Labelled Magnitude Scales (gLMS) at glucose solutions of 125mM, 250mM, 500mM, and 1000mM concentrations (20 ℃). Their current dietary intake was assessed via a four-non-consecutive-day weighed food record.

Results: Results showed that the sweet taste intensity and hedonic liking are positively correlated at 125mM ($r = 0.540$; $p < 0.001$) and negatively correlated at 500mM ($r = -0.748$; $p < 0.001$) and 1000mM ($r = -0.764$; $p < 0.001$) concentration of glucose solutions. Moreover, sweet taste intensity perceived at 1000mM glucose concentration was negatively correlated with dietary intake of total energy ($r = -0.403$; $p = 0.009$), carbohydrates ($r = -0.449$; $p = 0.003$), total sugars ($r = -0.421$; $p = 0.006$), glucose ($r = -0.411$; $p = 0.008$), fructose ($r = -0.408$; $p = 0.008$), and maltose ($r = -0.325$; $p = 0.038$). Also, the sweet hedonic liking at 1000mM glucose concentration was positively correlated with dietary intake of total energy ($r = 0.324$; $p = 0.039$), carbohydrates ($r = 0.360$; $p = 0.021$), total sugars ($r = 0.437$; $p = 0.004$), glucose ($r = 0.418$; $p = 0.007$), fructose ($r = 0.391$; $p = 0.012$), and maltose ($r = 0.463$; $p = 0.002$).

Conclusion: These results suggest an important link between sweet taste perception and dietary intake and support the theory that people who are more sensitive to sweet taste require a lower level of sweetness to achieve equal satisfaction, thus consume less sweet foods and beverages than those who are less sensitive to sweet taste.

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Abbreviations

AMDRs	Acceptable Macronutrient Distribution Ranges
AMPM	Automated Multiple-Pass Method
BIA	Bioelectrical Impedance Assessment
BMI	Body Mass Index
CHO	Carbohydrates
CI	Confidence Interval
CRD	Chronic Respiratory Diseases
CVD	Cardiovascular Disease
DP	Degree of Polymerization
FFQ	Food Frequency Questionnaire
gLMS	General Labelled Magnitude Scale
GPCR	G-Protein Coupled Receptors HDL
	High-Density Lipoprotein
IP3	Inositol-Trisphosphate
IP3R3	Isoform 3 of the IP3 Receptor
LDL	Small Dense Low-Density Lipoprotein
LMS	Labelled Magnitude Scale
MoH	Ministry of Health
NCDs	Non-Communicable Diseases
TRPM5	Transient Receptor Potential M5
PLC-β2	Phospholipase C-B2
RCTs	Random Controlled Trials
SEM	Standard Error of the Mean
SSBs	Sugar-Sweetened Beverages
T2D	Type 2 Diabetes
TRCs	Taste Receptor Cells
USDA	United States Department of Agriculture
VAS	Visual Analogue Scale
WHO	World Health Organization
%E	Percent of Total Energy Intake

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Chapter 1: Introduction

1.1 Background

From birth, humans have an innate desire for sweet tasting foods. This extends from historic times where access to sugar was limited, existing only in natural form; seasonally in honey, fruits and vegetables. More recently, improvements in cultivation methods of sugarcane and sugar beet have made sugar widely available and cheap to buy (Maniam, Antoniadis, Youngson, Sinha, & Morris, 2016). The food industry extensively adds sugar to various foods and beverages to increase their sweet taste and provide other important microbial and chemical functions (Hasanuzzaman et al., 2014; Sato & Miyawaki, 2016; Struyf et al., 2017). This increased availability has led to increased intakes of sugar and an associated increase in the prevalence of non-communicable diseases such as obesity and type-2 diabetes (Fung et al., 2009; Tasevska et al., 2012). In 2015, the World Health Organization (WHO) came up with a recommendation for maximum sugar intake, with the hope to improve global dental and general health (World Health Organization, 2015).

1.1.1 The increased prevalence of non-communicable diseases (NCDs) globally

Non-communicable diseases (NCDs) refer to medical conditions that are not infectious or transmissible. These chronic conditions generally progress slowly and require long-term treatment and care (World Health Organization, 2017c). The four major types of NCDs are cardiovascular diseases (CVDs), cancers, chronic respiratory diseases (CRDs), and type-2 diabetes (T2D). NCDs are today the leading cause of death globally. Approximately 40 million people die from NCDs every year, which accounts for 70% of all deaths worldwide. In addition, about 80% of global NCDs deaths are in the low- and middle-income countries (World Health Organization, 2017c).

Obesity, defined as a Body Mass Index (BMI) ≥ 30 kg/m^2 is a well-acknowledged risk factor for various NCDs (World Health Organization, 2017c). According to Ng et al. (2014), globally the number of overweight (BMI 25 kg/m^2 to 29.9 kg/m^2) and obese people increased from 857 million in 1980 to 2.1 billion in 2013. Despite knowledge of this anticipated increase, developed countries showed a significant rise in obesity rates throughout the past thirty years. In New Zealand, the adult (≥ 15 years) obesity prevalence has continuously grown from 26.5% in 2006/07 to 28.6% in 2011/12 and 30.7% in 2014/15 (Ministry of Health, 2015a). In the USA, 34.4% of adults in 2007/08 and 36.5% in 2011/14 were obese (Ogden, Carroll, Fryar, & Flegal, 2015). According to the 2014-15 Australian National Nutrition Survey, 35.5% of the adults (≥18 years) were overweight and an extra 27.9% were obese (Australian Bureau of Statistics, 2015). Moreover, in 2015, over 60% of the UK adults (≥16 years) were either overweight or obese and this trend remained at a similar level since 2010 (Health and Social Care Information Centre, 2016). In addition, among developing countries, where 62% of the global obese population live, the prevalence of overweight and obesity is constantly increasing, especially in the Pacific and the Caribbean countries. Furthermore, the rates of overweight and obesity in the Middle East (e.g. Egypt, Saudi Arabia) and Central America (e.g. Honduras) were as high or even higher than those in developed countries (Ng et al., 2014).

Diabetes is a metabolic disorder characterized by high blood glucose levels as a result of inadequate insulin production and/or ineffective use of insulin by the body. The three common types are type 1 (insulin-dependent), type 2 (non-insulin-dependent), and gestational diabetes (World Health Organization, 2017b). Type 2 diabetes (T2D) account for 90% of all diabetics. The various acute (e.g. diabetic ketoacidosis, hypoglycemia) and chronic (e.g. CVDs, diabetic nephrophty) complications of diabetes cause disability and death worldwide (World Health Organization, 2017b). Statistics from the International Diabetes Federation (2015) showed that diabetes prevalence increased from 8.3% (382 million) in 2013 to 8.8% (415 million) in 2015 among the world's adults aged 20 to 79 years. If the current trends continue, the total number of adults with diabetes is predicted to reach 642 million in 2040. Additionally, the top three countries with the largest number of adults with diabetes in 2015 were China (109.6 million), India (69.2 million), and the US (29.3 million). The US and China respectively spent $320 and $51 billion in 2015 on diabetes and its related health issues (International Diabetes Federation, 2015).

Obesity also increases the risk of developing CVDs; these are a class of medical conditions affecting the heart and blood vessels, such as coronary heart disease (CHD), cerebrovascular diseases and rheumatic heart diseases (World Health Organization, 2017a). Common modifiable risk factors for CVDs include smoking, physical inactivity, unhealthy diets, obesity, hypertension, diabetes, and high blood lipids (World Health Organization, 2017a). These risk factors are linked with behavior and lifestyle issues worldwide, which are tightly linked to industrialization, urbanization, and globalization (Institute of Medicine, 2010). Thus, not only developed counties but also developing countries experience a growing CVD burden (Institute of Medicine, 2010). In New Zealand, CVD is the leading cause of death, with around 30% of all deaths linked with CVD (Ministry of Health, 2015c). In the US, one in three deaths was due to CVD in 2013 and the direct and indirect costs of CVD were $316.6 billion from 2011 to 2012 (American Heart Association, 2016). In the UK, CVD caused 27% of all deaths in 2014 and the total CVD expenditure was around £4.3 billion (Townsend, Bhatnagar, Wilkins, Wickramasinghe, & Rayner, 2015). In developing countries like China, the number of people suffering from CVD raised from 230 million in 2011 to 290 million in 2013, and this number is predicted to continue to grow rapidly. According to the National Center for Cardiovascular Diseases (2014), CVD accounted for 41.9% of all deaths in the urban area and 44.8% in the rural area.

Hence, the increasing morbidity and mortality of NCDs compromise people’s quality of life and longevity and impose a great financial burden on the health care system and society as a whole.

1.1.2 Sugar intake and NCDs prevalence

Numerous epidemiological studies and controlled trials suggest that a high sugar intake is positively related to a higher risk of various NCDs including T2D and CVD (Apovian, 2004; Fung et al., 2009; Gupta et al., 2013; Hu & Malik, 2010; Malik, Popkin, Bray, Després, Willett, et al., 2010; Stephan, Wells, Brayne, Albanese, & Siervo, 2010; Tasevska et al., 2012; H Wang, Steffen, Zhou, Harnack, & Luepker, 2013). The surveillance study investigating trends in risk factors of CVD, recruited 2.3 million American adults (25 – 74 years) over 27 years revealed that across all gender, age, and weight categories, BMI increased as intakes of added sugar increased (H Wang et al., 2013). According to a meta-analysis by Malik, Popkin, Bray, Després, Willett, et al. (2010), which was based on 11 cohort studies involving 310,819 individuals, those who consumed 1-2 servings of sugar-sweetened beverages (SSB) per day were 26% more likely to develop T2D than those who consumed a serving of SSB less than once per month. Moreover, Tasevska et al. (2012) found that sugar intake was positively related to the risk of small intestine cancer, pleural cancer and esophageal adenocarcinoma in a 7.2-year-follow-up study of 435,674 middle-aged male and female adults. Additionally, the longitudinal study of Fung et al. (2009), which lasted for 24 years from 1980 and included 88,520 women (34 - 59 years), showed that SSB consumption was significantly correlated with CVD risk even after adjustment for the confounding dietary and lifestyle factors. Therefore, understanding how sugar intake is related to NCD prevalence might be helpful in preventing NCDs.

1.1.3 Sweet taste perception and its measurement

Apart from appearance, texture and aroma, taste is a very important factor contributing to food acceptance, which may further influence individuals' food choices and ultimately their nutritional status (N. Dias et al., 2012). The five widely acknowledged tastes are sweetness, sourness, bitterness, saltiness and umami (Trivedi, 2012). From an evolutionary point of view, people's ability to identify the five basic tastes is believed to be of vital importance to ensure adequate energy and nutrient intake and the rejection of potentially harmful or toxic foods for the human body to survive and function normally (Simon, de Araujo, Gutierrez, & Nicolelis, 2006). Specifically, sweet taste signals the presence of energy in foods, sourness indicates food spoilage, bitterness alerts to poisons, saltiness reveals the existence of minerals, and umami identifies protein in foods (Newman, Haryono, & Keast, 2013; Simon et al., 2006).

A taste is experienced when the electrical impulses, generated when chemical particles stimulate the taste receptor cells (TRCs) located mostly on the tongue, are transmitted to and interpreted by the brain. To activate taste receptors for any taste, the compound should reach a particular concentration in the oral cavity (R Keast & Roper, 2007). Taking sweetness as an example, aqueous solutions with very little sucrose may taste identical to water. As more sucrose is added, individuals would notice a difference between the aqueous solution and pure water even though they cannot identify any particular taste. This concentration is referred to as detection threshold. Accordingly, when the sucrose concentration is high enough that individuals specify the taste as sweetness, the recognition threshold is reached (R Keast & Roper, 2007). People's detection and recognition thresholds may vary greatly due to age, gender, medication use, disease etc. (Blakeslee & Salmon, 1935; Kahn, 1951; Sanders, Ayers, & Oakes, 2002; Yoshimura, 2002). Similarly, how intense people experience a sugar concentration (i.e. perceived sweet taste intensity), and how much they prefer (i.e. sweet taste hedonic liking) a given concentration of sucrose solution display great variations as well (R Keast & Roper, 2007).

The standard procedure to measure the detection and recognition thresholds of sweetness is the forced-choice ascending concentration series methods of limits (ASTM, 2008). However, the stimuli (e.g. sucrose, glucose, fructose), the media (e.g. water, yoghurt, biscuits), the concentration ranges, and the stopping rules engaged may vary from study to study (ASTM, 2008; Holt, Cobiac, Beaumont-Smith, Easton, & Best, 2000). Perceived sweet taste intensity and sweet taste hedonic liking were originally measured on Natick 9-point scales (D. Peryam & Pilgrim, 1957), where individuals chose a number from 1 (extremely weak) to 9 (extremely strong) to indicate the intensity and their preferences of a testing sample. However, due to great ceiling effects, the Visual Analog Scale (VAS) was then introduced in the 1960s (Aitken, 1969; Clarke & Spear, 1964). All the intermediate labels were dropped and individuals marked their perceived sweet taste intensity and sweet taste hedonic liking between the two extremes at the ends. Yet, to enable more accurate intra-individual comparisons, the general labeled magnitude scale (gLMS) standardizes the top anchor as the strongest imaginable sensation/liking of any kind (Bartoshuk et al., 2004). Also, the stimuli (e.g. sucrose, glucose), the media (e.g. water, cakes), and the concentrations range for testing may vary in different studies.

1.1.4 Dietary assessment of sugar intake

The common methods to assess the intakes of sugar and other nutrients are dietary history, food frequency questionnaire (FFQ), 24-hour food recall, and food record (Biro, Hulshof, Ovesen, & Cruz, 2002). Dietary history describes a detailed dietary pattern (e.g. including seasonal changes) over a certain period. However, the conduction of a standard dietary history requires well-trained interviewers and one to two hours of time, thus it is used more often in clinical setting (Gibson, 2005). A FFQ measures the frequency of consumption and in some instances portion size of a pre-determined list of foods over a given period of time, to obtain information on habitual dietary intake (Biro et al., 2002). FFQs are less time-consuming and less expensive when compared to 24-hour food recall and food record and can be self-administrated, thus they are commonly used in large-population epidemiological studies. However, the FFQ does not capture the daily variation in diet and the obtained food intakes tend to be over-reported (F. Thompson & Subar, 2008). When conducting a 24-hour food recall, the individual needs to recall the type and amount of all food and drinks consumed during the past 24 hours with the help of a trained interviewer (Biro et al., 2002). For a food record, individuals need to record the type and measure or estimate the quantity of the food and drink at the time of consumption (Biro et al., 2002). The administration of 24-hour food recall is relatively easy, quick and involves less participant response burden when compared to food record. Nevertheless, unlike a FFQ, neither single 24-hour food recall nor single food record is sufficient to reflect habitual dietary intakes. To solve this, 24-hour food recall and food record can be repeated for multiple days (Gibson, 2005). Furthermore, a weighed food record is considered the gold standard dietary assessment method due to its accuracy (Coulston, Boushey, & Ferruzzi, 2013). On the one hand, as the only prospective method, food record does not rely on memory but may influence the usual dietary intake because of the burden of the measuring and recording process compared to the other three retrospective methods (Coulston et al., 2013). On the other hand, food record is expensive and time-consuming to administer and to analyze. The higher response burden may result in a reduced response rate and reduced compliance. Additionally, multiple food record may be used to reflect habitual dietary intake (F. Thompson & Subar, 2008).

1.1.5 Sweet taste and sweet food consumption

In the study of Ettinger, Duizer, and Caldwell (2012), overweight women had a higher detection threshold for sweetness and tended to prefer higher sucrose concentrations than women with a normal body weight. Moreover, people with diabetes were reported to have higher recognition thresholds for sweetness compared to healthy controls (Chochinov, Ullyot, & Moorhouse, 1972; Lawson, Zeidler, & Rubenstein, 1979). In the study of Bustos-Saldaña et al. (2009), high blood glucose levels in T2D patients correlated with blunted sweet taste response. As stated earlier, taste perception plays an important role in food acceptance and dietary intake (N. Dias et al., 2012). An impaired sweet taste perception was postulated to increase the intake of sweet foods and beverages in diabetic patients, which may further worsen their glycemic control (Wasalathanthri, Hettiarachchi, & Prathapan, 2014). The potential influence of sweet taste perception on dietary intakes (Anderson, 1995) may provide another explanation for the increasing sugar intake worldwide and hopefully provide another angle to generate new avenues for the prevention and control of certain NCDs.

1.2 Justifications

To date, only a few studies have investigated the association between sweet taste perception and actual dietary intake in healthy individuals (Cicerale, Riddell, & Keast, 2012; Holt et al., 2000). For instance, the study of Holt et al. (2000) involved 69 Caucasian Australian (22.7±2.5 kg/m^2; 22.8±4.3 years) and 63 Malaysian (20.8±2.2 kg/m^2; 21.5±1.2 years) male and female university students, who were healthy, smoke-free, and living in Australia. Their perceived sweet taste intensity and sweet taste hedonic liking towards various levels of sucrose in different forms (e.g. aqueous solution, orange juice, and custard) were measured on a VAS scale. Moreover, their habitual intake of sweet-tasting food and drink was assessed via a culturally adapted FFQ. However, no significant correlation was observed between perceived sweet taste intensity and total sugar intake. Yet, the sweet taste hedonic liking was shown to be positively related to the intake of sugar and other sweet-tasting foods and drinks (Holt et al., 2000). Moreover, a study by Cicerale et al. (2012) included 85 university students in Australia (BMI: 21 ± 3, age: 21 ± 4 y), of which 89% were healthy females and the majority (95%) non-smokers. Their perceived sweet taste intensity towards one sucrose concentration (200 mM) was measured on a gLMS scale. Their dietary intake was obtained via a two-day food record. However, no correlations were found between perceived sweet taste intensity and intake of total energy and macronutrients. Mattes (1985) and J. Low, McBride, Keast, and Lacy (2016) also found no association between perceived sweet taste intensity and dietary intake in their studies. However, given the different methods used in these studies to assess sweet taste perception (e.g. VAS vs. gLMS) and dietary intake (FFQ vs. two-day food record), it is too early to consider this as the end of this topic (Bartoshuk, Duffy, Hayes, Moskowitz, & Snyder, 2006). Further research is needed to develop any clear conclusion. Hence, to further investigate the relationship between sweet taste perception and dietary intake, the current study was carried out in a group of women aged 20 to 40 years, living in New Zealand with the most updated tools to measure perceived sweet taste perception (i.e. gLMS) and dietary intake (four-non-consecutive-day weighed food record).

1.3 Aim:

The overall aim of this study is to better understand the link between sweet taste perception and dietary intake in 20-40 year old NZ European women.

1.3.1 Objectives:

- To assess the correlation between perceived sweet taste intensity and sweet taste hedonic liking at suprathreshold concentrations
- To examine the association between perceived sweet taste intensity and dietary intake of total energy, macronutrients and various sugars
- To examine the association between sweet taste hedonic liking and dietary intake of total energy, macronutrients and various sugars

1.4 Hypothesis:

We hypothesize that participants who perceive a sweet tastant as more intense tend to like it less and consume less sugar in their diet.

1.5 Thesis structure

There are four chapters in this thesis. The first chapter introduces the rationale significance of this study. The second chapter reviews how sweet taste perception is generated, how it differs between individuals and how it is measured, and also its correlations with dietary intakes. The third chapter is an original research manuscript of the entire study, the study design and results are presented and discussed. The fourth chapter contains the conclusion, strengths, limitations and practical application of the study results and presents some recommendation for future research.

1.6 Researchers' contribution

Table 1.1 Researchers' contributions to the study

Researchers	Contributions
Guojiao Cao	Main researcher, collected sensory and dietary data, entered and analyzed dietary data, interpreted and discussed results, author of the thesis
Prof Bernhard Breier	Academic supervisor, applied for funding, directed research strategy and study design, assisted with interpreting results, and reviewed the thesis
Dr Marilize Richter	Academic co-supervisor, assisted with statistical analysis and results interpretation, and reviewed the thesis
Shakeela Jayasinghe	Applied for ethics, designed the sweet taste study, developed the sensory procedure, recruited and screened participants, and collected and entered sensory data
Sophie Kindleysides	Assisted with recruiting and screening participants and collecting sensory data
Stacey Rivers	Assisted with collecting and entering sensory data

Chapter 2: Literature Review

2.1 The generation of sweet taste perception

An individuals' dietary consumption and ultimately their nutritional status (N. Dias et al., 2012) is influenced by a range of factors with a key contributor being food acceptance. An individual's food acceptance is influenced by appearance, texture and aroma as well as taste (N. Dias et al., 2012).

The five widely acknowledged tastes are sweetness, sourness, bitterness, saltiness and umami (Trivedi, 2012). From an evolutionary point of view, humans' ability to identify the five basic tastes is believed to ensure adequate intakes of energy, a variety of nutrients and the rejection of potentially harmful or toxic foods (Simon et al., 2006). Specifically, sweetness signals the presence of energy in food; sourness indicates food spoilage; bitterness alerts to poisons; saltiness reveals the existence of minerals; and umami identifies proteins in foods (Newman et al., 2013; Simon et al., 2006). Recently, fat taste has been identified as the sixth taste, which may also signal the presence of energy in food (Russell Keast & Costanzo, 2015).

Taste is primarily generated in the oral cavity, by taste buds. The tongue is packed with tiny bumps called papillae (Bachmanov & Beauchamp, 2007). Three of the four lingual papillae contain taste buds, which are fungiform, foliate and circumvallate papillae. Each taste bud consists of 50-100 taste receptor cells (TRCs) that has four morphologically distinct types (i.e. type I, II, III and the Basal (IV) cells) (Bachmanov & Beauchamp, 2007). The TRCs respond to a wide range of sweet tastants, such as caloric sugars and artificial sweeteners, which are located on the type II TRCs (Webb, Bolhuis, Cicerale, Hayes, & Keast, 2015). The sweet TRC is a heterodimer of two G-protein coupled receptors (GPCR), T1R2 and T1R3. When sweet tastants bind to the T1R2-T1R3 dimer, the intracellular signalling pathway is activated (**Figure 2.1**), transmitting the information via sensory afferent fibres to the sweet taste processing area in the brain (Prawitt et al., 2003; Xu et al., 2004).

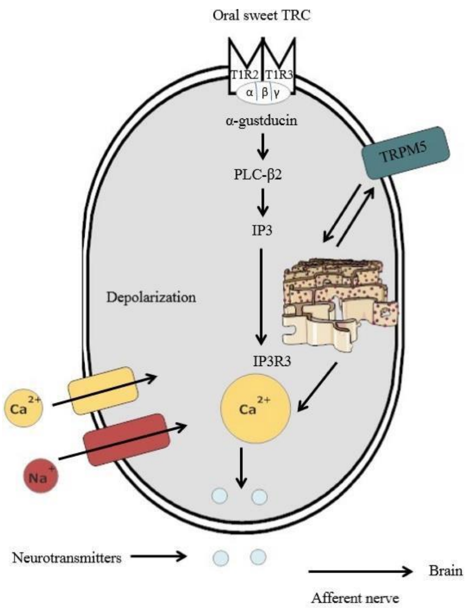


Figure 2.1 The oral intracellular signalling pathway of the transduction of sweet taste perception (Y. Low, Lacy, & Keast, 2014)

Once sweet tastants bind to the T1R2-T1R3 dimer, the α-gustducin is activated, which consequently activates an essential second messenger, namely, phospholipase C-β2 (PLC-β2) (Rössler, Kroner, Freitag, Noè, & Breer, 1998; Wong, Gannon, & Margolskee, 1996). The activation of PLC-β2 stimulates the generation of inositol-trisphosphate (IP3). Then, the isoform 3 of the IP3 receptor (IP3R3) increases the cytoplasmic level of calcium ions by mobilization from the endoplasmic reticulum (Pierce-Shimomura, Faumont, Gaston, Pearson, & Lockery, 2001). Accordingly, the transient receptor potential M5 (TRPM5) ion channels in the plasma membrane are opened (Prawitt et al., 2003). The resulting sodium entry induces depolarization, making calcium ions that enter through the calcium channel (Prawitt et al., 2003; Xu et al., 2004) further lead to the discharge of neurotransmitters from oral sweet TRCs. The sensory information is further carried by the afferent nerve to the brain areas designated for sweet taste processing.

2.2 The measurement of sweet taste perception

To measure taste perception, a few terms need to be defined. 1) Detection threshold; the lowest concentration at which a tastant is perceived but the corresponding taste still cannot be specified at this low concentration (Webb et al., 2015). 2) Recognition threshold; the concentration at which a taste can be distinguish and recognised clearly (R Keast & Roper, 2007). 3) Perceived intensity; the magnitude of a particular taste at supra-threshold concentrations, which is often specified by using various sensory scales (Webb et al., 2015). As the concentration increases, the perceived intensity increases as well, until peaking at a certain concentration and then declining afterwards (H Moskowitz, 1977). Alongside the above three sensory measurements, the hedonic liking of sweet taste, also at supra-threshold concentrations, is of great importance for its potential role on food consumption (Webb et al., 2015). Unlike perceived intensity, the patterns of hedonic liking can vary significantly, from a monotonic rise, to a sharp decline, or an inverse U shape function, with increasing concentrations (Kim, Prescott, & Kim, 2014; H Moskowitz, 1977).

2.3 Great variation in perceived sweet taste intensity and hedonic liking ratings

Individuals sensory and hedonic response to sweet taste may be influenced by numerous factors including genetics (i.e. the number of taste buds), age, gender, race and culture (Drewnowski, 1997).

The detection/recognition threshold of sweetness may be influenced by age, leptin levels, and it is likely that body size plays a role. According to Kennedy, Law, Methven, Mottram, and Gosney (2010), older adults (n=48; 63–85 years) have a significantly higher detection and recognition threshold than young adults (n=36; 18–33 years), with no significant difference between gender groups, suggesting a reduced sensitivity towards sweetness among older adults. In 90 young (21 - 30 years) and healthy adults, Nakamura et al. (2008) observed a diurnal change in the pattern of sweet recognition thresholds that paralleled the plasma leptin level, which hit the bottom in the morning and peaked at night. In regard to body size and sweet recognition threshold, results are conflicting. Hardikar, Höchenberger, Villringer, and Ohla (2017) found that obese (BMI > 30 kg/m^2) individuals had lower thresholds when compared to lean (BMI < 25 kg/m^2) individuals. However, Ettinger et al. (2012) found detection threshold of sucrose solutions was higher among overweight women (BMI > 25 kg/m^2) compared to women with a normal weight (BMI: 18.5-24.9 kg/m^2). Yet, Simchen, Koebnick, Hoyer, Issanchou, and Zunft (2006) observed no significant difference in terms of recognition threshold of sweetness between high (≥ 28 kg/m^2) and low (< 28 kg/m^2) BMI groups.

The sweet taste intensity may be related to age, gender, and probably body size. According to Kennedy et al. (2010), older adults (n=48; 63–85 years) rated the sweetness intensity significantly lower than young adults (n=36; 18–33 years). Fischer et al. (2013) found among 2374 adults with a mean age of 48.8 years that females tended to rate their perceived intensity of sweetness stronger than males. The role of body size on sweet taste intensity is conflicting as well. Hardikar et al. (2017) found that intensity ratings were significantly higher in the obese group (BMI > 30 kg/m^2) than in the lean group (BMI < 25 kg/m^2) for lower sweet concentrations. However, Sartor et al. (2011) found the overweight and obese (BMI ≥ 25 kg/m^2) individuals rated sweet taste less intense than the normal weight controls (18 kg/m^2 ≤ BMI < 25 kg/m^2).

The sweet hedonic liking is significantly altered by genetics, age, race and gender. According to Mennella, Pepino, and Reed (2005), preferences for sucrose and sweet foods and beverages in children were significantly related to genetic factors, whereas, such a correlation was not found among adults. However, in the study of Keskitalo, Knaapila, et al. (2007), where 146 individuals from 26 Finnish families (18–78 years) were involved, the heritability of hedonic rating for a sucrose solution (18.75% wt/vol) reached approximately 41%. Further, in this study (Keskitalo, Tuorila, et al., 2007), genetic factors explained 49% of the alteration in hedonic liking for a 20% (wt/vol) sucrose solution among 324 pairs of monozygous and dizygous twins (17–80 years). In regard to age and gender, Pepino and Mennella (2005) found that children and adolescents preferred sweeter foods and beverages than adults. This result has been supported by more recent studies (Mennella, Lukasewycz, Griffith, & Beauchamp, 2011; Schwartz, Issanchou, & Nicklaus, 2009). Monneuse, Bellisle, and Louis-Sylvestre (1991) and Hayes and Duffy (2008) found that men preferred higher intensities than women. Moreover, race was significantly related to sweet preferences in both children and adults (Mennella et al., 2005). By contrast, body size (i.e. adiposity) was not a strong predictor of liking sweet stimuli (Salbe, DelParigi, Pratley, Drewnowski, & Tataranni, 2004). The overweight and obese individuals often show a consistent preference for fat stimuli but not necessarily for sweet stimuli (Drewnowski, Brunzell, Sande, Iverius, & Greenwood, 1985).

In addition, many other factors, including pregnancy, use of medications (Naik, Shetty, & Maben, 2010), chemotherapy (Steinbach et al., 2009), radiotherapy (Redda & Allis, 2006), smoking, and medical conditions like cancers, diabetes, and oral and nasal diseases, may induce taste alternations. Cautions are needed when testing sensory and hedonic responses of taste-related studies.

2.4 Sensory and hedonic scales

2.4.1 Sensory and hedonic measuring scales

The measurement of sensory sensitivity and hedonic liking is essential to understand the roles sensory perception plays in influencing habits and general health and wellbeing. Sensory and hedonic scales provide an efficient approach for the assessment of the magnitude of perceived intensity and hedonic liking for various taste qualities (Lawless, Sinopoli, & Chapman, 2010; Lim, Wood, & Green, 2009).

2.4.2 Sensory scales

2.4.2.1 Sensory 9-point scale

A 9-point scale was first developed in late 1940s by D. R. Peryam and Girardot (1952) to study food preferences in the US military. It was then modified to a sensory version for rating of perceived intensity of various taste qualities (Drewnowski, Henderson, & Shore, 1997; Drewnowski, Henderson, Shore, & Barratt-Fornell, 1997; Kamen, Pilgrim, Gutman, & Kroll, 1961). The sensory 9-point scale contains nine intensity groups, where “1” stands for “not at all” and “9” for “extremely” of the tested sensation (**Figure 2.2**) (Drewnowski, Henderson, & Shore, 1997). The sensory 9-point scale has been widely used since then due to its simplicity and ease of use. However, later researchers found a few limitations of this scale especially after the discovery of supertasters, who experience the most intense tastes. Firstly, the sensory 9-point scale faced severe ceiling effects. No rating higher than “extremely strong” can be made, thus this scale lacks sensitivity to differentiate supertasters from medium tasters (Bartoshuk, Fast, & Snyder, 2005). Secondly, a sensory 9-point scale did not generate ratio-level data, which means that a rating of “6” did not necessarily register as twice as strong as a rating of “3” (Bartoshuk et al., 2006). Thirdly, even being good at within subject comparisons, due to individual genetic variations in taste and the fact that people cannot share sensory experiences, the sensory 9-point scale was generally considered be unable to generate valid across-group comparisons (Kalva, Sims, Puentes, Snyder, & Bartoshuk, 2014).

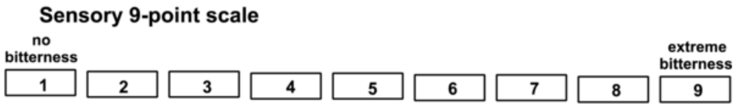


Figure 2.2 Sensory 9-point scale (Kalva et al., 2014)

2.4.2.2 Magnitude estimate

To solve the lack of ratio property of the sensory 9-point scale, magnitude estimates were developed by Stevens in 1957. For this procedure, individuals were required to assign numbers to each sample to indicate the perceived intensity relative to the first sample they tasted (S. Stevens, 1957). The first number being used was called the modulus, which can be fixed for all participants or freely chosen. The first sample to be tasted was called the standard, which can also be a fixed sample in the middle of a wide range, avoiding problems owing to starting with an extremely high or low standard stimulus, or it can be randomly selected. However, either a fixed modulus or a fixed standard stimulus is more vulnerable to rounding effects, namely the overuse of round numbers like 5, 10, 25, or 50 for ratings (H. Moskowitz, 1977). Moreover, randomization of the presenting order of all stimuli helps to reduce rating bias arising from sequential dependencies (Cross, 1973).

Theoretically, a magnitude estimate can provide ratio-level data (S. Stevens, 1957). Furthermore, as the participants can assign numbers relatively freely, magnitude estimate is not likely to have ceiling effects. However, since only relative instead of absolute perceived intensities were obtained, magnitude estimates are still not capable of providing valid across group comparisons. In addition, comparing to the sensory 9-point scale, magnitude estimates are more complicated and require appropriate participant training or orientation to ensure the quality of the data (H. Moskowitz, 1971).

2.4.2.3 Visual Analogue Scale (VAS)

The Visual Analogue Scale (VAS) was introduced in the 1960s to measure feelings (Aitken, 1969). To overcome the ceiling effects of the sensory 9-point scale, the VAS dropped all intermediate labels allowing participants to mark anywhere along a horizontal or vertical line with only two extreme anchors at the ends (**Figure 2.3**) (Stubbs et al., 2000). The distance from one end to the marked position was then measured and scored as the rating (Lawless et al., 2010). According to Price, McGrath, Rafii, and Buckingham (1983), the VAS generated ratio-level of pain rating. However, Wewers and Lowe (1990) and Bartoshuk et al. (2003) doubted the ratio-property of the VAS and believed that a VAS score of 60 is not necessarily twice as strong as a score of 30. Moreover, since the end-anchors may be interpreted differently among individuals, the VAS is not yet sufficient for valid across-group comparisons (Bartoshuk et al., 2003; Bartoshuk et al., 2004).

Figure 2.3 Visual Analogue Scale (VAS) (Ludy & Mattes, 2011)

2.4.2.4 Cross-modality matching

For a cross-modality matching procedure, the respondent is required to adjust the level of a certain modality to match various levels of a reference modality, for instance, matching brightness to loudness (J. Stevens & Marks, 1965). The reverse matching or matching both to a third modality is recommended to reduce the influences of regression bias (Cross, Tursky, & Lodge, 1975; S. S. Stevens & Greenbaum, 1966). Comparing to magnitude estimate, cross-modality matching is less likely to be subjected to round effects. Moreover, since concepts of numbers and ratio values are not needed, cross-modality matching can also be used for children and illiterates (Bond & Stevens, 1969; H Moskowitz, Kumaraiah, Sharma, Jacobs, & Sharma, 1975). However, the application of cross-modality matching is limited. On the one hand, it is impractical to adjust the stimulus continuously for modalities like olfaction, taste and common chemical sense. On the other hand, owing to fast adaption, the procedure involving modalities like thermal sense, olfaction and taste, may take longer and may impose heavy memory burden to the respondents to achieving good match and maintaining the level of adaptation (J. Stevens & Marks, 1980).

2.4.2.5 Magnitude matching

As mentioned earlier, previous sensory scales are not capable of valid across-group comparisons, owing to genetic variations in taste and the fact that individuals cannot share sensory experiences (Bartoshuk, 2000). Many cross-modality matching studies revealed that sensory ratings can be matched across various modalities (J. Stevens & Marks, 1965; S. S. Stevens, 1959). Even though there is no modality that can be perceived exactly the same by all individuals, the above problem can be solved if there is a standard modality not varying across groups (e.g., age, gender, etc.) with the stimuli of interest(Bartoshuk, 2000). Thus, J. Stevens and Marks (1980) developed magnitude matching, for which individuals are required to rate the perceived intensities of the test modality and the selected standard modality, which are unlikely to be related with each other, on a single common scale of sensory magnitude. For instance, if sweet taste is of interest, the reference standard should not be related to taste. Matching functions were then generated to reflect the perceived intensity of the test modality relative to the standard. Averagely, if the same number was assigned to two different stimuli, they were supposed to be the same at a sensory magnitude.

Compared to cross-modality matching, magnitude matching is fast and efficient. Due to absence of regression bias, reverse matching is not needed for magnitude matching, which reduces the burden for both the respondents and the experimenters (Bartoshuk et al., 2005). Moreover, since magnitude matching avoids the necessity of continuous stimulus adjustment, it can be applied to all continua including olfaction, taste and common chemical sensation (J. Stevens & Marks, 1980). Furthermore, the adaptation control for magnitude matching is relatively simpler, requiring only brief stimuli observation. By all means, the biggest advantage of magnitude matching is its ability to compare suprathreshold sensory magnitudes across groups (e.g. age, sex, sensory pathology) (J. Stevens & Marks, 1980).

2.4.2.6 Labelled Magnitude Scale (LMS)

Even though magnitude matching is considered the gold standard for valid across-group comparisons of sensory magnitudes (Bartoshuk et al., 2004), it does not provide semantic information. Moreover, given the ease and convenience of category scales (e.g. sensory 9-point scale), Green, Shaffer, and Gilmore (1993) developed the labelled magnitude scale (LMS), which was a category scale with ratio property, based on a large body of previous research. According to the literature, appropriate intervals among the semantic labels, which represented all possible sensory ratings, was the key to yielding ratio level data (Borg, Ljunggren, & Marks, 1985; Marks, Borg, & Ljunggren, 1983; Marks, Borg, & Westerlund, 1992). Borg (1961), Teghtsoonian (1971) and Teghtsoonian (1973) found that even denoting different absolute perceived intensities for various modalities, the semantic labels appeared consistent in terms of relative spacing across individuals and across domains (e.g. taste, odour, pain). Green et al. (1993) collected the sensory ratings of six labels via magnitude estimate and noticed a quasi-logarithmic spacing pattern. By adding the label of no sensation at the bottom, the empirical LMS was shown as Figure 2.4, where no sensation = 0, barely detectable = 1.4, weak = 6.1, moderate = 17.2, strong = 35.4, very strong = 53.3, and strongest imaginable = 100 (Green et al., 1996).

The LMS yielded similar psychophysical functions as magnitude estimate when assessing the magnitude of gustatory, nociceptive and thermal stimuli. Therefore, it was believed to generate ratio level data as magnitude estimate (Green et al., 1993). By further comparing to magnitude matching (with sound standard), Bartoshuk et al. (2004) discovered that the LMS revealed similar sensory differences among non-tasters, medium tasters and supertasters. Hence, the LMS was concluded as free of ceiling effects as magnitude matching.

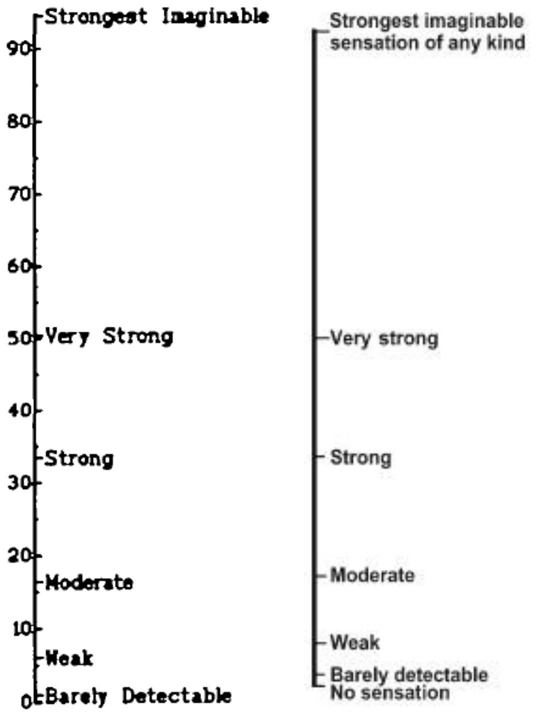


Figure 2.4 Labelled Magnitude Scale (LMS) (left) (Green et al., 1993) and General Labelled Magnitude Scale (gLMS) (right) (Ludy & Mattes, 2011)

2.4.2.7 General Labelled Magnitude Scale (gLMS)

Magnitude matching enables valid comparisons across groups by using a standard that is perceived systematically identical such as the brightness of light. Being inspired by this logic, Bartoshuk et al. (2004) replaced the top label of the existing LMS with “strongest imaginable sensation of any kind” aiming to yield valid across-group comparisons (**Figure 2.4**). The gLMS was presented as a vertical line, where no sensation = 0, barely detectable = 1.4, weak = 6, moderate = 17, strong = 34.7, very strong = 52.5, strongest imaginable sensation of any kind = 100. The distance from the bottom end to the line freely marked by the respondent was measured and scored as the sensory parameter (Ludy & Mattes, 2011).

According to Bartoshuk et al. (2004), gLMS generated similar response functions for non-tasters, medium taster, and supertasters as the magnitude matching. This suggested that gLMS is valid for sensory comparisons across groups when the ‘‘strongest imaginable sensation of any kind’’ is not correlated with the stimulus of interest.

Table 2.1 Comparisons of various sensory scales (Aitken, 1969; Bartoshuk et al., 2004; Green et al., 1993; D. R. Peryam & Girardot, 1952; J. Stevens & Marks, 1980; S. Stevens, 1957)

Sensory scales	Years	Semantic information	Ceiling effects	Ratio property	Across- group comparisons
Sensory 9-point scale	1949	Yes	Yes	No	No
Magnitude estimate	1957	No	No	Yes	No
Visual Analogue Scale (VAS)	1960s	No	Not sure	No	No
Magnitude matching	1980	No	No	Yes	Yes
Labelled Magnitude Scale (LMS)	1993	Yes	Not sure	Yes	No
General Labelled Magnitude Scale (gLMS)	1990s	Yes	No	Yes	Yes

As described in the methods section of chapter 3 (page 38), the research study manuscript, we used the sensory gLMS scale to measure sweet taste intensity in our study because it can simultaneously provide ordinal, semantic and ratio level measuring of perceived sweet taste intensity (Bartoshuk et al., 2004). Also, as a category scale, the sensory gLMS is easier to use, which makes the test produce simpler and brings less respondent burden. More importantly, the sensory gLMS generates valid across group comparisons (Bartoshuk et al., 2004), which means that the ratings of sweet taste intensity in this study would be fully validated and comparisons with other similar studies may be easily possible.

2.4.3 Hedonic liking scales

The hedonic 9-point scale, developed in 1949, has nine hedonic rating groups, which are 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, and 9 = like extremely (as Figure 2.5) (D. R. Peryam & Girardot, 1952). It is simple and easy to use, thus had since dominated the hedonic rating world for 50 years. However, the hedonic 9-point scale faces severe ceiling effects, resulting in skewed data. Moreover, it only generates ordinal but not ratio level data, and cannot provide valid across group comparisons (Kalva et al., 2014).

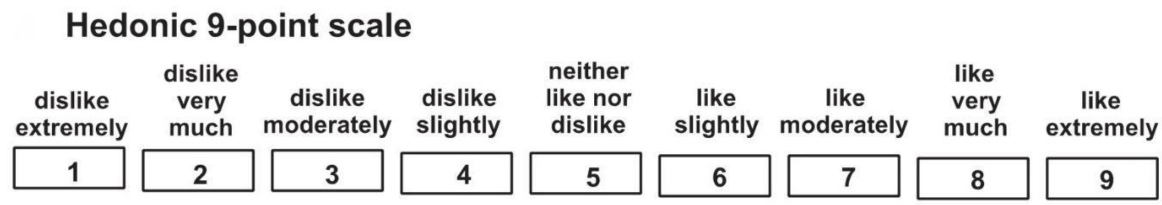


Figure 2.5 Hedonic 9-point Scale (Kalva et al., 2014)

Magnitude estimate (S. Stevens, 1957) can also be used for hedonic ratings, but mainly in basic research. Magnitude estimate provides ratio level data. However, the procedure is cumbersome and the quality of the data obtained often relies on the level of training that participants received (Schutz & Cardello, 2001). Thus, the magnitude estimate is not widely applied as a hedonic rating tool.

To generate ratio levels of hedonic rating and simultaneously simplify the procedure, three other scales were developed, which are labelled affective magnitude scale (LAM) by Schutz and Cardello (2001), labelled hedonic scale (LHS) by Lim et al. (2009) , and hedonic gLMS by (Bartoshuk, Catalanotto, Hoffman, Logan, & Snyder, 2012; Bartoshuk et al., 2004).

The three recent hedonic scales are all easy to use and are all capable of generating valid across group comparisons. Moreover, they have similar reliability and sensitivity to the hedonic 9-point scale but generate reduced ceiling effects (Lim et al., 2009). LAM, LHS and gLMS all provide semantic meanings, however, the descriptive labels they used are different. Only the label of “moderate liking/disliking” is shared by all three, yet its distance to the neutral point varied on every scale (shown as **Figure 2.6**), which is probably due to different psychophysical procedures that were used to develop them (Lim et al., 2009). As hedonic rating tools, LAM, LHS and gLMS may perform similarly well, however the magnitude ratios obtained may be different with each other (Lim et al., 2009).

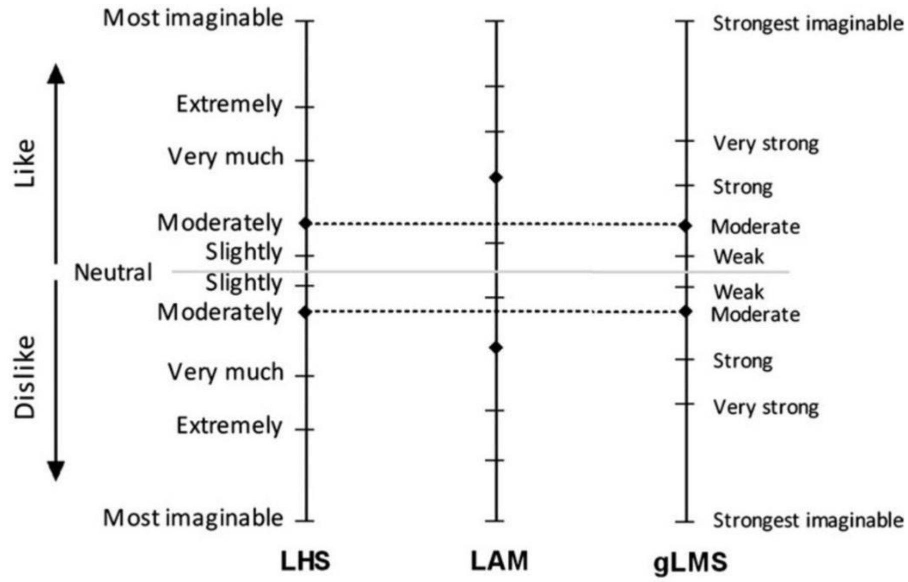


Figure 2.6 Comparisons of the three recent hedonic scales (Lim et al., 2009)

As described in the methods section of chapter 3 (page 39), the research study manuscript, we used the hedonic gLMS scale to measure sweet hedonic liking in our study because it is not only as valid as the hedonic 9-point scale when assessing hedonic liking but also faces less ceiling effects and further provides ratio level of data (Kalva et al., 2014). Moreover, by generating valid across group comparisons (Lim et al., 2009), the hedonic gLMS enables the sweet hedonic liking ratings of this study can be more possibly compared with other similar studies. Additionally, the hedonic gLMS is based on the same psychophysical procedures as the sensory gLMS that measures perceived taste intensity (Bartoshuk et al., 2004). The use of the hedonic gLMS along with the sensory gLMS would simplify the training process of the two scales and help the participants to understand how to use both scales more easily.

2.5 Sugars in our diet and its correlation with sweet taste and metabolic disease risks

2.5.1 Classification of sugars

Carbohydrates (CHOs) are one of the three macronutrients that provide energy for human bodies. According to the degree of polymerization (DP), namely the number of monomeric units in a macromolecule, carbohydrates can be divided into four groups, which are monosaccharides (DP = 1), disaccharides (DP = 2), oligosaccharides (DP = 3-9) and polysaccharides (DP > 9) (J. Thompson, Manore, & Vaughan, 2014). Sugars, also called simple carbohydrates, primarily refer to monosaccharides and disaccharides, which dissolve in water and generate a sweet taste (J. Thompson et al., 2014).

The common monosaccharides include glucose, fructose and galactose. Glucose is the building block of other dietary carbohydrates (e.g. starch and fiber) (J. Thompson et al., 2014). Once glucose is absorbed in the small intestine, it can be used to provide energy for all cells especially the brain, muscle, liver and adipose tissue. Fructose is the sweetest natural sugar that occurs in honey and many fruits. Galactose does not exist alone but is joined with glucose to form lactose, which can be found in milk and dairy products (Stephenson & Schiff, 2016).

The common disaccharides are sucrose, lactose, and maltose. Sucrose consists of one glucose molecule and one fructose molecule. It can be naturally found in honey, fruits, and vegetables; and also commercially prepared from sugar cane or sugar beets (J. Thompson et al., 2014). Lactose is composed of one galactose and one glucose molecules. Due to the lack of the enzyme to digest lactose, some people may experience stomach upset, such as gas and diarrhea, when consuming lactose-rich foods (e.g. milk, dairy products). Maltose (also called malt sugar) consists of two molecules of glucose. Maltose is not common in foods. It is produced when starch is digested by amylases (Stephenson & Schiff, 2016; J. Thompson et al., 2014).

2.5.2 Various functions of sugars in the food industry

Sugars are widely used in the food industry. Apart from providing a sweet taste, sugars serve various sensory, physical, microbial and chemical functions.

2.5.2.1 Sensory functions of sugars in food

Firstly, adding sweet taste to foods is the most notable role of sugars. Certain flavours may be enhanced or weaken due to interactions of sugars with other ingredients. For example, sugars may lower the acidity of tomatoes in tomato-based foods (Hasanuzzaman et al., 2014). Moreover, sugars influence the texture of foods and change the mouth feel of the food. In the process of candy making, different speeds and the degree of sugar crystallization may generate a series of textures ranging from soft fudges to hard candies (Miller & Hartel, 2015). Furthermore, sugars may contribute to the colours and appearance of foods. When baking, sucrose, glucose and fructose develop a brown colour through browning reactions, turning foods golden brown in the oven (Purlis, 2010).

2.5.2.2 Physical functions of sugars in food

The high water solubility of sugar is necessary to provide desirable sweetness and/or viscosity in foods and beverages (Sato & Miyawaki, 2016). Moreover, sugars effectively reduce the freezing point of products like ice cream and frozen desserts, contributing to the formation of fine ice crystals and improving the product's smoothness (Abbasi & Saeedabadian, 2015). Furthermore, sugars elevate the boiling point of solutions and enable more sugars to be dissolved. This is vital for the confection industry to create a supersaturated and highly concentrated solution, which determines the final consistency of the products (Ergun, Lietha, & Hartel, 2010).

2.5.2.3 Microbial and chemical functions of sugars in food

Sugars can be used as a preservative to increase the shelf life of processed products (Huxuan Wang et al., 2016). In jams and canned fruits, sugars dehydrate the microorganisms via absorbing water from the cells to depressing their growth and thus stopping subsequent food spoilage. Moreover, the fermentability of sugars is of great importance to the baking and brewing industries. When baking, yeasts ferment sugars to produce carbon dioxide, rising the dough more quickly and consistently and hastening the entire leavening process (Struyf et al., 2017). When brewing wine or beer, sugars are important sources of ethanol. The extent of sugar fermentation influences the alcohol content and flavour and sweetness of the final products (Lei et al., 2016).

Sugars appear to have a weak antioxidant property (Iqbal et al., 2017). This is useful to slow down the deterioration of the flavour, texture and colour of food products like canned fruits or vegetables (Canadian Sugar Institude, 2013).

2.5.3 Recommended and actual consumptions of sugars in different countries

Different terms for dietary sugars and recommended levels of consumption are used in different countries and by different organizations which are explained in detail in **Table 2.2.** The WHO strongly recommends an intake of free sugars less than 10% of total energy intake for both adults and children (World Health Organization, 2015). A further reduction to below 5% of total energy intake is also suggested for better oral health and body weight control. In the UK, the Public Health England (2015) recommends 5% of total energy intake into daily free sugars intakes in grams, which are less than 19g/day for children aged 4 to 6 years, less than 24g/day for 7 to 10 years, and less than 30g/day for children age above 11 years and adults. In the 2015-2020 Dietary Guidelines for Americans, the United States Department of Agriculture (USDA) recommends a daily intake of added sugars less than 10 % of total energy intake for both children aged over 2 years and adults. This target is based on food pattern modelling and national public health data to meet food group and nutrient requirements within calorie limits (USDA, 2015). Currently there is no specific recommended level of dietary sugars intake in NZ. However, by noticing the increasing evidence regarding the correlations between excessive intakes of free sugars and risks of dental caries and non-communicable diseases, the Ministry of Health introduced the concept of free sugars and has listed many practices to reduce free sugars intakes (Ministry of Health, 2015b).

Despite decreasing sugar intake in recent years, the average sugar intake is still above the recommended levels in many countries, which is 58.8 g/day of NMES in the UK (Public Health England, 2016), 76.7 g/day of added sugar (i.e. 14.6% of daily calories) in the US (Welsh, Sharma, Grellinger, & Vos, 2011), and 107 g/day of total sugars in New Zealand (Ministry of Health, 2011a). However, different terms of sugars used in different countries make direct comparisons of sugar intake difficult.

Table 2.2 Common terms regarding dietary sugars (Cummings & Stephen, 2007; Pehrsson et al., 2005; World Health Organization, 2003)

Terms	**Description**
Total sugars	For labeling purposes. Include all monosaccharides and disaccharides in foods
Intrinsic sugars	Sugars enclosed in the cell forming an integral part of unprocessed foods (e.g. sugars in whole fruits and vegetables)
Extrinsic sugars	Sugars not structural elements of foods and usually added to processed foods
Non-milk extrinsic sugars (NMES)	Extrinsic sugars except for lactose naturally occurring in milk
Added sugars	All sorts of caloric sweeteners added to foods and beverages during processing, home preparation or consuming
Free sugars	All monosaccharides and disaccharides added to foods and beverages by the manufacturer, cook or consumer, and sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates

2.5.4 Excessive sugar intake and non-communicable diseases (NCDs)

2.5.4.1 Excessive sugar intake and obesity

Excessive sugar consumption is known to contribute to obesity development since most sweet-tasting foods are nutrient-poor but energy-dense. Also, as a large contributor of sugar consumption worldwide, sugar-sweetened beverages (SSBs) have a weak satiety effect and have been shown to lead to incomplete compensation for total energy intakes (Malik, Schulze, & Hu, 2006). A meta-analysis, involving 25,745 children and 174,252 adults, showed 1 serving/day of SSBs (approximately one 350ml can) was associated with an increase of BMI by 0.06 (95% confidence interval (CI): 0.02, 0.10) units in children and a weight gain of 0.22 kg (95% CI: 0.09, 0.34 kg) in adults, in one year in random effects models (Malik, Pan, Willett, & Hu, 2013). A meta-analysis of randomised controlled trials (RCTs) revealed that decreased intake of added sugars was able to significantly reduce body weight by 0.80 kg (95% CI 0.39–1.21; $P < 0.001$), whereas increased sugar intake was linked to a weight gain of 0.75 kg (0.30–1.19; $P = 0.001$) (Te Morenga, Mallard, & Mann, 2012).

2.5.4.2 Excessive sugar intake and type 2 diabetes

In addition to the link with obesity development, excessive sugar intakes were postulated to increase the risk of type 2 diabetes (T2D) by increasing dietary glycaemic load, which further leads to insulin resistant and β-cell dysfunction (Schulze et al., 2004). A meta-analysis by Malik, Popkin, Bray, Després, and Hu (2010), which involved 310, 819 participants, found that individuals who consumed more SSBs (1-2 servings/day) had a 26% greater risk of developing T2D than those who consumed less (none or < 1 serving/month). By using an econometric model, Basu, Yoffe, Hills, and Lustig (2013) noticed that every extra sugar consumption of 150 kcal/person/day (about 1 serving/day) was associated with a 1.1% ($p < 0.001$) increase in T2D prevalence after adjustment for most confounding factors (e.g. age, income) among the overall populations. This effect of sugar consumption on the increase in T2D prevalence cannot be explained by physical activity, overweight or obesity.

2.5.4.3 Excessive sugar intake and cardiovascular diseases

Higher sugar consumption, especially of fructose may increase hepatic de novo lipogenesis, which further elevates the blood levels of triglycerides and decrease high-density lipoprotein (HDL) cholesterol and increases small dense low-density lipoprotein (LDL), leading to hypertension and accumulation of visceral adiposity and ectopic fat (Stanhope et al., 2009). After a median of 14.6 years follow up of 11,733 adults, compared to people who consumed over 10% of energy from added sugar, those who consumed less than 10% had lower hazard ratios of CVD mortality (i.e. 2.75 [1.40-5.42; P = 0.004], vs. 1.30 [95%CI, 1.09-1.55]). These findings were largely consistent across age, sex, and race groups (Yang et al., 2014). In the cross-sectional study of Welsh, Sharma, Argeseanu, and Vos (2011), 2252 US adolescents (13-18 years) were found to consume on average 21.4% of daily energy intake from added sugars. As the sugar consumption increases, the blood level of triglyceride also increased. The HDL level was found to be lower in those who consumed added sugars least (< 10% of daily energy intake) than those who consumed the most (25-30% of daily energy intake).

2.5.4.4 Excessive sugar intake and others diseases

Additionally, higher sugar consumption is also related to higher risks of other diseases like gout (Choi & Curhan, 2008), liver failure (Basaranoglu, Basaranoglu, Sabuncu, & Sentürk, 2013), pancreatic cancer and a range of other cancers (Aune et al., 2012).

2.5.5 Assessment of dietary intakes

Dietary intake assessment is widely used to indicate dietary intake, which include four major approaches. Each of them has their own advantages and disadvantages. The most appropriate approach would be depending on the purposes, sample size, cost and other characteristics of the study.

2.5.5.1 Diet history

Diet history provides a detailed assessment of dietary patterns during a relatively long period. The most common Burke diet history included a thorough interview about habitual eating pattern, a FFQ, and a 3-day food record (Burke, 1947). The major advantage of this approach is that, apart from the frequency and amount of foods consumed, this approach also collects dietary information such as meal pattern, food combination, seasonal changes, and so on (Biro et al., 2002). However, conducting a diet history takes a long time and is burdensome for the participants to complete. Moreover, it requires highly-trained professionals for both administration and coding, hence it is expensive (Gibson, 2005). In addition, the diet history approach is not well standardized, which makes reproduction and comparisons among different studies hard. Hence, this approach is mainly used in clinical setting even though it collects various dietary information (F. Thompson & Subar, 2008).

2.5.5.2 Twenty-four-hour food recall

The 24-hour food recall approach requires the respondents to report all foods and beverages they consumed over the preceding 24 hours (Biro et al., 2002). It is usually a structured interview done face to face or by telephone. Well-trained interviewers are necessary to help the respondents to recall all details needed via a few specific probes (Gibson, 2005). A typical single 24-hour food recall, such as the Automated Multiple-Pass Method (AMPM) by the U.S. Department of Agriculture (USDA) (Moshfegh et al., 2008), takes around 30-45 minutes. The 24-hour food recall can be repeated for multiple days to access habitual dietary intakes (Gibson, 2005). This approach does not require literacy and the respondent burden is relatively low, making it suitable for a broader range of the population. Also, since it is retrospective, the individual dietary behaviours would not be influenced (Biro et al., 2002). However, the accuracy of this approach might be somewhat compromised since it relies greatly on memory. The administration and processing of multiple recalls can be quite costly (F. Thompson & Subar, 2008).

2.5.5.3 Food frequency questionnaire

Food frequency questionnaire (FFQ) assesses how frequent foods from a particular list are consumed over a relatively longer period (e.g. a month, a year). Some FFQs add portion size questions to obtain qualitative intake data (F. Thompson & Subar, 2008). The respondent burden of this approach is modest and it is relatively inexpensive to administer and process on a large scale, especially when it is done online or via a machine-readable answer sheet. Therefore, FFQ is considered a good dietary assessment tool to assess habitual food intake of certain food groups and/or to establish dietary patterns especially in population studies (Coulston et al., 2013). However, FFQ does not capture the daily variation in diet and other dietary information (e.g. meal pattern, cooking methods, etc.). Also, the accuracy and quantification of energy and nutrient intakes obtained via FFQ can be lower than would generally be observed in food record due to a range of potential measurement errors (Gibson, 2005).

2.5.5.4 Food record

The food record approach asks respondents to record all foods and beverages they consumed during the day in great detail (Gibson, 2005). The portion size can be either estimated or weighed (with a scale or household measuring tools). Apart from the types and portion sizes of foods consumed, food record also collects other dietary information (e.g. eating habits, cooking methods) (F. Thompson & Subar, 2008). Food record does not rely on memory as all foods and beverages are recorded concurrently with consumption. Multiple food record may be used to reflect habitual dietary intakes (Gibson, 2005). However, there are a few disadvantages of this approach. Firstly, food record keeping requires the respondents to be both motivated and literate. This may potentially limit the use of this method in groups with low literacy, children, and studies with elderly. Consequently, the data collected may not be representative of the general population (Biro et al., 2002). Moreover, recording while eating may alter both the types and amounts of foods consumed. This is advantageous if food record is used as an intervention tool in weight loss programmes but is disadvantageous when food record is used to estimate habitual dietary intake (Coulston et al., 2013). Also, the data entry and coding for food record can be quite burdensome, time consuming and expensive. Despite these disadvantages, the food record approach is still considered an imperfect gold standard for dietary assessment (Coulston et al., 2013).

As described in the methods section of chapter 3 (page 39), the research study manuscript, we used a four-non-consecutive-day weighed food record to assess dietary intake of total energy, macronutrients and various sugars in our study. Comparing to FFQ and 24h food recall, the rates of under- and over-reporting of dietary intakes of food record are much lower (Biro et al., 2002). Moreover, considering the lack of a link between sweet taste perception and dietary intake in most of the previous studies that used FFQ or multiple 24-h food recall to assess food intake (Cornelis, Tordoff, El-Sohemy, & van Dam, 2017; Holt et al., 2000), an accurate and thorough record of all nutrients, especially sugars, is helpful to indicate the potential dietary related correlations with sweet sensation in the current study.

2.5.6 Sweet taste and dietary intake

Taste is generally considered to be an important contributor to food consumption. Since taste thresholds have limited utility in predicting experiences in the real world food environment (Bartoshuk et al., 2006; Duffy, Peterson, & Bartoshuk, 2004; Wise, Nattress, Flammer, & Beauchamp, 2016), most recent studies focused on the correlation between suprethereshold intensity and hedonic liking of taste and dietary intake. Such correlation was found to be significant for fat taste (Jessica Stewart et al., 2010; J Stewart & Keast, 2012), bitter taste (Dinehart, Hayes, Bartoshuk, Lanier, & Duffy, 2006; Turnbull & Matisoo-Smith, 2002), and salty taste (Mennella, Finkbeiner, Lipchock, Hwang, & Reed, 2014), yet not clear for sweet taste.

On the one hand, Kampov-Polevoy, Alterman, Khalitov, and Garbutt (2006) noted that individuals who preferred the strongest sucrose concentration (i.e. 830mM) tended to have an impaired control over eating sweet foods, suggesting potential influences of sweet taste hedonic liking on dietary consumption. On the other hand, in the study of Lanfer et al. (2012), 1696 children (6–9 years) from eight European countries indicated their preference by selecting either natural or sucrose-sweetened apple juice. The sweet preference was found not related to the frequency of consumptions of sweet foods. Divert et al. (2017) measured the hedonic liking for five levels of sucrose in three different forms (i.e. water, syrup and milk) via a hedonic 9-point scale among 101 children (7-12 years). The sweet taste hedonic liking scores were only weakly correlated with the intake of certain types of sweet foods (i.e. candy and snack) but not with that of added sugar. Cornelis et al. (2017) recalled the perceived sweet taste intensity ratings of 13 most common sweet foods via a modified gLMS among 349 adults, which was found to be not related to either sweet taste hedonic liking or self-reported dietary intake of these foods.

The above study results seemed not support the link between sweet taste perception and dietary intake. However, as suggested by Bartoshuk et al. (2006), the lack of a correlation between sweet taste perception and dietary intake in previous studies could be methodological problems, since the sweet tastants, the concentration ranges, the measuring methodologies or scales used varied greatly among different studies. Thus, the current study, reported in this thesis, is carried out with the most updated sensory and hedonic liking scales (i.e. sensory and hedonic gLMS scales) and the gold standard dietary assessment tool (i.e. a four-non-consecutive-day weighed food record) to further study the association between perceived sweet taste intensity and sweet taste hedonic liking and dietary intake.

2.6 Summary of the literature review

Excessive sugar intake contributes to higher risk of obesity and various NCDs. Sweet taste perception seems to play an important role in individual sugar consumption. A few studies had explored the correlation between sweet taste perception and dietary intakes, but the results are not consistent. This may be due to considerable methodological differences across these studies and methodological issues. Thus, it is necessary to further study this relationship by employing the most appropriate and the most accurate instruments that measure sweet taste perception and dietary intake within the context of the specific research inquiry aims of the study.

Chapter 3 – Research Project

The relationship between sweet taste perception and dietary intake

Abstract: Since the late 20th century, a high sugar intake has been related to the increased prevalence of obesity and non-communicable diseases like Type-2 diabetes, and some forms of cancer. Therefore, there is an urgent call to reduce sugar intake worldwide. Many studies have suggested that sweet taste perception plays an important role in the dietary intake of sugar. However, limited studies have investigated this and conflicting results are found.

The current study included 44 healthy New Zealand European women aged 20 to 40 years. Their perceived sweet taste intensity and sweet taste hedonic liking were assessed via general Labelled Magnitude Scales (gLMS) at glucose solutions of 125mM, 250mM, 500mM, and 1000mM concentrations (20 ℃). Their current dietary intake was assessed via a four-non-consecutive-day weighed food record.

Results showed that the perceived sweet taste intensity and sweet taste hedonic liking were positively correlated at 125mM ($r = 0.540$; $p < 0.001$) and negatively correlated at 500mM ($r = -0.748$; $p < 0.001$) and 1000mM ($r = -0.764$; $p < 0.001$) concentration of glucose solutions. Moreover, perceived sweet taste intensity at 1000mM glucose concentration was negatively correlated with dietary intake of total energy ($r = -0.403$; $p = 0.009$), carbohydrates ($r = -0.449$; $p = 0.003$), total sugars ($r = -0.421$; $p = 0.006$), glucose ($r = -0.411$; $p = 0.008$), fructose ($r = -0.408$; $p = 0.008$), and maltose ($r = -0.325$; $p = 0.038$). Also, sweet taste hedonic liking at 1000mM glucose concentration was positively correlated with dietary intake of total energy ($r = 0.324$; $p = 0.039$), carbohydrates ($r = 0.360$; $p = 0.021$), total sugars ($r = 0.437$; $p = 0.004$), glucose ($r = 0.418$; $p = 0.007$), fructose ($r = 0.391$; $p = 0.012$), and maltose ($r = 0.463$; $p = 0.002$).

These results suggest an important link between sweet taste perception and dietary intake and support the theory that people who are more sensitive to sweet taste require a lower level of sweetness to achieve equal satisfaction, thus consume less sweet foods and beverages than those who are less sensitive to sweet taste.

Keywords: sweetness, sweet taste intensity, hedonic liking, sugar intake

1. Introduction

Human beings have an innate love for sugar since it is a quick source of energy. Historically, sugars were rare and only naturally exist in honey, fruits and vegetables which are available for a limited time during the year. Today sugars are inexpensive and widely available worldwide (Maniam et al., 2016). In the food industry, sugar is extensively added to various foods and beverages due to its sweet taste and other important functional food-processing characteristics, such as a rising agent and as a preservative agent (Hasanuzzaman et al., 2014; Sato & Miyawaki, 2016; Struyf et al., 2017). However, since the late 20th century, high intake of sugar has been related to the increased prevalence of obesity and non-communicable diseases (NCDs) like Type 2 diabetes (T2D) (Fung et al., 2009; Tasevska et al., 2012). In 2015, the World Health Organization (WHO) suggested to reduce sugar intake to a maximum of 10% of total energy intake every day with the aim to improve the dental and general health status of the world's populations (World Health Organization, 2015).

Taste contributes significantly to food acceptance, and may further influence individuals' food choices and ultimately their nutritional status (N. Dias et al., 2012). As one of the six well identified tastes, sweetness signals the presence of energy in foods (Simon et al., 2006). Perceived sweet taste intensity and sweet taste hedonic liking display great variations in terms of age, gender, health status and so forth (R Keast & Roper, 2007). According to Wasalathanthri et al. (2014), impaired sweet taste perception was postulated to increase the intake of sweet foods and beverages in diabetic patients, which may further worsen their glycaemic control. The potential influence of perceived sweet taste intensity and sweet taste hedonic liking on dietary intake (Anderson, 1995; J. Low et al., 2016) may provide another explanation for the increasing sugar intake worldwide and may provide another angle to generate new avenues for the prevention and control of diet-related NCDs.

So far, a few researchers have studied how perceived sweet taste intensity and sweet taste hedonic liking correlate with dietary habits (e.g. consumption frequency of selected sweet foods and beverages, eating behaviours) but only a limited number of studies have investigated this at the individual nutrient level. Furthermore, these studies show contradicting results (Cicerale et al., 2012; Holt et al., 2000). The contradicting results in these studies may partially be due to a few methodological differences (Bartoshuk et al., 2006), including differences in the use of taste stimuli and their concentration range (e.g. sucrose vs. glucose), the sensory and hedonic scales (e.g. LMS vs. gLMS), the dietary assessment tools (e.g. food frequency questionnaire vs. food record), and statistical analysis. Therefore, the present study determined both perceived sweet taste intensity and sweet taste hedonic liking via the most reliable and most advanced sensory and hedonic scales (i.e. sensory and hedonic gLMS scales). This study further explored the associations between the two measures of sweet taste perception and dietary intake of total energy, macronutrients and various sugars using a four-non-consecutive-day weighed food record 44 NZ European women.

2. Materials and Methods

2.1 Study participants

Forty-four New Zealand European women aged 20 to 40 years old and generally healthy were required for this study. Women who were pregnant, breastfeeding, smoking, experiencing clinical disorders (e.g. Xerostomia, diabetes, chronic renal diseases), or receiving medication or therapies (e.g. antibiotics, chemotherapy) that may cause changes in taste perception were excluded via an online screening questionnaire (Appendix B). This study was recorded as a low risk research by the Human Ethics Committee of Massey University. Informed written consent (Appendix D) was collected from each participant before tests.

2.2 Study procedure

Two psychophysical measurements of sweet taste, namely perceived sweet taste intensity and sweet taste hedonic liking, were determined on four sessions (at least 24 hours apart and within one month) in this study. This allowed the assessment of the repeatability of the entire sensory procedure. Participants completed a health and demographic questionnaire (Appendix E), and their height (stadiometer), weight and body fat composition (Bioelectrical Impedance Assessment (BIA) InBody 230, Biospace, Cerritos, CA, USA) were also measured during the first session. Breakfast was provided after sensory testing on each testing morning. In addition, participants completed a four-non-consecutive-day weighed food record during the test month to reveal their food intake.

2.3 Perceived sweet taste intensity and sweet taste hedonic liking of suprathreshold glucose concentrations

All sensory tests were carried out between 7 and 10 a.m. in the sensory laboratory at the Massey University Albany campus. The perceived sweet taste intensity and sweet taste hedonic liking were tested in turn during each session. The sweet stimulus being used was glucose (dextrose monohydrate, Qinhuangdao Lihua Starch Co. Ltd., Qinhuangdao, China) dissolved in distilled water since glucose is a simple sugar that has been clearly linked with glucose metabolism (Aronoff, Berkowitz, Shreiner, & Want, 2004). All glucose solutions were freshly prepared by trained personnel and then pipetted into tasting cups on the test morning. For consistency, all test solutions were prepared for seven participants every time following a standard operating procedure. Thus, no more than seven participants were booked at the same day. Participants arrived after an overnight fast, starting from 10 pm the previous day (except for water), and refrained from tooth brushing at least one hour before the tests to exclude potential influence of hormonal changes and hunger levels on the rating of sweet taste perception (Nakamura et al., 2008). The room temperature was kept at 20℃ during the whole preparing and tasting processes.

According to Nakamura et al. (2008), the recognition threshold for glucose is approximately 95mM. To generate different responses, the suprathreshold concentrations of 125mM, 250mM, 500mM and 1000mM were chosen for the ratings of perceived sweet taste intensity and sweet taste hedonic liking. The four glucose samples were presented in a pre-randomized order for each participant. Participants were required to take the entire sample (10ml), swirl it around their whole mouth for three seconds, spit it out (i.e. the sip and spit technique (Martinez-Cordero, Malacara-Hernandez, & Martinez-Cordero, 2015)) and then rate perceived sweet taste intensity first and sweet taste hedonic liking subsequently on two separate gLMSs sheets. The next sample was presented 30 seconds after the previous one was collected back. Participants were asked to rinse their mouth with distilled water between samples.

The gLMS used for perceived sweet taste intensity rating (Appendix F) (Bartoshuk et al., 2004) was a vertical axis ranging from 0 to 100. It contained various intensity labels as follow: no sensation = 0, barely detectable sensation = 1.5, weak sensation = 6, moderate sensation = 17, strong sensation = 35, very strong sensation = 52, and strongest imaginable sensation of any kind = 100. The gLMS used for sweet taste hedonic liking rating (Appendix F) (Bartoshuk et al., 2012; Bartoshuk et al., 2004) was a vertical axis ranging from -100 to 100. The liking labels contained were strongest imaginable dislike of any kind = -100, very strongly dislike = -52, strongly dislike = -35, moderately dislike = -17, weakly dislike = -6, neutral = 0, weakly like = 6, moderately like = 17, strongly like = 35, very strong like = 52, strongest imaginable like of any kind = 100. Only the adjectives instead of the corresponding numbers were shown to the participants. They rated perceived sweet taste intensity and sweet taste hedonic liking anywhere along the corresponding gLMS. Numerical data was later generated to indicate magnitudes.

2.4 Four-non-consecutive-day weighed food record

A four-non-consecutive-day weighed food record (at least one weekend day was included) was used for this study to assess dietary intake of total energy, macronutrients and various sugars (including glucose, fructose, sucrose, lactose and maltose). According to Kirkpatrick et al. (2014), food record performed on a few consecutive days may not be representative for and individual’s diet due to related types and amounts of foods consumed (e.g. leftover). The taste testing day was excluded, because the breakfast provided in the morning may not have been part of their habitual diets.

Participants watched a detailed video that gave instructions on how to fill in the food record booklet (Appendix G), how to use the food record guide booklet (Appendix H) to describe eating-out meals, and how to use the digital scale (TANITA KD-200) provided. A reminder text message was sent before each of the days for which a food record needed to be completed. Participants were required to bring the food record booklet, which was checked for clarity and any missing detail was added in interviews with participants during the following visit of the research unit.

2.5 Data handling

2.5.1 Anthropometric data

BMI was calculated based on the height and weight measured for each participant using Excel 2016 (Microsoft, 2016). The mass of body muscle and of body fat was presented both in kilograms and in percent of total body weight for each participant. All anthropometric data were cross-checked by trained human nutrition students.

2.5.2 Perceived sweet taste intensity

Forty-one of the participants (93.2%) attended all four taste assessment sessions and the remaining three participants (6.8%) attended three sessions. The gLMS scores of perceived sweet taste intensity at each glucose concentration during each session were measured and recorded in the unit of millimetres and were cross-checked. The mean gLMS scores of the available sensory sessions (i.e. three or four sessions) were calculated for each of the 44 participants at each glucose concentration for later correlation analysis.

2.5.3 Sweet taste hedonic liking

Forty-two of the participants (95.5%) attended all four taste assessment sessions and the remaining two participants (4.5%) attended three sessions. The gLMS scores of sweet taste hedonic liking at each glucose concentration during each session were measured and recorded in the unit of millimetres and then were cross-checked. The mean gLMS scores of the available sensory sessions (i.e. three to four sessions) were calculated for each of the 44 participants at each glucose concentration for later correlation analysis.

2.5.4 Dietary intake

Forty-three of the 44 participants (97.7%) completed a four-non-consecutive-day weighed food record. All food record data were entered into the FoodWorks 7 (Xyris Software, Australia) by the same trained researcher. The FOODfiles 2010 (the New Zealand Institute for Plant and Food Research Limited and the Ministry of Health) were used primarily for dietary composition analysis. The detailed standard operation practices for data entry were shown as Appendix I. All dietary intake data were cross-checked by trained human nutrition students before any further statistical analysis.

The cut-offs used in the National Nutrition Survey 2008/09 in New Zealand (1000 – 5000 kcal, i.e. 4200 – 21,000 kJ) (Ministry of Health, 2011b) were applied for excluding over- and under- reporters. Consequently, two participants were excluded for dietary-related analysis due to a daily energy intake lower than 1000 kcal (i.e. 4200 kJ). Thirty-seven (90.2%) of the 41 eligible participants did four non-consecutive days, while the remaining four (9.8%) did four consecutive days or three consecutive days plus another day apart due to limited time available. As a result, the seven days of a week were evenly covered in the four-non-consecutive-day weighed food record even after the exclusion of three participants, which were 15.9%, 14.6%, 14.0%, 13.4%, 12.8%, 15.2% and 14.0% respectively from Monday to Sunday.

2.6 Statistical analysis

All statistical tests were run by SPSS Version 25 (IBM, 2017). Shapiro-Wilk Test was employed for normality testing. The variables that were not normally distributed were log transformed and the normality was retested. Intraclass correlation coefficient (ICC) (two-way random effects model, absolute agreement, average measures) was applied for the evaluation of the between-session correlation of perceived sweet taste intensity and sweet taste hedonic liking at the four sessions. An ICC value above 0.7 indicated good correlation, whereas a ICC value below 0.7 indicated moderate to low correlation (Newman & Keast, 2013). For variables distributed normally, Pearson's correlation was used. For variables not normally distributed even after log transformation, Spearman's correlation was used. Results were considered statistically significant if the p-value was lower than 0.05. All statistical tests were 2-tailed.

3. Results

All participants (n = 44) provided anthropometric and sweet taste perception data and 43 participants completed the four non-consecutive-day weighed food record.

3.1 Participants characteristics

The characteristics of the participants are shown as **Table 3.1**.

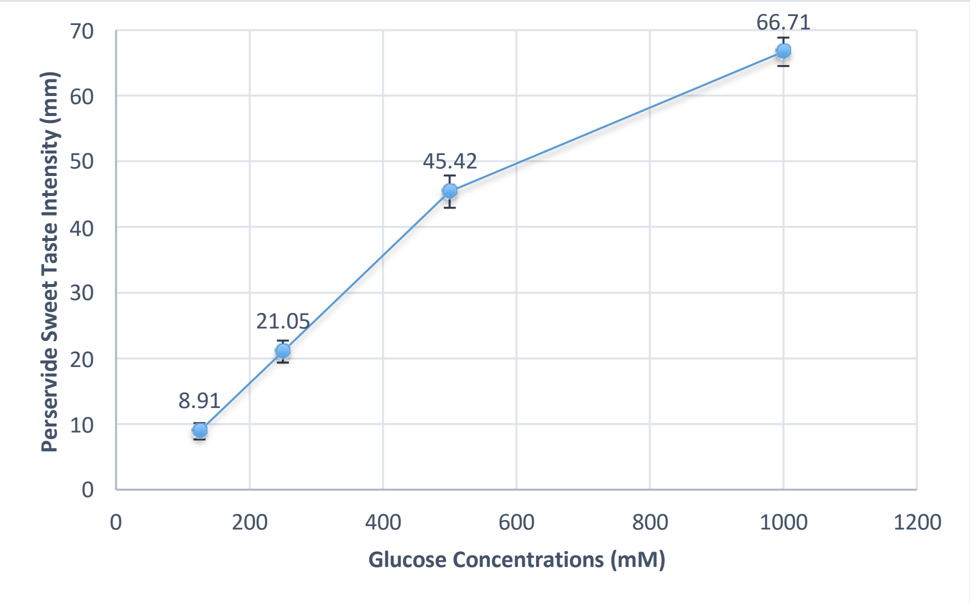
Table 3.1 Characteristics of participants (n = 44)

Characteristics	Mean (±SEM)
Age (years)	28.25 (±0.84)
Height (cm)	166.70 (±0.91)
Weight (kg)	67.24 (±1.50)
BMI (kg/m^2)	24.21 (±0.53)
Body muscle mass (kg)	25.32 (±0.44)
Body muscle mass (%) [1]	38.01 (±0.59)
Body fat mass (kg)	21.21 (±1.19)
Body fat mass (%) [1]	30.85 (±1.06)

BMI, body mass index
[1] % of total body weight

3.2 The perceived sweet taste intensity at suprathreshold concentrations

The gLMS scores for perceived sweet taste intensity of the four glucose concentrations are shown in **Figure 3.1**. As expected, the participants generally rated the glucose solutions at 125mM concentration as weak, 250mM concentration as moderate, 500mM concentration as strong, and 1000mM concentration as very strong sweet taste intensities. It is clear that when the glucose concentrations increased, the perceived sweet taste intensity increased as well.

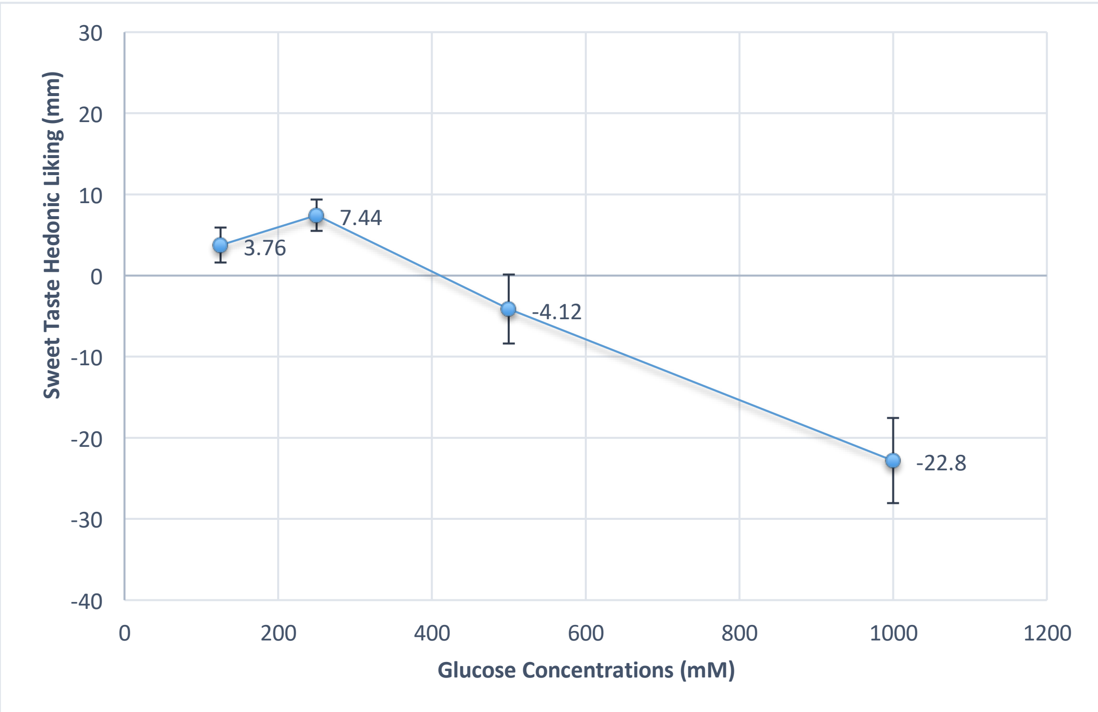


Error bars indicate SEM.
Mean gLMS scores of perceived sweet taste intensity of all four sensory sessions were used.

Figure 3.1 Participants' mean (±SEM) gLMS scores of perceived sweet taste intensity of all glucose concentrations (n = 44)

3.3 The sweet taste hedonic liking at suprathreshold concentrations

The gLMS scores of sweet taste hedonic liking of the four glucose concentrations are shown in **Figure 3.2**. The participants had generally neutral liking towards the 125mM and 500mM concentrations, and they weakly liked the 250mM concentration and moderately disliked the 1000mM concentration. However, as the glucose concentrations increased, the sweet taste hedonic liking increased to a peak and then declined.



Error bars indicate SEM.
Mean gLMS scores of sweet taste hedonic liking of the four sensory sessions were used.

Figure 3.2 Participants' mean (±SEM) gLMS scores of sweet taste hedonic liking of all glucose concentrations (n = 44)

3.4 The between-session repeatability of perceived sweet taste intensity and sweet taste hedonic liking

The between-session repeatability of perceived sweet taste intensity and sweet taste hedonic liking were highest at the 1000mM glucose concentration and stronger as the glucose concentrations increased (**Table 3.2**).

Table 3.2 The between-session repeatability of perceived sweet taste intensity and sweet taste hedonic liking (n = 44)

	ICC Average Measuresa			
	125 mM	**250 mM**	**500 mM**	**1000 mM**
Perceived Sweet taste intensity (mm)	0.65 (0.44, 0.80)	0.61 (0.38, 0.78)	0.81 (0.70, 0.90)	0.84 (0.74, 0.91)
Sweet taste hedonic liking (mm)	0.78 (0.65, 0.87)	0.67 (0.48, 0.81)	0.88 (0.81, 0.93)	0.90 (0.84, 0.94)

ICC, intraclass correlation coefficient
ICC values reported as mean (95% CI)
p < 0.001 for all between-session ICC measurements

3.5 Correlations between perceived sweet taste intensity and sweet taste hedonic liking

Perceived sweet taste intensity was positively correlated with sweet taste hedonic liking at 125mM glucose concentration but negatively correlated at 500mM and 1000mM glucose concentrations (**Table 3.3**). At the lowest concentration (i.e. 125mM), participants who perceived the glucose solution sweeter tended to like it more. In contrast, at higher concentrations (i.e. 500mM and 1000mM), participants who perceived the glucose solution sweeter tended to dislike it more. No correlation was observed between perceived sweet taste intensity and sweet taste hedonic liking at 250mM glucose concentration.

Table 3. 3 Correlations between perceived sweet taste intensity and sweet taste hedonic liking at all glucose concentrations (n=44)

	Perceived sweet taste intensity and sweet taste hedonic liking (mm)			
	125mM	**250mM**	**500mM**	**1000mM**
r	**0.540**[ǂ]	0.026[ǂ]	**-0.748**	**-0.764**
p	< 0.001	0.865	< 0.001	< 0.001

Mean gLMS scores of perceived sweet taste intensity and sweet taste hedonic liking of the four sensory sessions were used.
[ǂ] Spearman's correlation was used, otherwise, Pearson's correlation was applied.

3.6 Dietary intake

The mean intake of total energy, macronutrients and various sugars of the 41 eligible participants are shown in **Table 3.4.** Their percent energy from fat is relatively higher and that from carbohydrate is relatively lower than the Acceptable Macronutrient Distribution Ranges (AMDRs) recommended by the Ministry of Health (2006). Sucrose (43%) contributes the most to the total sugar intake, which is followed by fructose (21%), glucose (20%), lactose (13%) and maltose (3%) (**Figure 3.3**).

Table 3.4 Participants' dietary Intake of total energy, macronutrients and various sugars (n = 41)

Dietary intake[1]	**Mean (95% CI)**	**AMDRs [4]**
Total energy (kJ)	7698.03 (7156.11, 8239.95)	
Protein (g)	78.86 (73.05, 84.67)	
Total fat (g)	77.40 (70.42, 84.39)	
Carbohydrate (g)	189.61 (169.94, 209.29)	
Protein (%E) [2]	17.84 (16.57, 19.12)	15-25%E
Fat (%E) [2]	37.17 (34.88, 39.46)	20-35%E
CHO (%E) [2]	40.51 (37.90, 43.12)	45-65%E
Total Sugars (g) [3]	88.89 (76.90, 100.88)	
Glucose (g)	17.61 (14.92, 20.31)	
Fructose (g)	18.86 (15.96, 21.75)	
Sucrose (g)	38.82 (31.99, 45.66)	
Lactose (g)	11.27 (9.04, 13.50)	
Maltose (g)	2.81 (2.30, 3.33)	
Total sugars (%E) [2, 3]	19.44 (17.51, 21.37)	
Glucose (%E) [2]	3.89 (3.35, 4.43)	
Fructose (%E) [2]	4.23 (3.54, 4.91)	
Sucrose (%E) [2]	8.34 (7.23, 9.46)	
Lactose (%E) [2]	2.47 (2.01, 2.94)	
Maltose (%E) [2]	0.62 (0.51, 0.73)	

CHO carbohydrate
[1] Mean dietary intake of the four selected days were used.
[2] %E percent of total energy intake
[3] Total sugars include all mono- and di-saccharides.
[4] AMDRs Acceptable Macronutrient Distribution Ranges (AMDRs) by the National Health and Medical Research Council (2006)

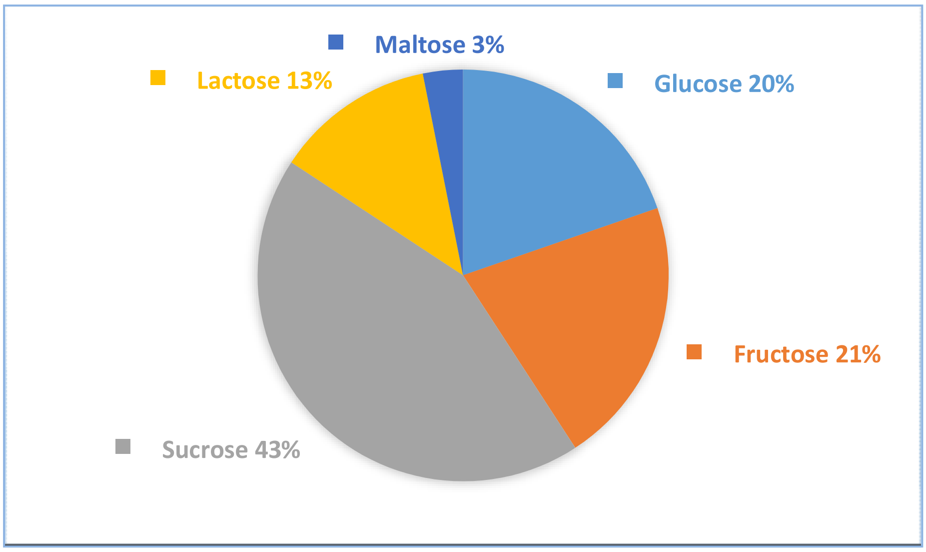


Figure 3.3 Contributions of single, mono- and di-saccharides to total sugar intake (n = 41)

3.7 Correlations between perceived sweet taste intensity and dietary intake of total energy, macronutrients and various sugars

The correlations between perceived sweet taste intensity and dietary intake of total energy, carbohydrate, total sugars, glucose, fructose, sucrose and maltose were significant at the 1000mM glucose concentration and stronger as the glucose concentrations increased (**Table 3.5, Figure 3.4 – 3.11**). When expressed as a percentage of energy, none of the dietary intake variables (except for percent energy from protein at 250mM glucose concentration) correlated with perceived sweet taste intensity (**Table 3.5**).

Table 3.5 Correlations between perceived sweet taste intensity and dietary intake of total energy, macronutrients and various sugars (n=41)

Dietary intake[1]		**Perceived sweet Taste Intensity** [4]			
		125mM	**250mM**	**500mM**	**1000mM**
Total energy (kJ)	r	-0.241	**-0.381**ǂ	**-0.358**	**-0.403**
	p	0.129	0.014	0.022	0.009
Protein (g)	r	-0.258	-0.098ǂ	-0.213	-0.203
	p	0.103	0.542	0.181	0.203
Fat (g)	r	-0.024	-0.179ǂ	-0.069	-0.188
	p	0.881	0.263	0.668	0.240
CHO (g)	r	**-0.320**	**-0.423**ǂ	**-0.432**	**-0.449**
	p	0.041	0.006	0.005	0.003
Protein (%E) [2]	r	-0.022	**0.314**ǂ	0.177	0.224
	p	0.894	0.045	0.269	0.158
Fat (%E) [2]	r	0.242	0.085ǂ	0.306	0.175
	p	0.128	0.596	0.051	0.275
CHO (%E) [2]	r	-0.173ǂ	-0.180ǂ	-0.139ǂ	-0.208ǂ
	p	0.278	0.259	0.385	0.191
Total sugars (g) [3]	r	-0.274	**-0.345**ǂ	**-0.423**	**-0.421**
	p	0.083	0.027	0.006	0.006
Glucose (g)	r	**-0.309**	**-0.337**ǂ	**-0.410**	**-0.411**
	p	0.049	0.031	0.008	0.008
Fructose (g)	r	-0.285	-0.276ǂ	**-0.413**	**-0.408**
	p	0.071	0.081	0.007	0.008
Sucrose (g)	r	-0.152ǂ	-0.274ǂ	-0.266ǂ	-0.270ǂ
	p	0.341	0.083	0.093	0.088
Lactose (g)	r	-0.261	-0.300ǂ	-0.190	-0.182
	p	0.100	0.056	0.234	0.255
Maltose (g)	r	-0.057	-0.053ǂ	-0.226	**-0.325**
	p	0.724	0.744	0.155	0.038
Total sugars (%E) [2, 3]	r	-0.164	-0.153ǂ	-0.246	-0.232
	p	0.305	0.339	0.120	0.145
Glucose (%E) [2]	r	-0.199	-0.195ǂ	-0.295	-0.269
	p	0.212	0.223	0.062	0.089
Fructose (%E) [2]	r	-0.191	-0.151ǂ	-0.277	-0.252
	p	0.232	0.348	0.080	0.112
Sucrose (%E) [2]	r	-0.090	-0.125ǂ	-0.154	-0.150
	p	0.574	0.437	0.338	0.349
Lactose (%E) [2]	r	-0.149	-0.186ǂ	-0.083	-0.046
	p	0.353	0.243	0.606	0.774
Maltose (%E) [2]	r	0.064	0.073ǂ	-0.076	-0.170
	p	0.690	0.652	0.636	0.287

CHO carbohydrate
[1] Mean dietary intake of the four selected days were used.
[2] %E percent of total energy intake
[3] Total sugars include all mono- and di-saccharides.
[4] Mean gLMS scores of perceived sweet taste intensity of the four sensory sessions were used.
ǂ Spearman's correlation was used, otherwise, Pearson's correlation was applied.

3.8 Correlations between sweet taste hedonic liking and dietary intake of total energy, macronutrients and various sugars

The correlations between sweet taste hedonic liking and dietary intake of total energy, carbohydrate, total sugars, glucose, fructose, sucrose and maltose were significant at the 1000mM glucose concentration and increased as the glucose concentrations increased (**Table 3.6, Figure 3.12 – 3.19**). When expressed as a percentage of energy, none of the dietary intake variables (except for percent energy from maltose at 1000mM glucose concentration) correlated with sweet taste hedonic liking (**Table 3.6**).

Table 3.6 Correlations between sweet taste hedonic liking and dietary intake of total energy, macronutrients and various sugars (n = 41)

Dietary intake [1]		**Sweet Taste Hedonic Liking** [4]			
		125mM	**250mM**	**500mM**	**1000mM**
Total energy (kJ)	r	-0.002ǂ	0.182	**0.312**	**0.324**
	p	0.991	0.255	0.047	0.039
Protein (g)	r	-0.033ǂ	0.015	0.188	0.131
	p	0.839	0.926	0.240	0.414
Fat (g)	r	0.004ǂ	0.077	0.100	0.189
	p	0.979	0.632	0.533	0.237
CHO (g)	r	-0.085ǂ	0.131	**0.342**	**0.360**
	p	0.596	0.414	0.029	0.021
Protein (%E) [2]	r	-0.002ǂ	-0.155	-0.130	-0.223
	p	0.992	0.333	0.417	0.161
Fat (%E) [2]	r	0.006ǂ	-0.129	-0.236	-0.094
	p	0.968	0.422	0.138	0.557
CHO (%E) [2]	r	-0.102ǂ	-0.085ǂ	0.040ǂ	0.221ǂ
	p	0.525	0.596	0.804	0.166
Total sugars (g) [3]	r	-0.035ǂ	0.181	**0.429**	**0.437**
	p	0.830	0.257	0.005	0.004
Glucose (g)	r	-0.166ǂ	0.022	**0.387**	**0.418**
	p	0.300	0.892	0.012	0.007
Fructose (g)	r	-0.144ǂ	0.086	**0.369**	**0.391**
	p	0.369	0.593	0.018	0.012
Sucrose (g)	r	-0.114ǂ	0.027ǂ	0.217ǂ	0.290ǂ
	p	0.476	0.866	0.173	0.066
Lactose (g)	r	-0.097ǂ	0.117	**0.311**	0.274
	p	0.545	0.465	0.048	0.083
Maltose (g)	r	0.053ǂ	0.144	**0.404**	**0.463**
	p	0.742	0.369	0.009	0.002
Total sugars (%E) [2, 3]	r	-0.072ǂ	0.073	0.299	**0.339**
	p	0.653	0.652	0.057	0.030
Glucose (%E) [2]	r	-0.196ǂ	-0.038	0.274	0.304
	p	0.220	0.813	0.083	0.053
Fructose (%E) [2]	r	-0.125ǂ	0.010	0.258	0.273
	p	0.436	0.951	0.103	0.084
Sucrose (%E) [2]	r	-0.102ǂ	0.016	0.157	0.222
	p	0.525	0.919	0.328	0.163
Lactose (%E) [2]	r	-0.061ǂ	0.134	0.224	0.148
	p	0.706	0.405	0.160	0.357
Maltose (%E) [2]	r	0.050ǂ	0.103	0.273	**0.349**
	p	0.756	0.521	0.084	0.025

CHO carbohydrate
[1] Mean dietary intake of the four selected days were used.
[2] %E percent of total energy intake
[3] Total sugars include all mono- and di-saccharides.
[4] Mean gLMS scores of sweet taste hedonic liking of the four sensory sessions were used.
ǂ Spearman's correlation was used, otherwise, Pearson's correlation was applied.

4. Discussion

This cross-sectional study describes the perceived sweet taste intensity and sweet taste hedonic liking ratings in 44 NZ European women aged 20 to 40 years using the gLMS scales and glucose solutions of 125mM, 250mM, 500mM, and 1000mM concentrations. Furthermore, dietary intake was assessed via a four-non-consecutive-day weighed food record. The identification of a dose-dependent change in the relationship between perceived sweet taste intensity and sweet taste hedonic liking at suprathreshold concentrations suggests that a sweet tastant is liked at a lower concentration and disliked at higher concentrations in a dose-dependent manner. Importantly, this study shows that total energy intake, and absolute intake of carbohydrate and sugars correlated negatively with perceived sweet taste intensity and positively with sweet taste hedonic liking of suprathreshold glucose concentrations in a dose-dependent manner. These results suggest an important role of sweet taste perception on dietary intake and support the theory that people who are more sensitive to sweet taste require a lower level of sweetness to achieve equal satisfaction, thus may consume less sweet foods and beverages than those who are less sensitive (Duffy, Hayes, Sullivan, & Faghri, 2009).

4.1 Dietary intake

The mean energy intake of the 44 young NZ female adults (7698 kJ) was slightly lower than the estimated energy requirement (8000–8400 kJ) for women of similar age and weight (National Health and Medical Research Council, 2006). The intake of total sugars in this study (89 g) was lower than that revealed in the 2008/09 National Nutrition Survey (107g) for the equivalent age and gender group (Ministry of Health, 2011a). According to the AMDRs (National Health and Medical Research Council, 2006), the participants of the sweet taste study consumed a lower mean fat (% of Energy) and higher mean carbohydrate (% of Energy) diet than the AMDRs suggest.

4.2 Perceived sweet taste intensity and sweet taste hedonic liking

The perceived sweet taste intensity changes along with increased sweet stimuli in this study (i.e. glucose). This is in agreement with a number of studies in the literature (Holt et al., 2000; Klein, Schebendach, Devlin, Smith, & Walsh, 2006; Wise et al., 2016). However, the rating scores of perceived sweet taste intensity in this study cannot be compared directly to that of other similar studies because most previous studies used sucrose as test stimuli as sucrose is the most common and natural form of sugars being consumed. Moreover, the concentration ranges and the sensory scales in this study are different from those in previous studies.

The pattern of sweet hedonic liking with increased sweet stimuli in this study showed an inverted U-shape, which was similar to that in the studies of Holt et al. (2000) and Wise et al. (2016) even though different test stimuli (e.g. glucose solutions vs. pudding sweetened with sucrose), concentration range, and sensory magnitude scales (e.g. gLMS vs. LMS) were employed.

4.3 Correlations between perceived sweet taste intensity and sweet taste hedonic liking

One of the most intriguing findings of the present study describes the change in the relationship between perceived sweet taste intensity and sweet taste hedonic liking with increasing concentrations of glucose, starting with a positive relationship at the lowest glucose concentration, and moving to a negative relationship at the two highest concentrations. Importantly, participants who perceived the two highest glucose concentrations as more sweet disliked the sweetness more than participants who perceived the solutions as less sweet. This change in the relationship between perceived sweet taste intensity and sweet taste hedonic liking suggests that the intensity measurements at suprathreshold concentrations relate more strongly to the hedonic experience. Furthermore, the finding that participants generally disliked the two highest concentrations has implications for the food industry, because these levels of sugars or other sweeteners are commonly found in sweet beverages. Our study suggests that there is ample scope to reduce the sugar content in sugar-sweetened beverages but still maintain hedonic liking.

Previous studies of perceived sweet taste intensity rating were not always correlated with rating for sweet taste hedonic liking since the latter has been described to be subject to more variability (Drewnowski, 1997). This could also be due to the higher variability observed in the methodology used in these studies as discussed above (Cornelis et al., 2017; Mattes, 1985).

4.4 Correlations between perceived sweet taste intensity and dietary intake

In the current study, the correlations between perceived sweet taste intensity and dietary intake of total energy, carbohydrate, total sugars, glucose, fructose, sucrose and maltose were significant and stronger as the glucose concentrations increased (**Table 3.4, Figure 3.4 – 3.11**). These data suggest an important link between perceived sweet taste intensity and dietary intake. Comparing to the lower and the medium glucose concentrations, the correlations tended to be more reliable and robust at a higher concentration (i.e. 1000mM). Given the recognition threshold of glucose solutions (i.e. 95mM), it is reasonable to suggest that lower concentrations like 125mM may be not high enough to generate a strong sensation. As the concentrations increase, the resulting sensations are stronger and the correlations with dietary intake increase. Thus, perceived sweet taste intensity rating based on a stronger stimulus seems to be a better predictor of dietary intake of total energy and various sugars.

The current data show a clear link between perceived sweet taste intensity and sweet taste hedonic liking assessments and dietary intake of total energy, carbohydrate, and various sugars of the participants in this study. However, we need to keep in mind that perceived sweet taste intensity rating for glucose solutions does not directly equate to the taste experiences of foods and beverages in real life. Compounds contained in food (e.g. fat, sodium, citric acid) other than sugars may generate other tastes that affect the sweet taste intensity perceived. Furthermore, in addition to taste, individual (e.g. knowledge and belief of and attitude towards foods) and environmental (e.g. food availability and affordability) factors also impact on food selection and consumption (Contento, 2011). Considering these various factors, this study suggests that the contribution of sweet taste perception to dietary intake of total energy, carbohydrate and various sugars opens up new avenues for the design of new dietary approaches to improve metabolic health. Hence, future strategies targeted at cutting down sugar intake should take individual sweet taste perception into considerations.

When expressed as a percentage of energy, none of the dietary intake variables (except for percent energy from protein at 250mM glucose concentration) correlated with perceived sweet taste intensity. This suggests there might be a relationship between perceived sweet taste intensity and total energy intake. Moreover, any further sugar intake would inevitably contribute to total energy intake. This might even be part of the reason why total energy intake significantly correlates with perceived sweet taste intensity.

A number of researchers have studied how perceived sweet taste intensity correlates with dietary habits (e.g. consumption frequency of selected sweet foods and beverages, eating behaviours) (Cornelis et al., 2017; Kampov-Polevoy et al., 2006; Lanfer et al., 2012) but only a limited number of studies have investigated this relationship at the individual nutrient level (Cicerale et al., 2012; Holt et al., 2000; J. Low et al., 2016; Mattes, 1985). Generally, previous studies showed no correlations between perceived sweet taste intensity and dietary intake variables (**Table 3.7**). To the best of our knowledge, the current study is the first that shows significant correlations between perceived sweet taste intensity and dietary intake of total energy, carbohydrate, and various sugars. The conflicting results may be attributed to a few methodological reasons. Firstly, the rating of perceived sweet taste intensity of different sweet stimuli, namely, glucose solutions in the current study and different sugars (i.e. sucrose, glucose, and fructose) in various matrix (i.e. water, juice, and biscuits) in previous studies, may vary greatly. Moreover, comparing to the multiple concentrations used in the current study, the only sucrose concentration in the study of Cicerale et al. (2012) seemed to be too low to indicate the sweet taste perception and dietary intake associations. Also, the FFQ used in the study of Holt et al. (2000) and J. Low et al. (2016) is not as accurate as the weighted food record in the current study, which is the gold standard dietary assessment tool so far, in the light of quantitative intake of individual nutrient. Furthermore, the current study adopted the latest sensory assessment scale (i.e. gLMS), which can generate valid across group comparisons. Even though it is not clear whether the gLMS is advantageous for correlation analysis, this could still be an important reason for the different results between the current study and other previous studies. In addition, the correlations between perceived sweet taste intensity and dietary intake in the current study were assessed individually for each selected concentration of glucose solution. However, J. Low et al. (2016) used the mean intensity scores of all concentrations of sweet stimuli for correlation tests.

Table 3.7 Studies that tested the correlations between perceived sweet taste intensity and dietary intake

Studies	Subjects	Stimuli	Concentrations	Sensory scale	Dietary assessment tool	Results
Mattes (1985)	35 healthy male and female adults	Sucrose solutions	5 concentrations from 50mM to 800mM)	Magnitude matching	7-day food record	No correlations between perceived sweet taste intensity and percent energy from protein, carbohydrate and fat (r = -0.25 to 0.18, p = 0.14 to 0.92).
Holt et al. (2000)	69 Caucasian Australian and 63 Malaysian university students who lived in Australia	Sucrose in aqueous solutions, orange juice, custard and biscuit	4-5 concentrations for each form	LMS	FFQ	No correlations between perceived sweet taste intensity for any concentrations and any forms of sucrose and dietary intake of total and added sugars in neither ethnic groups
Cicerale et al. (2012)	130 healthy university students	Sucrose solutions	200mM	gLMS	2-day food record	No correlation between sweet taste intensity and the intake of total energy and percent energy from protein, carbohydrate and fat
J. Low et al. (2016)	60 healthy women and men	Glucose, fructose and sucrose solutions	3 concentrations for each	gLMS	FFQ	No correlations between perceived sweet taste intensity and intake of total energy, percent energy from protein, carbohydrate, fat and total sugars for all caloric sugars (all $p > 0.01$). Note: A significance level of $p < 0.01$ was employed in this study.

4.5 Correlations between sweet taste hedonic liking and dietary intake

In the current study, the correlations between sweet taste hedonic liking and dietary intake of total energy, carbohydrate, total sugars, glucose, fructose, sucrose and maltose were significant and stronger as the glucose concentrations increased (**Table 3.5, Figure 3.11 – 3.19**). These correlations suggest a significant impact of sweet taste hedonic liking on dietary intake. Comparing to lower and medium concentrations, sweet taste hedonic rating based on a stronger stimulus seems to be a better predictor of dietary intake of total energy and various sugars.

As discussed above for perceived sweet taste intensity ratings, we need to keep in mind that sweet taste hedonic liking for glucose solutions does not directly equate to the taste experiences of foods and beverages in real life. It is important to be aware of that a range of individual and environmental factors influence dietary intake (Contento, 2011).

The sweet taste hedonic liking research in a number of previous studies has focused on correlations with dietary habits but limited studies have investigated quantitative nutrient intake. In the study of Mattes (1985), the sweet taste hedonic liking was assessed by the preferred concentration of sucrose solutions, which was not related to intake of percent energy from protein and fat but negatively correlated with the intake of carbohydrate ($r = -0.36$, $p = 0.04$). In the study of Holt et al. (2000), the sum of the preferred sucrose concentration in sucrose solutions, orange juice, custard and biscuit were positively correlated to the dietary intake of added sugars ($t = 2.48$, $p < 0.05$) even after adjustment for body weight, gender and ethnicity. These results are consistent with those of the current study, despite methodological differences in sweet stimuli, concentration range, hedonic scale, dietary assessment tools and statistical analysis for sweet taste intensity related studies (**Table 3.7**). It seems that dietary intake of total calories, carbohydrate and various sugars correlate more robustly with sweet taste hedonic liking for strong sweet stimuli than with perceived sweet taste intensity. However, the correlations found in this study can only establish a link between measures of sweet taste perception and increased intake of total calories, carbohydrate and various sugars, and importantly, it cannot establish the direction of this relationship.

5 Conclusion

The significant correlations found between perceived sweet taste intensity and sweet taste hedonic liking and dietary intake of total energy, carbohydrates and various sugars suggest an important role of sweet taste perception on dietary intake. Weak sweet stimuli at the lowest concentrations used in this study may already show the emerging relationship between perceived sweet taste perception and intake of total calories, carbohydrate and various sugars. Conversely it is tempting to speculate that individuals who are more sensitive to strong sweet stimuli may consume less total calories, carbohydrate and various sugars. Moreover, people who like strong sweet stimuli more are more likely to consume more total calories and sugars in their diet. These results in conjunction with the strong correlation between the two sweet taste perception variables may support the theory that people who are more sensitive to sweet taste require a lower level of sweetness to achieve equal satisfaction, thus consume less sweet foods and beverages than those who are less sensitive. Additionally, the employment of latest and accurate assessment tools of sweet taste perception and dietary intake is important to achieve strong data and meaningful results. Although the direction of the relationships found in the present cross-sectional study cannot be established, the data suggest that there is ample scope to reduce the sugar content in foods and still maintain hedonic liking.

Chapter 4: Conclusion

4.1 Main findings of the research

The present study shows a clear link between perceived sweet taste intensity and sweet taste hedonic liking, and dietary energy intake, and absolute intake of carbohydrate and sugars in a group of young women with normal BMI and relatively healthy food intakes. In the current study, we employed the most advanced and latest gLMS scales to measure perceived sweet taste intensity and sweet taste hedonic liking among 44 generally healthy New Zealand European women (20 – 40 years) by using four levels of glucose solutions. Perceived sweet taste intensity was significantly correlated with sweet taste hedonic liking in the study participants: positively at lower concentrations (i.e. 125mM) and negatively at higher concentrations (i.e. 500mM and 1000mM). This changing relationship between perceived sweet taste intensity and sweet taste hedonic liking with increasing glucose concentrations illustrates the importance of an individual's perception of sweet taste intensity.

We found significant correlations between the two measures of sweet taste perception and with dietary intake data obtained via a four-non-consecutive-day weighed food record. The perceived sweet taste intensity was negatively correlated with the intake of total energy, carbohydrate and sugars; the correlations increased with increasing concentrations of the tastant in the perceived sweet taste intensity test. Furthermore, the sweet taste hedonic liking was significantly positively correlated with the intake of total energy, carbohydrate and sugars; the correlations increased with increasing concentrations of the tastant in the sweet taste hedonic liking test. These correlations between perceived sweet taste intensity and sweet taste hedonic liking and the correlations with dietary intake of carbohydrates and various sugars suggests an important link between sweet taste perception and dietary intake. These data clearly support the hypothesis that individuals who are less sensitive to sweet taste tend to like higher levels of sweetness and consume more sugar to achieve equal levels of satisfaction (Duffy et al., 2009).

4.2 Application of the research

The significant role of sweet taste perception on dietary intake has important implications in view of the current prevalence of various NCDs and the strong correlations between excessive sugar intake and NCDs. According to A. Dias et al. (2015), variation in the TAS1R2 gene may contribute to lower perceived sweet taste intensity ratings and higher sugar consumption in people with a BMI over 25 kg/m^2. Further knowledge about the influence of sweet taste perception on dietary sugar intake, may benefit people who struggle with excessive sugar intakes due to poor sweet taste sensitivity. Future research should investigate the biological basis of this phenomenon.

Expanding related nutritional education is an effective approach to help individuals to cut down their dietary sugar intake (Contento, 2008). However, owing to the current global food environment, flooded with processed foods and beverages that are rich in sugars but relatively lower in price (Maniam et al., 2016), increasing the availability of healthy sugar-reduced options would be a more effective strategy to solve these issues. Even though a few governments like Mexico and Norway (Colchero, Rivera-Dommarco, Popkin, & Ng, 2017) encourage food manufactures to lower the sugar content of their products by issuing a sugar tax, the reformulation of processed foods has encountered a number of challenges when implementing this in practice (Cornelsen & Carreido, 2015). For instance, sugars serve several important functions in food manufacture other than just providing a sweet taste. Sugar provides a wide range of functions including the forming of fine ice crystals when making ice cream (providing important textural properties), shortening the leavening process when baking, and also aids to inhibit food spoilage (Hasanuzzaman et al., 2014; Sato & Miyawaki, 2016; Struyf et al., 2017). Alternative artificial or natural low caloric sweeteners (e.g. sucralose, stevia) may be able to provide a similar sweet taste as sugars, but are an unsuitable substitute to fulfil these other important functions. Introducing new ingredients to undertake these functions may increase production costs. Furthermore, there are also concerns about a loss of profit if sugar content is cut down in food products (Cornelsen & Carreido, 2015). However, with improvements of nutritional education, people are showing increasing interest in and demand for healthy, lower sugar alternatives to achieve better health outcomes. There are suggestions that food manufacturers who take the lead in reducing the sugar content of their products, or by offering more low sugar varieties, may gain greater market share in the near future (Cornelsen & Carreido, 2015).

The significant correlation between sweet taste perception and dietary intake in this study suggests that lowering the intake of sugar may potentially alter long-term sweet taste perception and preferences. Intervention studies have found that by decreasing sugar consumption, individuals perceived sweet stimuli as more intense, which can increase the liking for lower concentrations of sweet stimuli (Kishimura, 2016; Wise et al., 2016). Even though the long-term effects of a low sugar diet on sweet taste perception needs to be further verified, the findings of the present study are important and can be used to persuade food manufacturers to implement reducing the sugar content of their products without concern of losing customers.

4.3 Strengths of the research

There are a lot of strengths of the sweet taste study. Firstly, the latest sensory gLMS scale and hedonic gLMS scale used in this study can not only provide ordinal, semantic and ratio level measuring of perceived sweet taste intensity and sweet taste hedonic liking as other scales do, but also generate valid group comparisons for these two measurements of sweet sensation (Bartoshuk et al., 2004). Thus, the perceived sweet taste intensity and sweet taste hedonic liking data of the four levels of glucose solutions in this study has been fully validated and comparisons with other similar studies will be easily possible.

Secondly, in the current study, the perceived sweet taste intensity and sweet taste hedonic liking tests were repeated four times within one month to provide reliable ratings of perceived sweet sensitivity and sweet taste hedonic liking, which makes the correlations with dietary intake data more robust.

Thirdly, in the current study, multiple concentrations of sweet taste stimuli, ranging from very low to very high, were included to capture the changing patterns of perceived intensity and sweet taste hedonic liking. Furthermore, the correlations between sweet taste sensation and dietary intake were analyzed individually for each concentration. The failure to find a correlation between perceived sweet taste intensity and dietary intake in previous studies indicate it may be important to evaluate the above correlations at a range of concentrations.

Fourthly, the four-non-consecutive-day weighed food record used as dietary assessment method applied in this study is considered to be the gold standard dietary assessment tool. Comparing to FFQ and 24h food recall, the rates of under- and over-reporting of dietary intakes of food record are much lower (Gibson, 2005). Also, food record can better assess actual sugar consumption that can be easily omitted or forgotten from dietary recall assessment methods, yet are important for the purpose of this study. For instance, sugar from lollies consumed occasionally, sugars added to drinks, or contained in various spreads and dressings. An accurate and thorough record of all nutrients, especially sugars, is helpful to indicate any potential dietary related correlations with sweet sensation in the current study.

Fifthly, a few quality control strategies were employed to ensure the accuracy of the nutrient intake acquired from the food record in the sweet taste study. To increase the chance of completion, personalized dates were chosen by participants themselves with the help of a trained researcher. In addition, the instructions of how to keep a food record were repeated a few times and in different forms to make sure the participants understood the importance of the method and to record all food consumption honestly and accurately. A reminder text message was sent to each participant on the day before the food record day. Also, the food record was reviewed by the trained researcher with each participant to add more necessary but missing details and to improve the quality of food record. In addition, all food record data were entered and coded by the same researcher reducing the related subjective bias. A food record guide with pictures was provided for the participants to aid the participants to quantify portion size in dining out occasions.

4.4 Shortcomings of the research

There are a few limitations in this study. Firstly, the study sample was relatively small and quite homogeneous in terms of gender, body composition, age and race. The 44 New Zealand European women aged 20 to 40 years in this study were generally health-conscious and the majority of them (i.e. 90%) were within the normal BMI range (18.5 – 25 kg/m^2). Therefore, caution is needed when applying the results of this study to a wider and diverse population.

Secondly, the data entry of the current study was completed before the newest version of Foodworks programme (i.e. Foodworks 8) was released, which includes an updated food composition database for foods and beverages in New Zealand. For a few items (e.g. kale) that cannot be found in Foodworks 7, we chose a similar item instead, or borrowed the corresponding data from the USDA food composition database.

Thirdly, despite use of the gold standard dietary assessment tool, the inherent weaknesses of food record may still limit the accuracy of the dietary data obtained in this study. Specifically, food record may affect the usual eating behaviours and food selection of the participants, which tend to cause underreporting or reduce the representativeness of habitual dietary intakes (Biro et al., 2002). Also, due to the higher participant burden (F. Thompson & Subar, 2008), the quality of the food record varied between participants. In spite of a high quality digital scale provided, some participants still used household measuring tools (e.g. cups) or general descriptions (e.g. two large bananas) to record the amount of food they consumed. Some participants forgot to measure either raw or cooked weights of their meals. However, the shortcomings mentioned above occurred only in a very few situations and we are confident that the food record obtained in this study can be considered the most accurate and effective dietary assessment tool for the purpose of the current study.

4.5 Recommendations for future research

The correlations between sweet taste perception and dietary intake should be further tested for their reliability and robustness in a larger sample with diverse gender, age, body composition (e.g. obese *versus* normal BMI) and in different ethnic groups. Future studies should include multiple stimuli, especially stronger sweet tastants, to further explore the link between sweet taste perception on dietary intake or eating behaviour. Additionally, analysis should be run separately for different concentrations instead of only for the mean rating of all concentrations of taste stimuli.

Considering the various methodological differences in previous sensory studies (Bartoshuk et al., 2006), standard sensory and hedonic measuring procedures and scales are recommended to enable comparisons among similar studies and to draw consistent conclusions.

The current study showed that compared to weaker stimuli, a stronger stimulus provides a stronger correlation with, and can perhaps better predict relationships with dietary intake. Further research should explore whether sensory and hedonic tests towards a strong sweet stimulus could help to identify people who are more likely to consume excessive sugars for disease prevention, if they rate a strong sweet tastant significantly lower and/or show extremely higher liking to the tastant than the average level.

Finally, it is important to understand whether dietary interventions of reduced sweet food intake can change the perception of sweet taste intensity and liking. Future studies should investigate this to explore new avenues that enable a long-term reduction of sugar intake.

4.6 Conclusion

The overall aim of this study is to better understand the link between sweet taste perception and dietary intakes in 44 New Zealand European women (20 – 40 years). The study results revealed significant correlations between perceived sweet taste intensity and sweet taste hedonic liking and their important links with dietary energy intake, and absolute intake of carbohydrate and sugars in a group of young healthy women with normal BMI and relatively healthy food intakes. These correlations further support the theory that individuals who are less sensitive to sweet taste tend to like higher levels of sweetness and may consume more sugar to achieve an equal level of satisfaction (Duffy et al., 2009).

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Appendix A: Supplementary results

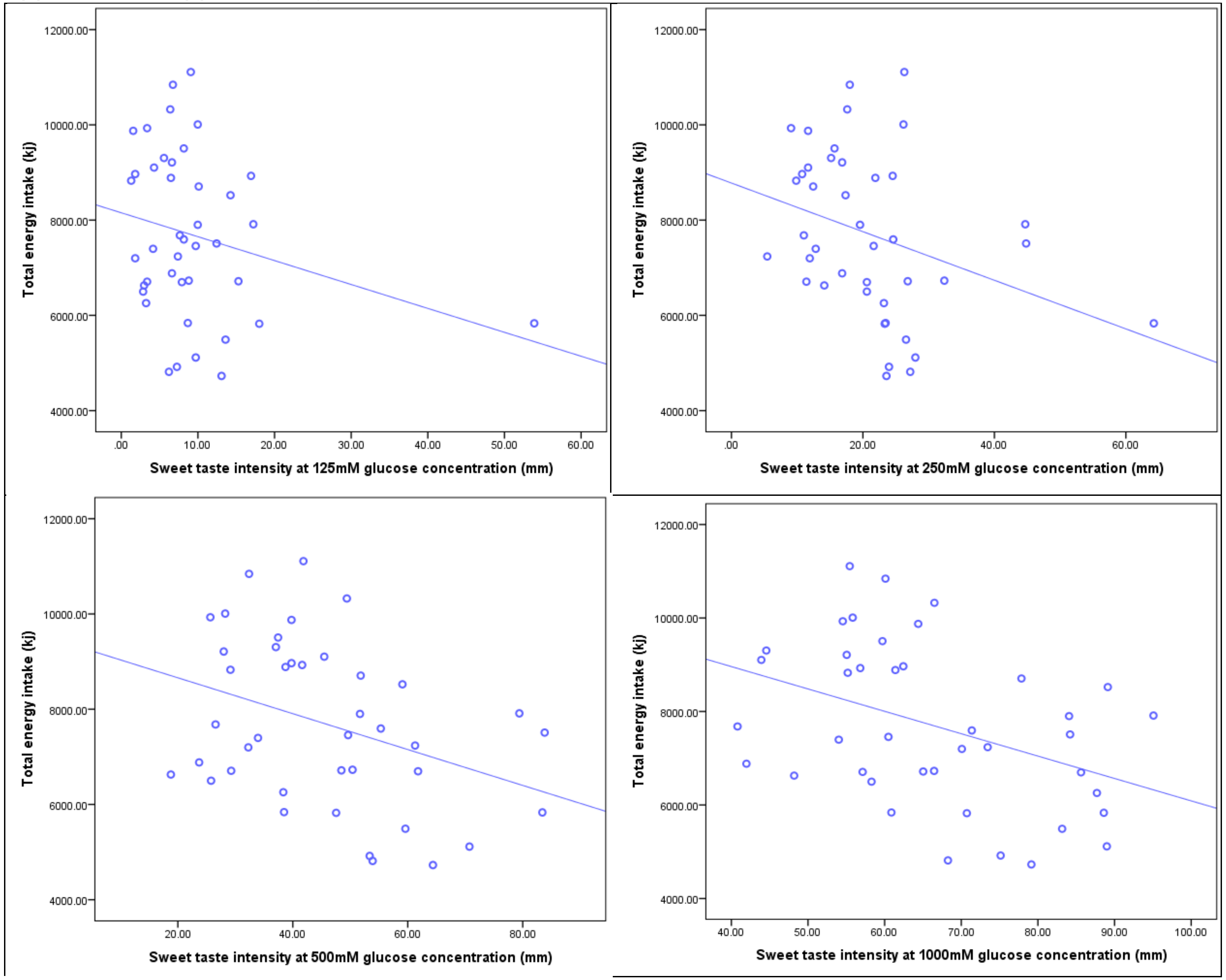


Figure 3.4 *Scatterplot of the Correlations between perceived sweet taste intensity and total energy intake at all glucose concentrations (n = 41)*

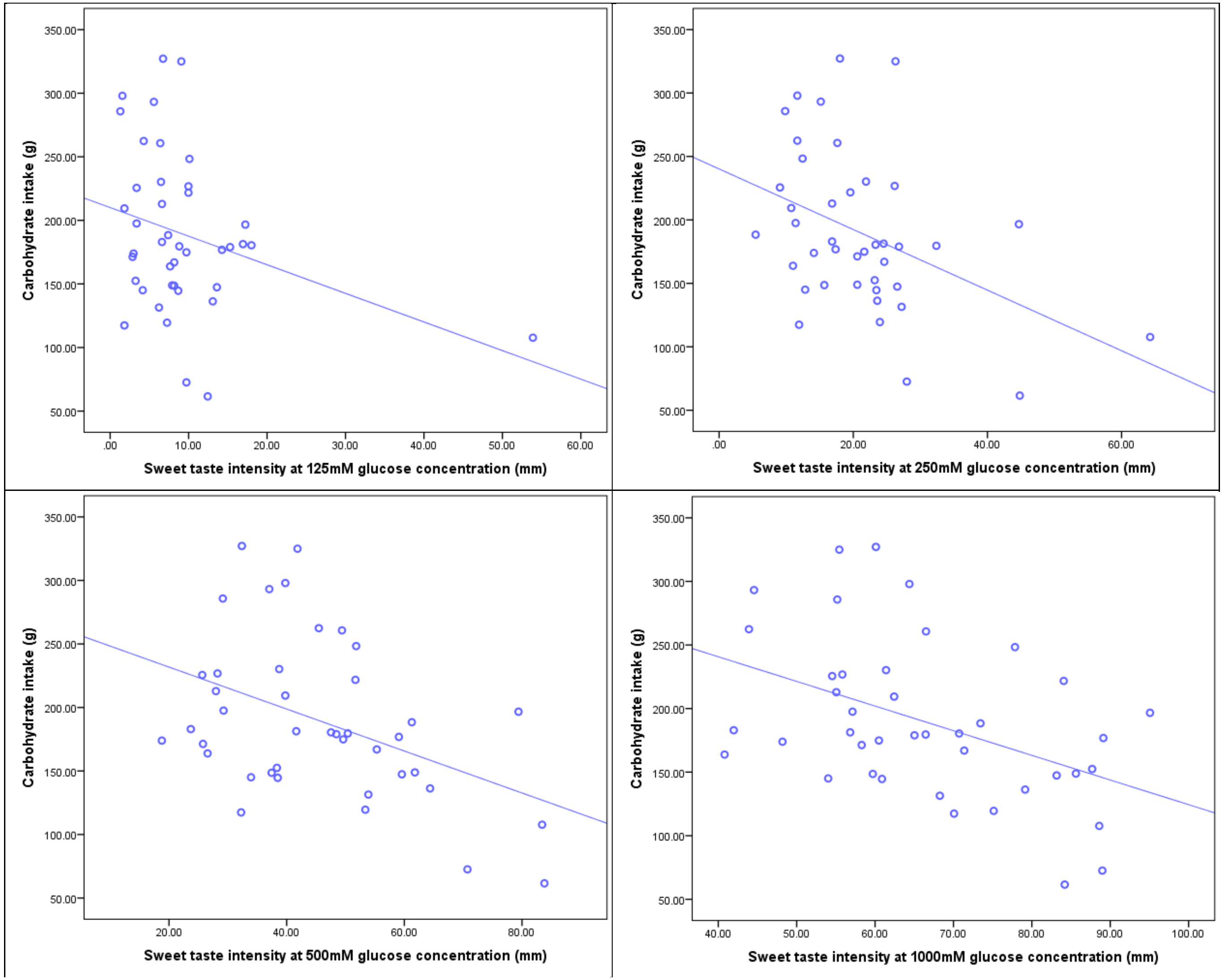


Figure 3.5 Scatterplot of the Correlations between perceived sweet taste intensity and carbohydrate intake at all glucose concentrations (n = 41)

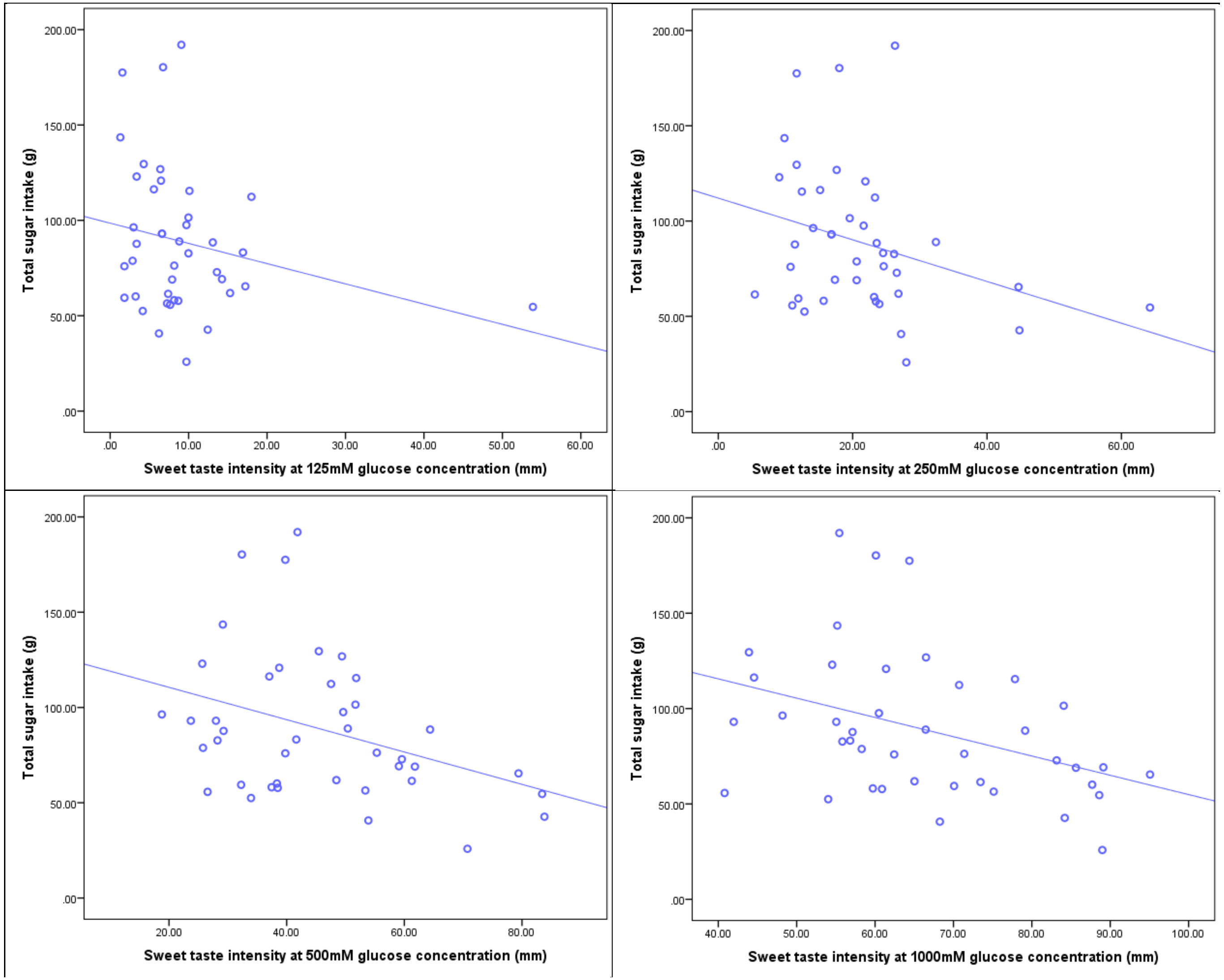


Figure 3.6 Scatterplot of the correlations between perceived sweet taste intensity and total sugar intake at all glucose concentrations (n = 41)

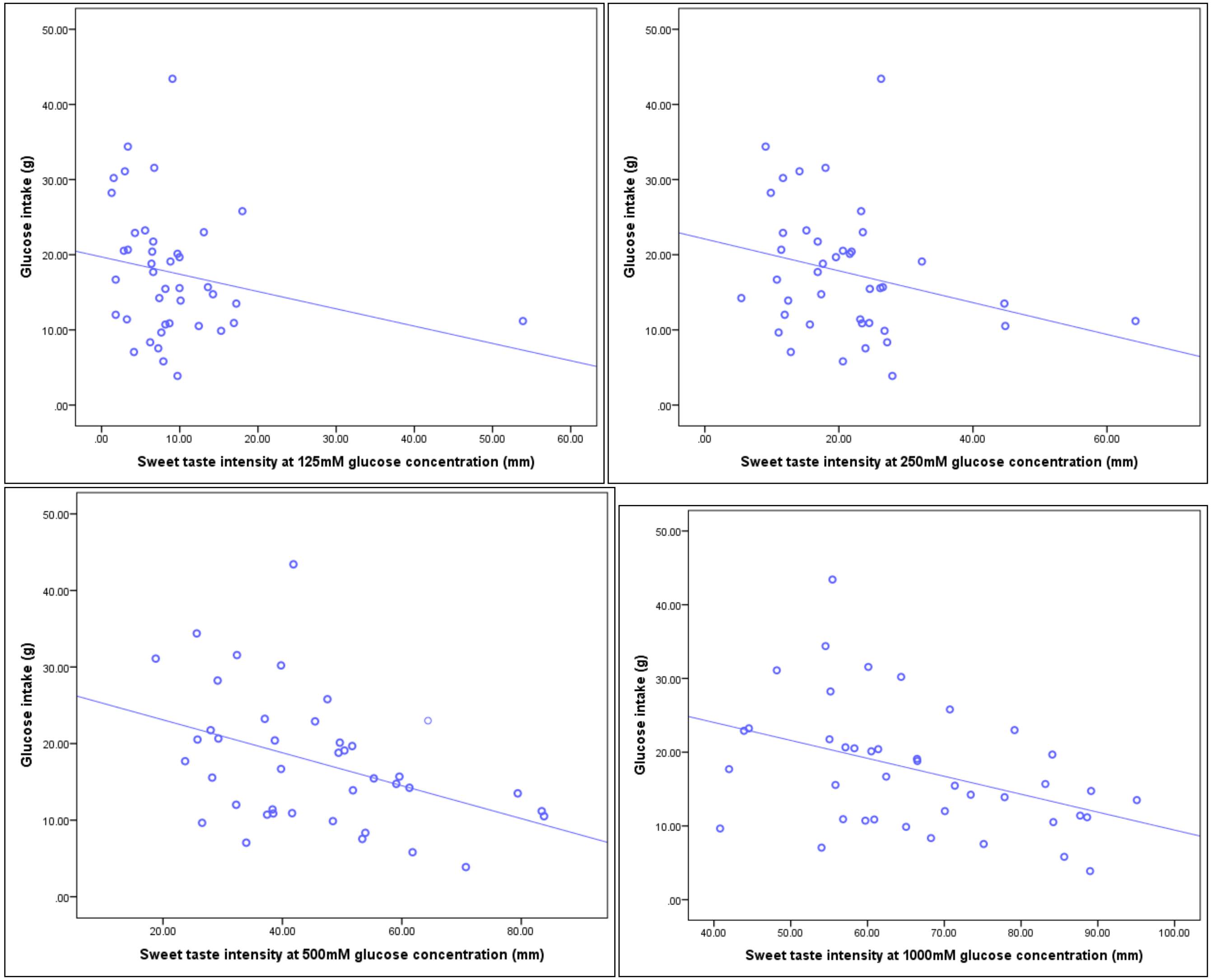


Figure 3.7 Scatterplot of the correlations between perceived sweet taste intensity and glucose intake at all glucose concentrations (n = 41)

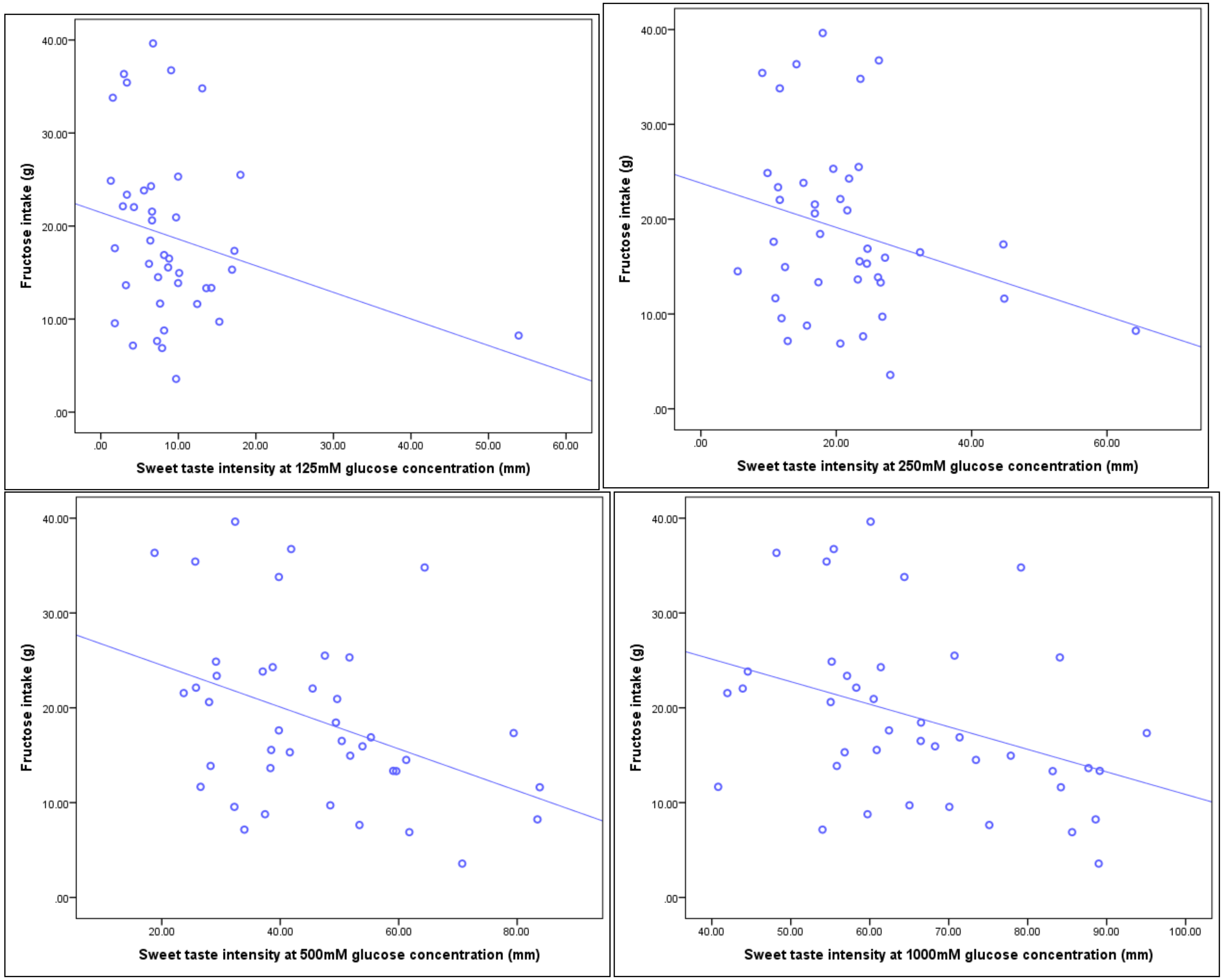


Figure 3.8 Scatterplot of the correlations between perceived sweet taste intensity and fructose intake at all glucose concentrations (n = 41)

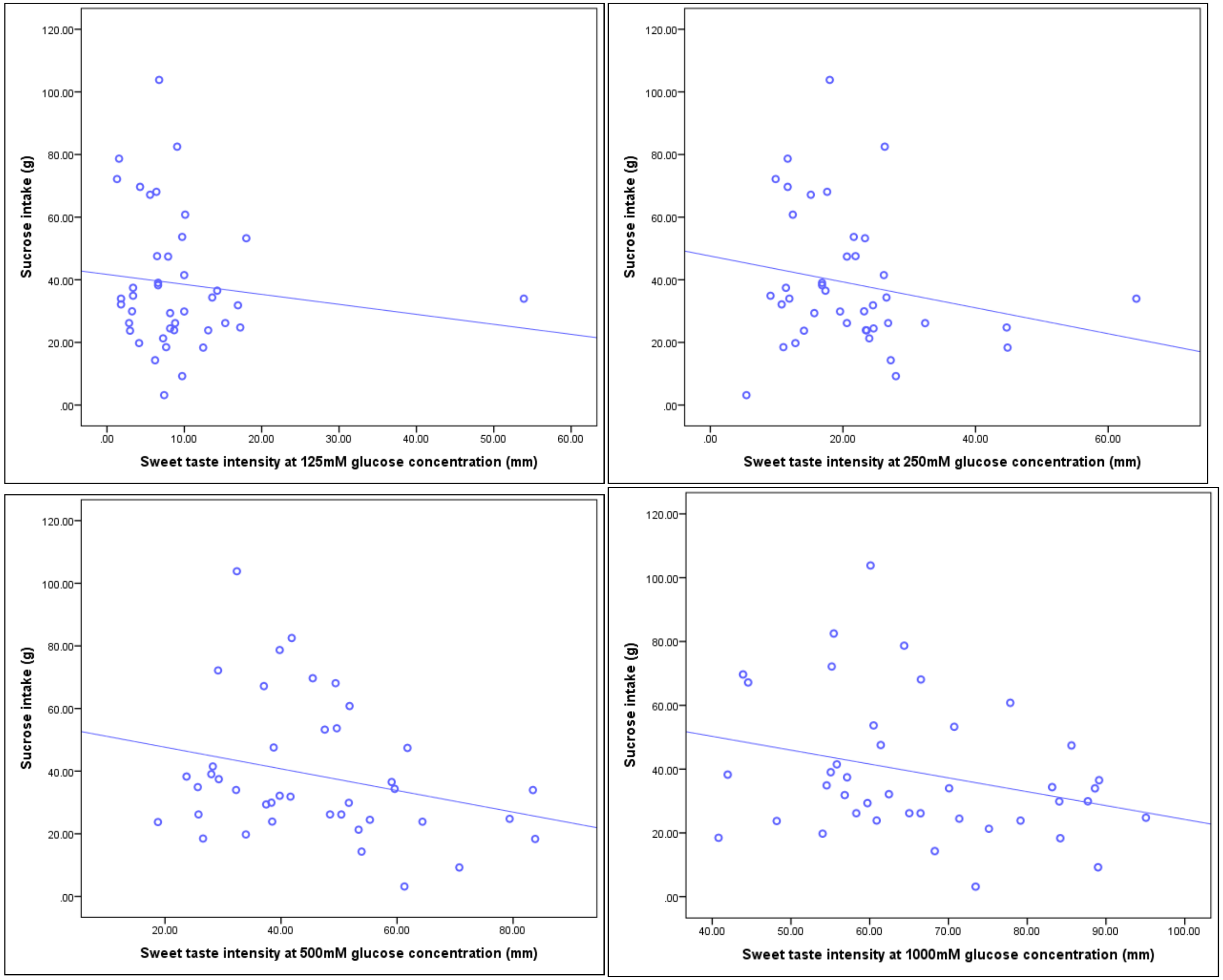


Figure 3.9 Scatterplot of the correlations between perceived sweet taste intensity and sucrose intake at all glucose concentrations (n = 41)

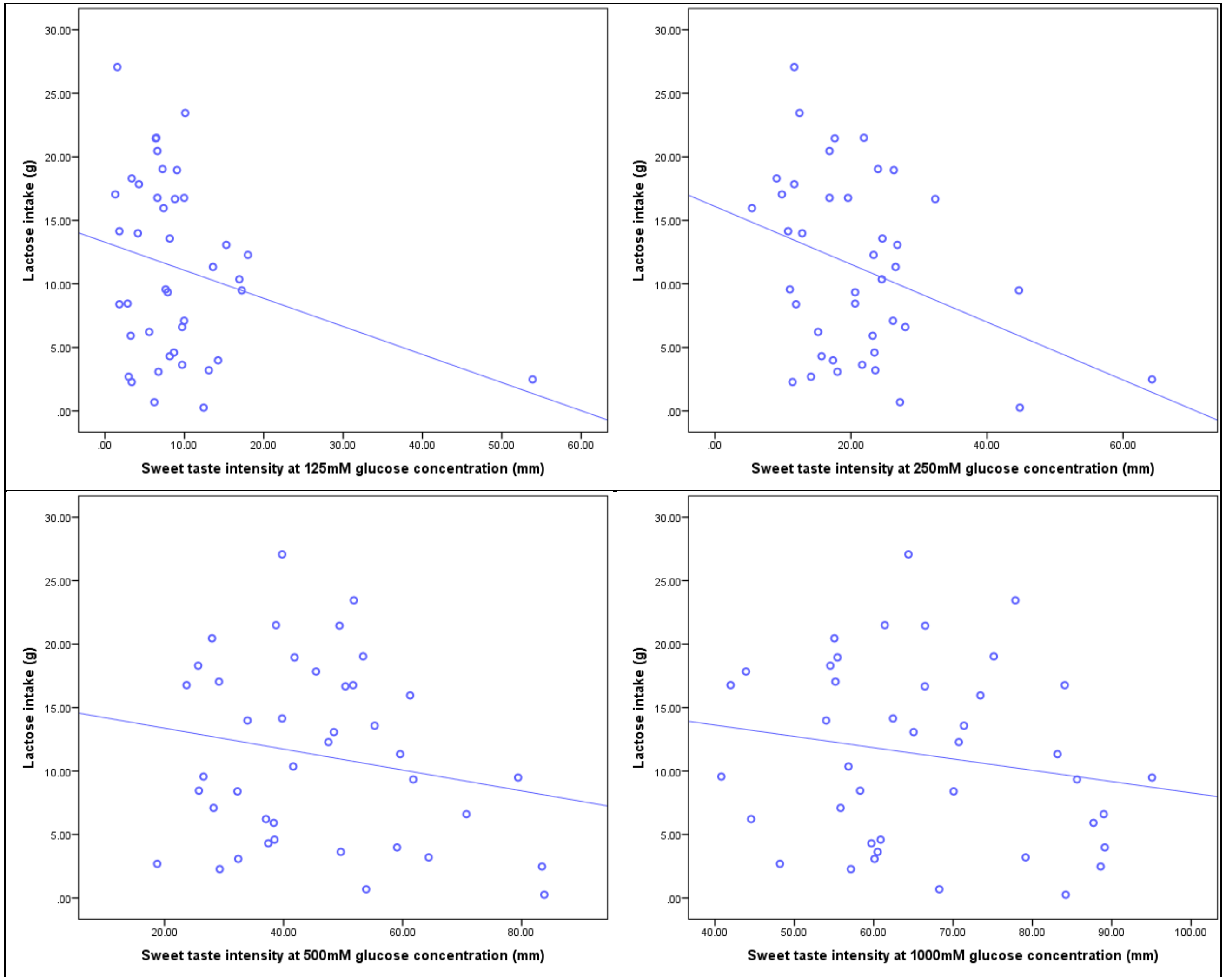


Figure 3.10 Scatterplot of the correlations between perceived sweet taste intensity and lactose intake at all glucose concentrations (n = 41)

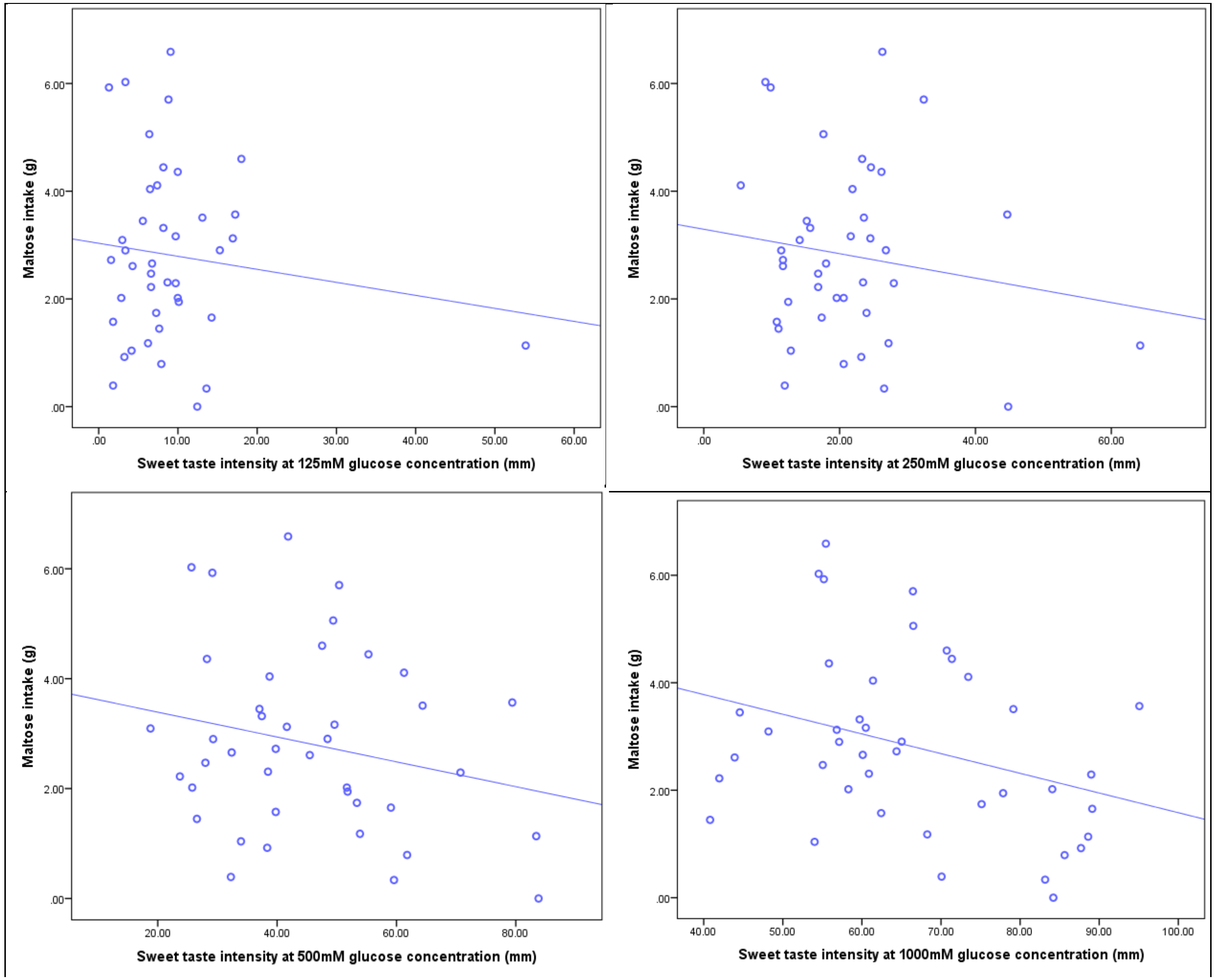


Figure 3.11 Scatterplot of the correlations between perceived sweet taste intensity and maltose intake at all glucose concentrations (n = 41)

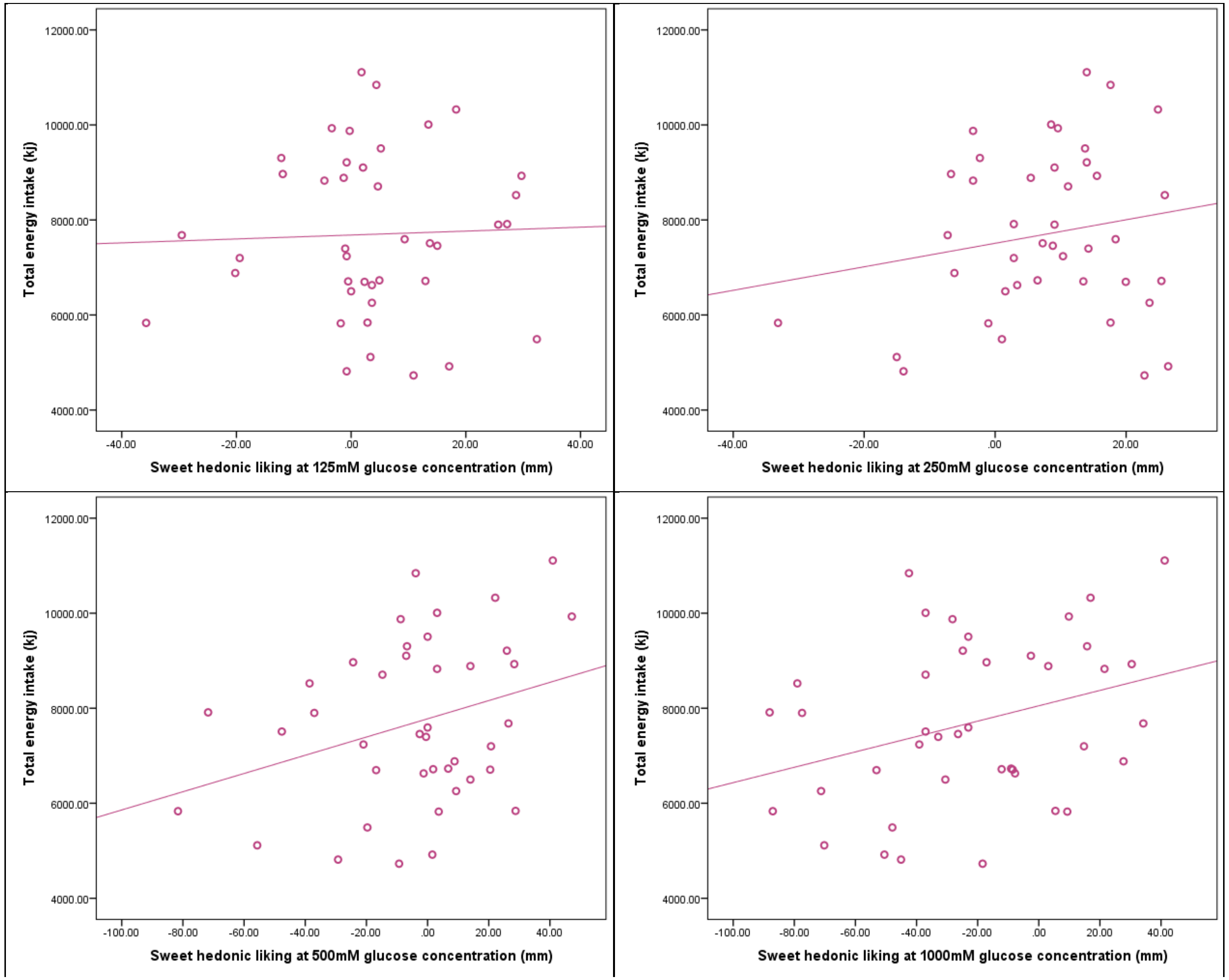


Figure 3.12 Scatterplot of the correlations between sweet taste hedonic liking and total energy intake at all glucose concentrations (n = 41)

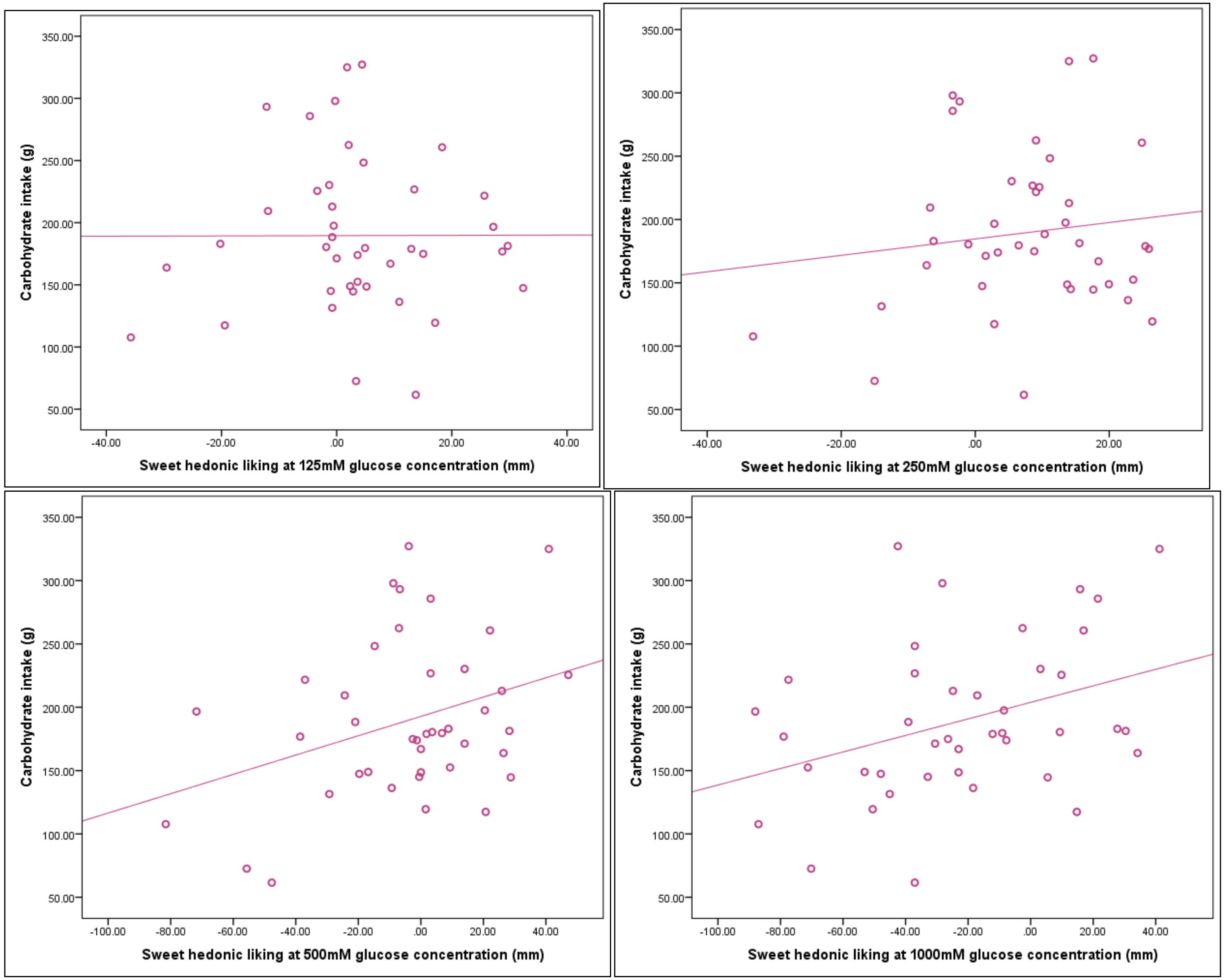


Figure 3.13 Scatterplot of the correlations between sweet taste hedonic liking and carbohydrate intake at all glucose concentrations (n = 41)

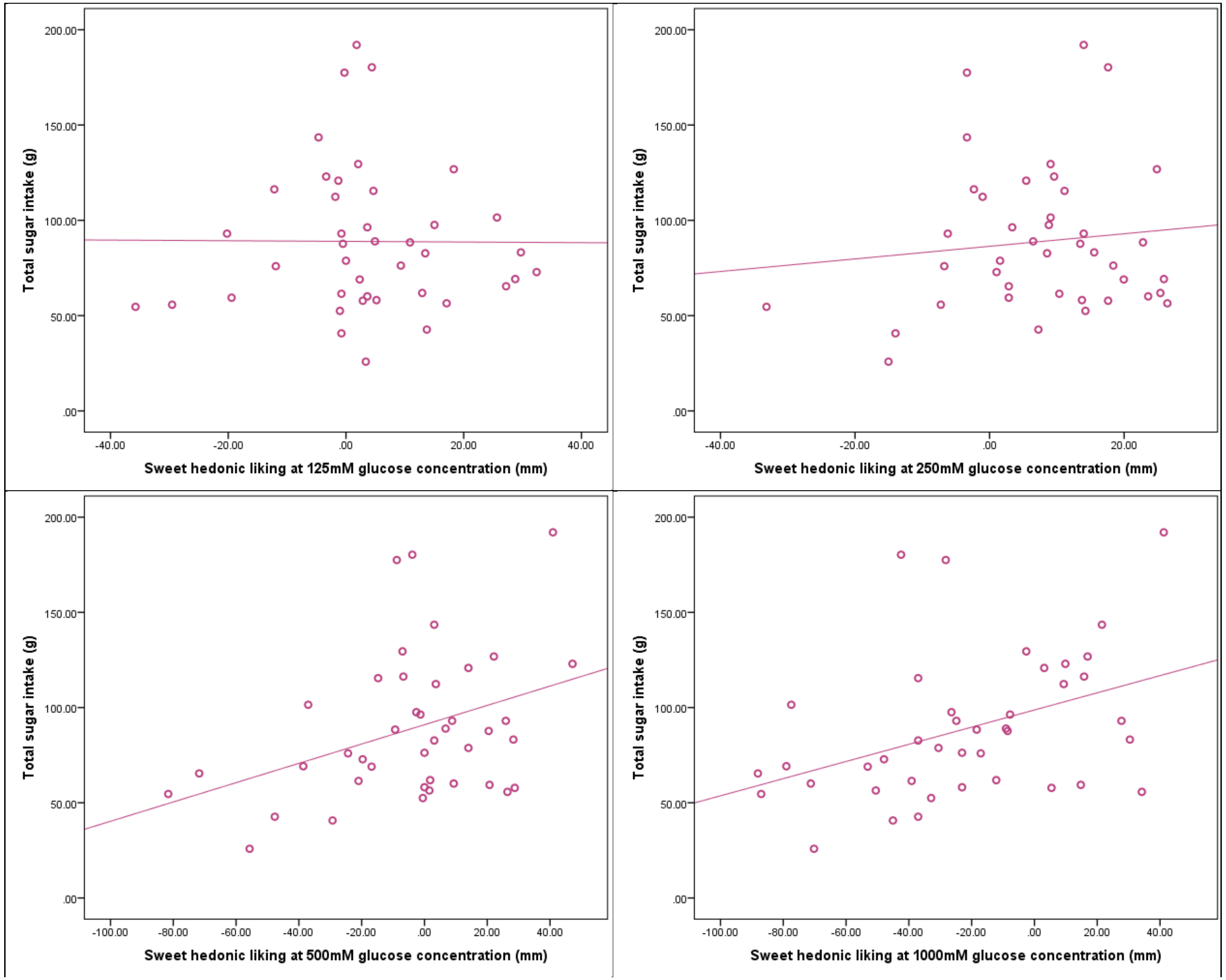


Figure 3.14 Scatterplot of the correlations between sweet taste hedonic liking and total sugar intake at all glucose concentrations (n = 41)

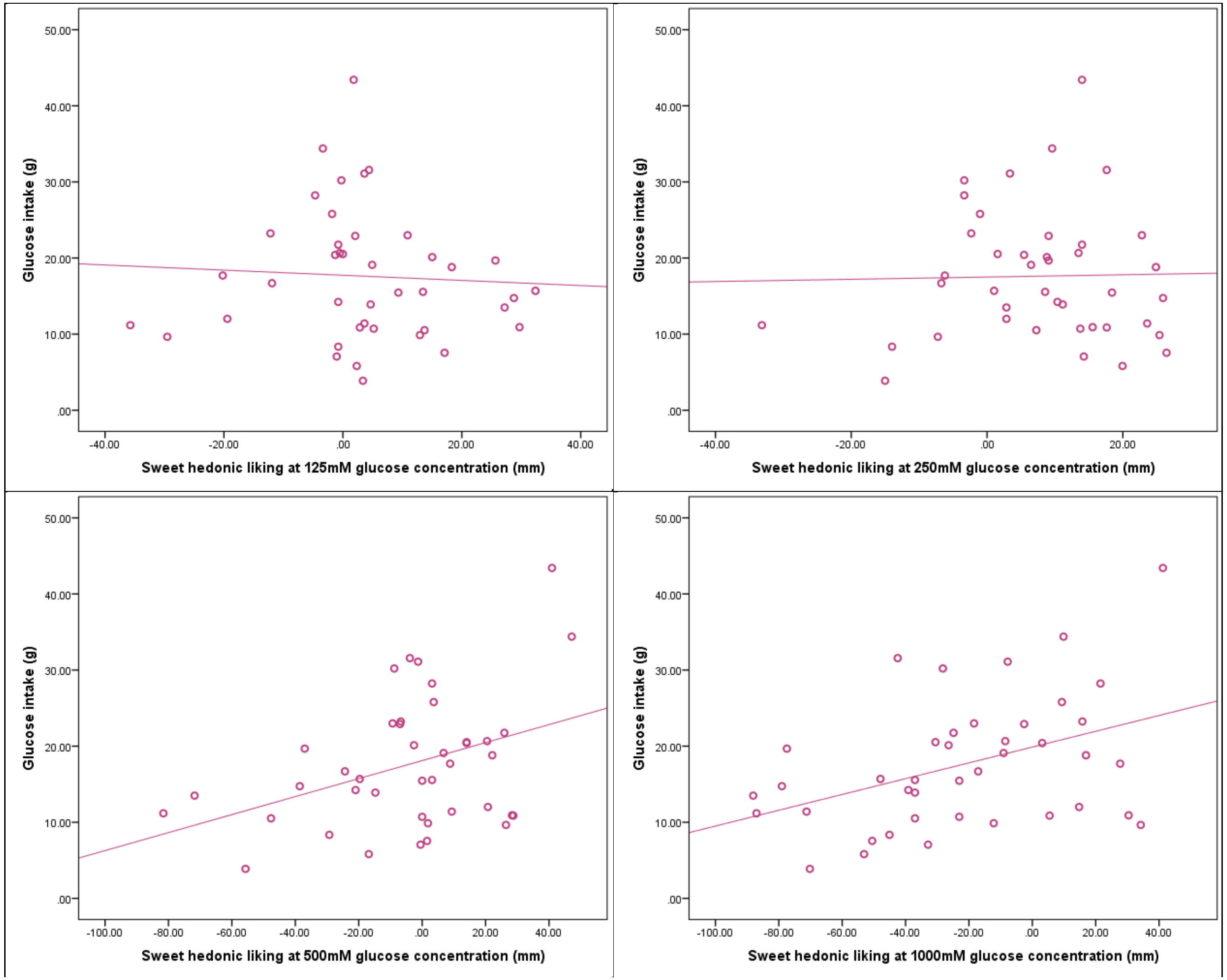


Figure 3.15 Scatterplot of the correlations between sweet taste hedonic liking and glucose intake at all glucose concentrations (n = 41)

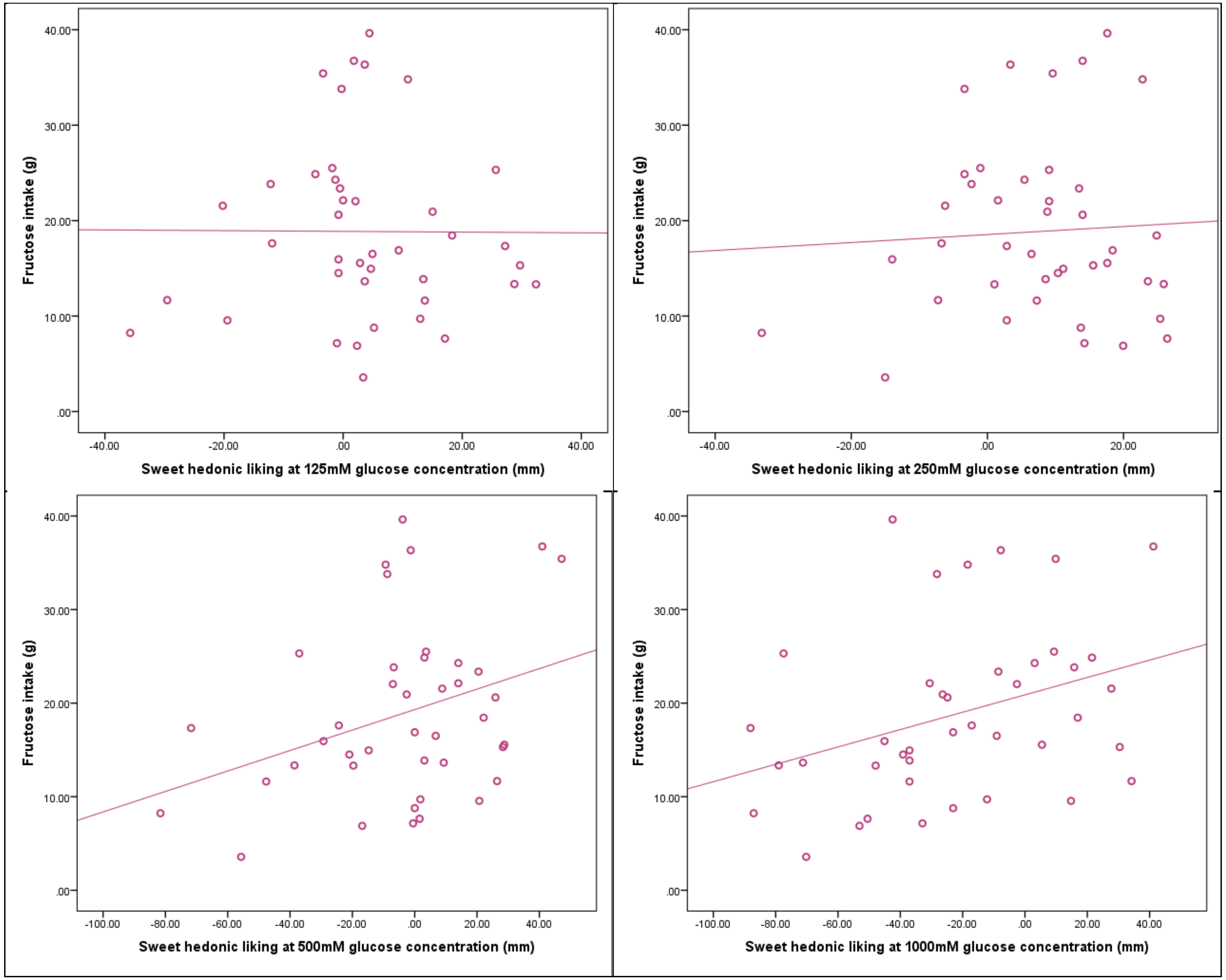


Figure 3.16 Scatterplot of the correlations between sweet taste hedonic liking and fructose intake at all glucose concentrations (n = 41)

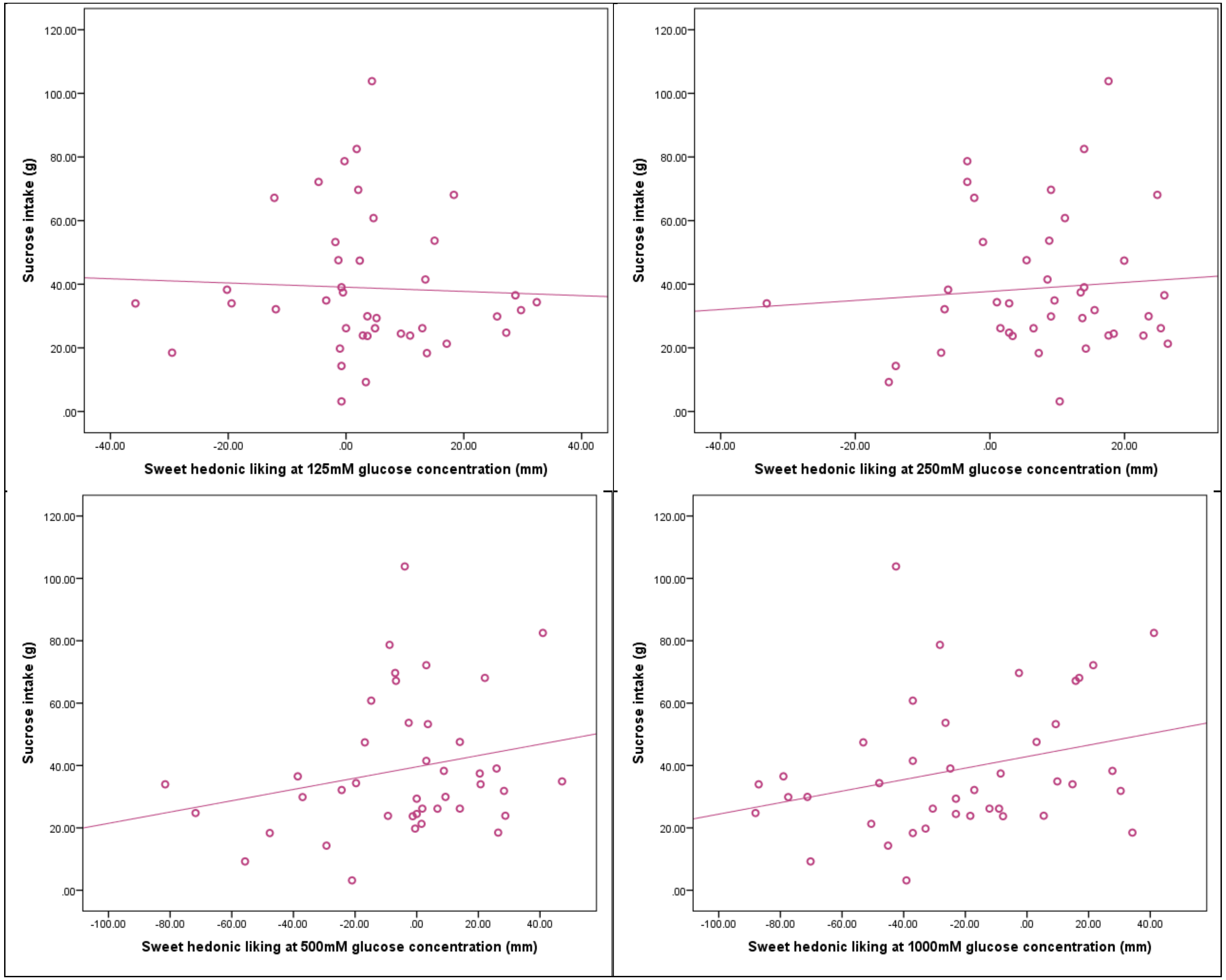


Figure 3.17 Scatterplot of the correlations between sweet taste hedonic liking and sucrose intake at all glucose concentrations (n = 41)

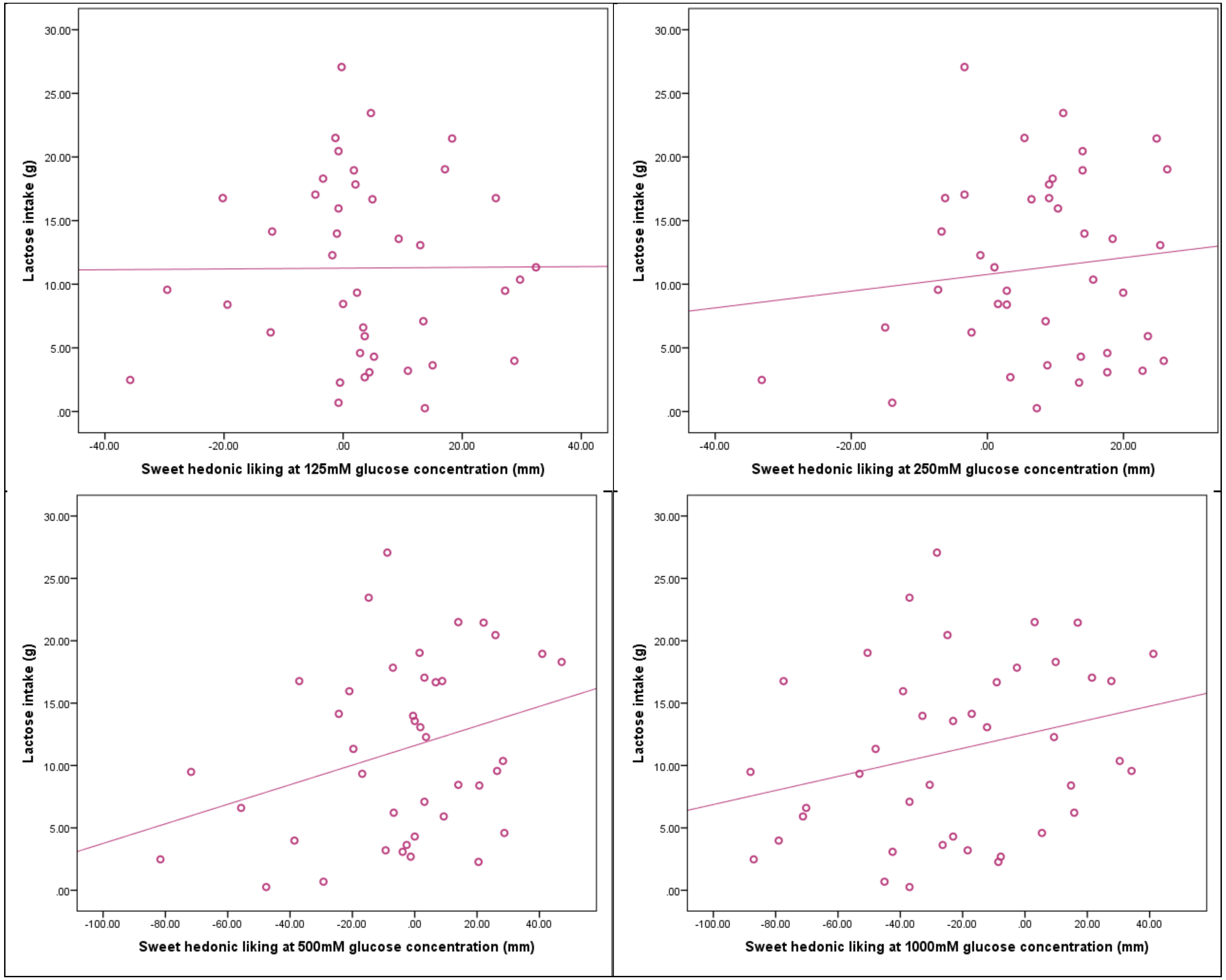


Figure 3.18 Scatterplot of the correlations between sweet taste hedonic liking and lactose intake at all glucose concentrations (n = 41)

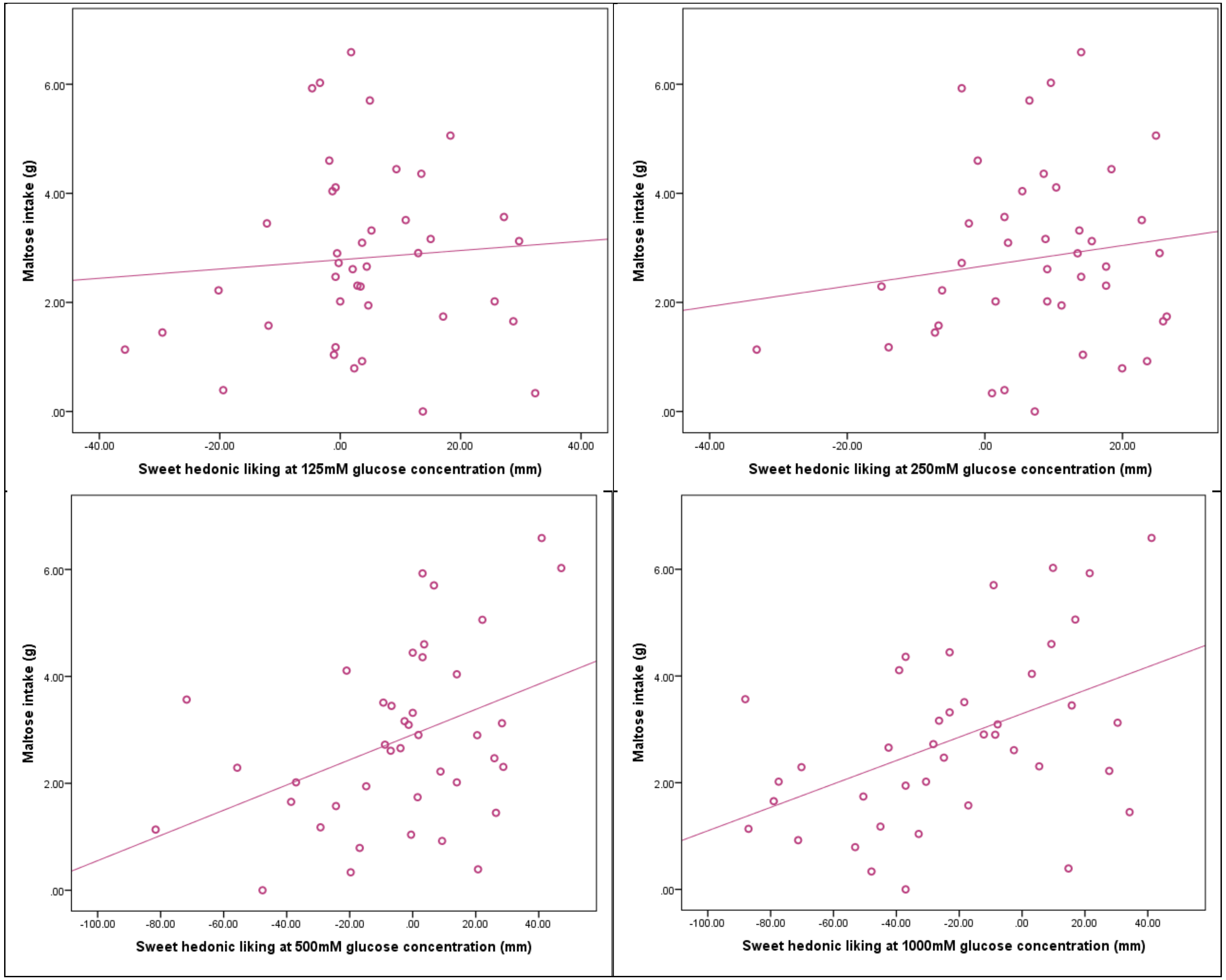


Figure 3.19 *Scatterplot of the correlations between sweet taste hedonic liking and maltose intake at all glucose concentrations (n = 41)*

Appendix B: Screening questionnaire

Sweet Taste Study Screening Questionnaire

Please fill in the following screening questionnaire that will be used to determine whether you fit the inclusion criteria as a study participant.

1. What is your gender?

Personal Details

2. Personal Details

First name:*
Family name:*
Preferred name:
Home address:
Suburb:
City/town:*
Post code:
E-mail address:*
Home phone:
Mobile number:

3. Date of birth:*

4. Your age:*

Years:
Months:

5. Ethnicity you most identify with*

New European
Maori
Pasifik Island
Asian
Indian
Middle Eastern/Latin American/African
Other (Specify)

General Health Status

6. Are you currently on a specific diet or exercise programme aimed at weight loss? Yes/no

7. Are you pregnant or breastfeeding? Yes/no

8. Do you currently have regular menstrual periods? Yes/no

9. Please provide the date of your last menstrual period

10. Over the last 12 months how often did your menstrual period occur?
Once every 3-5 weeks
Once every 6-8 weeks
Interval of > 2 months (irregular)
None

11. Are you currently using any form of hormonal contraception (e.g. pill, mirena, depo-provera)? Yes/no

12. Do you suffer from any chronic diseases (e.g. diabetes, cardiovascular)? Yes/no

13. Do you have any clinical cause for a dry mouth (e.g. Xerostomia or Sjogren's syndrome)? Yes/no

14. Have you been on any type of antibiotics over the last 3 months? Yes/no

15. Are there any other medical conditions you would like to inform us about? (e.g. surgery, cancer) Yes/no

16. Are you on any other medications?

17. Are you currently smoking or in the process of quitting?

Assessing allergy

To assess whether you are allergic to any of the tasting solutions please answer the following questions.

18. Are you allergic to glucose?

19. Please tell us how you found out about the sweet taste study:

Questionnaire complete

Thank you very much for taking your time to complete the questionnaire, we will be in touch with you shortly. In the meantime, if you have any further queries please do not hesitate to contact us on sweettastestudy@gmail.com

Appendix C: Participant information sheet

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

SWEET TASTE STUDY PARTICIPANT INFORMATION SHEET

We are researchers of Human Nutrition and Food Technology at Massey University and are looking for women to take part in the research on sweet taste.

Description of the project
Over the past few decades there has been an increased availability and consumption of low cost, readily available food and beverage products that are high in added sugar. Taste sensitivity to sweet varies considerably between individuals. As variations in taste sensitivity influences food choice, and thereby affects quality of life, there is much interest to understand the role of taste perception in the way people select food and how much they consume. Therefore the main aim of the project is to understand the relationship between sweet taste perception and food intake and behaviour.

Who can take part?
We are looking for women of

- New Zealand European ethnicity
- 20-40 years of age
- Not be pregnant or breastfeeding
- Who are non-smokers
- Have had regular menstrual periods for a year
- Not have any chronic illnesses or clinical cause for a dry mouth

Project Procedures
Prior to taking part in this study you will need to complete a screening questionnaire to assess your health status and medical conditions that may influence the results of the study.

The study requires you to attend **four sessions** each approximately 1.5 hours long at the sensory unit at Massey University Albany. You will be required to come for each session after an overnight fast and refrained from brushing your teeth at least an hour prior to the appointment. These appointments will be conducted between **7.30-8.30am on weekdays** and **selected weekends**. At each session you will undertake a **sensory test** and complete **one dietary questionnaire**. You will also maintain a **four-day weighed food record**. In addition, height, weight, and body fat % will be measured at the first session.

Sensory testing
Taste testing involves tasting sweet samples to determine your sensitivity to sweet taste. The 3 -Alternative Forced Choice (3-AFC) test will be used to determine sensitivity to sweet taste. You will be asked to take the whole cup of one sample (5-10mls), swirl it in your mouth for 3 seconds and then spit it out to a waste cup (swallowing may affect the results). Two of the three samples will be identical and one is different. You will pick the sample with the sweet taste and write the number down when you finish all the samples. After recording the number, you will be asked to return the tray with the form and empty cups. You will rinse your mouth with distilled water and wait for 20 seconds before you move to the next sample. In addition you will rate also 'intensity' and 'preference' of five sweet solutions on a scale.

Dietary analysis
You will be asked to keep a weighed food record of all food and beverages consumed over four days. At the first session you will watch a video that explains the procedure of a food record. At each of the next three visits you will complete one dietary questionnaire relating to your diet history, food choice and eating habits.

What will you receive?
You will be reimbursed for travel expenses with a $100 petrol voucher following the completion of testing (voucher received at the end of the fourth session). You will also receive a written report containing the main findings of the study once data analysis and interpretation is completed.

Confidentiality
All data collected will be used solely for research purposes and will be prepared for publication in a professional journal. All personal information will be kept confidential by assigning number codes to each participant. No names will be visible on any papers on which you provide information. If you are a student of one of the research teams please note that your academic grades will not be affected whether you decide to complete the study or withdraw at a later time. All data/information will be handled in confidence and will be stored in a secure location for five years on the Massey University Albany campus. After this time it will be disposed of by an appropriate staff member from the Food Technology department.

Participant's rights
You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- Decline to answer any particular question;
- Withdraw from the study at any time;
- Ask any questions about the study at any time during participation;
- Provide information on the understanding that your name will not be used unless you give permission to the researcher

Contact information
If you have any further questions or concerns about the project, either now or in the future, please contact the sweet taste study team on sweettastestudy@gmail.com

Specific contacts:
Professor Bernhard Breier B.Breier@massey.ac.nz
Shakeela Jayasinghe (PhD student) s.n.jayasinghe@massey.ac.nz

Human ethic committee Approval Statement
"This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.

If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher(s), please contact Professor John O'Neill, Director, Research Ethics, telephone 06 350 5249, email humanethics@massey.ac.nz".

Appendix D: Participants consent form

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Institute of Food, Nutrition and Human Health
Massey University
Private Bag 102-904
North Shore Mail Centre
Albany, Auckland
New Zealand
T 09 414 0800

SWEET TASTE STUDY

Participant Consent Form

I have read the Information Sheet and have had the details of the study explained to me.

My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I agree to participate in this study under the conditions set out in the Information Sheet.

Signature: .... **Date:** ....

Full Name ....

Appendix E: Health and demographic questionnaire

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

SWEET TASTE STUDY - Personal information, health and demographic questionnaire

First name: ____

Family name: ____

When did your last period start? (Day / month / year) ______________________

Are you pregnant or breastfeeding? Yes □ No □

Are you taking any form of medication, including traditional or homeopathic medicine and contraception?

Yes □ No □

Please specify the condition, the medication and the dosage in the table provided.

Condition	Medication	Dosage	Frequency

Are you taking any form of supplements, including tablets or drinks? Yes □ No □

If yes, what are the name, brand and dosage of the supplements you are taking?_____

(Will send details by email Yes □ No □)

Supplement	Brand	Dosage	Frequency

Do you follow a specific diet for health reasons? Yes □ No □

Please explain

____

____

____

Do you follow a specific diet aimed at weight loss? Yes □ No □

Please explain

____

____

____

Do you follow any diet for cultural or religious reasons? Yes □ No □

Please explain

____

____

____

Are you happy with your current body weight? Yes □ No □

Questions regarding physical activity

1. What is your occupation?

____

____

2. What is the main activity that your occupation requires?

____

____

3. Do you do a sport or other organised physical activity in addition to your job?
Yes □ No □

If yes, what types of activities ______________________________

____

a. How many times a week? ______________________________

____

____

b. How many minutes at a time? ___________________________

____

____

I would like to receive a brief report summarizing the main findings of the project:

Yes □ No □

I am willing to be contacted in future research projects within the Institute of Food, Nutrition and Human Health:

Yes □ No □

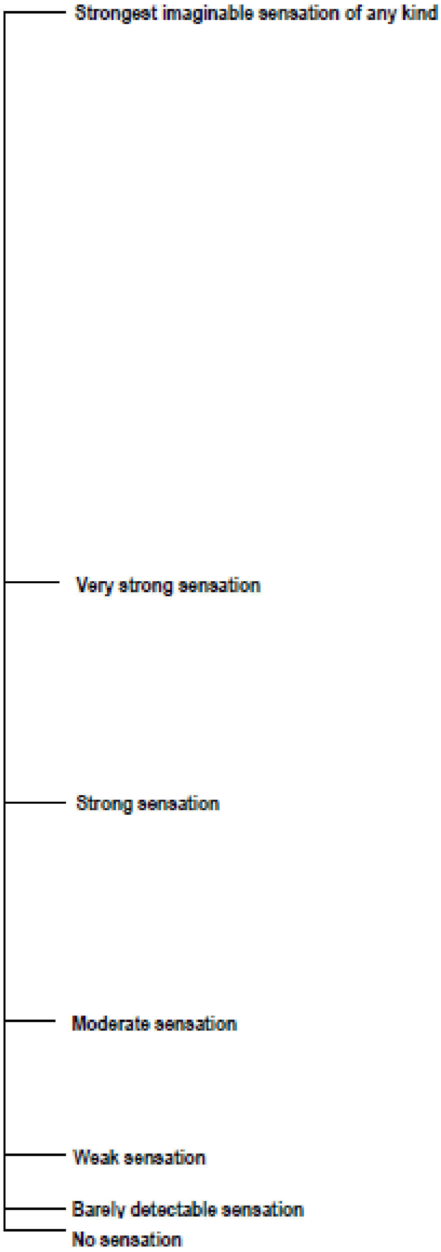
Appendix F: Perceived sweet taste intensity and sweet taste hedonic liking answer sheet

Sweet taste study rating

Subject ID .... D.O.B.................... Date.................. Session # ....

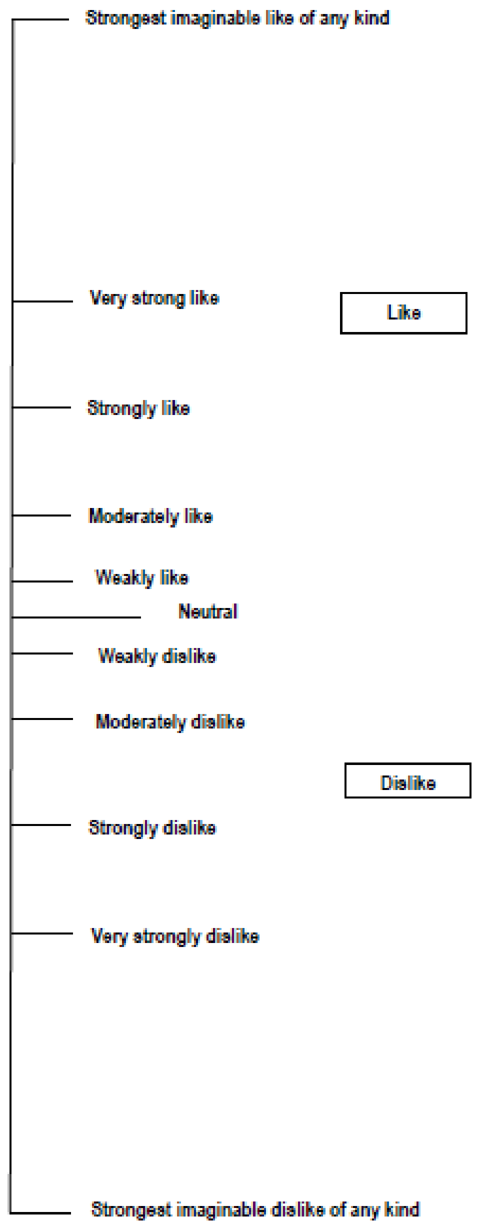
You will be given one sweet solution at a time. Please take the whole sample in your mouth and swirl it around for 3 seconds. Then spit the sample in to the waste cup and rate the following attributes of the sample you tasted by marking **anywhere** on the line. Please do not swallow any of the samples. Write the sample number next to the marking. You will taste 4 samples in total and rate attributes on the same scale.

Please rate the **sweetness** of the sample you tasted. Write the sample number next to the marking.



Please turn page

How much do you like the sweetness of the sample you tasted? Write the sample number next to the marking.



Please pass the tray to the lab and rinse your mouth with water before moving on to the next sample.

Appendix G: Food record booklet

MASSEY UNIVERSITY

COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Sweet taste study Weighed 4 Day Food Record

Thank you very much for taking part in the Study.

We are extremely grateful for your time, effort and commitment!

If you have any questions, please contact the sweet taste study researchers on: email: sweettastestudy@gmail.com or phone 0226388758

All information in this diary will be treated with the strictest confidence.
No one outside the study will have access to this.

What to do?

- Record all that you eat and drink on the following dates.

____

____

____

____

____

- If possible record food at the time of eating or just after – try to avoid doing it from memory at the end of the day.

- Include all meals, snacks, and drinks, even tap water.

- Include anything you have added to foods such as sauces, gravies, spreads, dressings, etc.

- Write down any information that might indicate **size or weight** of the food to identify the portion size eaten.

- Use a new line for each food and drink. You can use more than one line for a food or drink. See the examples given.

- Use as many pages of the booklet as you need.

Describing Food and Drink

- Provide as much detail as possible about the type of food eaten. For example **brand names and varieties / types** of food.

General description	**Food record description**
Breakfast example – cereal, milk, sugar	1 cup Sanitarium Natural Muesli 1 cup Pam's whole milk 1 tsp Chelsea white sugar
Coffee	1 tsp Gregg's instant coffee 1 x 200ml cup of water 2 Tbsp Meadow fresh light green milk
Pasta	1 cup San Remo whole grain pasta spirals (boiled)
Pie	Big Ben Classic Mince and Cheese Pie (170g)

- Give details of all the **cooking methods** used. For example, fried, grilled, baked, poached, boiled…

General description	**Food record description**
2 eggs	2 size 7 eggs fried in 2tsp canola oil 2 size 6 eggs (soft boiled)
Fish	100g salmon (no skin) poached in 1 cup of water for 10 minutes

- When using foods that are cooked (eg. pasta, rice, meat, vegetables, etc), please record the **cooked portion** of food.

General description	**Food record description**
Rice	1 cup cooked Jasmine rice (cooked on stove top)
Meat	90g lean T-bone steak (fat and bone removed)
Vegetables	½ cup cooked mixed vegetables (Wattie's peas, corn, carrots)

- Please specify the **actual amount of food eaten** (eg. for leftovers, foods where there is waste)

General description	**Food record description**
Apple	1 x 120g Granny Smith Apple (peeled, core not eaten – core equated to ¼ of the apple)
Fried chicken drumstick	100g chicken drumstick (100g includes skin and bone); fried in 3 Tbsp Fern leaf semi-soft butter

- **Record recipes** of home prepared dishes where possible and the proportion of the dish you ate. There are blank pages for you to add recipes or additional information.

Recording the amounts of food you eat

It is important to also record the quantity of each food and drink consumed. This can be done in several ways.

- By using household measures – for example, cups, teaspoons and tablespoons. Eg. 1 cup frozen peas, 1 heaped teaspoon of sugar.

- By weight marked on the packages – eg. a 425g tin of baked beans, a 32g cereal bar, 600ml Coke

- Weighing the food – this is an ideal way to get an accurate idea of the quantity of food eaten, in particular for foods such as meat, fruits, vegetables and cheese.

- For bread – describe the size of the slices of bread (eg. sandwich, medium, toast) – also include brand and variety.

- Using comparisons – eg. Meat equal to the size of a pack of cards, a scoop of ice cream equal to the size of a hen's egg.

- Use the food record instructions provided to help describe portion sizes.

General description	Food record description
Cheese	1 heaped tablespoon of grated cheese 1 slice cheese (8.5 x 2.5 x 2mm) 1 cube cheese, match box size Grated cheese, size 10B

- If you go out for meals, describe the food eaten in as much detail as possible.

- ***Please eat as normally as possible - don't adjust what you would normally eat just because you are keeping a diet record and be honest! Your food record will be identified with a number rather than your name.***

Example day

Time food was eaten	Complete description of food (food and beverage name, brand, variety, preparation method)	Amount consumed (units, measures, weight)
Example 7:55am	Sanitarium weetbix	2 weetbix
" "	Anchor Blue Top milk	150ml
" "	Chelsea white sugar	2 heaped teaspoons
" "	Orange juice (Citrus Tree with added calcium – nutrition label attached)	1 glass (275 ml)
10.00am	Raw Apple (gala)	Ate all of apple except the core, whole apple was 125g (core was ¼ of whole apple)
12.00pm	Home made pizza (recipe attached)	1 slice (similar size to 1 slice of sandwich bread, 2 Tbsp tomato paste, 4 olives, 2 rashers bacon (fat removed), 1 Tbsp chopped spring onion, 3 Tbsp mozzarella cheese)
1.00pm	Water	500ml plain tap water
3.00pm	Biscuits	6 x chocolate covered Girl Guide biscuits (standard size)
6.00pm	Lasagne	½ cup cooked mince, 1 cup cooked Budget lasagne shaped pasta , ½ cup Wattie's creamy mushroom and herb pasta sauce, ½ cup mixed vegetables (Pam's carrots, peas and corn), 4 Tbsp grated Edam cheese
6.30pm	Banana cake with chocolate icing (homemade, recipe attached)	1/8 of a cake (22cm diameter, 8 cm high), 2 Tbsp chocolate icing
" "	Tip Top Cookies and Cream ice cream	1 cup (250g)
7.30pm	Coffee	1 tsp Gregg's instant coffee 1 x 300ml cup of water 2 Tbsp Meadow fresh blue top milk 2 tsp sugar

Date________________________________ **DAY 1**

Time food was eaten	**Complete description of food (food and beverage name, brand, variety, preparation method)**	**Amount consumed**

Date______________________________ DAY 1 continued

Time food was eaten	Complete description of food (food and beverage name, brand, variety, preparation method)	Amount consumed

Recipes (Day 1)

Date________________________________ DAY 2

Time food was eaten	Complete description of food (food and beverage name, brand, variety, preparation method)	Amount consumed

Date_________________________________ **DAY 2 continued**

Time food was eaten	Complete description of food (food and beverage name, brand, variety, preparation method)	Amount consumed

Recipes (Day 2)

Date_____________________________________ **DAY 3**

Time food was eaten	Complete description of food (food and beverage name, brand, variety, preparation method)	Amount consumed

Date__________________________________ **DAY 3 continued**

Time food was eaten	**Complete description of food (food and beverage name, brand, variety, preparation method)**	**Amount consumed**

Recipes (Day 3)

Date__________________________________ **DAY 4**

Time food was eaten	**Complete description of food (food and beverage name, brand, variety, preparation method)**	**Amount consumed**

Date________________________________ **DAY 4 continued**

Time food was eaten	Complete description of food (food and beverage name, brand, variety, preparation method)	Amount consumed

Recipes (Day 4)

Date______________________________ **(spare pages)**

Time food was eaten	**Complete description of food (food and beverage name, brand, variety, preparation method)**	**Amount consumed**

Date__________________________________ (spare pages)

Time food was eaten	Complete description of food (food and beverage name, brand, variety, preparation method)	Amount consumed

Appendix H: Food record guide

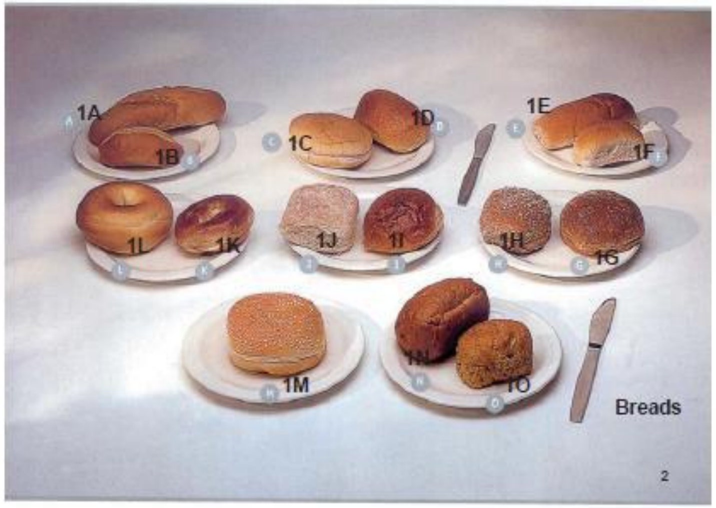
MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

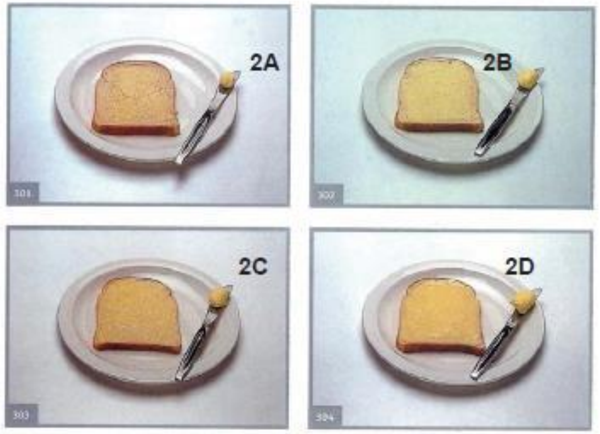
Food Record Guide

Institute of Food Nutrition and Human Health
Massey University

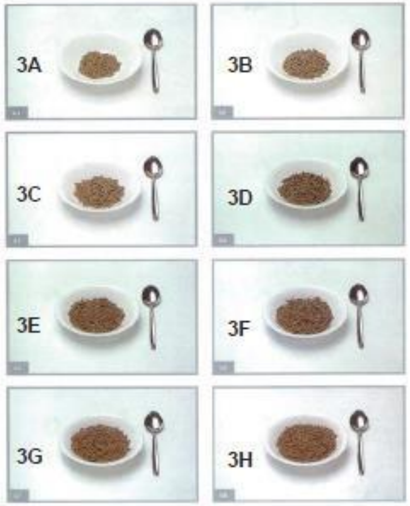
If you have any questions please contact sweet taste study researchers on:
E-mail: sweettastestudy@gmail.com
Phone: 0226388758

1

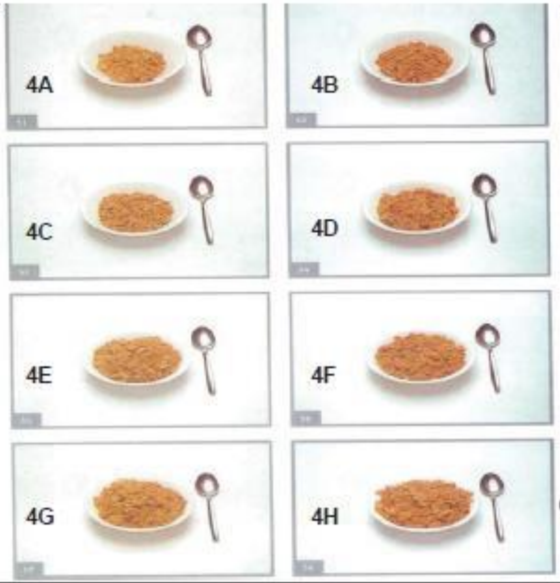




Butter or Margarine 3

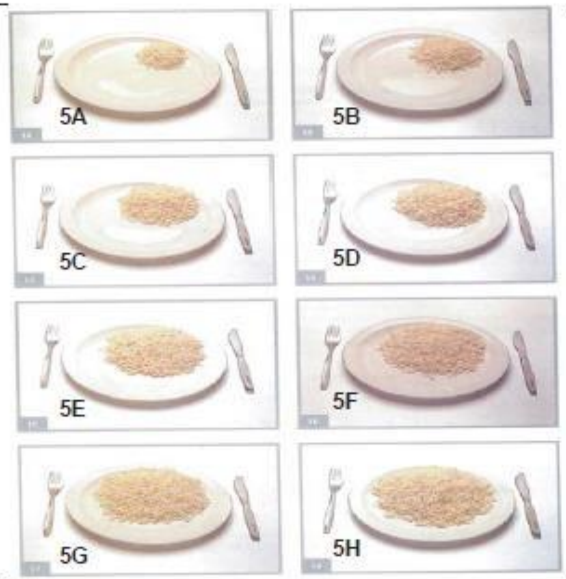


All Bran
4



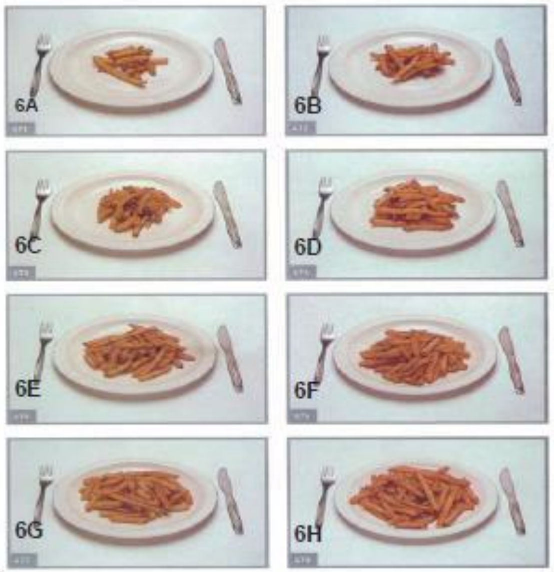
Cornflakes

5



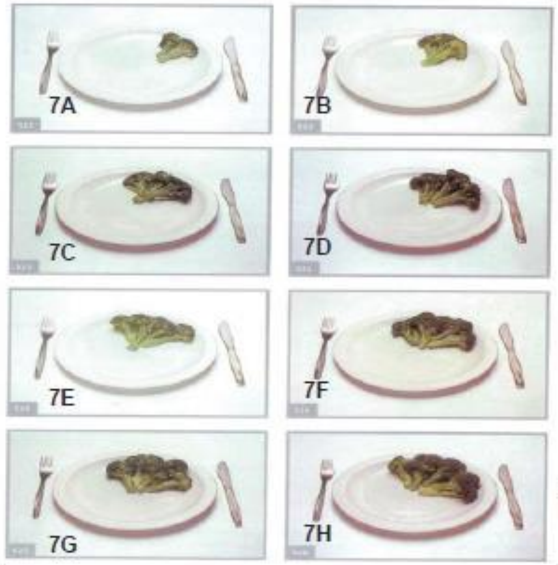
Rice

6



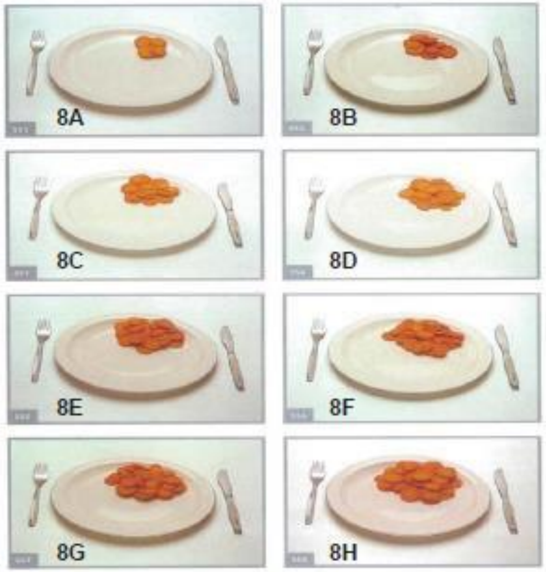
French fries

7



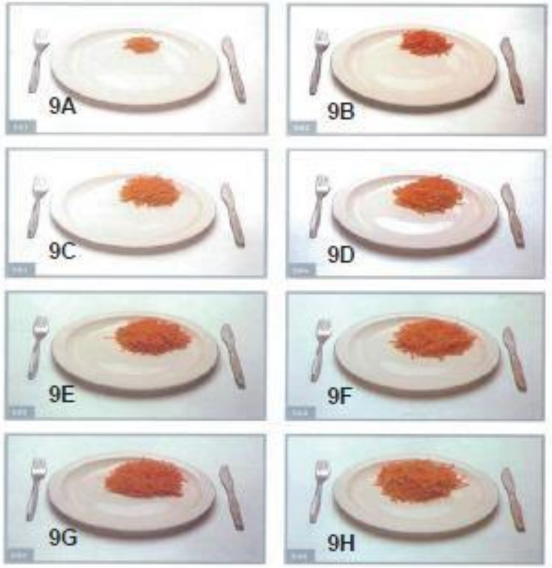
Broccoli

8



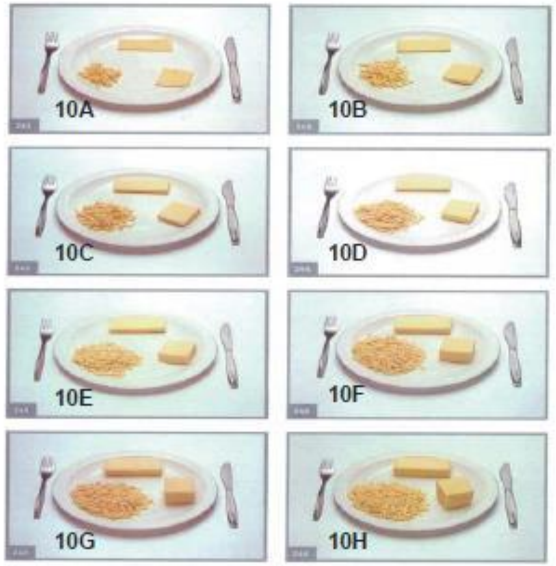
Sliced carrots

9



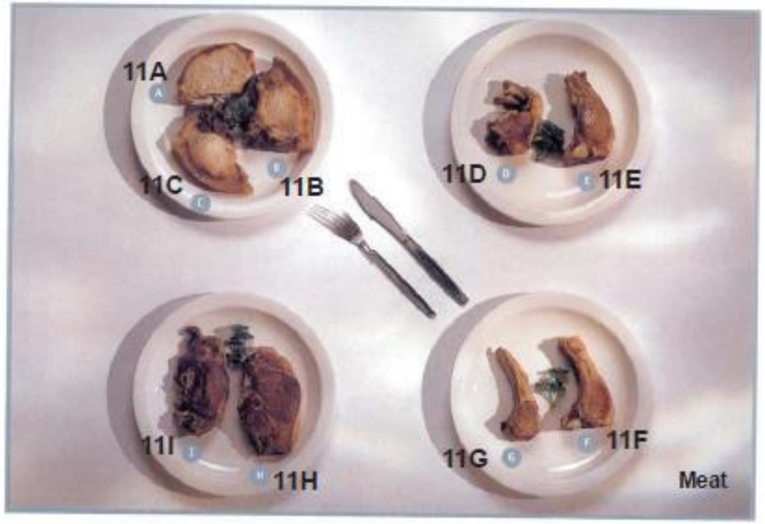
Grated carrots

10



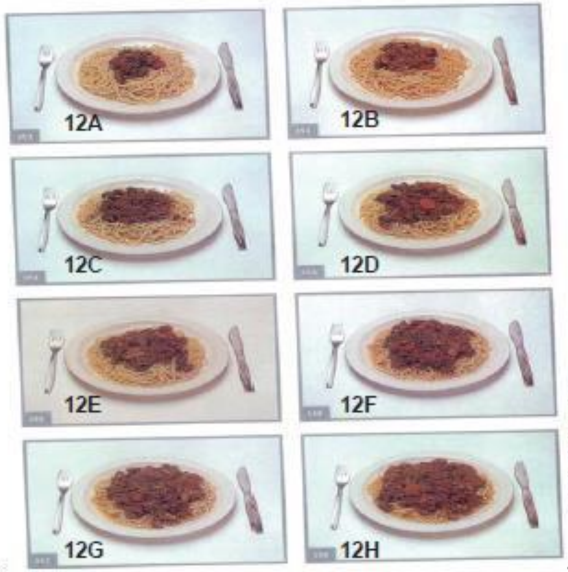
Cheese

11



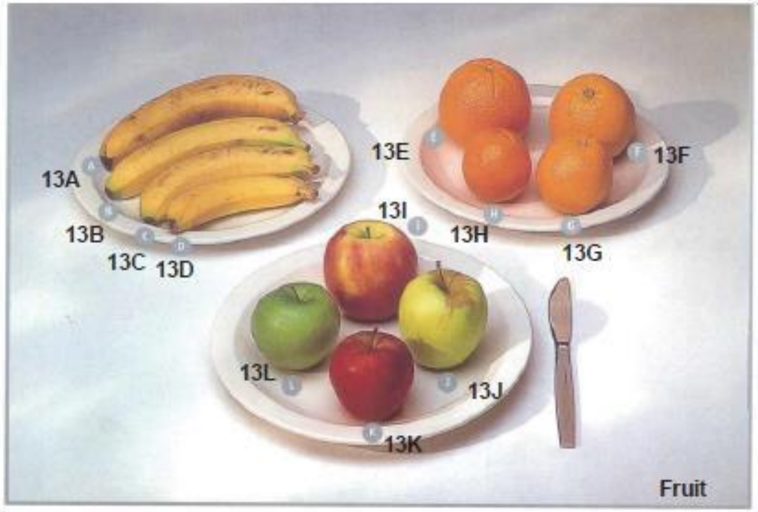
Meat

12

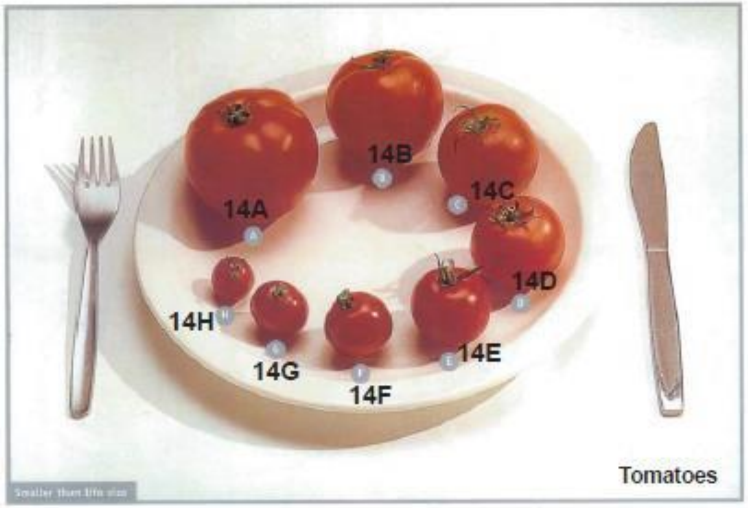


Pasta and Mince or Stew

13



14



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Appendix I: Assumptions for dietary intake entry

Food	**Assumption**
Teaspoon	5g
Dessertspoon	10g
tablespoon	15g
Pint	450ml
Punnet	125g
Almond milk	Soy milk
Oat milk	Rice milk
Milk	Select Auckland, May option
Silver top milk	4% of total amount entered as cream, the rest as whole milk
Tea	All as (Tea, herbal, ready to drink) except for black and fruit tea
Red wine	All as (Wine, red, medium)
White wine	All as (Wine, white, medium)
Coffee	Small 200ml = 30ml espresso + 170ml milk Medium 300ml = 60ml espresso + 240ml milk Large 400ml = 90ml espresso + 310ml milk
Oil	Composite if not specified
Aioli	Mayonnaise commercial
Salt/pepper	A pinch is 1/16 tsp (≈ 0.0625tsp) Use table salt unless otherwise specified
Spice	All as (Allspice, ground)
Peanut butter	Select salt and sugar added option unless otherwise specified
Chewy gum lollies	Fruit gums
Raw meat	70% of the weight of raw meat is the weight of cooked meat when cooked weight is not specified
Raw vegetables	80% of the weight of raw vegetables is the weight of cooked vegetables when cooked weight is not specified
Capsicum	Yellow → green Orange → red
Lettuce	All as (Lettuce, Cos)
Kale	All as (Brussel Sprouts, inner leaves, raw)
Rice	100g raw rice yield 243g by boiling
Pasta	100g raw pasta yield 243g by boiling
Potato	100g raw potato yield 97g by boiling
Kumara	100g raw kumara yield 103g by steaming
Pumpkin	100g raw pumpkin yield 84g by steaming
Canned fish	Drained weight = 80% of original amount
1 Regular KFC chips	120g
1 Regular KFC chicken bites	159g

Food	Assumption
Miso soup	1tsp miso + 1 cup water
Black forest cake	75g chocolate cake + 15g cream + 10g berry jam
Mixed berries(100g)	33g blueberry + 33g raspberry + 34g boysenberry (all frozen)
Regular hot chocolate (250ml)	3tbs drinking chocolate powder + 230ml milk