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# **Sensory perceptions of oral nutritional supplements by older adults**

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This thesis is submitted to University College Dublin in fulfillment of the requirements for the degree of Doctor of Philosophy (PhD)



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September 2021

## **DECLARATION BY THE CANDIDATE**

I hereby certify that the submitted work is my own work, was completed while registered as a candidate for the degree stated on the Title Page, and I have not obtained a degree elsewhere on the basis of the research presented in this submitted work

---

Emma Regan

September 2021

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## List of Abbreviations

A-TDL	Alternated Temporal Drivers of Liking
ANOVA	Analysis of Variance
CATA	Check-all-that-apply
CATA-I	Check-all-that-apply with ideal
gLMS	general Labelled Magnitude Scale
gDOL	generalized Degree of Liking scale
IPM	Ideal Profile Method
Medications DMAT	Medications with associated Dry Mouth or Altered Taste
MPI	Milk Protein Isolate
MMSE	Mini Mental Scale Exam
ONS	Oral Nutritional Supplements
O/W	Oil-in-water emulsion
PCA	Principal Component Analysis
SEM	Standard Error of the Mean
TCATA	Temporal Check-all-that-apply
TDS	Temporal Dominance of Sensations
VAS	Visual Analogue Scales
W/O	Water-in-oil emulsion
WPI	Whey Protein Isolate

## Abstract

Oral Nutritional Supplements (ONS) combined with dietary counselling have proven clinical benefits in improving nutritional status and alleviating undernutrition in older adults. However, ONS are often associated with negative sensory experiences and as a result poor adherence has been reported. This thesis evaluated the sensory perception and liking of ONS in older adult cohorts with a view to improving adherence. Different sensory methodologies were used to test their appropriateness for older adults, thus advancing sensory science methodology for this population cohort.

Initially, Chapter 2 sought to measure the effectiveness of the Check-all-that-apply (CATA) methodology to investigate the differences in sensory perception of ONS between younger (aged 18-35 years) and community dwelling older adults (aged 65+ years) over successive sips of a full volume of two ONS (one high viscosity and one low viscosity). The study also sought to measure the effects of ONS consumption on thirst, hunger, and fullness. The results indicated significantly lower levels of hunger and thirst in the older cohort than the younger cohort. Hunger sensations decreased with consumption volume of ONS while the thirst sensations increased significantly with increasing consumption volume in both age cohorts. Significant differences in texture perception with age were observed with the younger cohort selecting 'Watery' significantly more than the older cohort for ONS 1 and 'Thick' and 'Viscous' significantly more for ONS 2. The study showed that the CATA methodology is appropriate for use with older adults. The findings enhanced the understanding of how an older population experience ONS and drivers of 'liking'. This information has the potential to enhance ONS adherence and ultimately improve the nutritional status of older people.

The work from Chapter 2 provided important insight on the sensory perception of ONS between older and younger adult cohorts, but few studies have examined ONS within the different older adult cohorts. Chapter 3 therefore sought to investigate the effects of older age, dentures, and medications on sensory perception, liking, and intake of a high and low viscosity ONS and assess the effects of ONS consumption on appetite. The results revealed that over 75 year olds had significantly lower appetite than the 65–74 year olds on tasting both ONS. Denture wearing influenced

the mouthfeel while medication status effected the flavour perception of the high viscosity ONS. Liking did not change across the five sips for any study cohort, however, sensory perception changed with increasing sips. This study provided insight on factors affecting ONS adherence in older adults. Avoiding perceptions of watery/runny mouthfeel while maintaining creaminess may improve acceptability and adherence. The study builds on the findings of Chapter 2 by justifying the CATA methodology for use in different older adult cohorts.

Chapter 2 and 3 offered interesting insight on the differences in texture perception with age and highlighted the importance of mouthfeel attributes in driving ONS liking and disliking. Therefore, Chapter 4 built on this work by investigating the differences in dynamic texture perception between older (aged 65+ years) and younger (aged 18-35 years) adults across a range of texturally modified ONS. To develop nutritional beverages for older adults, understanding their dynamic sensory perception is vital. Limited research has used Temporal Dominance of Sensations (TDS) methodology to evaluate the dynamic texture perception of beverages with older adults. Therefore, Chapter 4 also sought to measure the effectiveness of this methodology in evaluating the dynamic texture perception of ONS in older adults. The results from this chapter revealed that older adults indicated significantly fewer dominances based on significantly fewer attributes, waited significantly longer before selecting their first attribute, and for each attribute selection generally. However, TDS curves with distinct peaks were generated by both age cohorts, with similarities in dominant texture attributes. The low viscosity ONS were perceived similarly by the two age cohorts. Older adults perceived the high viscosity supplements significantly 'Sweeter', 'Smoother', and 'Creamier' in the second half of the tasting sequence than younger adults who more often referred to 'Aftertaste', 'Mouthcoating', and 'Thick'. The older adults liked high viscosity supplements significantly more than the younger adults. This chapter justifies the TDS methodology for dynamic evaluations of beverage products with older adults.

Chapter 2 highlighted that thirst sensation increases with ONS consumption. This combined with older adults' tendency to suffer from diminished thirst sensation may contribute to reduced liking and adherence of ONS. Chapter 5 therefore aimed to investigate how alterations in the viscosity profiles, protein content, and sweetness of ONS impact on thirst, mouth-drying, pleasantness to consume water, and taste in

mouth after consumption of ONS. In addition to this the study cohort was segmented into different subgroups to see if factors such as age, dentures, medication status, gender, or salivary flow rate have an impact on thirst. Osmolality of each of the ONS was measured and salivary flow rates were recorded. The results indicated that most of the study cohort were suffering from diminished thirst sensation and had low salivary flow rates. Each of the ONS were hypertonic solutions which may be a contributing factor to the increased thirst experienced after ONS consumption. The 5 % Milk Protein Isolate (MPI) and 5 % Whey Protein Isolate (WPI) ONS had significantly higher osmolality than the other ONS. Thirst ratings before and after tasting the ONS were low. Protein type and content, viscosity, and sweetness did not significantly impact the thirst, mouth-drying, taste in mouth, and pleasantness for water consumption after consuming the ONS. However, the Visual Analogue Scales (VAS) used in this study may lack the sensitivity to describe changes in thirst, mouth-drying, taste in mouth, and pleasantness for water consumption across the different ONS. Further research is warranted to compare the use of the VAS with an alternative method such as a paired comparison test. Significant differences between subgroups of the cohort were observed. Non-denture wearers and individuals taking no medications reported significantly higher thirst after consuming the sweetened ONS compared to those wearing dentures and taking medications respectively. Female panellists had significantly higher ratings for pleasantness to consume water after the sweetened ONS and liked these ONS less than male panellists. Therefore, the chapter further enhanced the understanding of how different cohorts of older adults experience ONS.

# **Chapter 1**

## **Literature Review**

# Chapter 1: Literature Review

## 1.1 Introduction

Global life expectancy has increased significantly in recent years (United Nations, 2019). This increase, coupled with falling fertility rates, has led to rapid ageing of the global population (World Health Organisation, 2017). As a result, the population of individuals aged 65 years or older is growing annually and is predicted to rise from its 2019 level of 703 million persons to 1.5 billion by 2050, accounting for 16 % of the global population (United Nations, 2019). With increasing global life expectancy, it is often assumed that older adults will live longer lives in good health, however, this is not necessarily the case. Malnutrition remains a common concern in the over 65s age group and is impacting negatively on the health of older adults on a global scale (Kaiser *et al.*, 2010; Kvamme *et al.*, 2011). Malnutrition is described as an imbalance in nutrient intake (either excessive or insufficient) which causes alterations in body form and function leading to many adverse health effects (Stratton, Green and Elia, 2003; Lochs *et al.*, 2006; Canadian Malnutrition Task Force, 2015). The predominant form of malnutrition in the elderly stems from reductions in food and caloric intake (undernutrition), with 5-10 % of community dwelling older adults reported to suffer from undernutrition (Doets and Kremer, 2016; Bardon *et al.*, 2020). There are several contributing factors which are thought to lead to such reductions in food intake from psychological and environmental factors such as loneliness, isolation, and financial circumstances to physiological factors, decreased physical activity, and changing energy requirements (Smoliner *et al.*, 2008). Undernutrition has many associated negative health effects such as sarcopenia, osteoporosis, increased frailty, decreased functional competence, and a general increase in morbidity and mortality (Kaiser *et al.*, 2010; Kennedy *et al.*, 2010; Kvamme *et al.*, 2011; Field and Duizer, 2016; Song *et al.*, 2016). These negative effects of undernutrition are linked with increased general practitioner and outpatient visits, in addition to increased hospital admissions (Bardon *et al.*, 2020), placing an economic burden on healthcare systems (Abizanda *et al.*, 2016; Volkert *et al.*, 2019).

Given the extent and severity of some of the issues relating to undernutrition and due to the predicted population increase of this age category, it is becoming increasingly important for food researchers to understand the factors that influence

food and caloric intake in older adults to combat this growing concern (Field and Duizer, 2016). There are many factors influencing food choice and intake; social, cognitive state, financial conditions, culture, and health, to name but a few (Pereira and Van der Bilt, 2016). One predominant factor influencing food choice is sensory perception of foods (Field and Duizer, 2016). Sensory perception of foods occurs throughout oral processing and incorporates a myriad of sensations; taste, smell, touch, sight, and sound (Delwiche, 2004). With increasing age sensory function and perception decline, often leading to a reduction in food intake. A detailed understanding of age associated alterations in sensory perception is essential for developing food products for this age cohort that are both suitable from a nutritional point of view and are also appealing to consume. This review will provide a detailed overview of the age-related physiological changes which affect the sensory perception, liking, and overall intake of foods in older adults.

One approach to managing and alleviating undernutrition in older adults is through the prescribing of Oral Nutritional Supplements (ONS) (Lochs *et al.*, 2006; Özçağlı, Stelling and Stanford, 2013). ONS are predominantly emulsion based ready-made, auxiliary liquid, semi-solid, or powder style dietary food products which are specifically designed to counteract malnutrition by delivering essential macronutrients, micronutrients, and calories in a small food portion (Lochs *et al.*, 2006; Stratton and Elia, 2010; British Association of Parenteral and Enteral Nutrition, 2016). While prescribing ONS coupled with dietary counselling has been shown to successfully manage undernutrition in older adults (Agarwal *et al.*, 2013), this can only be achieved if the full prescribed amount is consumed (Rahemtulla *et al.*, 2005; Özçağlı, Stelling and Stanford, 2013; Thomas *et al.*, 2016). However, poor adherence to ONS has been reported in both community and non-community dwelling older adults (Gosney, 2003; McMurdo *et al.*, 2009; Özçağlı, Stelling and Stanford, 2013). This poor adherence to ONS is partly attributed to undesirable sensory properties as well as issues of sensory fatigue, and build-up of unpleasant taste, aftertaste, and mouthfeel attributes with ONS consumption volume (Gosney, 2003; Rahemtulla *et al.*, 2005; Methven *et al.*, 2010; Nieuwenhuizen *et al.*, 2010). Low ONS adherence in older adults could also relate to changes in sensory perception with age. With this in mind there is a need to understand in as much detail as possible the different factors

which influence the perception and liking of ONS in older adults in order to improve adherence. This is the focus of the research completed in this thesis.

To set the scene for this work this literature review will begin by discussing the global older adult population followed by a detailed overview of the age-related alterations in the sensory perception, liking, and overall intake of foods in older adults. Subsequently, the challenges associated with conducting sensory analysis in older adults and the application of different sensory methodologies for understanding the age-related perceptual changes will be discussed. In the final section of this review the current methods of alleviating undernutrition will be examined, as will the potential application for the design of innovative food structures such as emulsions to alleviate undernutrition.

## **1.2 Older adults**

As previously mentioned, the global population is currently undergoing significant ageing and as a result the population of older adults is increasing on a global scale (United Nations, 2019). It has been reported that in this day and age the majority of individuals globally will live to 60 years of age and older (United Nations, 2007; World Health Organisation, 2018), with persons aged 65 years in the years 2015 to 2020 expected to survive an additional 17 years, particularly in the worlds more developed regions (United Nations, 2019). Ageing is not only happening within the global adult population but also within the older adult population itself (United Nations, 2013). The population of individuals aged 80 years and older in many countries is the fastest growing population segment (Kremer, 2006), with the proportion of individuals aged 80 years predicted to reach 830 million by the year 2100 which is seven times the recorded number in 2013 (United Nations, 2013).

There is no standardised definition for older adults, however, in developed countries the ages of 60+ and 65+ years are most commonly used and accepted definitions of 'elderly' or 'older adults' (World Health Organisation, 2002). For the purpose of this thesis the term 'older adults' will refer to those aged 65 years and older. Often older adults are classified as one population cohort; however, older adults are not considered to be a homogeneous group (Binstock, 1985; Seccombe and Ishiikuntz, 1991). Older adults are highly diverse not only from a physiological perspective but also from a psychological, sociological, and functional perspective

(Seccombe and Ishii-Kuntz, 1991; World Health Organisation, 2015). For example, individuals that are aged 85 years and older are more likely to suffer ill health, declining mental capacity, and require help to perform basic activities than individuals that are under the age of 85 years (Seccombe and Ishii-Kuntz, 1991). Therefore, rather than making assumptions about older adults as one collective group it is important to study the different sub-groups of older adults in detail and independently of one another. While there are many different methods of classifying this population cohort, one commonly used method is to divide older adults into different sub-groups based on age: the young-old (65-74 years), the middle-old or old-old (75-84 years), and the oldest-old (85+ years) (Seccombe and Ishii-Kuntz, 1991; Zizza, Ellison and Wernette, 2009; Murphy and Vertrees, 2017; Lee *et al.*, 2018).

### **1.3 Sensory perception in the older adult**

Given the rise in global life expectancy it is growing increasingly important to ensure that the older adult population cohort remain both healthy and functional (Mathers, 2015; Bardon *et al.*, 2020). However, in general an individual's health will often as not decline with age (Mena *et al.*, 2020), with issues such as malnutrition remaining highly prevalent in this population cohort (Kaiser *et al.*, 2010; Kvamme *et al.*, 2011; Bardon *et al.*, 2020). Good nutrition plays a major role in improving the health of older adults as they progress through life (Mena *et al.*, 2020). Therefore, it is important to understand the different factors that are controlling both food choice and intake in older adults to combat these growing health concerns (Kvamme *et al.*, 2011; Field and Duizer, 2016). How an individual perceives their food from a sensory point of view plays a significant role in driving their liking and intake of foods not only from a quantity perspective but also from a quality perspective (Doets and Kremer, 2016; Field and Duizer, 2016). The sensory perception of foods is a complex process that incorporates the stimulation of all five sensory systems: taste, smell, touch, sight, and sound (Delwiche, 2004). As individuals age numerous physiological and non-physiological factors can lead to an impairment in the sensory perception of foods. This impairment of sensory perception particularly in relation to taste and smell with increasing age often reduces food interest, liking, and enjoyment leading to an overall reduction in food intake (Doets and Kremer, 2016; Methven, Jimenez-Pranteda and Lawlor, 2016). The most important senses when it comes to food

perception are the senses which provide information about flavour (Nordin, 2017). Therefore, the effects of ageing on taste perception and olfactory perception will be discussed below. In addition to this the effects of ageing on oral somatosensory perception will be discussed as will the oral processing of foods by older adults, and food liking in older adults.

### **1.3.1 Taste perception**

The gustatory system plays a critical role in the flavour perception of foods and beverages. Taste is the perception which is experienced when nutrients, chemicals, or other substances in the mouth react with taste receptor cells (Breslin, 2013). Taste receptor cells are located in the taste buds which are found in different types of taste sensitive areas known as papillae within the mouth, on the tongue and soft palate (Kremer, 2006; Doets and Kremer, 2016; Field and Duizer, 2016). When an individual consumes a food, it is chewed and dissolved into the saliva where it is partially digested by salivary enzymes (Breslin, 2013). It is at this point that different tastants or taste stimuli are released into the saliva, where they travel through salivary secretions and mucus to the taste buds (Kremer, 2006; Breslin, 2013). In the taste buds these taste stimuli then interact with their specific taste receptors cells which evokes a taste sensation (Kremer, 2006; Scanlon and Sanders, 2010; Doets and Kremer, 2016; Field and Duizer, 2016). Not only is taste important in flavour perception, but it is also vital in the differentiation of foods that are safe for consumption and those that are not. Taste also plays an extremely important role in the regulation of swallowing and salivation and is a critical driving factor behind the motivation for eating (Frank, Hettinger and Mott, 1992).

It is possible for individuals of all ages to suffer from loss of taste perception; however, the prevalence is much higher in the over 65 age category (Song *et al.*, 2016). Loss of taste perception is generally categorized into three different groups based on the level of deterioration; ageusia (total loss of taste), hypogeusia (reduced ability to taste), and dysgeusia (distortion of taste) (Sanders, Ayers and Oakes, 2002; Schiffman, 2009). As an individual ages, numerous physiological changes can occur within the oral cavity (Imoscopi *et al.*, 2012), which can contribute directly to the increased prevalence of taste disorders and impairment of taste perception in older adults. Typically, the life span of taste buds is approximately 8-12 days (Feng, Huang and Wang, 2014; Doets and Kremer, 2016), however, the ageing process can disrupt

the regeneration of taste buds and cause a loss in taste bud homeostasis (Chandrashekar *et al.*, 2006; Field and Duizer, 2016). This disruption of taste bud regeneration may lead to reduced numbers of taste buds in older adults, particularly those within the middle-old adult cohort (Zizza, Ellison and Wernette, 2009) with previous research reporting that the number of taste buds located in the circumvallate papillae decreased substantially in 74-85 year olds (Arey, Tremaine and Monzingo, 1935; Shimizu, 1997; Feng, Huang and Wang, 2014). In addition to this, the density of taste buds in the epithelium has also been reported to decrease in older adults (Shimizu, 1997; Kano *et al.*, 2007; Feng, Huang and Wang, 2014). It would be expected that the loss in taste bud homeostasis and the diminished taste bud density associated with ageing would contribute largely to the age associated impairments in taste perception. This, however, may not be the case as other studies have reported minimal to no loss in the total number of human taste buds with ageing (Seiberling and Conley, 2004; Kremer, 2006; Doets and Kremer, 2016). Despite these conflicting views what is clear is that the regeneration of taste cells within the taste buds has been reported to change or decrease with age (Feng, Huang and Wang, 2014). Therefore, it is probable that the age related alterations in taste cell regeneration combined with changes in the taste cell membrane may be responsible in part for the impairment in taste perception with age (Kremer, 2006). Other physiological changes within the oral cavity that may affect taste perception include the thinning and drying of mucosae as a result of declining keratinization (Imoscopi *et al.*, 2012), the reduction in the amount of saliva and alterations in the amino acid composition of saliva (Doets and Kremer, 2016), and the replacement of acini in the salivary glands with fibrous connective tissue (Imoscopi *et al.*, 2012).

In addition to physiological changes, some non-physiological factors may also contribute to taste impairment and taste disorders in older adults. Medications for one are considered one of the most significant contributors to taste disturbances and taste disorders in older adults (Tomita and Yoshikawa, 2002; Schiffman, 2009; Ogawa *et al.*, 2017). It is estimated that over 170 drugs can affect taste (Tomita and Yoshikawa, 2002), these include cardiovascular drugs, anti-inflammatory drugs, anti-depressants/anti-psychotic drugs, antibiotics, and metabolic drugs all of which are commonly prescribed drugs in older adults (Imoscopi *et al.*, 2012). As an individual ages their likelihood of suffering from chronic diseases increases resulting in an

increase in medication use with age (Ogawa *et al.*, 2017). This increase in medication use can be seen particularly in the middle-old (Zizza, Ellison and Wernette, 2009) and the oldest-old (85+ years) adult cohorts. In Ireland alone it is estimated that 90 % of those aged over 75 years are taking medications on a regular basis (Richardson *et al.*, 2012). Not only does the likelihood of medication use increase with age but so too do the number of medications used by older adults. Polypharmacy refers to the use of five or more medications by one single individual (Fulton and Riley Allen, 2005; Morin *et al.*, 2018). Morin *et al.* (2018) previously reported an increase in the incidence rate of polypharmacy from 16.8 % in 65-74 year olds to 33.2 % in individuals aged over 96 years. This increase in polypharmacy with age will have a negative effect on taste perception as evidenced by previous research which reported that complaints of dysgeusia and threshold level taste losses were highest in older adult cardiovascular patients who were taking the greatest number of medications (Schiffman, 2007). Other common contributors to taste disorders and taste impairment in older adults are poor oral hygiene resulting in various oral diseases (Boyce and Shone, 2006; Imoscopi *et al.*, 2012; Field and Duizer, 2016), systemic diseases such as hyper/hypothyroidism, pulmonary disease, cancer, Alzheimer's disease, and hypertension (Imoscopi *et al.*, 2012), zinc and vitamin B deficiencies, smoking, and excessive alcohol consumption (Fukasawa *et al.*, 2005; Vellappally *et al.*, 2007; Imoscopi *et al.*, 2012).

The sense of taste encompasses five taste elements: bitter, salty, sour, sweet, and umami (Doets and Kremer, 2016; Field and Duizer, 2016; Song *et al.*, 2016). A large and growing body of literature has investigated the changes in the perception of these five taste components with age. Much of this literature pays particular attention to taste detection thresholds (Methven *et al.*, 2012). Of these studies the majority have reported that taste detection thresholds for all five taste elements (bitter, salty, sour, sweet, and umami) increase with age, with some increasing up to two-fold (Methven *et al.*, 2012; de Souza *et al.*, 2013; Doets and Kremer, 2016; Field and Duizer, 2016). This decline in taste perception has many negative implications for the older adult. For example, older adults may require higher levels of salt and sugar to recognise a sense of saltiness or sweetness, this in turn may cause individuals to use excessive amounts of salt, sugar, and sweeteners to improve food flavour

leading to higher incidences of cardiovascular diseases, obesity, and diabetes (Imoscopi *et al.*, 2012).

The review of Methven *et al.* (2012) highlighted that while much of the available literature has reported that taste detection thresholds increase with age, some studies have found no effects for some of the taste modalities, while one study reported a decrease in taste-detection thresholds with age. These contradictory findings may be explained by the variation in study cohorts in terms of age and gender ratios in addition to differences in participant inclusion and exclusion criteria such as denture wearers (Methven *et al.*, 2012). This highlights the heterogeneity among older adult cohorts emphasising the importance for studying the sensory perception of foods and beverages within different segments of older adult cohorts such as the young-old (65-74 years), the middle-old (75-84 years), the old-old (85+ years), medication users, non-medication users, denture wearers, and non-denture wearers as opposed to grouping all older adults together as one cohort.

### **1.3.2 Olfactory perception**

The olfactory system also plays an imperative role in the flavour perception of foods and beverages. When an individual consumes a food or beverage different volatile odour components and flavours are released which enter the nose through the nostrils by sniffing (orthonasally) or the oral cavity by chewing (retronasally). These volatile components then combine with their specific olfactory receptors which send a signal to the brain (Duffy, Backstrand and Ferris, 1995; Doty and Kamath, 2014; Field and Duizer, 2016).

Similar to taste perception it is well documented that olfactory function declines as an individual progresses through life (Seo and Hummel, 2009). Early research reported that up to half of the older adult population experience olfactory impairment on a major level (Doty *et al.*, 1984), with more recent research reporting that one in four older adults may experience olfactory dysfunction (Karpa *et al.*, 2010; Sulmont-Rosse *et al.*, 2015). This decline in olfactory function is evident particularly around 50-60 years of age, however, it has been reported to decline further as an individual progresses past 70 years of age (Hori, Matsuda and Ichikawa, 2015). There are numerous different factors both physiological and non-physiological which are thought to contribute to this decline in olfactory function with age. Physiological factors include but are not limited to; changes in the olfactory tissue, a decline in

olfactory receptors, and a decrease in the size of the olfactory bulb (Field and Duizer, 2016). Other non-physiological factors include environmental factors such as overexposure to toxins (Field and Duizer, 2016) and different diseases such as cancer, liver disease, rhinosinusitis, Alzheimer's disease, Parkinson's disease, cardiovascular disease, and allergies (Schubert *et al.*, 2012; Field and Duizer, 2016). Finally, like taste perception a number of different medications can alter olfactory perception (Schiffman and Graham, 2000).

Olfactory dysfunction in older adults has many associated negative effects such as reduced flavour perception of foods, possibly having a direct effect on food liking and thus intake, with one study reporting that 29 % of older adults with olfactory dysfunction consumed less food (Aschenbrenner *et al.*, 2008). Therefore, it is important to come up with strategies to counteract these negative effects. One approach is through the flavour enhancement of foods however this lacks scientific support (Kremer, Holthuysen and Boesveldt, 2014).

### **1.3.3 Oral somatosensory perception**

Oral somatosensory perception refers to the perception of the somatic sensations within the mouth including texture, temperature, and trigeminal sensations all of which provide an individual with information on the structure and feel of a food within the mouth (Haggard and de Boer, 2014; Doets and Kremer, 2016).

Food texture is an important driving factor behind food liking and acceptance (Guinard and Mazzucchelli, 1996; Roininen *et al.*, 2003). For older adults in particular food texture is very important, as greater focus is often given to food texture to compensate for the declining flavour perception which occurs with age (Szczesniak, 1990; Forde and Delahunty, 2002; Withers, Gosney and Methven, 2013). Food texture has previously been defined by Szczesniak (2002) as "the sensory and functional manifestation of the structural, mechanical, and surface properties of foods detected through the senses of vision, hearing, touch, and kinesthetics". Oral texture perception is dependent on numerous components of the masticatory system including the lips, tongue, saliva, and cheeks (Mioche, 2004; Song *et al.*, 2016). As an individual ages numerous physiological changes occur within the oral cavity that can cause alterations in food texture perception. These physiological changes include age related impairments in dental health such as increased rates of tooth loss, flattening of teeth, and an increase in tooth wear (Mioche, 2004; Polzer,

Schimmel and Biffar, 2010; Field and Duizer, 2016). Reductions in saliva production and flow, and xerostomia (dry mouth) are also commonly associated with ageing (Affoo *et al.*, 2015), in addition to impaired oral health status (Field and Duizer, 2016), and alterations in saliva composition and chewing efficiency (Doets and Kremer, 2016).

Even though texture perception is one of the most important contributors to food acceptability particularly in older adults, there are limited studies which have investigated the effects of age on food texture perception (Field and Duizer, 2016; Shupe, Resmondo and Lockett, 2018). Of the limited studies a number have reported changes in food texture perception with age. Forde and Delahunty (2002) reported that older adults found it more difficult to rate differing textures than younger adults and were less capable of discriminating between the different textures. Other researchers reported lower creaminess perception in older adults than in younger adults (Kremer, Mojet and Kroeze, 2005; Kremer, Mojet and Kroeze, 2007). Older adults have also been shown to perceive attributes such as elasticity and fattiness as less intense than younger adults (Kremer, Mojet and Kroeze, 2007). While hardness has been recognised as a more dominant attribute in older adults than younger adults (Hutchings *et al.*, 2014a). Not only have differences in texture perception with age been reported but differences in food texture preferences have also been observed with age. Roininen *et al.* (2003) reported that younger adults preferred rough, crispy, crunchy, and hard textures compared to older adults who preferred textures that are easy to eat. Although, it is important to note that while the older adults preferred easy eating experiences this was only to a certain degree, with textures such as very soft and very smooth not being appreciated by this cohort (Roininen *et al.*, 2003).

Taking all the above into consideration it is evident that changes in both texture perception and preferences are observed with older age, however, most of this research has been conducted with solid foods. To date little attention has been paid to the effects of ageing on the texture perception and preferences of liquid products. Of the limited research that is available, one study using corn syrup solutions found that viscosity perception declined with age (Smith *et al.*, 2006), while another study found no decline in texture perception with age but did report a greater sensitivity for mouth-drying which was enhanced by ageing (Withers, Gosney and Methven, 2013).

Further research in this area is increasingly important given the importance of beverage products such as ONS in alleviating undernutrition and thus enhancing the health of older adults globally. Previous research has reported texture as a driver for reduced liking of ONS in older adults (Gosney, 2003; den Boer, Boesveldt and Lawlor, 2019). Therefore, understanding the texture perception and preferences of beverage products in older adults would not only be of benefit from an academic point of view but would also provide important information for manufacturers to promote enjoyment and nutrient intake in older adults.

#### **1.3.4 Oral processing of foods**

The oral processing of foods is essential in food consumption and plays a critical role in aroma, taste, and texture perception in addition to the appreciation and sensory pleasure of foods (Chen, 2009; Field and Duizer, 2016; Vandenberghe-Descamps *et al.*, 2016). Food and beverage oral processing involves several steps: ingestion, processing, and swallowing. As an individual ages changes in dental status and oral physiology are commonly reported (Ketel *et al.*, 2019; Ketel *et al.*, 2020). These changes will influence each of the steps in food oral processing leading to changes in food perception, liking, and preference in this age cohort.

The teeth play a critical role in food oral processing through the mastication and breakdown of foods (Field and Duizer, 2016). As previously mentioned, (Section 1.3.3) tooth loss rates are increased with age with previous research reporting that 7 % of individuals aged 54-64 years had no natural teeth compared to 40 % of individuals aged over 75 years (Sheehan, McGarrigle and O'Connell, 2017). Teeth will also become much flatter with age and may even have chips and fracture lines due to wear and tear over the years (Polzer, Schimmel and Biffar, 2010; Field and Duizer, 2016; Lamster *et al.*, 2016). These two adaptations make masticatory function more difficult and less effective in this population group (Field and Duizer, 2016). As a result, there is an increased likelihood that old-old (75-84 years), and oldest-old (85+ years) adults will require partial or full dentures to replace missing teeth. However, dentures do not match the masticatory performance of natural teeth, as the ability to reduce particle size is poorer and longer chewing durations and chewing strokes are required to reach a point at which the bolus is safe to swallow (Hildebrandt *et al.*, 1997; Mishellany-Dutour *et al.*, 2008). As a result, elderly individuals have a higher tendency to consume foods which require minimum

chewing (Amarya, Singh and Sabharwal, 2015). Dentures have also been reported to limit the ability to move foods around the mouth which in turn will cause less stimuli to reach the palate papillae (Duffy, Cain and Ferris, 1999; Withers, Gosney and Methven, 2013). This will have a direct impact on the oral processing of liquids as this process mainly involves the movement of fluids from the front to the back of the mouth (Ketel *et al.*, 2019). As a result of this, previous research has suggested that denture wearers may regard mouthfeel attributes of beverages as more important (Withers, Gosney and Methven, 2013), however, further research in this field is warranted.

Saliva also plays an important role in food and beverage oral processing and consumption (Chen, 2009). Saliva not only aids food bolus formation and lubrication for safe swallowing (Field and Duizer, 2016; Vandenberghe-Descamps *et al.*, 2016), it also drives food and beverage acceptance through the modulation of texture, taste, and aroma perception, as well as aiding oral clearance therefore protecting oral and dental health (Vandenberghe-Descamps *et al.*, 2016). Despite its importance in food and beverage oral processing, little research has focused on the influence of ageing on food oral processing through salivation, with the majority of research focusing on mastication (Vandenberghe-Descamps *et al.*, 2016). A decrease in saliva production and an overall reduction of salivary flow is associated with ageing (Affoo *et al.*, 2015; Field and Duizer, 2016) as well as an increase in xerostomia (dry mouth) (Locker, 1995; Field and Duizer, 2016). In addition to this individuals taking higher numbers of medications are more likely to suffer from dry mouth (Hori, Matsuda and Ichikawa, 2015), and as previously mentioned (Section 1.3.1) the likelihood of medication use increases with age particularly past 75 years. Such issues related to salivary output in elderly individuals can lead to problems such as difficulty swallowing and oral processing, which will have a direct effect on food and beverage enjoyment (Bourdiol, Mioche and Monier, 2004; Field and Duizer, 2016).

The tongue and the muscles in the jaw are vital in effective food oral processing. As an individual ages the onset of sarcopenia (muscle loss) is frequently observed. Sarcopenia has an effect on the muscles in the tongue causing weakness which affects the ability of an individual to effectively process and swallow food (Alsanei and Chen, 2014). Sarcopenia can also affect the muscles in the jaw which will have a direct impact on bite force (Field and Duizer, 2016). As a result, an

individual is required to increase their level of chewing and overall duration of chewing, both of which will only be appropriate in an individual with proper dentition (Mishellany-Dutour *et al.*, 2008; Field and Duizer, 2016).

Taking the above into consideration it is evident that older age can affect the oral processing of foods in a number of different ways. If individuals cannot process their foods adequately this can lead to reduced food intake (Gray-Stuart, Jones and Bronlund, 2017; Krop *et al.*, 2018; Ketel *et al.*, 2020). Therefore, it is essential for foods for older adults to be tailored to meet these issues. The rheological properties of liquid foods and the mechanical properties of solid foods directly influence their oral processing behaviour and their eating rate (Wee *et al.*, 2018; Aguayo-Mendoza *et al.*, 2019; Ketel *et al.*, 2020). The manipulation of the texture profiles and viscosity of food and beverages for older adults will therefore improve their uptake (Ketel *et al.*, 2020). However, to effectively tailor foods and beverages towards the changes in both mastication and salivation it is important to understand the oral processing behaviour of these texturally manipulated foods in the different cohorts of older adults such as denture wearers and individuals to report suffering from dry mouth or taking medications causing dry mouth. This remains an area for further research, with particular attention required with liquid products, as little research has focused on the oral processing behaviour of liquid and semi-solid food products (Ketel *et al.*, 2020).

### **1.3.5 Food liking in older adults**

The age related alterations in sensory perception may have a direct impact on the pleasantness of food and beverages and therefore their liking and enjoyment in the older adult cohort (Doets and Kremer, 2016). A change in food liking and enjoyment in the older adult may influence their motivation to eat, leading to a reduction in the intake of certain groups of food and beverages in this population cohort (Doets and Kremer, 2016). As a result, there is a growing requirement for further understanding of the factors driving liking and disliking of foods and beverages in older adults. Furthermore, future research should focus on different segments of the older adult population cohort (Field and Duizer, 2016) as it is evident from the above discussions that not all older adults may perceive food and beverages the same (Section 1.3.4). For example, denture wearers may have different drivers of liking for foods and beverages than non-denture wearers as these individuals may place greater importance on mouthfeel attributes of beverages (Withers, Gosney and Methven,

2013). This information will be important for future food design strategies for older adults.

## **1.4 Sensory methodologies in the older adult**

Due to the impairments in sensory function with age there is a growing requirement for the development of food products with optimum sensory profiles for older adults. To drive these food design strategies, it is essential to conduct sensory evaluations with older adults as this will improve the understanding of their sensory perception and preferences (Maitre, Symoneaux and Sulmont Rosse, 2015; Methven, Jiménez-Pranteda and Lawlor, 2016). However, this remains a largely under researched field of sensory science due to the different challenges that are associated with this group (Methven, Jimenez-Pranteda and Lawlor, 2016). Several questions remain unanswered at present as to which sensory methods can be deemed appropriate for use with older adult cohorts. The following section will discuss the challenges in conducting sensory analysis with older adults and the practical recommendations for counteracting these challenges when designing sensory tests for this cohort. In addition to this, a number of different sensory methodologies and their use with older adults will be critically reviewed.

### **1.4.1 Challenges in conducting sensory analysis with older adults.**

Conducting sensory evaluations with older adults presents a number of challenges which are not observed with other age groups (Methven, Jimenez-Pranteda and Lawlor, 2016). These challenges must be taken into consideration when designing sensory tests for use with this population cohort. The deterioration of vision is often the most notable of the physiological changes associated with ageing (Methven, Jimenez-Pranteda and Lawlor, 2016). In Ireland alone it has been reported that older adults (>75 years) are twice as likely to report their vision as poor compared to adults aged 50-74 years (Cronin, O'Regan and Kenny, 2011). As a result, older adults may struggle to read sensory questionnaires and instructions (Methven, Jimenez-Pranteda and Lawlor, 2016). This in turn will make it difficult for them to follow, comprehend, and complete sensory questionnaires. Furthermore, raising this issue with the panel leader may result in potential embarrassment for the participant (Maitre, Symoneaux and Sulmont-Rossé, 2015). The participants may therefore continue to use the sensory questionnaire without alerting the panel leader of this

difficulty. This may lead to misuse of the sensory questionnaire, and the ratings or feedback provided may not be truly representative of participant data. It is therefore critical when designing sensory questionnaires for older adults that the print on the scoring sheets, consent forms, information sheets, and any line scales is large and easy-to-read (Maitre, Symoneaux and Sulmont-Rossé, 2015). Hearing impairment is another common complaint associated with ageing. During the ageing process different structural changes occur in the ear which can lead to the onset of hearing loss in older adults (Whitbourne, 2002; Doets and Kremer, 2016). This impairment may cause difficulties in understanding and following instructions, which may lead to the inability to complete the questionnaire in the desired manner (Methven, Jimenez-Pranteda and Lawlor, 2016). To rule out any confusion, test instructions should be delivered both in written form and orally (with clarity and appropriate volume) (Maitre, Symoneaux and Sulmont-Rossé, 2015).

With age comes an increased incidence of cognitive decline. This decline in cognitive function can lead to issues with memory, attention capacity, problem solving, and reasoning (Maitre, Symoneaux and Sulmont-Rossé, 2015). The sensory evaluation of foods requires individuals to form opinions and answer questions on their perceptions and experiences of food and beverages. The question-answer process involves several complex cognitive functions from understanding and interpretation, information retrieval and processing, to judgment and communication (Schwarz and Knäuper, 2005; Kutschar, Weichbold and Osterbrink, 2019). Therefore, a decline in cognitive function may lead to confusion and difficulties in the ability to understand instructions and questions which will have a direct effect on the question-answer process and ultimately the sensory evaluation of food and beverages. In addition to this, problems with attention capacity and memory will make it difficult for older adults to focus on the sensations experienced throughout the tasting of food and beverages which may lead to issues when evaluating their perception. Older adults are also more likely to have slower reaction times than younger adults (Fozard *et al.*, 1994; Deary and Der, 2005; Hutchings *et al.*, 2014a) which may affect their ability to perform dynamic sensory evaluations of foods. Taking all the above into consideration a number of measures should be taken when designing sensory evaluations for older adult cohorts. Firstly, it is critical to ensure that effective pre-screening protocols are followed. The Mini Mental Scale

Examination (MMSE) can be used to evaluate the mental status of older adults (Cheah *et al.*, 2011). This is a rapid test which applies 11 questions that tests all five areas of cognitive function (Cheah *et al.*, 2011). The maximum score in the MMSE is 30, for the purpose of effective sensory evaluations, individuals should score at least 20 in the MMSE (Maitre, Symoneaux and Sulmont-Rossé, 2015). In addition to efficient pre-screening protocols, sensory questionnaires should be designed so that they are easy to follow, and any scales are kept simple (Methven, Jimenez-Pranteda and Lawlor, 2016). Finally, older adults may require longer or shorter evaluation times depending on the methodology being used, and also more training sessions.

Other challenges include reduced dexterity and weakness with age. This may cause problems when holding and handling samples in addition to difficulties in completing the sensory questionnaire (Methven, Jimenez-Pranteda and Lawlor, 2016). This further supports the above recommendation to allow adequate time for older adults to complete the sensory evaluation process. The ability to write may also be affected by age and some elderly individuals may be unable to write (Maitre, Symoneaux and Sulmont-Rossé, 2015). It may therefore be necessary for the panel leader to act as a scribe to these individuals, however, it is important to ensure that the scribe does not influence the individual's answers. Not all sensory evaluations require written questionnaires some sensory evaluations may involve the use of a computer. This presents another set of issues as some elderly individuals may be relatively computer illiterate (Maitre, Symoneaux and Sulmont-Rossé, 2015). As a result, they may be embarrassed and unsure of how to complete the computerised questionnaires and therefore it is important that these individuals are given sufficient training on how to use the computer prior to the sensory evaluation.

A common concern when conducting sensory evaluations with any age group is to minimise risk of choking during the session. As older adults may have dentures or missing teeth their ability to break down certain solid foods is hindered. This coupled with swallowing difficulties and decreased saliva production and flow will increase the risk of choking in this group of individuals. Therefore, when selecting test foods for sensory evaluations with older adults it is important to take this into consideration. The portion size as well as the sample set size must also be carefully considered as older adults have a higher tendency to suffer from digestive issues and may also

become fatigued with large sample sets (Maitre, Symoneaux and Sulmont-Rossé, 2015; Methven, Jimenez-Pranteda and Lawlor, 2016).

Finally, one of the most predominant concerns when conducting sensory evaluations in older adults is the recruitment of participants. With many sensory studies reporting a low number of study participants (Methven, Jimenez-Pranteda and Lawlor, 2016). This will often lead to a lack of study power whereby sensory studies are unable to report significant differences and the results cannot be reported with confidence. Not only is participant recruitment difficult with this population cohort but there are also higher dropout rates with older adults than younger adults (Maitre, Symoneaux and Sulmont-Rossé, 2015). Older adult cohorts are also highly heterogeneous with different factors such as dentures, medication status, and health status all impacting their perception of food and beverages in different ways (Methven, Jimenez-Pranteda and Lawlor, 2016). This is an important consideration for sensory scientists when designing sensory tests as these different cohorts will likely provide different feedback on food and beverages. Therefore, as previously highlighted (Section 1.3) the segregation of older adult cohorts into different cohorts such as denture wearers and non-denture wearers, medication users and non-medication users will provide more in depth knowledge on the perception of food and beverage products in older adults.

#### **1.4.2 Hedonic testing in the older adult**

Hedonics refers to the pleasantness, preference, pleasure, liking, and overall acceptance of a food product (Ares *et al.*, 2015a). Given the impact that age-related sensory impairment has on the liking, pleasantness, enjoyment, and thus intake of food and beverages in the older adult population cohort, there is a need to conduct hedonic testing of food and beverage products with this age group. This will provide important insights which will drive food design strategies aimed at improving food liking, enjoyment, and ultimately uptake in this cohort. However, it is important to ensure that the hedonic method applied is appropriate for use in this age cohort in order to provide accurate data (Methven, Jimenez-Pranteda and Lawlor, 2016).

There are several different methods which can be used to measure hedonics, these include hedonic ranking, paired preference tests, and hedonic rating. Hedonic rating is the most commonly adopted method for evaluating hedonics in older adults (Methven, Jimenez-Pranteda and Lawlor, 2016). These rating methods are often

categorised into; (1) categorical scales such as the 9-point hedonic scale, (2) unstructured liking scales such as Visual Analogue Scales, and (3) putatively ratio-level liking scales such as the Labelled Affected Magnitude Scale (Yeung *et al.*, 2021). In studies involving older adult cohort's hedonic category scales are used extensively for measuring food and beverage liking and disliking (Barylko-Pikielna *et al.*, 2004; Methven, Jimenez-Pranteda and Lawlor, 2016). These scales have been used with both healthy older adults and institutionalised older adults (Methven, Jimenez-Pranteda and Lawlor, 2016). Their widespread use with older adults predominantly stems from the fact that these scales are relatively simple, easy to use and understand which makes them preferential for older individuals (Barylko-Pikielna *et al.*, 2004; Methven, Jimenez-Pranteda and Lawlor, 2016). Of the different hedonic category scales the most widely used scale in sensory science is the 9-point hedonic scale (Methven, Jimenez-Pranteda and Lawlor, 2016). This scale has been used in a large number of studies with older adult cohorts (Methven, Jimenez-Pranteda and Lawlor, 2016) with an array of different products including beverages (Kozłowska *et al.*, 2003; Barylko-Pikielna *et al.*, 2004; Withers *et al.*, 2014), biscuits (Tsikritzi *et al.*, 2014), Oral Nutritional Supplements (Methven *et al.*, 2010; Özçağlı, Stelling and Stanford, 2013), and meat products (Rothenberg *et al.*, 2007).

The 9-point hedonic scale has been shown to have very good repeatability when used with an older adult cohort for the assessment of beverages, with previous research using orange juice samples stating that there was no advantage of hedonic ranking over hedonic rating in terms of repeatability (Barylko-Pikielna *et al.*, 2004). However, some important issues have been highlighted when using these scales with older adult cohorts. Previous research has noted difficulties in discriminating liking between samples (Barylko-Pikielna *et al.*, 2004; Dermiki *et al.*, 2013). This may be because of miss-use of the scale due to confusion, or sample size being too small (Methven, Jimenez-Pranteda and Lawlor, 2016). Insufficient numbers of subjects will lead to low statistical power and therefore an increased likelihood of a false positive result (Dumas-Mallet *et al.*, 2017). Other researchers have reported higher usage of the upper end of the scale in older adults than younger adults (Forde and Delahunty, 2002; Kozłowska *et al.*, 2003) which may be due to individuals aiming to please the panel leader, or difficulties in understanding the use of the scale (Kozłowska *et al.*, 2003; Methven, Jiménez-Pranteda and Lawlor, 2016). It is therefore important when

using this scale in future studies to ensure that effective recruitment strategies are implemented prior to conducting hedonic ratings in older adults. It is also critical to ensure that the participants are informed to give their honest opinion during the test and reassured that there are no right or wrong answers, and that any expression of product dislike will not offend the researcher. If these measures are taken into consideration this will ensure that the scales are used in the correct manner by older adult cohorts in future studies.

As highlighted above hedonic scales can provide valuable insights on both liking and disliking of food and beverage products in older adult cohorts. However, if a sensory questionnaire comprises both hedonic scales and a sensory profiling questionnaire such as Check-All-That-Apply (CATA) or Temporal Dominance of Sensations (TDS) there is potential to gain a better understanding of how the sensory characteristics influence the liking or disliking of a food or beverage (Thomas *et al.*, 2016). This approach has been successfully adopted with older adults by Thomas *et al.* (2018) who used a novel sensory method known as “Alternated Temporal Drivers of Liking” (A-TDL) to evaluate ONS. This A-TDL questionnaire consisted of a TDS questionnaire and hedonic scales. By adopting this method, the researchers were able to report that characteristics such as vanilla and praline drove positive liking for an ONS while attributes such dry and metallic drove negative liking (Thomas *et al.*, 2018). This is a clear example of the important insights that can be drawn from the use of these methods. Previous research has also combined the CATA method with 9-point hedonic scales with older adults (Ruark *et al.*, 2016; Romaniw *et al.*, 2021), however, the sensory characteristics impacting liking or disliking were only computed in one of these two studies (Romaniw *et al.*, 2021). It is clear that there is limited research which has focused on the drivers of liking and disliking of food and beverage products in older adults. However, this approach has the potential to provide food and beverage manufacturers with vital insight on characteristics that should be promoted or avoided in food and beverages for older adults, ultimately improving enjoyment and uptake. To the best of the author’s knowledge no previous research has used the CATA methodology in conjunction with hedonic scaling to determine drivers of liking and disliking of beverages products in older adult cohorts. Therefore, future research should take this into consideration as it would advance sensory science methodology for older adults.

### **1.4.3 Check-all-that-apply in the older adult.**

The CATA method has become increasingly widespread to acquire information on the sensory perception of different food and beverage products (Adams *et al.*, 2007; Methven, Jiménez-Pranteda and Lawlor, 2016; Grasso *et al.*, 2017). This method consists of a multiple-choice questionnaire whereby panellists are asked to select from a list of different descriptive attributes all of the attributes which they feel best describe the product they are tasting (Ares and Jaeger, 2015; Methven, Jiménez-Pranteda and Lawlor, 2016). The CATA approach is a rapid sensory method that does not require panellist training, is easy to use, and has been proven to produce reliable (Jaeger *et al.*, 2013) and reproducible results (Ares *et al.*, 2010; Bruzzone, Ares and Giménez, 2012; Ares and Jaeger, 2015). In addition to this, unlike other sensory methods such as TDS the CATA methodology also offers the benefit that a greater number of sensory attributes can be made available for selection.

Although it has had widespread usage for sensory characterisation of an array of different products from dessert products (Vidal *et al.*, 2013; Bruzzone *et al.*, 2015; Ghanbari *et al.*, 2017), to meat products (Jorge *et al.*, 2015; Grasso *et al.*, 2017; Pires *et al.*, 2021), bakery products (Tarancon *et al.*, 2015; Biro *et al.*, 2020; Cayres *et al.*, 2020), and even beverages (Cardinal *et al.*, 2015; Nascimento *et al.*, 2020; Cotter *et al.*, 2021), the CATA methodology has been rarely used with older adult cohorts (Ruark *et al.*, 2016). CATA is a relatively simple method for older adults compared to other sensory methods as the process of selecting a number of descriptive terms from a list is straight forward and user-friendly making it particularly suitable for individuals suffering from a decline in cognitive function (Adams *et al.*, 2007; Ruark *et al.*, 2016). A CATA evaluation is also quick which as stated previously (Section 1.4.1) is important when working with an elderly cohort due to their decreased attention capacity and their increased tendency to become fatigued (Methven, Jimenez-Pranteda and Lawlor, 2016). The ability to conduct a CATA evaluation either using a computer or with paper ballots is also preferential with the older adult population. Taking all of the above into consideration the CATA method shows good potential for use in this population group.

To the best of the author's knowledge only three studies to date have applied the CATA technique with older adult cohorts. Ruark *et al.* (2016) compared the use of the Ideal Profile Method (IPM) to the CATA questionnaire with ideal (CATA-I) in a

cohort of older adults and a cohort of younger adults. The findings illustrated that in terms of both perceived difficulty scores and elapsed time the CATA method was easier for the older adults to use than the IPM. The older adults were also capable of discriminating amongst the products using both CATA-I and IPM and used the methods similarly to the younger adults. Scott *et al.* (2017) using CATA, sorting, and projective mapping with older adults, also observed that the CATA methodology was the most appropriate out of the three rapid profiling techniques for use with older adults. Given the success of the CATA method in the two previous studies a more recent study used the CATA methodology to investigate the sensory perception of nutrient dense foods specifically tailored for older adult cohorts (Romaniw *et al.*, 2021).

While the above research has effectively used the CATA methodology with older adult cohorts, there remains a number of different gaps in this field of study that future research should look to address. Firstly, the above studies have used between 20 and 23 descriptive terms in their CATA questionnaires, however, CATA questionnaires can be composed of anywhere between 10 and 40 terms (Ares and Jaeger, 2015). Therefore, future research should increase the number of CATA terms used as this will determine whether larger term lists are appropriate for use with older adult cohorts. The need for such an approach is in agreement with previous recommendations by Scott *et al.* (2017). Another important observation as highlighted in Section 1.4.2 is the potential for CATA questionnaires combined with hedonic scaling to provide insights on the characteristics which modulate liking and disliking of food and beverages in older adults. However, to date, only one study to the best of the author's knowledge has adopted this approach with older adults. The need for such an approach was also highlighted by Scott *et al.* (2017), who stated that future work should investigate the associations between the changes in perception and liking of food and beverages. Finally, of the limited studies using CATA with older adults these have focused on one bite or one sip of a product. This however is not representative of the normal food consumption pattern (Thomas *et al.*, 2016). While some previous research has used multi-sip approaches with older adults this research adopted the TDS methodology (Thomas *et al.*, 2018), with limited research using the CATA methodology over multiple bites or sips of a food or beverage product. The CATA methodology has in more recent years been extended

to include a temporal element (Temporal Check-All-That-Apply) (Castura *et al.*, 2016). This methodology can be used both with untrained and trained sensory panellists and provides more detailed information of the dynamic sensory profiles of food and beverage products throughout consumption than TDS (Ares *et al.*, 2015b; Ares *et al.*, 2016).

#### **1.4.4 Temporal Dominance of Sensations in the older adult**

The TDS technique has been used increasingly to assess the dynamic sensory perception of food and beverages (Zorn *et al.*, 2014; Schlich, 2017; Rizo *et al.*, 2019). This method requires panellists to identify and select the dominant sensation which they experience from a list of different sensory attributes throughout an allocated time period (Pineau *et al.*, 2009; Pineau and Schlich, 2015). If the dominant sensation changes at any stage throughout the allocated tasting period, the panellists are instructed to select the new dominant attribute, this process continues until the evaluation time is finished (Di Monaco *et al.*, 2014). The dominant sensation is described as the sensation which captures the attention of the panellist the most (Labbe *et al.*, 2009) or in other words the sensation which is “popping up” the most (Pineau *et al.*, 2009). Therefore, this method relies entirely on the ability of the panellists to distinguish the dominant sensation from a list of different sensory descriptors (Pineau and Schlich, 2015).

The TDS method is advantageous as it supplies important information on the sequence of attribute perceptions throughout the consumption of a food product from initial intake right the way through to swallowing (Pineau and Schlich, 2015). TDS is a rapid sensory technique that allows panellists to select several attributes along tasting and unlike other sensory methods it does not require intense training sessions on the use of different scales (Di Monaco *et al.*, 2014; Pineau and Schlich, 2015). Given its advantages the TDS method has been used in numerous published sensory studies to evaluate an array of different food and beverage products. However, many of these studies use convenience cohorts of relatively narrow age and demographic profiles, with few studies using older adult cohorts, aged over 65 years.

The TDS technique was first successfully validated for use with older adults by Hutchings *et al.* (2014a) where it was applied to measure the differences in the dynamic texture perception between young and older adults using four different nut

types (almonds, cashews, macadamias, and peanuts). The study revealed that although the time taken to first select an attribute and the time taken to change an attribute selection was slower in the older adult cohort, clear TDS curves were generated by both old and young adults and intrasubject variability in the TDS sequence did not differ between the two age groups (Hutchings *et al.*, 2014a). This allowed the researchers to deem the TDS technique suitable for use with an older age cohort, a finding which was further supported by a subsequent study which concluded that for food texture perception the TDS technique is an appropriate sensory methodology for use with older subjects (Hutchings *et al.*, 2014b). More recently, the TDS technique was successfully used to investigate the differences in dynamic texture perception of sausages between older and younger adults (Aguayo-Mendoza *et al.*, 2020).

While the above researchers have demonstrated the appropriateness of the TDS methodology for use with older adults, these papers solely focus on the evaluation of both solid and semi-solid foods. Liquid products are likely to be more difficult for participants to undertake TDS than solid products, and hence it is of interest to see how older adults manage liquids with TDS. To the best of the author's knowledge only one study to date appears to have used the TDS methodology with liquid products in an older adult cohort. This study combined the TDS method with 'liking' to develop a novel sensory method known as "Alternated Temporal Drivers of Liking" (A-TDL) (Thomas *et al.*, 2018). This method was used with a cohort of older adults for the evaluation of two commercial ONS. The findings stated that the TDS method was simple to use, instinctive, and the task appeared to be understandable by older adults (Thomas *et al.*, 2018). Despite the important insights that this study provides on the use of TDS for the evaluation of liquid products with older adults, this remains an under-researched field. The above mentioned studies (Hutchings *et al.*, 2014a; Hutchings *et al.*, 2014b; Aguayo-Mendoza *et al.*, 2020) have clearly illustrated the effectiveness of the TDS technique in evaluating the dynamic texture perception of solid and semi-solid foods in older adult cohorts. Future research should apply the TDS technique to evaluate the dynamic texture perception of beverage products with older adults as far too little attention has been paid to the effects of ageing on the texture perception of liquid products.

## **1.5 Undernutrition in the older adult**

As previously mentioned, (Section 1.1) the proportion of the global population aged over 65 years is continuously rising. Despite general good health malnutrition remains a common concern in this population cohort globally (Kaiser *et al.*, 2010; Kvamme *et al.*, 2011). In the developed world the most common form of malnutrition associated with community dwelling older adults is undernutrition which predominantly stems from insufficient energy and protein intake (Elia, Russell and Stratton, 2010; Abidanza *et al.* 2016; Dominguez Castro *et al.*, 2020). Previous reports have estimated anywhere between 5-10 % of community dwelling older adults to suffer from this form of malnutrition (Doets and Kremer, 2016; Bardon *et al.*, 2020). The causes for undernutrition in older adults are multi-factorial and include but are not limited to factors such as acute or chronic disease (de van der Schueren *et al.*, 2016), sensory impairment of taste and smell (de van der Schueren *et al.*, 2016; Methven, Jimenez-Pranteda and Lawlor, 2016), difficulties with oral processing of foods such as biting and chewing (Feldblum *et al.*, 2007; Schilp *et al.*, 2011), and reduced appetite (Schilp *et al.*, 2011), in addition to psychological factors such as cognitive decline or impairment (Feldblum *et al.*, 2007; Smoliner *et al.*, 2008; Bardon *et al.*, 2020), stress and depression (Feldblum *et al.*, 2007; Johansson *et al.*, 2009; Schilp *et al.*, 2011), loneliness, isolation and living alone (Smoliner *et al.*, 2008; de van der Schueren *et al.*, 2016; Bardon *et al.*, 2020). Undernutrition has many associated negative health effects such as sarcopenia, osteoporosis, decreased functional competence, frailty, a general increase in morbidity and mortality, and worse disease outcomes to name but a few (Field and Duizer, 2016; Bardon *et al.*, 2020). These detrimental health effects of undernutrition will result in increased general practitioner visits, outpatient visits, and increased hospital admissions, all of which will place an economic burden on healthcare systems globally. Therefore, there is a growing need to feed this expanding elderly population with nutrient dense foods. However, in order to do this an understanding of the nutritional requirements of older adults is necessary.

### **1.5.1 Nutritional Requirements of older adults**

With ageing an individual's body composition will change, the onset of which is particularly evident past 70 years of age (Genton *et al.*, 2011; Chernoff, 2016; Clegg and Williams, 2018; World Health Organisation, 2019). These alterations in body

composition include a decrease in total body weight, lean body mass, total body water, and bone density (Genton *et al.*, 2011; Chernoff, 2016; Clegg and Williams, 2018). In addition to this there is also a reduction in energy expenditure with age which is thought to decline by approximately 150 kcal per decade (Roberts and Dallal, 2005). These two factors combined, result in older adults having lower daily energy requirements than younger adults (Bales and Ritchie, 2002; Roberts and Dallal, 2005; World Health Organisation, 2019). While energy requirements are reduced with age it is important to note that older adults may require higher protein intake than younger adults to counteract the progressive decline in muscle mass (sarcopenia). Some studies have recommended up to 1.2 g/kg of body weight per day for healthy older adults (Bauer *et al.*, 2013; Clegg and Williams, 2018; Rosenberger *et al.*, 2019) and 1.2-1.5 g/kg body weight per day for older adults at risk of or suffering from malnutrition (Deutz *et al.*, 2014; Clegg and Williams, 2018).

Sufficient vitamin and mineral intake are fundamental in obtaining a good nutritional status in older adults (Bolzetta *et al.*, 2015). While the recommendations for vitamins and minerals are the same for older adults as they are for younger adults, certain vitamins and minerals are of particular importance for older adult cohorts (Clegg and Williams, 2018). Calcium and vitamin D for example are critical for the preservation of bone mineral density and the prevention of fractures (Clegg and Williams, 2018). Vitamin E on the other hand has the potential to prevent conditions such as atherosclerosis, Alzheimer's and Parkinson's disease, and cancer (Chernoff, 2016). While vitamin K plays a critical role in bone metabolism and has been shown to reduce fracture risk when given in high doses (Chernoff, 2016).

Despite the importance of certain vitamins and minerals for older adults this population cohort are highly sensitive to nutritional deficiencies due to insufficient nutrient intake. The National Adult Nutrition Survey (2011) reported that in Ireland alone over half of those aged 65+ years who took part in the survey had mean vitamin D intakes of less than 5 µg daily and that 37.3 % of men and 28.7 % of women were below the estimated average requirement (da Silva *et al.*, 2014) for magnesium. This study also stated that 17 % of men aged over 65 had insufficient intake of vitamin C and 13 % of women had insufficient intakes of folate. Other inadequate nutrient intakes included calcium, vitamin B2, and vitamin A (The National Adult Nutrition Survey, 2011).

### **1.5.2 Prevention and alleviation of undernutrition in older adults**

There are numerous strategies that are necessary to prevent and alleviate undernutrition in older adults. First and foremost, successful identification of undernutrition is essential, this can be accomplished through dietetic screenings and consultations (Pauly, Stehle and Volkert, 2007; Hubbard *et al.*, 2012). Once identified, undernutrition can then be managed through dietetic counselling, dietary modification, and food fortification and supplementation (Hubbard *et al.*, 2012; Roberts *et al.*, 2019). Dietary modification and food fortification play an important role in the prevention and alleviation of undernutrition in older adults. However, it is highly important that the foods provided for older adults are carefully adapted to meet their specific nutritional requirements while also taking account of their loss of appetite and deterioration in sensory perception. Previous reports have suggested that the flavour enhancement of foods may improve food intake in frail older adults (Roberts *et al.*, 2019). While energy and protein-based food fortification has been reported as an effective means of improving nutrient uptake in older adults (Morilla-Herrera *et al.*, 2016; Mills *et al.*, 2018; Roberts *et al.*, 2019), the most effective means of alleviating undernutrition in older adults is through the use of ONS supplementation combined with dietary counselling (Reinders *et al.*, 2019; Castro *et al.*, 2020). However, these supplements are only effective in improving nutritional status and alleviating undernutrition in older adults if the full portion is consumed (Thomas *et al.*, 2016).

### **1.6 Oral Nutritional Supplements**

As mentioned above, one approach to effectively managing and alleviating undernutrition in older adults is through the prescribing of commercially available products which are commonly known within the healthcare setting as Oral Nutritional Supplements (ONS) (Lochs *et al.*, 2006; Stratton and Elia, 2007; Özçağlı, Stelling and Stanford, 2013; Kokkinidou *et al.*, 2018). As previously mentioned, (Section 1.1) ONS are predominantly emulsion based ready-made, auxiliary liquid, semi-solid, or powder style dietary food products which are specifically designed to counteract malnutrition by delivering essential macronutrients, micronutrients, and calories in a small food portion (Lochs *et al.*, 2006; Stratton and Elia, 2010; British Association of Parenteral and Enteral Nutrition, 2016). There is a wide range of commercially available ONS (Table 1) which can be found in multiple flavours and forms such as

cans, cartons, and bottles (Kennedy *et al.*, 2010). While a large number of these ONS are used in the treatment of undernutrition in older adults some are designed for use with very specific conditions and diseases, therefore, not every ONS will be appropriate for every individual (Kokkinidou *et al.*, 2018). Even within the range of ONS that are suitable for undernutrition, the type of ONS prescribed for older adults will depend generally on the causes, extent, and severity of undernutrition (den Boer, Boesveldt and Lawlor, 2019). A standard ONS for undernutrition will consist of approximately 1.5 kcal/mL and anywhere from 14 to 20 % protein, 25 to 35 % fat, and 50 to 60 % carbohydrates, as well as an array of vitamins and minerals (Ralph, 2000; Kennedy *et al.*, 2010). However, it is important to note that an ONS can contain up to 4 kcal/mL depending on the severity of undernutrition (Hubbard *et al.*, 2012). The amount of ONS prescribed has been shown to range from 237 kcal to 1080 kcal per day (Hubbard *et al.*, 2012; den Boer, Boesveldt and Lawlor, 2019).

If used effectively ONS coupled with dietary counselling have been demonstrated to successfully manage undernutrition in older adults, and promote weight gain, improvements in nutritional intake, and a general decrease in mortality risk (Agarwal *et al.*, 2013; Kokkinidou *et al.*, 2018; den Boer, Boesveldt and Lawlor, 2019). This will only be achieved if the full prescribed amount is consumed (Rahemtulla *et al.*, 2005; Özçağlı, Stelling and Stanford, 2013; Thomas *et al.*, 2016). However, this is often not the case and poor adherence to ONS which in some cases can be as low as 37 % has been reported in both community and non-community dwelling older adults (Gosney, 2003; McMurdo *et al.*, 2009; Özçağlı, Stelling and Stanford, 2013). This poor adherence to ONS is partly linked to the undesirable sensory properties of ONS including but not limited to their sweetness, texture, and mouthfeel as well as issues of taste fatigue and build-up of aftertaste with consumption volume (Gosney, 2003; Rahemtulla *et al.*, 2005; Nieuwenhuizen *et al.*, 2010). Therefore, to improve uptake and adherence of ONS there is a need to conduct sensory evaluations of ONS with older adults as this will provide information on the sensory attributes which affect the palatability and ultimately uptake of these products (Özçağlı, Stelling and Stanford, 2013).

Some previous research has explored the sensory profiles and liking of ONS. Harper *et al.* (2001) revealed that ONS were equally as acceptable as other commercially-available high energy foods, and that taste alone does not account for

the poor adherence to ONS (Harper *et al.*, 2001). More recently, Kennedy *et al.* (2010) demonstrated that increased sweetness intensity was linked with ONS dislike in both older and younger adults. The most preferred ONS flavour in this study was a chocolate flavour ONS, likely due to this ONS being perceived as less sweet than the other ONS. In another major study Methven *et al.* (2010) found that 'mouth-drying', 'metallic', and 'mouthcoating' attributes built-up with increasing consumption of ONS and this had a direct impact on liking which declined in older adults. While Kennedy *et al.* (2010) and Methven *et al.* (2010) both offer an interesting perspective on the sensory attributes which influence the palatability and liking of ONS, these studies only investigated up to a consumption volume of 40 mL. A standard serving of ONS is typically greater than 40 mL, therefore, there is potential to further this work by investigating the sensory profile of ONS over the consumption of one full standard serving (Tsikritzi *et al.*, 2014).

Thomas *et al.* (2016) assessed the sensory perception of two ONS over the course of consumption of the full volume using a TDS method followed by a hedonic scale (A-TDL). The findings showed the ONS which was liked less was consumed in lower volumes, resulted in an increase in thirst with increasing sips, and more negative drivers of liking such as 'dry', 'metallic', and 'filming'. Furthering this research Thomas *et al.* (2018) assessed two ONS with older adults twice daily, in a mode to replicate full daily consumption of an ONS. The study demonstrated that drinking ONS led to increased thirst. This increase in thirst was likely due to a build-up in dry sensations as the thirst scores increased by 0.33 points when the attribute 'dry' was dominant. The findings from these two studies clearly indicate the importance of investigating the sensory profiles of ONS over the consumption of a full standard serving. Future research should continue to adopt this multi-sip, full volume approach and perhaps further this field by evaluating the appropriateness of other sensory methodology such as the check-all-that-apply technique for multi-sip evaluations of ONS with older adults.

Not only does the research conducted by Thomas *et al.* (2016) and Thomas *et al.* (2018) offer significant advancements to the field of sensory methodology, this research also highlights an important issue relating to increased thirst with ONS consumption in older adults. This combined with older adults' tendency to suffer from diminished thirst sensation (Schlanger, Lynch Bailey and Sands 2010; Morley, 2015;

Picetti *et al.*, 2017) may be an important contributor to reduced liking and adherence of ONS as individuals may not wish to finish the full volume. Therefore, to improve ONS adherence it is important for ONS manufacturers to gain a deeper understanding of the factors that are driving this increase in thirst. However, this remains vastly under-researched. One possible driver for thirst with ONS consumption may be their viscosity. It has previously been reported that as ONS consumption volume increases there is a build-up of mouthcoating attributes which are disliked (Methven *et al.*, 2010). Viscosity has previously been reported to affect both mouthfeel and texture perception (Courregelongue, Schlich and Noble, 1999). Therefore, it is likely that individuals will have an increased desire to drink during and after the consumption of high viscosity ONS as a means of getting rid of these unpleasant sensations (den Boer, Boesveldt and Lawlor, 2019). Another factor which may impact thirst profiles during ONS consumption is the protein content and type of protein present in ONS. It has been previously reported that high protein dairy beverages can cause mouth-drying (Withers *et al.*, 2013) with whey protein-based beverages in particular exhibiting unpleasant mouthfeel properties such as astringency and mouth-drying (Lee and Vickers, 2008; Bull *et al.*, 2017). This build-up in mouth-drying may be an important contributor to increased thirst perception during ONS consumption as Thomas *et al.* (2016) previously reported the attribute dry as a temporal driver of thirst for ONS. The sweetness intensity of an ONS may also have a direct effect on thirst during ONS consumption, as previous reports stated that the high sweetness of ONS is a driver for ONS dislike (Gosney, 2003). In addition to this, Withers *et al.* (2014) reported that increased sweetness increased the build-up of mouth-drying. This build-up of mouth-drying would likely have a direct effect on thirst perception. Recognising the importance in improving ONS adherence in older adults, there remains a gap in the literature when it comes to the drivers of thirst during ONS consumption in older adults. Future research should investigate the effects of viscosity, proteins, and sweetness of ONS on thirst profiles in older adults. Finally, it is important to note that from a physiological perspective thirst is predominantly caused by a decline in fluid volume and an increase in the concentration of osmotically active particles (osmolality) (Di Bartola, 2006; Kohlmeier, 2015; Stanhewicz and Kenney, 2015). An increase in concentration of solutes such as sodium, glucose, and other small particles can all increase osmolality, causing

thirst (Kohlmeier, 2015). For this reason, the osmolality of ONS may also impact thirst experienced with consumption. Hypertonic beverages (330 mOsmol/kg) which have an osmolality greater than plasma osmolality (270 – 295 mOsmol/kg) (Leiper, 2013) will result in a net secretion of water from the bloodstream into the intestine, which can cause dehydration, this may in turn lead to an increase in thirst sensation (Maughan, 2001). As ONS typically consist of high levels of minerals and carbohydrates it is likely that these products are hypertonic in nature, which may be a possible link to why ONS can cause increased thirst with increased consumption volume, however, the links between ONS osmolality and thirst remain under-researched and further research in this area would be beneficial.

Another factor which is likely linked to low intake and adherence of ONS is their unpleasant satiating properties (den Uijl *et al.*, 2015; den Boer, Boesveldt and Lawlor, 2019). Given that 11-15 % of community dwelling older adults, 19-52 % of hospitalised older adults, and 12-66 % of older adults in nursing home settings are reported to experience poor appetite (van der Meij *et al.*, 2015), this is an important point to consider. Hospital patients and non-community dwelling older adults are the predominant consumer of ONS on a regular basis. The unpleasant satiating properties of ONS may therefore result in difficulties with ONS adherence and reduce their effectiveness in a cohort already experiencing diminished appetite. ONS as previously mentioned are rich in macronutrients, typically containing 14 to 20 % protein, 25 to 35 % fat, and 50 to 60 % carbohydrates (Ralph, 2000; Kennedy *et al.*, 2010). It is therefore not surprising that these energy dense supplements contribute to increased satiety. The satiating power of food and beverage products is reliant on its protein, carbohydrate, fat, and fibre content, with protein being the most satiating macronutrient, followed by carbohydrates, and then fats (protein > carbohydrate > fat) (Blundell and MacDiarmid, 1997; Paddon-Jones *et al.*, 2008; Brennan *et al.*, 2012; Chambers, McCrickerd and Yeomans, 2015; Dougkas and Ostman, 2016). The enhanced satiating effects caused by protein is due in part to the fact that protein ingestion brings about a different profile of satiety-related hormonal signals than other macronutrients (Hall *et al.*, 2003; Batterham *et al.*, 2006; Bertenshaw, Lluich and Yeomans, 2013). Another physiological mechanism underlying the increased satiating power of proteins is diet induced thermogenesis (Halton and Hu, 2004). It is however important to note that the sensory experience and oro-sensory cues

associated with ingesting protein is also an important contributing factor to its high satiating effects (Bertenshaw *et al.*, 2013; Masic and Yeomans, 2013). It has previously been reported that characteristics such as thickness and creaminess that are consistent with the presence of energy enhanced the satiating effects of a beverage (Yeomans and Chambers, 2011; Bertenshaw, Lluch and Yeomans, 2013). As ONS are high protein beverages this is an important point of consideration for ONS manufacturers.

Previous research has highlighted that the satiating properties of ONS may be influenced somewhat by the texture aspects of the ONS such as their thickness (den Boer, Boesveldt and Lawlor, 2019). Previous studies have reported that food intake increases with decreasing viscosity (Westerterp-Plantenga and de Graaf, 2008; Zijlstra *et al.*, 2008) due in part to the fact that thicker products have a greater tendency to be consumed at a slower rate (Viskaal-van Dongen, Kok and de Graaf, 2011; den Boer, Boesveldt and Lawlor, 2019) which leads to higher/longer orosensory stimulation and higher/longer transit time through the oral cavity (Zijlstra *et al.*, 2008; den Boer, Boesveldt and Lawlor, 2019), both of which trigger a satiety response (Chambers, 2016). It is therefore likely that higher viscosity ONS will contribute to increased satiety and lower intake. The impact of ONS viscosity in addition to thirst as mentioned above remains a critical point for future consideration. The current approach adopted by ONS manufacturers to improve uptake and adherence of ONS in individuals who are struggling to consume the full volume is to concentrate beverage-style ONS into compact and shot-style modes of delivery (den Boer, Boesveldt and Lawlor, 2019). This is supported by previous research which showed that lower-volume energy dense ONS are ideal to improve ONS uptake and adherence in individuals who may find it difficult to consume larger volumes (Hubbard *et al.*, 2010; Stange *et al.*, 2013; Lombard *et al.*, 2014). However, it is important to consider the effects that this may have on the ONS viscosity as the process of compacting these ONS may increase thickness (den Boer, Boesveldt and Lawlor, 2019). Therefore, care should be taken to ensure the final viscosity falls within a desirable range for ONS consumers.

The final point to consider is that while the sensory profiles, the increased thirst, and unpleasant satiating effects associated with ONS consumption may contribute directly to reduced uptake and adherence of ONS, low ONS adherence in older

adults could also merely be associated with the changes in sensory perception experienced with age. As previously discussed, (Section 1.3) an impairment in sensory perception occurs with older age and is often linked with altered food perception, liking and enjoyment, interest, and intake (Sanders, Ayers and Oakes, 2002; Doets and Kremer, 2016; Methven, Jimenez-Pranteda and Lawlor, 2016). Previous studies which have been mentioned above have examined the impact of age on some sensory properties of ONS. Kennedy *et al.* (2010) observed that higher sweetness intensity was linked with product dislike in both younger (mean age 23 years) and older (mean age 74 years) adults. Both cohorts rated the sweetness intensity of ONS similarly. While Methven *et al.* (2010) concluded that sweet taste thresholds were higher in older cohorts than in a younger cohort. These studies give some understanding of the differences in sensory perception of ONS between older and younger adult cohorts, however, few studies have examined ONS within the different older adult segments (the young-old (65-74 years), the old-old (75-84 years), and the oldest-old (85+ years)). Although some studies have explored the sensory profiles of ONS within older adult cohorts (Methven *et al.*, 2009; Özçağlı, Stelling and Stanford, 2013; Thomas *et al.*, 2018) they are heavily weighted towards the lower end of 65-74 year olds. Examining the sensory perception of ONS between the different segments of the older adult population cohort is important, since the effects of sensory impairment, particularly in relation to taste and texture perception, are more likely to be observed in those above 74 years. In addition to this, there remains a gap in the literature in relation to the effects of physiological and non-physiological factors such as medication usage and dentures on the perception and liking of ONS.

## **1.7 Formulating Oral Nutritional Supplements**

As mentioned above (Section 1.5) older adults have unique nutritional needs, not only do they require higher protein intake than younger adults, but they often also require increased vitamin and mineral supplementation due to the onset of deficiencies in vitamins such as vitamin D, C, B2, and A and minerals including calcium. ONS supplementation is an effective means in improving the nutritional status of older adults as these food products contain a broad range of essential macronutrients and micronutrients often in the form of small volume beverage

systems. The macro- and micro-nutrients in ONS consist of both fat soluble and water soluble constituents. For this reason, ONS are predominantly emulsion based systems as these are effective delivery systems for both fat and water soluble micronutrients, essential for improving the nutritional status of older adults.

The two most commonly occurring emulsions in food systems are oil-in-water emulsions (O/W) and water-in-oil emulsions (W/O). ONS are predominantly oil-in-water emulsion based products meaning that they consist of a lipid phase in the form of oil droplets, that is dispersed into an aqueous phase in the form of water (Bot *et al.*, 2020). The lipid phase of ONS commonly consists of a mixture of vegetable oils (Bot *et al.*, 2020). The most frequently used vegetable oils in ONS are canola oil, coconut oil, corn oil, palm oil, rapeseed oil, and sunflower oil (Table 1). However, a standard ONS for undernutrition will likely consist of either rapeseed oil, sunflower oil, or a mixture of both (Table 1). This lipid phase of an ONS will act as a solvent for all the important lipophilic bioactive compounds such as fat soluble vitamins, antioxidants, and essential oils (Chee *et al.*, 2005; Bot *et al.*, 2020). The water phase of an ONS within which the lipid phase is dispersed, is enriched with the hydrophilic components of an ONS such as the water soluble vitamins and minerals, salts, sugars, flavours, preservatives, carbohydrates, and proteins (Mc Clements, 2005; Bot *et al.*, 2020). It is clear from Table 1 that a wide range of carbohydrates are used in ONS formulations, some of the most frequently used carbohydrates include maltodextrin, sucrose, and glucose syrup. The primary protein source for ONS stems from milk derived proteins, however, plant based proteins are also used and it is not uncommon for mixtures of both dairy and plant proteins to be present in ONS (Bot *et al.*, 2020).

The phospholipids, polysaccharides, and proteins within an ONS not only are important in providing the essential macronutrients for these nutrient dense beverages, but they also play a vital role in their stabilisation. One of the greatest challenges regarding emulsions is their thermodynamic instability which causes them to destabilise under different processing conditions such as heat, freezing, or storage (Chee *et al.*, 2005; Arancibia *et al.*, 2011; Drapala, Mulvihill and O'Mahony, 2018). This instability can result from either physical or chemical destabilisation. Physical destabilisation can occur through gravitational separation, droplet aggregation, or phase inversion (McClements, 2005; Bot *et al.*, 2020; McClements, 2020). Chemical

instability on the other hand occurs due to processes such as hydrolysis and oxidation which cause the composition of the droplets within an emulsion to be altered (Singh and Sarkar, 2011). As a result, emulsifiers and stabilisers must be incorporated into ONS to improve their stability, these commonly include hydrocolloids, low molecular weight surfactants including phospholipids, mono/di-glycerides, and biopolymers such as polysaccharides and proteins (Krog and Sporsø, 2004; Arancibia *et al.*, 2011).

The thermodynamic instability of emulsions can also affect their bioactive compounds causing them to lose their bioaccessibility and bioavailability. The bioaccessibility of a bioactive compound refers to the amount of the substance that is released from the beverage matrix and then resolubilised into structures called mixed micelles (Huo *et al.*, 2007; McClements and Xiao, 2012). The bioavailability on the other hand refers to the amount of the bioactive compound that is absorbed, reaching the bloodstream (Flynn, 2007; Turner and Agatonovi-Kustrin, 2007; Johanson, 2010). Due to the importance of ONS in improving nutrient intake in older adults the bioaccessibility and bioavailability of the bioactive compounds within the ONS is of critical importance. Lipophilic bioactive compounds in particular have low oral bioavailability because of their poor solubility and chemical stability in the digestive conditions (Gonnet, Lethuaut and Boury, 2010; Teleki, Hitzfield and Eggersdorfer, 2013; Ozturk, 2017). Therefore, there is a growing requirement to encapsulate the lipophilic bioactive compounds within O/W beverage systems (Choi and McClements, 2020). In doing so this will improve their handling, their ability to disperse in the water phase, and their chemical stability, which will in turn prevent the bioactive compounds from degradation ultimately improving their efficacy, bioavailability, and bioaccessibility (Ozturk, 2017; Choi and McClements, 2020). The size of the droplets within the lipophilic phase of an O/W emulsion plays a role in the bioaccessibility and bioavailability of the lipophilic bioactive compounds. O/W nanoemulsions, where the lipid phase droplet diameters are less than 200 nm have become increasingly important for use in beverage products due to their smaller droplet dimensions which permits them to be more stable when it comes to gravitational separation and droplet aggregation (McClements, 2011; Ozturk, 2017; Choi and McClements, 2020). Aside from their improved stability O/W nanoemulsions are particularly advantageous as they can stabilise, protect, and deliver health promoting bioactive compounds by

encapsulating them in the oil core (Ozturk, 2017). This will improve the dispersibility of the lipophilic bioactive compounds as well as their stability and their bioavailability (Choi and McClements, 2020). Nanoemulsions are typically produced via high energy methods such as high pressure valve homogenization, ultrasonication, and microfluidization, or low energy methods including spontaneous emulsification and emulsion phase inversion (Ozturk, 2017; Choi and McClements, 2020). Strict protocols must be in place when formulating nanoemulsions to control the composition of the lipid phase, the lipid phase particle size, and the interfacial properties (Choi and McClements, 2020). The production conditions and the nanoemulsion composition must therefore be carefully considered to achieve this (Choi and McClements, 2020). All of the above are key considerations when formulating ONS to maximise the stability, bioaccessibility, and bioavailability of nutrients and health promoting bioactives.

The fact that ONS are emulsion based is not only beneficial from a nutritional point of view, but this is also favourable from a sensory perspective as the physicochemical properties of emulsions can be easily tailored in order to meet specific characteristics in relation to appearance, texture, and flavour. This is particularly advantageous from a textural point of view as both texture and mouthfeel have previously been reported as drivers for dislike of ONS (Gosney, 2003; Methven *et al.*, 2010; den Boer, Boesveldt and Lawlor, 2019). Therefore, the ability to manipulate the texture profiles of ONS with ease will allow the design and formulation of ONS with desirable texture profiles, thus improving uptake and adherence. The texture of an ONS is influenced by the lipid phase, the water phase, and interfacial layer characteristics (Chung and McClements, 2014). Within the lipid phase of an ONS the concentration, composition, and size of fat droplets has an effect on the perceived texture of a food emulsion. For example, an increase in both fat droplet size and concentration within an emulsion has been found to increase the perceived 'creaminess', 'thickness', richness', 'smoothness', and 'fattiness' (de Wijk and Prinz, 2005; Bayarri and Costell, 2009; Arancibia, 2011; Chojnicka-paszun, de Jongh and de Kruif, 2012; Ciron *et al.*, 2012; Chung *et al.*, 2013; Chung and McClements, 2014). This approach may be favourable when formulating ONS for older adults as it has been established that with increasing age the perception of texture attributes such as 'creaminess' and 'fattiness' declines (Kremer, Mojet and Kroeze, 2007;

Doets and Kremer, 2016). In addition to this previous research has highlighted that denture wearers may regard mouthfeel attributes of beverages as more important than non-denture wearers (Withers, Gosney and Methven, 2013), while thick and mouthcoating beverages also have the ability to aid salivation and to mask off-tastes resulting from medication usage (Schiffman *et al.*, 1998; Stratton and Elia, 2006; Withers, Gosney and Methven, 2013). Therefore, from a texture and mouthfeel perspective, the ability to achieve perceptions of 'thick', 'creamy', and 'smooth' should help to improve ONS acceptability in the older adult population. The properties of the aqueous phase of ONS also have an effect on their texture profiles, with the degree of texture increase dependent on the concentration, composition, and conformation of the constituents within the aqueous phase as well as their various interactions (Dickinson, 2013; Chung and McClements, 2014). For example, the addition of biopolymers such as polysaccharides (carrageenans, agars, alginates, pectins, gums, starch, starch derivatives, cellulose, cellulose derivatives), and proteins (gelatin, caseins, whey, biopolymer blends) to the aqueous phase of an ONS will act as thickening agents and increase their viscosity due to their structuring, stabilising, and thickening abilities (McClements 2005; Dickinson, 2009; Arancibia, 2011). As previously stated, (Section 1.3.4) age related physiological changes can lead to the onset of swallowing difficulties and as a result it is important that ONS are thickened to varying degrees to counteract this issue. The above highlights the ability to increase the viscosity of ONS by manipulating the aqueous and lipid phases and the benefits that this may have in improving uptake and adherence of ONS in older adult cohorts. However, increasing the viscosity of ONS may not always be favourable. As previously highlighted (Section 1.6) an increase in ONS viscosity can cause an increase in thirst and satiety in older adults which may lead to lower intake. Therefore, future research should focus on determining the desirable viscosity range of ONS, as this is an important contributor to ONS uptake and adherence in older adults.

In addition to the texture of ONS their flavour is critical not only in driving ONS acceptance but also in determining their perceived quality (Roberts and Taylor, 2000; McClements, 2005). As ONS are emulsion based their flavour is predominantly determined by the dispersion of flavour components between the different phases of the emulsion, and their subsequent release during oral processing which allows them

to reach the necessary sensory receptors in the nose and mouth (Larsson and Larsson, 1997; McClements, 2005; Chung and McClements, 2014). This release profile is driven by flavour partitioning and mass transport kinetics, both of which are dependent on: (1) the emulsion characteristics such as the particle size distribution, interfacial properties, and the volume of the dispersed phase; (2) the flavour molecule characteristics including size, electric charge, and polarity; (3) the physicochemical properties from rheology to polarity, and finally; (4) their capability of binding and solubilising with other food constituents (McClements, 2005; Lekrisompong *et al.*, 2010; Chung and McClements, 2014). Therefore, to change the flavour and taste profiles the emulsion composition, concentration, characteristics, or physicochemical properties of the ONS will need to be altered through optimised processing conditions and formulations, in order to stimulate the release profile.

As previously mentioned, (Section 1.6) one of the predominant factors affecting ONS adherence is their undesirable sweetness profiles. This is a topic of increasing interest for sensory scientists and ONS manufacturers with a growing body of research investigating the sweetness profiles of ONS (Methven *et al.*, 2009; Methven *et al.*, 2010; den Boer, Boesveldt and Lawlor, 2019). While a wide range of carbohydrates used in ONS formulations can contribute to these elevated sweetness levels, it is evident from Table 1 that two of the most commonly used saccharides in ONS are sucrose and glucose syrup, with these often being used in conjunction with one another. One research study highlights the success of ONS emulsion reformulation in reducing sweetness levels. This study by Methven *et al.* (2009) replaced sucrose with Palatinose™ in an ONS and observed that this reduced both the sweetness and dairy flavour of the ONS. Further reductions in sweetness were then observed when the 25 % glucose syrup was replaced with a low-dextrose equivalent maltodextrin (Methven *et al.*, 2009). However, it is also important to note that the high sweetness levels of ONS often serve a purpose. As previously mentioned ONS are nutritionally dense beverages which contain combinations of macro- and micro-nutrients. Each of these nutrients will impart specific sensory properties some of which are unpleasant and can lead to off-tastes and aftertastes (Delompre *et al.*, 2019). Therefore, the elevated sweetness levels of ONS often serves to mask these off notes. If the sweetness levels are significantly reduced

these off-tastes will become more apparent which in turn may cause reduced ONS uptake. One approach around this may be to expand the range of flavours available as opposed to reducing the sweetness levels, as some flavours may be perceived as less sweet than others but may still effectively mask the unpleasant off-notes. This has previously been highlighted by Kennedy *et al.* (2010) who demonstrated that the most preferred ONS flavour in their study was a chocolate flavour ONS, likely due to this ONS being perceived as less sweet than the other ONS.

## **1.8 Concluding remarks**

With an ever ageing global population, it is clear that strategies must be implemented to alleviate serious health concerns such as undernutrition in the older adult population cohort. In order to do so it is important for food researchers to understand the factors that influence food choice and intake in this age cohort such as the sensory perception of food. This review highlights that there is a large body of research regarding the decline in sensory perception in older adults. However, the effective application of different sensory techniques to evaluate the sensory perception of foods in this age category remains a largely under researched area. In particular, specific sensory techniques such as CATA and TDS have been used only in a very limited number of studies for older adults. As these sensory methodologies have the ability to provide rapid, reliable, and reproducible data regarding the sensory profiles of food products their application with older adults is beneficial.

Older adult cohorts are highly heterogeneous with different factors such as dentition/dentures, medication status, and health status all impacting their perception of food and beverages in different ways. This is an important consideration for sensory scientists when designing sensory tests as these different cohorts will likely provide different feedback on food and beverages. However, in spite of the heterogeneity of this population cohort current sensory studies tend to treat this cohort as one. There is a growing need for studies which focus on the segregation of older adult cohorts into different cohorts such as denture wearers and non-denture wearers, medication users and non-medication users as this will provide more in depth knowledge on the perception of food and beverage products in older adults.

One of the most successful means of alleviating undernutrition is through the use of ONS, however, adherence to these supplements is often quite poor due to

their undesirable sensory profiles. Taking this into account, it is critical to conduct sensory evaluations of ONS with older adults to rectify this issue. The majority of research in this field has focused on the flavour profiles of ONS paying particular attention to their sweetness levels and its effects on ONS uptake and adherence. However, limited research has focused on the texture profiles of ONS. The viscosity of ONS has been shown to increase the thirst levels and satiety experienced by older adults during the consumption of ONS. These factors will likely contribute to the full volume of ONS not being consumed. It would be of particular interest both from an ONS manufacturers point of view and academically to determine the desirable viscosity range of ONS, as this is likely an important contributor to ONS uptake and adherence in older adults. Furthering this, the factors which drive thirst with ONS consumption have not yet been clarified.

Taking all of the above into consideration it is clear that this literature review has highlighted a number of significant knowledge gaps in this field. These knowledge gaps are addressed in the research objectives of this thesis which are outlined in the following section.

## **1.9 Research objectives**

The overarching aim of this thesis was to advance scientific knowledge on the perception and liking of ONS by older adult cohorts with a view to providing important insight into formulation strategies to improve adherence. The thesis also aimed to advance sensory science methodology for older adults by utilising different sensory techniques to test their appropriateness for use with this population cohort. More specifically the objectives of this thesis were to:

- Investigate the effects of age on the sensory perception, thirst, hunger, and fullness during the consumption of a full volume of ONS.
- Determine the critical sensory attributes that drive liking and disliking of ONS in older adults.
- Investigate effects of older age, dentures, and medications on the sensory perception, liking, appetite, and intake of ONS.
- Examine the dynamic texture perception and preferences of ONS in older adults.
- Determine factors driving thirst with ONS consumption in older adults.

- Measure the effectiveness of the CATA and TDS methodology to investigate the differences in sensory perception of beverage products between older and younger adults.

The research is divided into four experimental chapters with the aims and objectives outlined in the introduction section of each experimental chapter.

## **1.10 Research hypotheses**

The research objectives of this thesis will be achieved through the following hypotheses:

- In older adults, physiological and non-physiological factors influence the perception, liking, drivers of liking and disliking, and intake of ONS.
- Thirst experienced with ONS consumption will be impacted by (1) physico-chemical properties of ONS, and (2) physiological and non-physiological factors in older adults.
- CATA method can be used to evaluate ONS and differences in perceptions between young and old adult cohorts.
- TDS can be used for dynamic sensory evaluations of beverages with older adult cohorts. Viscosity can impact perception and liking of ONS in older adults.

**Table 1.** Range of commercially available ONS in Ireland, their use, macronutrient content and sources.

<b>Name</b>	<b>Style</b>	<b>Indications</b>	<b>Calories kcal/100mL</b>	<b>Protein g/100</b>	<b>Protein source</b>	<b>Carbohydrate g/100g</b>	<b>Carbohydrate source</b>	<b>Fat g/100mL</b>	<b>Fat source</b>
ActaCal Creme	Dessert Style	Short-bowel syndrome, intractable malabsorption, pre-op. prep. of undernourished patients, total gastrectomy, bowel Fistulae, disease-related malnutrition, inflammatory bowel disease	150	7.5	Milk proteins, Potassium caseinate, Calcium caseinate	19.0	Maltodextrin, Sucrose, Modified starch	4.9	Rapeseed oil
Nutricrem	Dessert style	Disease related malnutrition	180	10	Milk protein concentrate, Calcium caseinate, Potassium caseinate, Isolated soya protein	18.8	Maltodextrin, Sucrose, Starch, Carrageenan	7.2	Rapeseed oil

**Table 1 (continued).** Range of commercially available ONS in Ireland, their use, macronutrient content and sources.

<b>Name</b>	<b>Style</b>	<b>Indications</b>	<b>Calories kcal/100mL</b>	<b>Protein g/100</b>	<b>Protein source</b>	<b>Carbohydrate g/100g</b>	<b>Carbohydrate source</b>	<b>Fat g/100mL</b>	<b>Fat source</b>
Nutlis Complete Crème Level 3	Dessert style	Dysphagia, disease related malnutrition, intractable malabsorption	245	6.9	Cows milk proteins	29.1	Glucose syrup, Sugar, Inulin, Oligofructose, Arabic gum, Soy-poly-saccharides, Cellulose, Resistant starch, Pectin Carrageenan	9.4	Rapeseed oil, Sunflower oil
Nutlis Stage 4	Dessert style	Dysphagia, disease related malnutrition	137	6.9	Cows milk whey protein isolate	17.0	Sugar, Maltodextrin, Inulin, Arabic gum, Oligofructose, Soy-poly-saccharides, Cellulose, Resistant starch, Pectin, Agar	4.0	Rapeseed oil, Sunflower oil
Ensure Plus Crème	Dessert style	Dysphagia, disease related malnutrition, intractable malabsorption	137	5.7	Milk protein, Soy protein isolate	18.4	Sucrose, Modified corn starch, Maltodextrin	4.5	Canola oil, High oleic Sunflower + Corn oil

**Table 1 (continued).** Range of commercially available ONS in Ireland, their use, macronutrient content and sources.

<b>Name</b>	<b>Style</b>	<b>Indications</b>	<b>Calories kcal/100mL</b>	<b>Protein g/100</b>	<b>Protein source</b>	<b>Carbohydrate g/100g</b>	<b>Carbohydrate source</b>	<b>Fat g/100mL</b>	<b>Fat source</b>
Fresubin 2kcal Crème	Dessert style	Dysphagia, disease related malnutrition, intractable malabsorption, short bowel syndrome, pre-op. prep.	200	10	Milk protein	22.5	Sucrose, Glucose syrup, Maize starch, Maltodextrin	7.8	Sunflower oil, Rapeseed oil
Forticreme Complete	Dessert style	Disease related malnutrition	160	9.5	Cows milk protein	19.2	Sugar, Glucose syrup, Modified starch	5.0	Sunflower oil, Rapeseed oil
Nutillis Complete Level 3	Pre-thickened beverage	Dysphagia, disease related malnutrition	245	9.6	Milk proteins	29.1	Maltodextrin, Inulin, Oligofructose, Arabic gum, Soy Polysaccharides, Cellulose, Resistant starch, Sucrose	9.3	Vegetable oils
Fresubin Thickened Level 2	Pre-thickened beverage	Dysphagia, disease related malnutrition	150	10	Milk protein	12	Sucrose, Maltodextrin, Inulin	6.7	Sunflower oil, Rapeseed oil

**Table 1 (continued).** Range of commercially available ONS in Ireland, their use, macronutrient content and sources.

<b>Name</b>	<b>Style</b>	<b>Indications</b>	<b>Calories kcal/100mL</b>	<b>Protein g/100</b>	<b>Protein source</b>	<b>Carbohydrate g/100g</b>	<b>Carbohydrate source</b>	<b>Fat g/100mL</b>	<b>Fat source</b>
Fresubin Thickened Level 3	Pre-thickened beverage	Dysphagia, disease related malnutrition	150	10	Milk protein	12	Sucrose, Maltodextrin, Inulin	6.7	Sunflower oil, Rapeseed oil
Calogen Extra Shots	Shot-style beverage	Disease related malnutrition, malabsorption states	400	5	Cows milk protein caseinates, whey protein hydrolysate	4.5	Sugar, Carboxy-methyl-cellulose, Micro-crystalline cellulose, Maltodextrin	40.3	Sunflower oil, Rapeseed oil
Ensure Plus Compact	Compact beverage	Disease related malnutrition	240	10.2	Milk proteins	28.8	Hydrolysed corn starch, Sucrose	9.35	Canola oil, High oleic Sunflower oil, Corn oil
Altraplen Compact	Compact milkshake	Disease related malnutrition	240	9.6	Milk protein concentrate, Milk protein, Soya protein	28.8	Glucose syrup, Sucrose	9.6	Rapeseed oil
Fresubin 5kcal Shots	Shot-style beverage	Disease related malnutrition, malabsorption states	500	0	N/A	4	Sucrose	53.8	Rapeseed oil, Medium chain tri-glycerides

**Table 1 (continued).** Range of commercially available ONS in Ireland, their use, macronutrient content and sources.

<b>Name</b>	<b>Style</b>	<b>Indications</b>	<b>Calories kcal/100mL</b>	<b>Protein g/100</b>	<b>Protein source</b>	<b>Carbohydrate g/100g</b>	<b>Carbohydrate source</b>	<b>Fat g/100mL</b>	<b>Fat source</b>
Fortisip Compact	Compact milkshake	Disease related malnutrition	240	9.6	Cows milk proteins	29.7	Glucose syrup	9.3	Rapeseed oil, Sunflower oil
Fortisip Compact Fibre	Compact milkshake	Disease related malnutrition	240	9.5	Cows milk proteins	25.2	Glucose syrup, Oligofructose, Galacto-oligosaccharides, pectin, fructo-oligosaccharides	10.4	Rapeseed oil, Sunflower oil
Fortisip Compact Protein	Compact milkshake	Disease related malnutrition	240	14.4	Cows milk protein	24.4	Maltodextrin, Sugar	9.4	Rapeseed oil, Sunflower oil
Fresubin 2kcal mini drink	Compact beverage	Disease related malnutrition	200	10	Milk protein	22.5	Glucose syrup, Sucrose, Maltodextrin	7.8	Rapeseed oil, Sunflower oil
Fresubin 2kcal fibre mini-drink	Compact beverage	Disease related malnutrition	200	10	Milk protein	21.7	Glucose syrup, Sucrose, Inulin, Maltodextrin, Wheat dextrin	7.8	Rapeseed oil, Sunflower oil

**Table 1 (continued).** Range of commercially available ONS in Ireland, their use, macronutrient content and sources.

<b>Name</b>	<b>Style</b>	<b>Indications</b>	<b>Calories kcal/100mL</b>	<b>Protein g/100</b>	<b>Protein source</b>	<b>Carbohydrate g/100g</b>	<b>Carbohydrate source</b>	<b>Fat g/100mL</b>	<b>Fat source</b>
Fresubin 2kcal	Beverage	Dysphagia, disease related malnutrition, intractable malabsorption, short bowel syndrome, pre-op.	200	10	Milk protein	22.5	Glucose syrup, Sucrose, Maltodextrin	7.8	Rapeseed oil, Sunflower oil
Fresubin Protein Energy	Beverage	Dysphagia, disease related malnutrition, intractable malabsorption, short bowel syndrome, pre-op.	150	10	Milk protein	12.1	Sucrose, Maltodextrin	6.7	Rapeseed oil, Sunflower oil
Altraplen Protein	Milkshake	Post-op., disease related malnutrition	150	10	Milk protein concentrate, Isolated soya protein, Calcium caseinate, Potassium caseinate	15	Maltodextrin, Glucose syrup	5.6	Vegetable oil

**Table 1 (continued).** Range of commercially available ONS in Ireland, their use, macronutrient content and sources.

Name	Style	Indications	Calories kcal/100mL	Protein g/100	Protein source	Carbohydrate g/100g	Carbohydrate source	Fat g/100mL	Fat source
Calogen	Beverage	Energy enhancer in sip and tube feeds, milk replacer in protein restricted diets, electrolyte restricted patients	450	0	N/A	0.1	Sucrose	50	Canola oil, Sunflower oil
Calogen Extra	Beverage	Energy enhancer in sip and tube feeds, dietary supplementation, fortification	400	5	Cows milk protein caseinates, Whey protein hydrolysate	4.5	Sucrose	40.3	Rapeseed oil, Sunflower oil
Liquigen	Beverage	MCT ketogenic diet, energy enhancer in sip and tube feeds	454	0	N/A	0	N/A	50.4	Modified palm kernel, Coconut oil
Ensure Plus	Milkshake	Disease related malnutrition, anorexia, poor appetite, pre/post-op., neurological disorders	150	16.7	Milk protein isolate, Calcium and Sodium caseinates, Soy protein isolate	53.8	Maltodextrin, Corn syrup, Sucrose,	29.5	Canola oil, Corn oil

**Table 1 (continued).** Range of commercially available ONS in Ireland, their use, macronutrient content and sources.

<b>Name</b>	<b>Style</b>	<b>Indications</b>	<b>Calories kcal/100mL</b>	<b>Protein g/100</b>	<b>Protein source</b>	<b>Carbohydrate g/100g</b>	<b>Carbohydrate source</b>	<b>Fat g/100mL</b>	<b>Fat source</b>
Ensure Plus Juice	Juice	Disease related malnutrition, short bowel syndrome, intractable malabsorption, pre-op., dysphagia, inflammatory bowel disease, total gastrectomy, bowel fistula	150	4.8	Milk protein	32.7	Maltodextrin, Sucrose	0	
Ensure Plus Yoghurt Style	Yoghurt style beverage	Disease related malnutrition, short bowel syndrome, intractable malabsorption, pre-op., dysphagia, inflammatory bowel disease, total gastrectomy, bowel fistula	150	6.25	Milk proteins	20.2	Sucrose, Maltodextrin	4.92	High oleic sunflower oil, Canola oil, Corn oil

**Table 1 (continued).** Range of commercially available ONS in Ireland, their use, macronutrient content and sources.

<b>Name</b>	<b>Style</b>	<b>Indications</b>	<b>Calories kcal/100mL</b>	<b>Protein g/100</b>	<b>Protein source</b>	<b>Carbohydrate g/100g</b>	<b>Carbohydrate source</b>	<b>Fat g/100mL</b>	<b>Fat source</b>
Ensure Plus Savoury	Savoury beverage	Disease related malnutrition, anorexia, pre/post-op., neurological disorders, malignant disease	150	16.7	Milk proteins, Soy protein isolate	53.8	Maltodextrin	29.5	Canola oil, Corn oil
Cubitan	Beverage	Dietary management of chronic wounds	125	10	Milk protein concentrate	11.7	Maltodextrin, Sucrose	3.5	Vegetable oils
Fortisip	Milkshake	Disease related malnutrition	150	6	Milk protein	18.4	Maltodextrin, Sucrose	4.8	Vegetable oils
Fortisip Extra	Milkshake	Disease related malnutrition	159	9.8	Cows milk proteins	18.1	Maltodextrin, Sugar, Glucose syrup	5.3	Rapeseed oil, Sunflower oil
Fortisip 2kcal	Milkshake	Disease related malnutrition	200	10	Cows milk proteins	20.8	Glucose syrup, Sugar	8.5	Rapeseed oil, High oleic sunflower oil, Sunflower oil

**Table 1 (continued).** Range of commercially available ONS in Ireland, their use, macronutrient content and sources.

<b>Name</b>	<b>Style</b>	<b>Indications</b>	<b>Calories kcal/100mL</b>	<b>Protein g/100</b>	<b>Protein source</b>	<b>Carbohydrate g/100g</b>	<b>Carbohydrate source</b>	<b>Fat g/100mL</b>	<b>Fat source</b>
Fortisip Yoghurt Style	Yoghurt style beverage	Disease related malnutrition	150	5.9	Whey protein	18.7	Glucose syrup, Sugar, Pectin	5.8	Rapeseed oil, Sunflower oil
Fortijuice	Juice	Low fat diets, supplement diets	150	4	Milk protein	33.5	Glucose syrup, Maltodextrin, Sucrose	0	
Fresubin Energy Fibre	Beverage	Dysphagia, disease related malnutrition, intractable malabsorption, short bowel syndrome, pre-op.	150	5.6	Milk protein	17.8	Maltodextrin, Sucrose, Wheat dextrin, Inulin, Cellulose	5.8	Rapeseed oil, Sunflower oil
Fresubin Energy	Beverage	Dysphagia, disease related malnutrition, intractable malabsorption, short bowel syndrome, pre-op.	200	10	Milk protein	22.5	Maltodextrin, Sucrose	7.8	Vegetable oils

**Table 1 (continued).** Range of commercially available ONS in Ireland, their use, macronutrient content and sources.

<b>Name</b>	<b>Style</b>	<b>Indications</b>	<b>Calories kcal/100mL</b>	<b>Protein g/100</b>	<b>Protein source</b>	<b>Carbohydrate g/100g</b>	<b>Carbohydrate source</b>	<b>Fat g/100mL</b>	<b>Fat source</b>
Fresubin Original	Beverage	Dysphagia, disease related malnutrition, intractable malabsorption, short bowel syndrome, pre-op.	100	3.8	Milk protein, Soya protein	13.8	Maltodextrin, Sucrose	3.4	Rapeseed oil, Sunflower oil
Fresubin Jucy Drink	Juice	Dysphagia, disease related malnutrition, intractable malabsorption, short bowel syndrome, pre-op.	150	4	Whey protein	33.5	Glucose syrup, Sucrose, Maltodextrin	0	
Fresubin 2kcal Fibre	Beverage	Dysphagia, disease related malnutrition, intractable malabsorption, short bowel syndrome, pre-op.	200	10	Milk protein	21.7	Glucose syrup, Sucrose, Inulin, Maltodextrin	7.8	Rapeseed oil, Sunflower oil

**Table 1 (continued).** Range of commercially available ONS in Ireland, their use, macronutrient content and sources.

<b>Name</b>	<b>Style</b>	<b>Indications</b>	<b>Calories kcal/100mL</b>	<b>Protein g/100</b>	<b>Protein source</b>	<b>Carbohydrate g/100g</b>	<b>Carbohydrate source</b>	<b>Fat g/100mL</b>	<b>Fat source</b>
Ensure Can	Milkshake	Disease related malnutrition, anorexia, poor appetite, pre/post-op., neurological disorders	150	5.5	Sodium and calcium caseinates, Soy protein isolate	21.1	Maltodextrin, Sucrose	4.81	Canola oil, Corn oil, High oleic sunflower oil
Ensure Plus Fibre	Beverage	Disease related malnutrition, constipation, diarrhoea, anorexia, pre/post-op., neurological disorders	160	16.1	Milk proteins, Soy protein isolate	52.1	Hydrolysed corn starch, Maltodextrin, Sucrose, Fructo-oligo-saccharides, Oat Fibre, Gum Arabic, Soy-poly-saccharides,	28.6	Canola oil, High oleic sunflower oil, Corn oil
Ensure 2kcal	Beverage	Disease related malnutrition, liver disease, malignant disease, pre/post-op., bolus feeding, moderate burns	200	16.8	Milk proteins	42.1	Hydrolysed corn starch, Sucrose, Fructo-oligo-saccharides	40.1	High oleic sunflower oil, Soy oil, Canola oil

**Table 1 (continued).** Range of commercially available ONS in Ireland, their use, macronutrient content and sources.

<b>Name</b>	<b>Style</b>	<b>Indications</b>	<b>Calories kcal/100mL</b>	<b>Protein g/100</b>	<b>Protein source</b>	<b>Carbohydrate g/100g</b>	<b>Carbohydrate source</b>	<b>Fat g/100mL</b>	<b>Fat source</b>
Nutrison Energy Multi Fibre	Beverage	Disease related malnutrition in patients requiring bolus feeding	154	6	Cows milk proteins	18.4	Maltodextrin, Sugar, Soy-poly-saccharides, Oligofructose, Resistant starch, Arabic gum, Cellulose, Inulin	5.8	Rapeseed oil, Sunflower oil
Scand-ishake	Powder	Disease related malnutrition	507	4.8	Cow's milk caseinate	67.0	Maltodextrin, Sucrose	24.5	Soybean oil, Palm oil
Calshake	Powder	Disease related malnutrition, short bowel syndrome, intractable malabsorption, pre-op. prep. of malnourished patient, dysphagia, inflammatory bowel disease, following total gastrectomy, bowel fistula.	500	4.1	Milk protein	65.5	Dried glucose syrup, Dextrose, Maltodextrin, Sucrose	24.4	Palm oil, Coconut oil, Rapeseed oil

**Table 1 (continued).** Range of commercially available ONS in Ireland, their use, macronutrient content and sources.

<b>Name</b>	<b>Style</b>	<b>Indications</b>	<b>Calories kcal/100mL</b>	<b>Protein g/100</b>	<b>Protein source</b>	<b>Carbohydrate g/100g</b>	<b>Carbohydrate source</b>	<b>Fat g/100mL</b>	<b>Fat source</b>
Complan Shake	Powder	Disease related malnutrition	445	15.4	Skimmed milk	62.5	Maltodextrin, Sucrose	14.8	Palm olein, Sunflower oil
Ensake	Powder	Disease related malnutrition, malabsorption	436	8.1	Milk proteins, Soy protein isolate	67.1	Hydrolysed corn starch, Sucrose	15.1	High oleic sunflower oil, Soy oil, Coconut oil
Ensure Shake	Powder	Disease related malnutrition	443	17.8	Whey protein concentrate	59.0	Dried glucose syrup, Maltodextrin, Sugar	15.1	Palm fat
Foodlink Complete	Powder	Disease related malnutrition	444	21	Skimmed milk powder	56	Maltodextrin, Caster sugar	7.4	Refined palm oil
Foodlink Complete with Fibre	Powder	Disease related malnutrition	423	19	Skimmed milk powder	52	Sugar, Maltodextrin, Inulin, Caster sugar	14	Refined palm oil
Fresubin Powder Extra	Powder	Disease related malnutrition	420	17.5	Whey protein	6.0	Maltodextrin, Sucrose	10.9	Rapeseed oil powder, Medium chain tri-glycerides powder

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## **Chapter 2**

**Exploring how age influences sensory perception, thirst, and hunger during the consumption of oral nutritional supplements using the check-all-that-apply methodology.**

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## **Chapter 2: Exploring how age influences sensory perception, thirst, and hunger during the consumption of oral nutritional supplements using the check-all-that-apply methodology.**

### **2.1 Introduction**

The population aged 60 years or older is growing by 3 % annually and is predicted to reach 2 billion by 2050 (United Nations, 2017). Meeting the nutritional requirements of this older cohort is essential to maintain their health and quality of life (Leslie and Hankey, 2015; Doets and Kremer, 2016; Ruark *et al.*, 2016). However, food and caloric intake of the older adult is often insufficient (Field and Duizer, 2016) with up to 10 % of community dwelling older adults suffering from undernutrition (Doets and Kremer, 2016).

There are numerous factors contributing to undernutrition in older adults including loss of appetite (Donini, Savina and Cannella, 2003; Leslie and Hankey, 2015). The impairment of sensory perception in relation to taste and smell with increasing age reduces food interest (Doets and Kremer, 2016). As a result of the impairments in sensory function with age, there is a growing requirement for the development of food products with optimum sensory properties for older adults. It is therefore essential to conduct sensory evaluations with older adults to improve the understanding of their sensory perception and preferences (Maitre, Symoneaux and Sulmont-Rossé, 2015; Methven, Jimenez-Pranteda and Lawlor, 2016). This remains a largely under researched area of sensory science due to the challenges associated with this age group (Methven, Jimenez-Pranteda and Lawlor, 2016). There is a need to determine which sensory methods can be deemed affective for use with older adults.

The Check-all-that-apply (CATA) method has been used increasingly to assess the sensory properties of food and beverages (Adams *et al.*, 2007; Methven, Jimenez-Pranteda and Lawlor, 2016; Grasso *et al.*, 2017). This method comprises a multiple-choice questionnaire whereby panellists are asked to select from a list of descriptive attributes which best describe the product (Ares and Jaeger, 2015; Methven, Jimenez-Pranteda and Lawlor, 2016). Although CATA has had widespread use for the sensory characterisation of many foods and beverages, it has been rarely used with older adults. Therefore, further work is required to understand and assess

the suitability of CATA for older adults (Piqueras-Fiszman, Ares and Varela, 2011; Ruark *et al.*, 2016).

Traditional sensory methods are predominantly conducted using one bite or one sip of product not reflecting normal food consumption patterns (Thomas *et al.*, 2016). Recent studies have evaluated products over increasing bites and sips (Schlich *et al.*, 2013; Zorn *et al.*, 2014; Thomas *et al.*, 2016; Galmarini, Visalli and Schlich, 2017; Thomas *et al.*, 2018). However, to date this approach has predominantly utilised methods such as Temporal Dominance of Sensations (TDS) and Temporal Check-All-That-Apply (TCATA) (Thomas *et al.*, 2016) with no previous studies to the best of the author's knowledge applying a CATA evaluation over multiple bites or sips. The need for such an approach was highlighted by Ruark *et al.* (2016).

Oral nutritional supplements (ONS) combined with dietary counselling is successful in improving dietary uptake and alleviating undernutrition in older adults (Agarwal *et al.*, 2013; den Boer, Boesveldt and Lawlor, 2019). However, these supplements are only successful in improving nutritional status if the full portion is consumed (Thomas *et al.*, 2016). This is not always achieved due to their undesirable sensory profiles and adherence to ONS has been reported to be as low as 37 % in some cases (Gosney, 2003). To date, other research groups have explored the sensory profiles of ONS with increasing consumption volume (Methven *et al.*, 2010; Thomas *et al.*, 2016; Thomas *et al.*, 2018). Methven *et al.* (2010) used a sequential profile method to evaluate the sensory perception of ONS over repeat consumption (8 × 5 mL aliquots) and showed that mouth-drying, metallic, and mouthcoating attributes built-up with increasing consumption of ONS. Thomas *et al.* (2016) assessed the sensory perception of two ONS over the course of consumption of the full volume using a TDS method followed by a hedonic scale (A-TDL) and showed a decrease in liking and an increase in thirst with increasing sips due to the build-up of a mouthcoating. Furthering this research Thomas *et al.* (2018) assessed two ONS with older adults, in a mode to replicate full daily consumption and reported that both ONS increased thirst.

Although previous studies have explored the sensory profiles of ONS using a range of different sensory techniques (Methven *et al.*, 2010; Thomas *et al.*, 2016; Thomas *et al.*, 2018), no study has applied the CATA methodology with ONS. The

CATA method offers the benefit that a greater number of sensory attributes can be made available for selection.

The main aim of this study was to advance sensory science methodology for older cohorts. The research sought to apply the CATA methodology to investigate the differences in sensory perception of ONS, when a full volume, over multiple sips is consumed. Both younger and older adults were included in the study to assess if indeed CATA is an appropriate methodology for the older cohort and to deepen the knowledge of how perceptions differ with age. In addition to investigating taste, texture, and liking preferences, the study also considered, thirst, hunger, and fullness as these influence ONS adherence. In addition to the methodology development, the study was designed to deepen the understanding of how an older population experience ONS and to identify factors likely to improve ONS adherence and ultimately enhance the nutritional status of older people.

## **2.2 Materials and Methods**

### **2.2.1 Samples**

Thirty ONS from a range of different companies were evaluated for their apparent viscosity (Section 2.2.2), these included semi-solid/dessert style, thickened, compact/shot-style and beverage-style supplements. The thirty products were formulated for a range of different conditions, however the grounds on which they were selected for this study was to ensure a representation of a broad range of textures and viscosities.

Based on the results for apparent viscosity two ready-to-drink beverage-style ONS were selected for use. Of the beverage-style supplements analysed the lowest and highest apparent viscosity values obtained at a shear rate of  $50.1 \text{ s}^{-1}$  were 0.007 and 0.177 Pa.s. The two ONS selected for this study represent the upper and lower ends of this range. Throughout this chapter these two supplements are referred to as ONS 1 (low viscosity) and ONS 2 (high viscosity). ONS 1 and 2 were vanilla flavoured ready-to-drink beverage-style supplements consisting of milk proteins, vegetable oils, maltodextrin, and sucrose as well as many essential vitamins and minerals. Both supplements differed significantly in energy density and protein content with ONS 1 presenting as a moderate energy and protein beverage-style ONS and ONS 2 presenting as a high energy and protein pre-thickened beverage-

style ONS. The full nutritional composition of ONS 1 and ONS 2 is displayed in Appendix 1. As this study was predominantly focused on the sensory perception of the ONS, the protein and energy content were not standardised between the two supplements.

### **2.2.2 Rheological analysis**

The rheology of 30 commercial ONS was measured using a Physica MCR 301 Rheometer (Anton Paar, Graz, Austria), flow curves displayed in Appendix 2. The rheometer was fitted with a cone-and-plate geometry (diameter: 50 mm, cone angle: 2 °) and the temperature was set and maintained at room temperature (21 °C) throughout the analysis. All measurements were conducted in triplicate. Prior to analysis the samples were stirred at 200 rpm at 21 °C for 10 minutes using a laboratory stirrer (IKA RCT basic, IKA® Werke, GmbH and Co. KG, Germany). The sample was loaded on to the plate and allowed to equilibrate two minutes prior to analysis. Shear stress values were measured at shear rates from 0.1 to 1000 s<sup>-1</sup> with a ramp of 120 seconds.

### **2.2.3 Participants**

A total of 160 panellists were recruited for this sensory study. This group was divided into a test group which consisted of 80 panellists (untrained, 35 men and 45 women, aged over 65, mean age 73.7 ± 7.9) and a control group (untrained, 35 men and 45 women, aged 18-35, mean age 25.3 ± 3.8). Panellists were recruited through word-of-mouth and poster advertisements and were non-vanilla rejectors and regular consumers of dairy based drinks. Each panellist signed a written informed consent agreement before participating in the experiment. For this study the test group consisted of healthy older adults as opposed to undernourished older adults as the recruitment of 80 undernourished older adults is very challenging and this population cohort are considered vulnerable. Therefore, this study will act solely as a pilot CATA study and future work should be conducted with undernourished older adults. This sensory project was approved by the UCD Human Research Ethics Committee (Ref. No. LS-17-50).

### **2.2.4 Term generation**

A list of thirty different sensory attributes (Table 2.1) was created based on a lexicon previously used in similar sensory studies (Ruark *et al.*, 2016; Thomas *et al.*, 2016), along with two focus group sessions performed by (1): a panel of eight researchers

from the UCD Institute of Food and Health (2 men and 6 women, mean age  $24.2 \pm 2.5$ ), and then (2): six over 65 year olds (3 men and 3 women, mean age  $68.8 \pm 3.5$ ). The panellists were instructed to taste both ONS and list all the vocabulary relating to the products. After tasting the supplements, the recorded vocabulary was discussed among the panellists in the focus group and a final list of terms was selected based on the general consensus of agreement. The final list of attributes consisted of 17 texture/mouthfeel attributes and 13 taste/flavour attributes; these attributes were presented together in one list on the CATA questionnaire. A list of attribute definitions is supplied in Appendix 3. The order of terms on the CATA questionnaire was randomised between subjects according to Williams Latin Square Design (Williams, 1949), which removed any possibility of order-based bias in responses to questions.

**Table 2.1** Sensory terms used in the check-all-that-apply (CATA) task.

Texture/Mouthfeel	Taste/Flavour
Soft	Caramel
Viscous	Sweet
Smooth	Grassy
Dry	Metallic
Custard-like	Coffee
Mouthcoating	Vanilla
Gloopy	Artificial
Watery	Medicinal
Creamy	Milky
Astringent	Hazelnut
Airy	Bitter
Oily	Aftertaste
Thick	Chocolate
Grainy	
Silky	
Runny	
Jelly-like	

### **2.2.5 Experimental session**

The experimental trials took place over two 20-minute sessions in a sensory laboratory at room temperature (21 °C) under white lighting in accordance with ISO 8589 (ISO-Standard, 2007). Panellists consumed one of the two ONS in each session. The samples were presented in balanced order randomly allocated. Given that one of the aims of this study was to evaluate the changes in hunger and fullness levels with increasing consumption volume, subjects were instructed not to eat for two hours prior to the sensory sessions. Panellists were also not allowed to consume water at any stage during the sensory session. Prior to beginning the sensory evaluation baseline measurements for hunger, fullness, and thirst were measured using Visual Analogue Scales 100 mm (VAS) (Flint *et al.*, 2000).

Over the course of both sensory sessions five samples (40 mL each) of the same ONS were presented in a monadic sequential order (at room temperature) to the panellists in a balanced rotation order (Williams, 1949). Panellists were provided with the 40 mL of ONS in 60 mL clear plastic cups labelled with randomised three-digit sample codes. The panellists were allocated three minutes to consume the full 40 mL sample and complete the sensory questionnaire. On the questionnaire they were instructed to record their overall liking using a 9-point structured hedonic scale ranging from 'dislike extremely' to 'like extremely'. They were then instructed to check all the sensory terms which they believed best described the supplement which they had just consumed from the list of CATA attributes. Finally, they were asked to evaluate their hunger, fullness, thirst, and desire to drink more of the sample on 100 mm VAS (Flint *et al.*, 2000) anchored on the left-hand side with "not at all" and the right-hand side with "extremely". This evaluation process was repeated following each 40 mL serving. By the end of both sensory sessions the panellists had consumed one bottle (200 mL) of each ONS.

### **2.2.6 Data Analysis**

Overall liking, hunger, thirst, fullness, and desire to eat were analysed using a mixed model analysis of variance (ANOVA) with age as the between subject factor, and sip and ONS as the within subject repeated measures, to determine the significant differences between age and ONS and furthermore age and sips.

Frequency of selection of each CATA attribute were determined by calculating the number of individuals who selected each attribute for both age cohorts with both samples. A Fishers exact test (Chi squared) was performed to determine the significant differences between age and attribute selection frequency for both samples. To determine the significant differences in attribute selection frequency between each sip within both age groups, a Cochran's Q test was used. All statistical analysis was conducted using IBM®SPSS® (version 24.0 for Windows) (IBM Corp., USA).

The penalty-lift analysis for the CATA data was completed by determining the differences between the mean liking scores when an attribute was selected, versus the mean liking scores when an attribute was not selected (Meyners, Castura and Carr, 2013). This was completed using XLSTAT (Addinsoft, France).

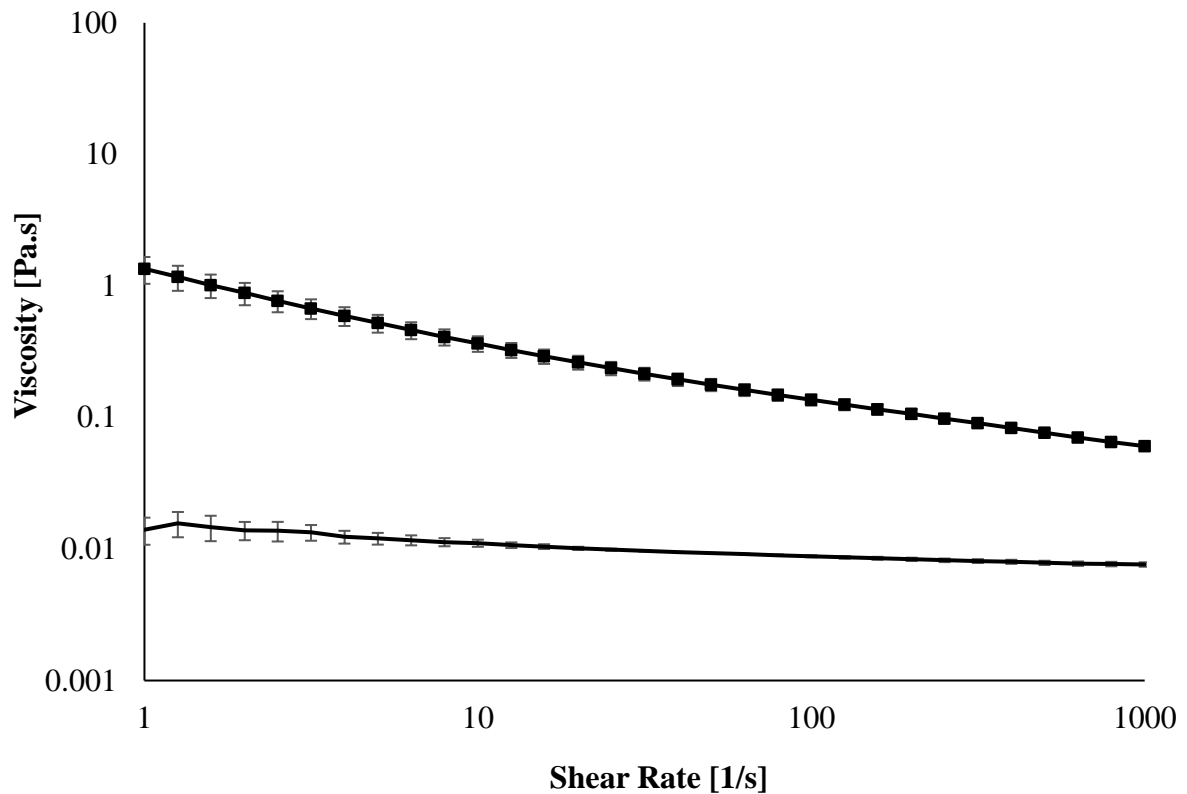
## **2.3 Results**

### **2.3.1 Sample Selection**

As previously mentioned, the two supplements selected for use in the sensory evaluation were chosen based on rheological data (as discussed below). The study sought to compare a high and low viscosity product as high viscosity products are associated with mouthcoating which is reported to contribute to ONS dislike (Methven *et al.*, 2010), which may subsequently affect adherence. As the nutritional profiles of the two supplements differ, no comparisons are made on the hunger or fullness ratings between the two supplements.

### **2.3.2 Rheology**

Figure 2.1 shows the flow curves for both ONS. There were significant differences ( $p \leq 0.05$ ) in viscosity of the two ONS in line with the study design. ONS 2 had a syrup like consistency with viscosity ranging from 4.56 to 0.06 Pa.s over a shear rate of 0.1 to 1000  $s^{-1}$ . The flow behaviour of this supplement is evidently pseudoplastic with a decrease in viscosity on shearing. ONS 1 on the other hand had low viscosity levels ranging from 0.02 to 0.01 Pa.s over a shear rate of 0.1 to 1000  $s^{-1}$  and exhibited Newtonian flow behaviour.



**Figure 2.1** Flow curves of ONS 1 (—) and ONS 2 (—■) with error bars representing standard deviation.

### 2.3.3 Subject data

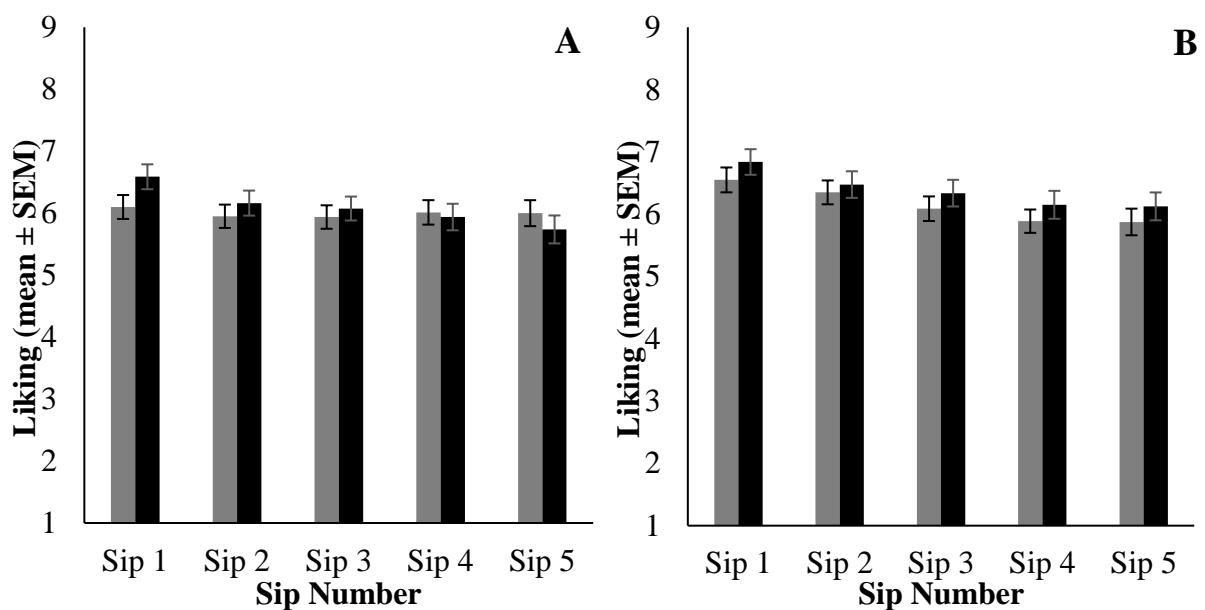
Table 2.2 summarises the differences between the younger and older cohorts. The number of subjects taking medications where dry mouth is reported (The Royal Pharmaceutical Society, 2019) was greater in the older adult cohort. Likewise, the number of subjects with at least one missing tooth, one artificial tooth, and suffering from dry mouth was also significantly higher in the older cohort. This reflects the different oral status between the two age cohorts.

**Table 2.2** Participants demographics for both the older and younger cohort

	Older subjects ( <i>n</i> =80)	Younger subjects ( <i>n</i> =80)
Number of males/females	35/45	35/45
Age (mean $\pm$ SD, range)	73.7 $\pm$ 7.9 (65-97)	25.3 $\pm$ 3.8 (18-35)
Number of subjects taking medications (at least weekly)	52	7
Number of subjects taking medications where dry mouth is reported as a common/very common side effect (The Royal Pharmaceutical Society, 2019)	22	4
Number of subjects taking medications where altered taste is reported as a common/very common side effect (The Royal Pharmaceutical Society, 2019)	14	2
Number of subjects to report suffering from dry mouth	14	0
Number of subjects to report suffering from oral/gum disease	3	0
Number of subjects suffering from frequent colds	6	8
Number of smokers	4	10
Number of subjects with at least 1 missing tooth	54	7
Number of subjects with at least 1 artificial tooth	36	0

### 2.3.4 Liking

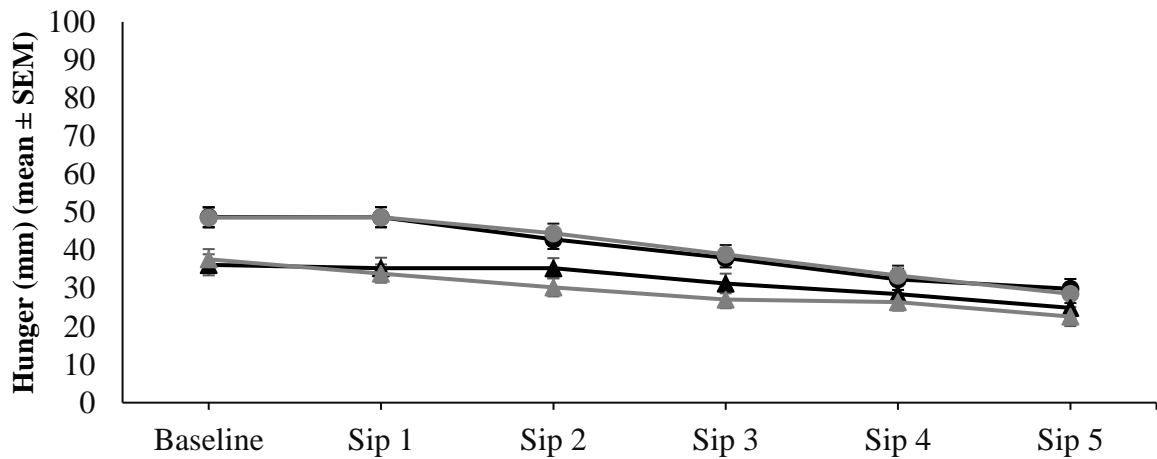
Average liking scores for both age cohorts and ONS are shown in Figures 2.2A and 2.2B. ONS 1 and 2 both scored between 5 and 7 (neither like nor dislike - like moderately) on a 9-point hedonic scale for liking. On average the overall liking scores declined by less than 1 scale point with increasing consumption volume from sip 1 to sip 5. The overall liking scores did not differ significantly between the two age cohorts nor the two ONS. The mixed model ANOVA showed that overall (across both ONS) liking decreased significantly with consumption volume. There were no significant interactions for liking.



**Figure 2.2** Mean ratings for liking at each sip (40 mL) for both younger (■) and older (■) adults for (A) ONS 1 and (B) ONS 2 with error bars representing the standard errors of the means.

### 2.3.5 Hunger

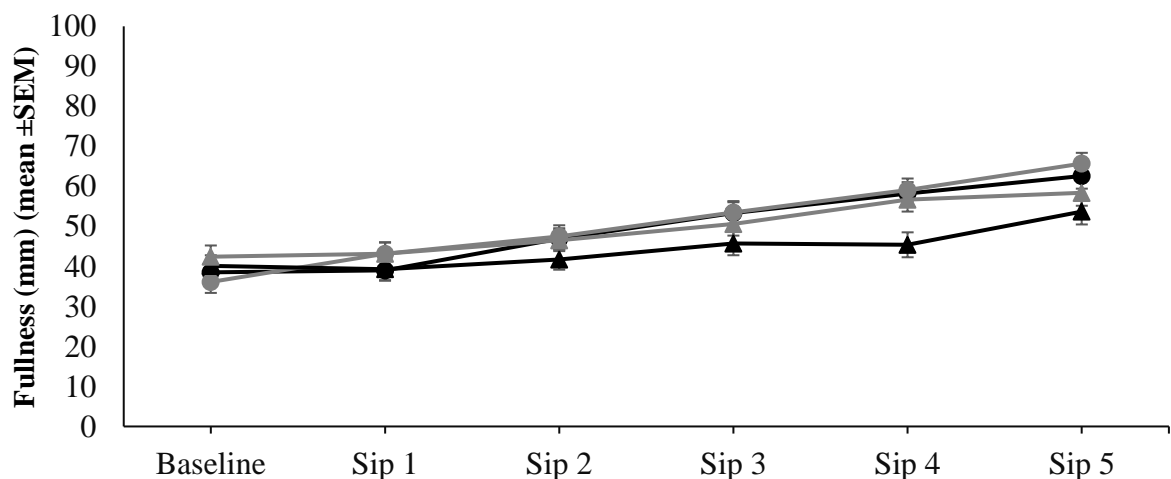
Average hunger ratings after each sip for both age cohorts and ONS are shown in Figure 2.3. The hunger profiles declined significantly ( $p \leq 0.001$ ) with increasing volume of consumption for both age cohorts and ONS. Hunger ratings were significantly different between the two age cohorts ( $p \leq 0.05$ ) with the younger cohort on average hungrier than the older cohort both before and after consumption. The mixed model ANOVA showed a significant effect for hunger with sip number ( $p \leq 0.001$ ) and a significant sip by age interaction ( $p \leq 0.001$ ). However, there were no significant ONS by sip or ONS by age interactions.



**Figure 2.3** Mean ratings for hunger at each sip (40 mL) for ONS 1 in both younger (—○) and older adults (—▲) and ONS 2 in younger (---○) and older adults (---▲), with error bars representing the standard errors of the means.

### 2.3.6 Fullness

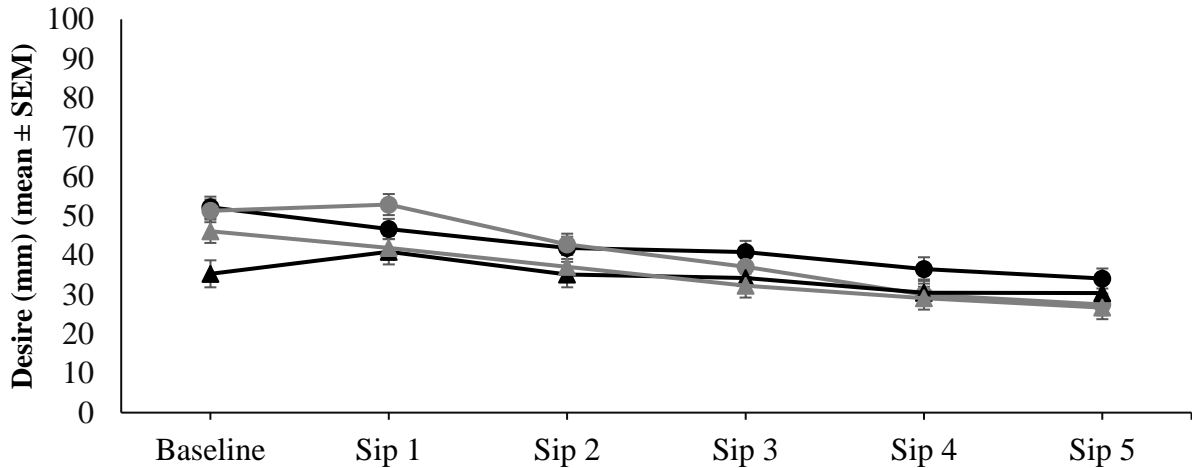
The VAS ratings for fullness at each sip for both age categories and ONS were assessed (Figure 2.4). There is a clear trend of increasing fullness with each successive sip for both age cohorts and ONS with the exception of ONS 1 in the older cohort which had a less pronounced increase between sips 1 and 4. There were significant effects for sip number ( $p \leq 0.001$ ) and for ONS ( $p \leq 0.05$ ), however, there were no significant differences in fullness profiles between the two age cohorts. A significant interaction existed for sip by age, but no other significant interactions were recorded.



**Figure 2.4** Mean ratings for fullness at each sip (40 mL) for ONS 1 in both younger (—○) and older adults (—▲) and ONS 2 in younger (---○) and older adults (---▲), with error bars representing the standard errors of the means.

### 2.3.7 Desire

The desire to consume more of the ONS declined gradually with each 40 mL volume consumed in both age cohorts (Figure 2.5). There was a significant effect for sip number and a significant sip by ONS interaction ( $p \leq 0.001$ ). There were, however, no significant differences in desire between the two ONS or the two age cohorts.

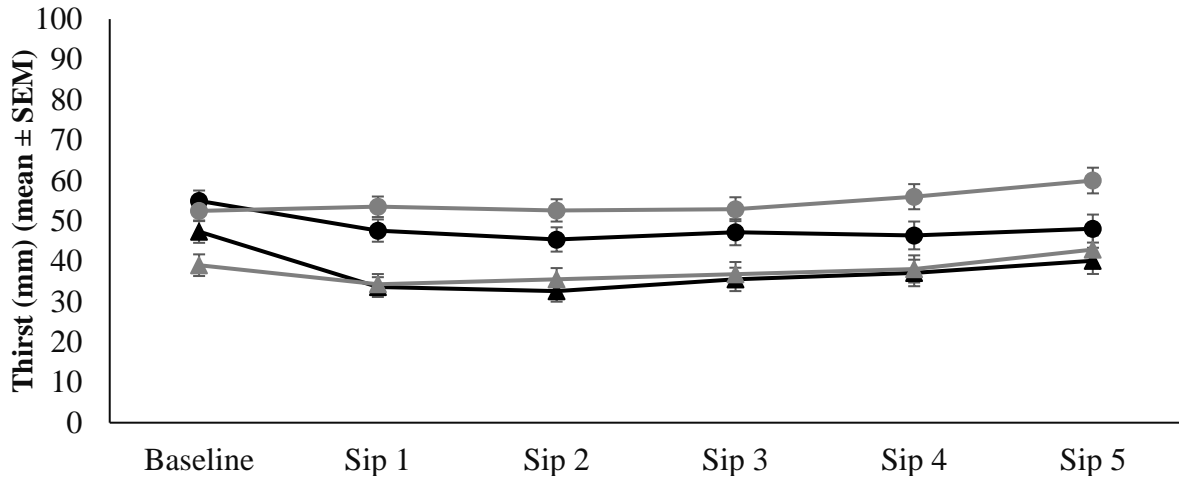


**Figure 2.5** Mean ratings for the desire to consume more ONS at each sip (40 mL) for ONS 1 in both younger (●) and older adults (▲) and ONS 2 in younger (◐) and older adults (◑), with error bars representing the standard errors of the means.

### 2.3.8 Thirst

Average thirst ratings with each sip for both age groups and ONS are shown in Figure 2.6. Overall thirst scores of the younger cohort increased by less than 1 scale point for ONS 1 and by 6.5 scale points for ONS 2 between sips 1 and 5. In contrast, the older cohort's thirst ratings increased by 6.5 scale points for ONS 1 and 8.6 scale points for ONS 2 over the 5 sips.

The thirst profiles were significantly different ( $p \leq 0.001$ ) between the two age cohorts with the younger cohort on average thirstier than the older cohort. The mixed model ANOVA showed a significant difference in thirst profiles between the two supplements ( $p \leq 0.05$ ) with ONS 2 contributing to higher thirst ratings in both age cohorts. There was also a significant effect ( $p \leq 0.001$ ) for thirst with sip number.



**Figure 2.6** Mean ratings for thirst at each sip (40 mL) for ONS 1 in both younger (●) and older adults (▲) and ONS 2 in younger (○) and older adults (△), with error bars representing the standard errors of the means.

### 2.3.9 CATA

#### 2.3.9.1 Number of attributes selected

The average number of attributes selected by both age cohorts across the five different sips for both ONS differed (Table 2.3). The older cohort selected less attributes on average to describe the two ONS than the younger cohort. However, based on the results of the mixed model ANOVA these differences were not significant ( $p = 0.055$ ).

**Table 2.3** Differences between the two age groups in the number of attributes selected across all five sips for both ONS (no significant differences were observed between the two age cohorts using a mixed model ANOVA).

	Sip 1		Sip 2		Sip 3		Sip 4		Sip 5	
	ONS 1	ONS 2	ONS 1	ONS 2	ONS 1	ONS 2	ONS 1	ONS 2	ONS 1	ONS 2
	1	2	1	2	1	2	1	2	1	2
18-35	7 ± 2	8 ± 3	7 ± 2	8 ± 3	7 ± 2	8 ± 3	7 ± 2	8 ± 3	7 ± 3	8 ± 3
Over 65	6 ± 4	7 ± 4	6 ± 4	7 ± 4	6 ± 4	7 ± 4	6 ± 4	7 ± 4	6 ± 4	7 ± 4

#### 2.3.9.2 Attribute selection frequency

The attribute selection frequency for both age groups at each sip level for ONS 1 and ONS 2 are illustrated in Tables 2.4 and 2.5 respectively. The most frequently selected attributes chosen by both age cohorts to describe ONS 1 were 'Milky',

'Smooth', 'Sweet', and 'Vanilla' while for ONS 2 the terms 'Creamy', 'Smooth', 'Sweet', 'Thick', and 'Vanilla' were chosen most frequently.

The Fishers exact test (Chi squared) revealed significant differences ( $p \leq 0.01$ ) between the two age cohorts in the selection of 5 of the 30 attributes for ONS 1; 'Hazelnut', 'Metallic', 'Milky', 'Vanilla', and 'Watery' and 4 of the 30 attributes for ONS 2; 'Chocolate', 'Mouthcoating', 'Thick', and 'Viscous'. For ONS 1 these 5 terms were selected significantly more by the younger cohort, whereas, for ONS 2 the term 'Chocolate' (sip 2) was selected significantly more by the older cohort with the remaining attributes ('Mouthcoating', 'Thick', and 'Viscous') selected more by the younger cohort (at different sip levels).

A Cochran's Q test revealed significant differences ( $p \leq 0.01$ ) in the frequency of selection of several attributes with increasing consumption in both age cohorts. For the younger cohort the selection of the attributes 'Metallic' and 'Runny' decreased significantly with increasing consumption volume for ONS 1. Whereas, for ONS 2 the selection of 'Caramel' decreased. In contrast, for the older cohort no significant differences existed in the attribute selection frequency during ONS 1 consumption, however, for ONS 2, the selection of 'Chocolate' increased significantly with sip number.

**Table 2.4** Frequency of selection of CATA terms for both age cohorts at each sip for ONS 1.

	Sip 1		Sip 2		Sip 3		Sip 4		Sip 5	
	18-35 %	65+ %	18-35 %	65+ %	18-35 %	65+ %	18-35 %	65+ %	18-35 %	65+ %
Airy <sup>ns</sup>	7 <sup>aq</sup>	10 <sup>dq</sup>	10 <sup>as</sup>	10 <sup>ds</sup>	12 <sup>au</sup>	10 <sup>du</sup>	12 <sup>aw</sup>	10 <sup>dw</sup>	19 <sup>ay</sup>	12 <sup>dy</sup>
Aftertaste <sup>ns</sup>	27 <sup>aq</sup>	31 <sup>dq</sup>	31 <sup>as</sup>	30 <sup>ds</sup>	32 <sup>au</sup>	42 <sup>du</sup>	37 <sup>aw</sup>	45 <sup>dw</sup>	40 <sup>ay</sup>	34 <sup>dy</sup>
Artificial <sup>ns</sup>	20 <sup>aq</sup>	7 <sup>dq</sup>	25 <sup>as</sup>	15 <sup>ds</sup>	22 <sup>au</sup>	11 <sup>du</sup>	17 <sup>aw</sup>	14 <sup>dw</sup>	21 <sup>ay</sup>	10 <sup>dy</sup>
Astringent <sup>ns</sup>	6 <sup>aq</sup>	2 <sup>dq</sup>	6 <sup>as</sup>	1 <sup>ds</sup>	7 <sup>au</sup>	5 <sup>du</sup>	7 <sup>aw</sup>	6 <sup>dw</sup>	11 <sup>ay</sup>	5 <sup>dy</sup>
Bitter <sup>ns</sup>	7 <sup>aq</sup>	1 <sup>dq</sup>	1 <sup>as</sup>	2 <sup>ds</sup>	4 <sup>au</sup>	2 <sup>du</sup>	2 <sup>aw</sup>	5 <sup>dw</sup>	5 <sup>ay</sup>	2 <sup>dy</sup>
Caramel <sup>ns</sup>	47 <sup>aq</sup>	37 <sup>dq</sup>	40 <sup>as</sup>	42 <sup>ds</sup>	44 <sup>au</sup>	37 <sup>du</sup>	45 <sup>aw</sup>	32 <sup>dw</sup>	42 <sup>ay</sup>	37 <sup>dy</sup>
Chocolate <sup>ns</sup>	2 <sup>aq</sup>	6 <sup>dq</sup>	4 <sup>as</sup>	7 <sup>ds</sup>	2 <sup>au</sup>	10 <sup>du</sup>	5 <sup>aw</sup>	9 <sup>dw</sup>	6 <sup>ay</sup>	11 <sup>dy</sup>
Coffee <sup>ns</sup>	5 <sup>aq</sup>	11 <sup>dq</sup>	5 <sup>as</sup>	14 <sup>ds</sup>	5 <sup>au</sup>	10 <sup>du</sup>	4 <sup>aw</sup>	10 <sup>dw</sup>	5 <sup>ay</sup>	9 <sup>dy</sup>
Creamy <sup>ns</sup>	31 <sup>aq</sup>	51 <sup>dq</sup>	37 <sup>as</sup>	42 <sup>ds</sup>	41 <sup>au</sup>	46 <sup>du</sup>	41 <sup>aw</sup>	49 <sup>dw</sup>	41 <sup>ay</sup>	47 <sup>dy</sup>
Custard-like <sup>ns</sup>	21 <sup>aq</sup>	24 <sup>dq</sup>	17 <sup>as</sup>	29 <sup>ds</sup>	19 <sup>au</sup>	31 <sup>du</sup>	20 <sup>aw</sup>	30 <sup>dw</sup>	17 <sup>ay</sup>	24 <sup>dy</sup>
Dry <sup>ns</sup>	9 <sup>aq</sup>	5 <sup>dq</sup>	5 <sup>as</sup>	5 <sup>ds</sup>	10 <sup>au</sup>	7 <sup>du</sup>	11 <sup>aw</sup>	5 <sup>dw</sup>	11 <sup>ay</sup>	6 <sup>dy</sup>
Gloopy <sup>ns</sup>	1 <sup>aq</sup>	6 <sup>dq</sup>	2 <sup>as</sup>	4 <sup>ds</sup>	2 <sup>au</sup>	2 <sup>du</sup>	2 <sup>aw</sup>	4 <sup>dw</sup>	4 <sup>ay</sup>	6 <sup>dy</sup>
Grainy <sup>ns</sup>	0 <sup>aq</sup>	2 <sup>dq</sup>	0 <sup>as</sup>	0 <sup>ds</sup>	2 <sup>au</sup>	2 <sup>du</sup>	0 <sup>aw</sup>	2 <sup>dw</sup>	0 <sup>ay</sup>	1 <sup>dy</sup>
Grassy <sup>ns</sup>	4 <sup>aq</sup>	0 <sup>dq</sup>	0 <sup>as</sup>	1 <sup>ds</sup>	0 <sup>au</sup>	2 <sup>du</sup>	2 <sup>aw</sup>	2 <sup>dw</sup>	2 <sup>ay</sup>	1 <sup>dy</sup>
Hazelnut	26 <sup>aq</sup>	9 <sup>dr</sup>	22 <sup>as</sup>	14 <sup>ds</sup>	22 <sup>au</sup>	6 <sup>dv</sup>	24 <sup>aw</sup>	10 <sup>dw</sup>	24 <sup>ay</sup>	7 <sup>dz</sup>
Jelly-like <sup>ns</sup>	0 <sup>aq</sup>	0 <sup>dq</sup>	0 <sup>as</sup>	2 <sup>ds</sup>	0 <sup>au</sup>	0 <sup>du</sup>	1 <sup>aw</sup>	1 <sup>dw</sup>	1 <sup>ay</sup>	2 <sup>dy</sup>
Medicinal <sup>ns</sup>	7 <sup>aq</sup>	6 <sup>dq</sup>	10 <sup>as</sup>	5 <sup>ds</sup>	9 <sup>au</sup>	6 <sup>du</sup>	9 <sup>aw</sup>	7 <sup>dw</sup>	10 <sup>ay</sup>	9 <sup>dy</sup>
Metallic	21 <sup>aq</sup>	4 <sup>dr</sup>	16 <sup>abs</sup>	4 <sup>ds</sup>	10 <sup>abu</sup>	4 <sup>du</sup>	14 <sup>abw</sup>	5 <sup>dw</sup>	9 <sup>by</sup>	2 <sup>dy</sup>
Milky	64 <sup>aq</sup>	54 <sup>dq</sup>	79 <sup>as</sup>	54 <sup>dt</sup>	72 <sup>au</sup>	49 <sup>dv</sup>	71 <sup>aw</sup>	47 <sup>dx</sup>	69 <sup>ay</sup>	54 <sup>dy</sup>
Mouthcoating <sup>ns</sup>	17 <sup>aq</sup>	19 <sup>dq</sup>	21 <sup>as</sup>	24 <sup>ds</sup>	27 <sup>au</sup>	25 <sup>du</sup>	26 <sup>aw</sup>	34 <sup>dw</sup>	34 <sup>ay</sup>	26 <sup>dy</sup>
Oily <sup>ns</sup>	5 <sup>aq</sup>	4 <sup>dq</sup>	12 <sup>as</sup>	9 <sup>ds</sup>	7 <sup>au</sup>	5 <sup>du</sup>	10 <sup>aw</sup>	2 <sup>dw</sup>	9 <sup>ay</sup>	5 <sup>dy</sup>
Runny	45 <sup>aq</sup>	37 <sup>dq</sup>	34 <sup>abs</sup>	31 <sup>ds</sup>	35 <sup>abu</sup>	35 <sup>du</sup>	30 <sup>abw</sup>	27 <sup>dw</sup>	25 <sup>by</sup>	32 <sup>dy</sup>
Silky <sup>ns</sup>	27 <sup>aq</sup>	36 <sup>dq</sup>	32 <sup>as</sup>	30 <sup>ds</sup>	25 <sup>au</sup>	29 <sup>du</sup>	36 <sup>aw</sup>	31 <sup>dw</sup>	35 <sup>ay</sup>	37 <sup>dy</sup>
Soft <sup>ns</sup>	21 <sup>aq</sup>	37 <sup>dq</sup>	24 <sup>as</sup>	40 <sup>ds</sup>	24 <sup>au</sup>	32 <sup>du</sup>	26 <sup>aw</sup>	42 <sup>dw</sup>	34 <sup>ay</sup>	27 <sup>dy</sup>
Smooth	52 <sup>aq</sup>	50 <sup>dq</sup>	59 <sup>as</sup>	54 <sup>ds</sup>	65 <sup>au</sup>	45 <sup>du</sup>	60 <sup>aw</sup>	46 <sup>dw</sup>	59 <sup>ay</sup>	45 <sup>dy</sup>
Sweet <sup>ns</sup>	54 <sup>aq</sup>	47 <sup>dq</sup>	47 <sup>as</sup>	55 <sup>ds</sup>	52 <sup>au</sup>	50 <sup>du</sup>	56 <sup>aw</sup>	49 <sup>w</sup>	55 <sup>ay</sup>	50 <sup>dy</sup>
Thick <sup>ns</sup>	2 <sup>aq</sup>	6 <sup>dq</sup>	2 <sup>as</sup>	7 <sup>ds</sup>	6 <sup>au</sup>	9 <sup>du</sup>	9 <sup>aw</sup>	7 <sup>dw</sup>	12 <sup>ay</sup>	9 <sup>dy</sup>
Vanilla	69 <sup>aq</sup>	59 <sup>dq</sup>	65 <sup>as</sup>	52 <sup>ds</sup>	69 <sup>au</sup>	46 <sup>dv</sup>	70 <sup>aw</sup>	46 <sup>dx</sup>	69 <sup>ay</sup>	49 <sup>dy</sup>
Viscous	2 <sup>aq</sup>	2 <sup>dq</sup>	6 <sup>as</sup>	1 <sup>ds</sup>	4 <sup>au</sup>	1 <sup>du</sup>	7 <sup>aw</sup>	5 <sup>dw</sup>	5 <sup>ay</sup>	4 <sup>dy</sup>
Watery	51 <sup>aq</sup>	26 <sup>dr</sup>	52 <sup>as</sup>	29 <sup>dt</sup>	47 <sup>au</sup>	30 <sup>du</sup>	46 <sup>aw</sup>	34 <sup>dw</sup>	44 <sup>ay</sup>	26 <sup>dy</sup>

Different superscript letters denote significant differences in attribute selection frequency for ONS 1: (a, b, c) between each sip for 18-35s, (d, e, f) between each sip for over 65s, (q, r) between the two groups within sip 1, (s, t) between the two groups within sip 2, (u, v), between the two groups within sip 3, (w, x) between the two groups within sip 4, (y, z) between the two groups within sip 5, (ns) no significant difference.

**Table 2.5** Frequency of selection of CATA terms for both age cohorts at each sip for ONS 2.

	Sip 1		Sip 2		Sip 3		Sip 4		Sip 5	
	18-35 %	65+ %	18-35 %	65+ %	18-35 %	65+ %	18-35 %	65+ %	18-35 %	65+ %
Airy <sup>ns</sup>	2 <sup>aq</sup>	5 <sup>dq</sup>	11 <sup>as</sup>	4 <sup>ds</sup>	7 <sup>au</sup>	5 <sup>du</sup>	10 <sup>aw</sup>	4 <sup>dw</sup>	10 <sup>ay</sup>	6 <sup>dy</sup>
Aftertaste <sup>ns</sup>	35 <sup>aq</sup>	30 <sup>dq</sup>	35 <sup>as</sup>	32 <sup>ds</sup>	32 <sup>au</sup>	36 <sup>du</sup>	34 <sup>aw</sup>	29 <sup>dw</sup>	35 <sup>ay</sup>	37 <sup>dy</sup>
Artificial <sup>ns</sup>	10 <sup>aq</sup>	4 <sup>dq</sup>	14 <sup>as</sup>	4 <sup>ds</sup>	19 <sup>au</sup>	7 <sup>du</sup>	14 <sup>aw</sup>	6 <sup>dw</sup>	19 <sup>ay</sup>	14 <sup>dy</sup>
Astringent <sup>ns</sup>	7 <sup>aq</sup>	1 <sup>dq</sup>	6 <sup>as</sup>	2 <sup>ds</sup>	10 <sup>au</sup>	4 <sup>du</sup>	10 <sup>aw</sup>	5 <sup>dw</sup>	10 <sup>ay</sup>	9 <sup>dy</sup>
Bitter <sup>ns</sup>	1 <sup>aq</sup>	1 <sup>dq</sup>	7 <sup>as</sup>	0 <sup>ds</sup>	1 <sup>au</sup>	2 <sup>du</sup>	2 <sup>aw</sup>	1 <sup>dw</sup>	4 <sup>ay</sup>	2 <sup>dy</sup>
Caramel	54 <sup>aq</sup>	37 <sup>dq</sup>	36 <sup>bs</sup>	42 <sup>ds</sup>	44 <sup>abu</sup>	45 <sup>du</sup>	37 <sup>bw</sup>	41 <sup>dw</sup>	36 <sup>by</sup>	35 <sup>dy</sup>
Chocolate	1 <sup>aq</sup>	4 <sup>dq</sup>	1 <sup>as</sup>	14 <sup>et</sup>	2 <sup>au</sup>	9 <sup>deu</sup>	1 <sup>aw</sup>	7 <sup>dew</sup>	5 <sup>ay</sup>	7 <sup>dey</sup>
Coffee <sup>ns</sup>	7 <sup>aq</sup>	15 <sup>dq</sup>	7 <sup>as</sup>	14 <sup>ds</sup>	5 <sup>au</sup>	14 <sup>du</sup>	6 <sup>aw</sup>	11 <sup>dw</sup>	5 <sup>ay</sup>	12 <sup>dy</sup>
Creamy <sup>ns</sup>	81 <sup>aq</sup>	75 <sup>dq</sup>	80 <sup>as</sup>	80 <sup>ds</sup>	76 <sup>au</sup>	74 <sup>du</sup>	76 <sup>aw</sup>	76 <sup>dw</sup>	79 <sup>ay</sup>	74 <sup>dy</sup>
Custard-like <sup>ns</sup>	41 <sup>aq</sup>	45 <sup>dq</sup>	49 <sup>as</sup>	46 <sup>ds</sup>	44 <sup>au</sup>	44 <sup>du</sup>	42 <sup>aw</sup>	54 <sup>dw</sup>	47 <sup>ay</sup>	49 <sup>dy</sup>
Dry <sup>ns</sup>	4 <sup>aq</sup>	6 <sup>dq</sup>	7 <sup>as</sup>	10 <sup>ds</sup>	5 <sup>au</sup>	14 <sup>du</sup>	11 <sup>aw</sup>	10 <sup>dw</sup>	15 <sup>ay</sup>	11 <sup>dy</sup>
Gloopy <sup>ns</sup>	21 <sup>aq</sup>	9 <sup>dq</sup>	19 <sup>as</sup>	11 <sup>ds</sup>	25 <sup>au</sup>	12 <sup>du</sup>	24 <sup>aw</sup>	10 <sup>dw</sup>	16 <sup>ay</sup>	12 <sup>dy</sup>
Grainy <sup>ns</sup>	0 <sup>aq</sup>	4 <sup>dq</sup>	0 <sup>as</sup>	1 <sup>ds</sup>	0 <sup>au</sup>	2 <sup>du</sup>	0 <sup>aw</sup>	1 <sup>dw</sup>	0 <sup>ay</sup>	2 <sup>dy</sup>
Grassy <sup>ns</sup>	0 <sup>aq</sup>	2 <sup>dq</sup>	0 <sup>as</sup>	1 <sup>ds</sup>	1 <sup>au</sup>	1 <sup>du</sup>	0 <sup>aw</sup>	4 <sup>dw</sup>	0 <sup>ay</sup>	2 <sup>dy</sup>
Hazelnut <sup>ns</sup>	17 <sup>aq</sup>	19 <sup>dq</sup>	20 <sup>as</sup>	15 <sup>ds</sup>	24 <sup>au</sup>	14 <sup>du</sup>	19 <sup>aw</sup>	14 <sup>dw</sup>	24 <sup>ay</sup>	16 <sup>dy</sup>
Jelly-like <sup>ns</sup>	2 <sup>aq</sup>	4 <sup>dq</sup>	4 <sup>as</sup>	4 <sup>ds</sup>	2 <sup>au</sup>	6 <sup>du</sup>	7 <sup>aw</sup>	4 <sup>dw</sup>	5 <sup>ay</sup>	5 <sup>dy</sup>
Medicinal <sup>ns</sup>	5 <sup>aq</sup>	6 <sup>dq</sup>	5 <sup>as</sup>	10 <sup>ds</sup>	4 <sup>au</sup>	4 <sup>du</sup>	5 <sup>aw</sup>	9 <sup>dw</sup>	11 <sup>ay</sup>	9 <sup>dy</sup>
Metallic <sup>ns</sup>	10 <sup>aq</sup>	4 <sup>dq</sup>	14 <sup>as</sup>	2 <sup>ds</sup>	7 <sup>au</sup>	2 <sup>du</sup>	6 <sup>aw</sup>	6 <sup>dw</sup>	9 <sup>ay</sup>	2 <sup>dy</sup>
Milky <sup>ns</sup>	51 <sup>aq</sup>	41 <sup>dq</sup>	56 <sup>as</sup>	37 <sup>ds</sup>	52 <sup>au</sup>	32 <sup>du</sup>	47 <sup>aw</sup>	41 <sup>dw</sup>	59 <sup>ay</sup>	40 <sup>dz</sup>
Mouthcoating	56 <sup>aq</sup>	36 <sup>dq</sup>	54 <sup>as</sup>	32 <sup>dt</sup>	47 <sup>au</sup>	41 <sup>du</sup>	52 <sup>aw</sup>	46 <sup>dw</sup>	50 <sup>ay</sup>	39 <sup>dy</sup>
Oily <sup>ns</sup>	7 <sup>aq</sup>	6 <sup>dq</sup>	12 <sup>as</sup>	5 <sup>ds</sup>	9 <sup>au</sup>	7 <sup>du</sup>	10 <sup>aw</sup>	7 <sup>dw</sup>	10 <sup>ay</sup>	10 <sup>dy</sup>
Runny <sup>ns</sup>	4 <sup>aq</sup>	10 <sup>dq</sup>	7 <sup>as</sup>	10 <sup>ds</sup>	6 <sup>au</sup>	10 <sup>du</sup>	7 <sup>aw</sup>	10 <sup>dw</sup>	9 <sup>ay</sup>	10 <sup>dy</sup>
Silky <sup>ns</sup>	37 <sup>aq</sup>	37 <sup>dq</sup>	35 <sup>as</sup>	31 <sup>ds</sup>	32 <sup>au</sup>	32 <sup>du</sup>	29 <sup>aw</sup>	40 <sup>dw</sup>	37 <sup>ay</sup>	42 <sup>dy</sup>
Soft <sup>ns</sup>	39 <sup>aq</sup>	45 <sup>dq</sup>	32 <sup>as</sup>	45 <sup>ds</sup>	34 <sup>au</sup>	42 <sup>du</sup>	30 <sup>aw</sup>	45 <sup>dw</sup>	44 <sup>ay</sup>	45 <sup>dy</sup>
Smooth <sup>ns</sup>	67 <sup>aq</sup>	59 <sup>dq</sup>	62 <sup>as</sup>	49 <sup>ds</sup>	57 <sup>au</sup>	56 <sup>du</sup>	67 <sup>aw</sup>	59 <sup>dw</sup>	66 <sup>ay</sup>	55 <sup>dy</sup>
Sweet <sup>ns</sup>	52 <sup>aq</sup>	54 <sup>dq</sup>	55 <sup>as</sup>	46 <sup>ds</sup>	60 <sup>au</sup>	57 <sup>du</sup>	57 <sup>aw</sup>	47 <sup>dw</sup>	56 <sup>ay</sup>	60 <sup>dy</sup>
Thick	71 <sup>aq</sup>	40 <sup>dr</sup>	74 <sup>as</sup>	45 <sup>dt</sup>	71 <sup>au</sup>	51 <sup>du</sup>	72 <sup>aw</sup>	45 <sup>dx</sup>	75 <sup>ay</sup>	49 <sup>dz</sup>
Vanilla <sup>ns</sup>	64 <sup>aq</sup>	50 <sup>dq</sup>	67 <sup>as</sup>	51 <sup>ds</sup>	66 <sup>au</sup>	55 <sup>du</sup>	66 <sup>aw</sup>	56 <sup>dw</sup>	59 <sup>ay</sup>	51 <sup>dy</sup>
Viscous	30 <sup>aq</sup>	12 <sup>dq</sup>	26 <sup>as</sup>	15 <sup>ds</sup>	31 <sup>au</sup>	9 <sup>dv</sup>	24 <sup>aw</sup>	12 <sup>dw</sup>	29 <sup>ay</sup>	14 <sup>dy</sup>
Watery <sup>ns</sup>	1 <sup>aq</sup>	1 <sup>dq</sup>	2 <sup>as</sup>	2 <sup>ds</sup>	1 <sup>au</sup>	5 <sup>du</sup>	7 <sup>aw</sup>	9 <sup>dw</sup>	4 <sup>ay</sup>	6 <sup>dy</sup>

Different superscript letters denote significant differences in attribute selection frequency for ONS 2: (a, b, c) between each sip for 18-35s, (d, e, f) between each sip for over 65s, (q, r) between the two age groups within sip 1, (s, t) between the two age groups within sip 2, (u, v) between the two age groups within sip 3, (w, x) between the two age groups within sip 4, (y, z) between the two age groups within sip 5, (ns) no significant difference.

### **2.3.9.3 Number of discriminating attributes**

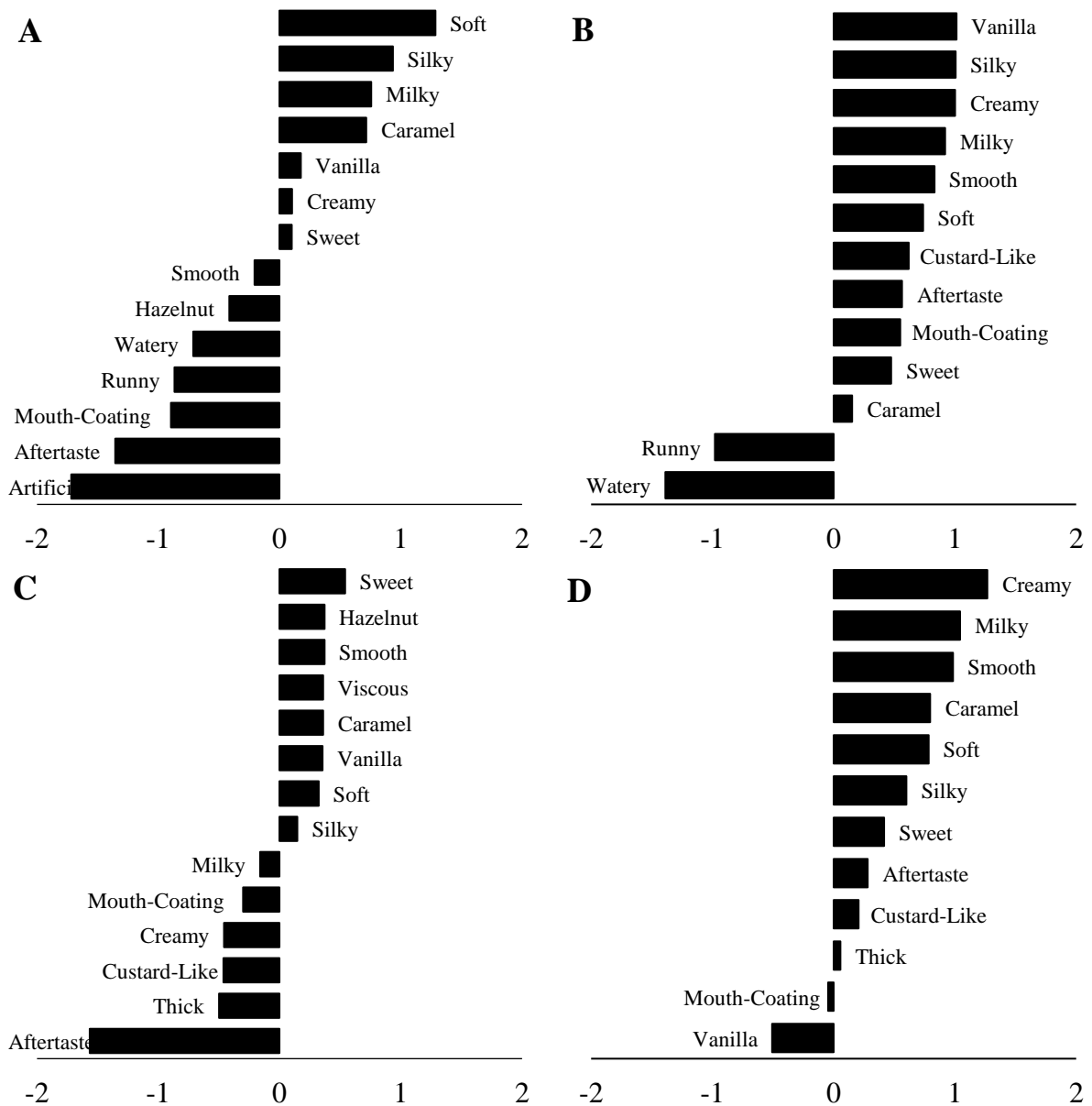
Significant differences ( $p \leq 0.05$ ) in the selection of 10 of the 30 sensory attributes between the two ONS were observed for the younger age cohort. With this cohort selecting the attributes 'Milky', 'Runny', and 'Watery' significantly more to describe ONS 1 than ONS 2 and the attributes 'Creamy', 'Custard-like', 'Gloopy', 'Mouthcoating', 'Soft', 'Thick', and 'Viscous' significantly more to describe ONS 2 than ONS 1. Similar results were observed in the older cohort with significant differences ( $p \leq 0.05$ ) existing in the selection of 9 of the 30 attributes between the two ONS. This cohort selected the attributes 'Artificial', 'Runny', and 'Watery' significantly more to describe ONS 1 than ONS 2 and the attributes 'Creamy', 'Custard-like', 'Gloopy', 'Mouthcoating', 'Thick', and 'Viscous' significantly more to describe ONS 2 than ONS 1.

### **2.3.10 Penalty-lift analysis**

Penalty-lift analysis was conducted on ONS 1 and ONS 2 in both age cohorts at sip 5 (Figure 2.7). The purpose of the penalty-lift analysis was to determine which attributes drove liking and disliking in the two age cohorts. To improve the accuracy of the results, attributes which were selected by 20 % of participants or less were removed from the penalty-lift analysis (Popper, 2014).

The penalty-lift analysis revealed that the two main drivers for ONS 1 liking in the younger cohort were 'Soft' and 'Silky' which caused an increase in liking by 1.3 and 0.9 scale points respectively. The two main drivers for ONS 1 dislike in this cohort were 'Artificial' and 'Aftertaste' which caused a decrease in liking of 1.7 and 1.4 points. In the older cohort the most important drivers for ONS 1 liking were 'Vanilla', 'Silky', and 'Creamy' all of which caused an increase in liking of 1 scale point, while the most notable drivers of dislike were 'Watery' and 'Runny'.

In ONS 2 'Sweet' was the main driver of liking in the younger cohort and increased liking by 0.5 points. Similar to ONS 1, 'Aftertaste' was an important driver of dislike for ONS 2 in the younger cohort and decreased liking by 1.6 scale points on average. 'Creamy' and 'Milky' were the main promoters of ONS 2 liking in the older cohort causing an increase of 1.3 and 1 points respectively, while 'Vanilla' was the predominant driver of ONS 2 dislike in this cohort causing an average decline in liking score of 0.5 points. Noteworthy is the fact that more drivers of disliking are apparent in the younger cohort for both ONS than in the older cohort.



**Figure 2.7** Results of the penalty-lift analysis for ONS 1 in **(A)** younger and **(B)** older adults and ONS 2 in **(C)** younger and **(D)** older adults. The values indicate a change in liking when an attribute was selected compared to when it was not selected by panellists at sip 5.

## 2.4 Discussion

This study used CATA methodology to investigate the differences in sensory perception of ONS between younger and community dwelling older adults over successive sips of a full volume of two ONS where the volume served during consumption is controlled. In addition to assessing taste perceptions and liking

profiles, hunger, fullness, and thirst were quantified as these may influence ONS adherence.

The study selected two ONS with contrasting flow behaviours. The high viscosity product was selected as mouthcoating has been reported to be positively correlated with apparent viscosity, therefore, this product would be expected to provide more mouthcoating than the low viscosity product (Aime *et al.*, 2001). A build-up of mouthcoating with increased ONS consumption has been previously reported as being disliked (Methven *et al.*, 2010), and may therefore have a subsequent effect on ONS adherence. For this reason, both high and low viscosity supplements were selected to determine whether lower viscosity ONS exhibit more desirable sensory profiles therefore contributing to higher liking.

It has also been reported that low intake and adherence of ONS is due in part to their unpleasant satiating properties (den Uijl *et al.*, 2015; den Boer, Boesveldt and Lawlor 2019), a factor which may be influenced somewhat by the texture aspects of the ONS such as their thickness (den Boer, Boesveldt and Lawlor 2019). Previous studies have reported that food intake increases with decreasing viscosity (Zijlstra *et al.*, 2008) due in part to the fact that thicker products have a greater tendency to be consumed at a slower rate (Viskaal-van Dongen, Kok and de Graaf, 2011 ; den Boer, Boesveldt and Lawlor 2019) which leads to higher/longer orosensory stimulation and higher/longer transit time through the oral cavity (Zijlstra *et al.*, 2008; den Boer, Boesveldt and Lawlor 2019), both of which trigger a satiety response (Chambers, 2016). It is therefore expected that the higher viscosity supplement may contribute to increased satiety and lower intake. However, the author recognises that the nutritional profiles of the two supplements in this study differ, therefore, no comparisons are made on the hunger or fullness ratings between the two supplements. The author therefore recommends that future research should adopt the approach taken by den Boer, Boesveldt and Lawlor (2019) who adjusted the texture of the same ONS using thickeners to adjust the thickness without modifying the energy content.

#### **2.4.1 Sensory Perception (CATA Profiling)**

With regards to the sensory perception of the ONS it was evident that consumption volume only had a slight effect on the sensory profiles of the ONS in both age cohorts. The younger cohort selected the attributes 'Metallic' and 'Runny' significantly

less with increasing sips for ONS 1. Whereas, for ONS 2 within the younger cohort the selection of the attribute 'Caramel' decreased significantly with increasing consumption volume. This result is in agreement with Thomas *et al.* (2018), who showed that the selection of 'Caramel' became more infrequent with increasing sips. However, the work of Thomas *et al.* (2018) was conducted with participants aged between 60 and 75 years and therefore these results are not directly comparable with those obtained from the younger cohort in this study. In contrast, for the older cohort no significant differences existed in the attribute selection frequency during ONS 1 consumption. This suggests that the older adults were less aware of any changes in flavour profiles with increasing consumption volume. These findings were somewhat surprising as other studies (Methven *et al.*, 2010; Thomas *et al.*, 2016) have reported an increase in off-notes during the consumption of ONS such as 'Metallic' which is often due to the presence of certain minerals such as iron sulphate (Lim and Lawless, 2006). This difference between the studies may be due in part to the differences in the type of sensory method used. It is plausible that the CATA sensory method was not as sensitive as the sequential profiling and A-TDL methods employed by Methven *et al.* (2010) and Thomas *et al.* (2016) respectively. Therefore, the CATA method may lack the sensitivity to measure changes in perception as consumption of ONS progresses. However, this study did not include a control sensory method to compare this. Therefore, it would be of interest if future research studies could compare the use of the CATA methodology over multi-sip intake alongside a control method such as descriptive analysis to draw more effective conclusions on this matter. Another point worth noting is the possibility of habituation or anticipation of responses with the repeated delivery of the same CATA questionnaire after each sip. Perhaps the lack of change in attribute profiles with sip progression is due in part to this.

In relation to attribute selection frequency the younger cohort selected more flavour/taste attributes than the older cohort as they selected the attributes 'Hazelnut', 'Metallic', 'Milky', and 'Vanilla' significantly more than the older cohort to describe ONS 1. For ONS 2 the older cohort selected the attribute 'Chocolate' significantly more than the younger cohort, however, ONS 2 was a 'Vanilla' flavoured supplement, therefore, the selection of this attribute may perhaps be explained by the declining taste perception which occurs with age (Methven *et al.*, 2012). This age-

related decline in taste perception may be as a result of numerous age related physiological factors such as, reduction in taste bud density and the replacement of acini in the salivary glands with fibrous connective tissue (Imoscopi *et al.*, 2012) as well as increased incidences of oral and systemic diseases (Imoscopi *et al.*, 2012; Field and Duizer, 2016) and frequent use of prescription drugs (Fukasawa *et al.*, 2005; Boyce and Shone, 2006). It was evident from the subject screenings in this study that not unsurprisingly, the number of individuals taking prescription drugs on a weekly basis was significantly higher in the older cohort than the younger cohort. It was also apparent that the number of older adults taking medications where altered taste is reported as a common or very common side effect (The Royal Pharmaceutical Society, 2019) was significantly higher in the older adult cohort. This possibly impacted on the older cohort selection of the attribute 'Chocolate' significantly more than the younger cohort.

Interestingly, texture perception of the ONS appeared to differ between the two age cohorts which was reflected in the attribute selection with the younger cohort selecting 'Watery' significantly more than the older cohort for ONS 1 and 'Thick' and 'Viscous' significantly more for ONS 2. This suggests that the older cohort were less aware of the textural changes between the two supplements than the younger cohort. This finding may be attributed to the age-related alterations to oral hygiene, dental health, salivary flow and composition, and palate covering all of which have a direct influence on texture perception (Roininen *et al.*, 2003; Doets and Kremer, 2016). The oral status of the two age cohorts in this present study directly reflects these age-related changes with the number of older subjects with at least one missing tooth, one artificial tooth, and suffering from dry mouth significantly higher in the older cohort than the younger cohort. In addition to this the number of older adults taking medications where dry mouth is reported (The Royal Pharmaceutical Society, 2019) was greater in the older cohort. Therefore, it is likely that the differences in oral status between the two cohorts contribute in part to the differences in the selection of texture attributes to describe the two ONS. The present results are consistent with the findings of Roininen *et al.* (2004) who suggested that larger numbers of textural attributes are identified by younger population groups to describe the texture of foods, Hutchings *et al.* (2014) who showed younger consumers select more texture

attributes than older consumers when using TDS, and Smith *et al.* (2006) who reported that viscosity perception deteriorates with age.

Although the texture perception of the ONS appeared to differ between the two age cohorts, this study also showed that the older cohort could discriminate between the two ONS, with the subjects selecting the attributes 'Runny' and 'Watery' significantly more to describe ONS 1 than ONS 2 and the attributes 'Gloopy', 'Mouthcoating', 'Thick', and 'Viscous' significantly more to describe ONS 2 than ONS 1. A finding which corroborates with those of Withers, Gosney and Methven (2013) that suggested both younger and older adults are capable of perceiving differences in the thickness of milk samples. Taking this into consideration it is evident that community dwelling older adults were capable of perceiving differences in texture between the two ONS, however, the younger cohort were able to discriminate between the two ONS more effectively than the older cohort as illustrated in the differences in attribute selection frequency.

Although this study was conducted solely in community dwelling older adults, it is likely that the above findings will also be mimicked in patient groups of undernourished older adults and dependent living older adults. Therefore, further research should extend this work to include an undernourished patient cohort.

#### **2.4.2 The implications for the use of older adults in CATA studies.**

Overall, 25 out of 30 attributes for ONS 1 and 26 out of 30 attributes for ONS 2 were statistically similar between the two age cohorts and there were no significant differences between the two age cohorts in the number of attributes selected. Both age cohorts were able to significantly discriminate between the two ONS products. Therefore, it is evident that older adults were very capable of using the CATA methodology and could discriminate between the two ONS using CATA. Taking this into account, this study suggests that the CATA methodology is an appropriate technique for community dwelling older subjects and therefore its use with this population cohort to evaluate ONS can be justified. However, the lack of change in the CATA profile from sip to sip in both age cohorts suggests that the CATA methodology may lack the sensitivity in assessing changes in perception as products are consumed.

The justification of the CATA method for use with older adults is highly beneficial as the CATA methodology is a relatively simple method for older adults

compared to other sensory methods as the process of selecting a number of descriptive terms from a list is relatively straight forward and user-friendly making it particularly suitable for individuals suffering from a decline in cognitive function (Adams *et al.*, 2007; Ruark *et al.*, 2016). It is also quick to perform, which is important when working with an older adult cohort due to their decreased attention capacity and their increased tendency to become fatigued (Methven, Jiménez-Pranteda and Lawlor, 2016). The ability to conduct a CATA evaluation without using a computer is also preferable in older adult populations. The CATA method unlike other sensory methods also offers the added benefit that a large number of sensory attributes can be made available for selection.

### **2.4.3 Liking**

Previous studies have demonstrated a dislike of ONS due to their undesirable sensory properties (Gosney, 2003; Kennedy *et al.*, 2010). Other studies have also highlighted a decrease in liking of ONS with increased consumption volume (Methven *et al.*, 2010; Thomas *et al.*, 2016; Thomas *et al.*, 2018). Based on this knowledge, it was therefore expected that in this present study both age cohorts would rate the ONS low in terms of liking and that liking would decline in both age cohorts with repeat consumption. The findings from this study were however unable to support this position, as both age cohorts reported to 'neither like nor dislike' or 'like moderately' the ONS indicating that both age cohorts found the ONS tolerable. The present results also found that an increase in consumption volume of ONS had a minimal effect on liking reduction in both age cohorts.

Multiple factors may have contributed to these findings. Firstly, the panellists in this study were aware that the beverages which they were consuming were 'medical nutrition' which may have influenced their liking responses as they would have considered the supplements good for their health and therefore may have compromised on liking. Moreover, Thomas *et al.* (2018) previously highlighted that sensory booths are not the most appropriate environment for sensory evaluations of this nature. It is possible that when completing sensory evaluations within the environment of a sensory booth individuals may feel that any expression of product dislike will offend the researcher. As a result, they may feel compelled to give false results to please the researcher. Taking this into account evaluations conducted at

home or in hospital or care home settings may potentially yield a better representation of real-life perception of ONS.

As mentioned above, previous research groups have found ONS liking to decline with increased consumption volume, which is thought to be due in part to the build-up of negative mouthfeel attributes such as mouth-drying and metallic, over consumption volume (Methven *et al.*, 2010; Thomas *et al.*, 2016; Thomas *et al.*, 2018). It was, therefore, surprising that no relationship was found between increasing consumption volume and liking decline in this present study. However, the supplements chosen in this study were different to those used in previous studies (Methven *et al.*, 2010; Thomas *et al.*, 2016; Thomas *et al.*, 2018). Therefore, it is possible that the two ONS in this study happen to have more desirable flavour profiles and fewer off-notes/better off-note masking.

There were similarities in liking responses between the two age cohorts, indicating that these test populations (who were not regular consumers of ONS) certainly found the product acceptable. As the study reflects a first tasting of ONS for the panellists, this is a possible source of bias in this study. Taking this into consideration this study acts solely as a pilot CATA study and future work should be extended to include an undernourished older adult group who are regular consumers of ONS.

#### **2.4.4 Appetite**

An increase in consumption volume of five sips led to a steady decline in hunger ratings of both age cohorts with both ONS. There was also a clear trend of increasing fullness with each successive sip for both age cohorts. These results are not surprising considering the participants consumed a total of 200 mL of ONS across the 5 sips which equates to a 200 kcal and 7.6 g protein intake following the consumption of ONS 1 and a 300 kcal and 20 g protein intake following the consumption of ONS 2. However, these results differ to insights from Hubbard *et al.* (2012) who noted that ONS had little suppressive effect on appetite and food intake and Thomas *et al.* (2018) who reported that the consumption of ten sips of ONS (protein intake of 15 g  $\pm$  0.5 g) only slightly reduced hunger status by 0.4 scale points. It is possible that the differences between this present study and that of Thomas *et al.* (2018) are due in part to the differences in the type of ONS evaluated. While the total protein intake of the ONS in the study by Thomas *et al.* (2018) was 15

g  $\pm$  0.5 g, volume or energy density consumed is not known. Therefore, it is plausible that the differences in the two studies may be due to possible differences in total volume and energy density of the ONS served to panellists.

It was also apparent from this present study that the hunger profiles were significantly different between the two age cohorts with the younger cohort on average hungrier than the older cohort throughout the consumption of both ONS. These results may be explained by the diminished appetite in this age cohort which occurs due to a number of factors including lack of physical activity, psychological issues such as depression, and physiological factors including age-related adjustments in body composition, reductions in total energy expenditure, the slowing of gastric emptying, and an increase in rapid satiety signals which lead to early satiation (Donini, Savina and Cannella, 2003; Leslie and Hankey, 2015; Doets and Kremer, 2016). The older cohort in this study comprised healthy community dwelling older adults; however, it is predominantly dependent living malnourished older adults that are regular consumers of ONS, a population cohort that will suffer from even greater diminished appetite. As a result, some older individuals will not have the capacity to consume the full serving of ONS as it will be too filling, thus reducing adherence.

As the volume consumed in this study was controlled, panellists had no choice but to consume one full bottle (200 mL) of ONS in each sensory session. However, in real life situations, the decline in hunger that occurs with increased consumption volume, coupled with the reduced hunger profiles and diminished appetite in older adults may lead to individuals not finishing the full ONS. Taking this into consideration the results of this study support the current strategies which are focused on compacting beverage-style ONS into lower volume concentrated ONS (den Boer, Boesveldt and Lawlor, 2019). Finally, it is also important to note that the portion size consumed in each of the CATA evaluations was 200 mL (1 bottle), however, in some cases individuals may be recommended up to 8 bottles per day depending on whether the supplement is being used for complete nutrition or supplementary nutrition (Fresenius Kabi, 2019). Therefore, to capture real insights of ONS consumption future studies will need to take this into account.

Interestingly, the sensation of thirst increased significantly with increasing volume of consumption of ONS in both age cohorts. A finding which is in accordance

with previous research by Thomas *et al.* (2018), who reported that the consumption of ten sips of ONS in an older adult population group strongly increased thirst ratings causing an increase of 2 points on the thirst scale. Thomas *et al.* (2018) also reported the attribute 'Dry' as a temporal driver of thirst for ONS and Methven *et al.* (2010) reported a build-up of mouth-drying with increasing consumption volume of ONS. In the current study a significant increase in the selection of 'Dry' was not observed in either age cohort for either ONS with increasing consumption volume. 'Mouthcoating' was however selected frequently throughout the tasting period in both age cohorts particularly with ONS 2 the thicker supplement, therefore it is possible that this contributed to an increase in thirst.

It has been reported that the presence of whey proteins may increase in-mouth dryness through their precipitation on the tongue contributing directly to an increase in thirst sensation (Sano *et al.*, 2005; Withers *et al.*, 2014; Bull *et al.*, 2017; Thomas *et al.*, 2018). The older cohort with a higher tendency for altered salivary composition and reduced muscle strength will also find it more difficult to clear any unpleasant 'Mouthcoatings' causing an increase in thirst and making ONS consumption more challenging (Withers, Gosney and Methven, 2013).

The thirst profiles between the two age cohorts were significantly different with the younger cohort on average thirstier than the older cohort. It is possible that older adults experience less thirst, due to age related physiological changes (Kenney and Chiu, 2001; Schols *et al.*, 2009). The number of individuals in the present study reporting to suffer from dry mouth and taking medications where dry mouth is reported (The Royal Pharmaceutical Society, 2019) was significantly higher in the older cohort than the younger cohort. It is therefore likely that these differences in oral status may have played a role in the reduced thirst ratings in the older cohort. Lack of thirst in older adults has previously been reported as a possible driving factor for decreased ONS adherence (Gosney, 2003).

## **2.5 Conclusion**

The findings demonstrate that the CATA methodology was effective in discriminating between the two ONS when used by community dwelling older adults. The older adults selected attributes for the ONS at similar rates to the younger adults. This suggests that the CATA sensory technique is appropriate for use with community

dwelling older adults. However, the CATA methodology may lack the sensitivity to describe changes in perception of ONS as intake is progressed. Further research is warranted to compare the use of the CATA methodology over multi-sip intake alongside a control method such as descriptive analysis. The study provided greater insight into the differences in the drivers of liking and disliking of ONS between younger and older adults. Hunger and thirst profiles differed between the two age cohorts with the older adults remaining less hungry and thirsty throughout the consumption of ONS than the younger adults. While hunger sensations decreased with consumption volume, the thirst sensations increased significantly with increasing consumption volume of ONS in both age cohorts. Future work should be conducted with dependent living and hospitalised older adults to investigate the effectiveness of the CATA methodology to evaluate ONS in this population cohort.

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## **Chapter 3**

**Exploring how age, medication usage, and dentures effect the sensory perception and liking of oral nutritional supplements in older adults.**

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**\*Data analysis completed on the same cohort of 80 older adults from Chapter 2.**

## **Chapter 3: Exploring how age, medication usage, and dentures effect the sensory perception and liking of oral nutritional supplements in older adults.**

### **3.1 Introduction**

Undernutrition is a common phenomenon associated with adults aged 60 years or over (World Health Organisation, 2017; Roberts *et al.*, 2019), with 5-10 % of community dwelling older adults reported to suffer from undernutrition (Doets and Kremer, 2016; Bardon *et al.*, 2020). Prescribing Oral Nutritional Supplements (ONS) (Lochs *et al.*, 2006; Özçağlı, Stelling and Stanford, 2013) coupled with dietary counselling, has been used successfully to manage undernutrition in these older adults (Agarwal *et al.*, 2013). However, a successful outcome is dependent on the consumption of the full prescribed amount of ONS (Rahemtulla *et al.*, 2005; Özçağlı, Stelling and Stanford, 2013; Thomas *et al.*, 2016). Poor adherence to ONS, has been reported in both community and non-community dwelling older adults (Gosney, 2003; McMurdo *et al.*, 2009; Özçağlı, Stelling and Stanford, 2013). Adherence is defined as the extent to which an individual's behaviour with regards to taking medication, following a diet, and/or executing lifestyle changes, corresponds with healthcare recommendations (World Health Organisation, 2003). This poor adherence to ONS is partly attributed to undesirable sensory properties as well as issues of sensory fatigue, and build-up of aftertaste with ONS consumption volume (Gosney, 2003; Rahemtulla, *et al.*, 2005; Nieuwenhuizen *et al.*, 2010).

Low ONS adherence in older adults could also relate to changes in sensory perception with age. An impairment in sensory perception particularly in relation to taste and smell occurs gradually over time and is often linked with altered food perception, liking and enjoyment, interest, and intake (Sanders, Ayers and Oakes, 2002; Doets and Kremer, 2016; Methven, Jimenez-Pranteda and Lawlor, 2016). Therefore, it is essential for ONS manufacturers to understand the effects of age on the sensory perception of these supplements to improve ONS liking, intake, and thus adherence in the older age cohort. Texture has previously been reported as an important factor in liking for ONS (Gosney, 2003; den Boer, Boesveldt and Lawlor, 2019). Therefore, it is important for ONS manufacturers to understand the effects of age on both texture and taste of ONS. This is also of importance for academia as

there is continuing scientific interest in understanding the perception of foods by older adults and how this cohort differ in relation to other population cohorts.

Previous studies have examined the impact of age on some sensory properties of ONS. Kennedy *et al.* (2010) observed that higher sweetness intensity was linked with product dislike in both younger (mean age 23.0 years) and older (mean age 74.4 years) adults. Both cohorts rated the sweetness intensity of ONS similarly. Chapter 2 of this thesis, using check-all-that-apply methodology in a younger (mean age 25.3 years) and an older (mean age 73.5 years) cohort, found that texture perception of ONS were significantly different between the age groups. While these studies give some understanding of the differences in sensory perception of ONS between older and younger adult cohorts, few studies have examined ONS within the different older adult segments. The older adult population can be divided into the young-old (65-74 years), the old-old (75-84 years), and the oldest-old (85+ years) (Murphy and Vertrees, 2017). Although some studies have explored the sensory profiles of ONS within older adult cohorts (Methven *et al.*, 2009; Özçağlı, Stelling and Stanford, 2013; Thomas *et al.*, 2018) they are heavily weighted towards the lower end of 65-74 year olds. Therefore, further work is required to understand and assess the differences in the sensory perception and liking of ONS between young-old, old-old, and oldest-old adult cohorts.

Examining the sensory perception of ONS between the different segments of the older adult population cohort is vital, since the effects of sensory impairment, particularly in relation to taste and texture perception, are more likely to be observed in those above 74 years. This is especially evident for taste, where it has been reported that the average number of taste buds decreases substantially between the ages of 74 and 85 years (Feng, Huang and Wang, 2014; Ogawa *et al.*, 2017). Furthermore, medications are considered the most significant contributors to taste disturbances or disorders in older adults (Tomita and Yoshikawa, 2002; Schiffman, 2009; Ogawa *et al.*, 2017). Medication use increases with age, particularly past 75 years, with Morin *et al.* (2018) reporting an increase in the incidence rate of polypharmacy from 17 % to 33 % as age increased from 65 to 74 years to 96 years, respectively.

Rates of tooth loss also increase with age (Polzer, Schimmel and Biffar, 2010) with Sheehan, McGarrigle and O'Connell (2017) reporting that 7 % of individuals

aged 54-64 years had no natural teeth compared to 40 % of individuals aged over 75 years. As a result, there is an increased likelihood that old-old and oldest-old adults will require partial or full dentures to replace missing teeth. Since dentures do not match the masticatory performance of natural teeth (Hildebrandt *et al.*, 1997; Mishellany-Dutour *et al.*, 2008), and can limit the movement of foods around the mouth resulting in less palate papillae stimuli (Duffy, Cain and Ferris, 1999; Withers, Gosney and Methven, 2013), this will also impact texture perception.

Recognising the importance of studying the sensory perception and liking of ONS between the young-old, old-old, and oldest-old adult cohorts, there also remains a gap in the literature in relation to the effects of physiological and non-physiological factors such as medication usage and dentures on the perception and liking of ONS. The aim of this study was therefore to advance the understanding of how older adults perceive ONS by investigating the effects of age, denture wearing, and medication usage on the sensory perception, liking, and intake of ONS. To allow for investigation of both taste and textural perception, two ONS of differing viscosities, one low viscosity (0.009 Pa.s at shear rate 50.1 s<sup>-1</sup>) and one high viscosity (0.177 Pa.s at shear rate 50.1 s<sup>-1</sup>) were used.

## **3.2 Materials and Methods**

### **3.2.1 Samples**

Two vanilla flavoured ready-to-drink beverage-style ONS were selected for use in this study. The products were the same as those used in Chapter 2 and were manufactured by Fresenius Kabi (Fresenius Kabi, Bad Homburg vor der Höhe, Germany). The two ONS exhibited apparent viscosity values of 0.009 and 0.177 Pa.s respectively at a shear rate of 50.1 s<sup>-1</sup> and represented the lower and upper ends of the viscosity range for commercial beverage-style ONS. A shear rate of 50.1 s<sup>-1</sup> was chosen, as a shear rate of 50 s<sup>-1</sup> has been reported as a typical oral shear rate (Withers, Gosney and Methven, 2013). Similarly, to Chapter 2 the two ONS will be referred to throughout the remainder of the Chapter as ONS 1 (low viscosity ONS) and ONS 2 (high viscosity ONS).

### **3.2.2 Participants**

The study cohort of eighty untrained volunteers aged over 65 years from Chapter 2 were used in this Chapter. Table 3.1 illustrates a breakdown of the participant

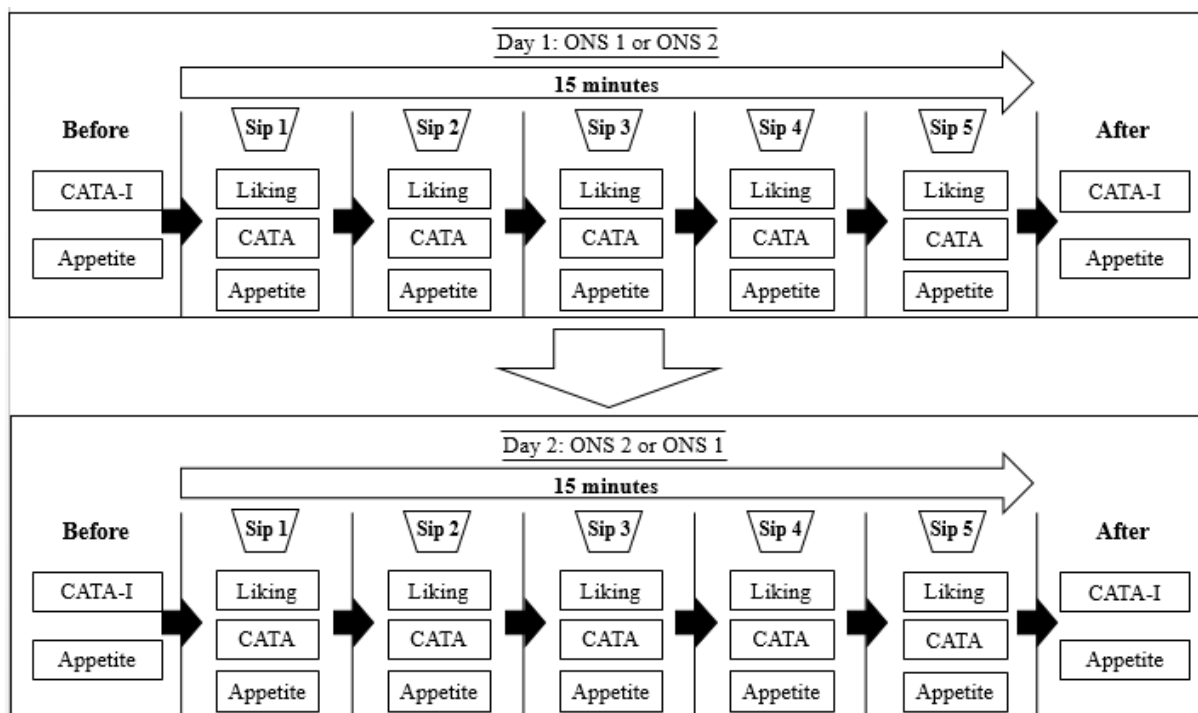
demographics within the full study cohort, the 65-74 year olds, and the over 75 year olds. Briefly, of the 80 participants, n = 51 were aged between 65 and 74 years and n = 29 were aged 75 years or over, with the oldest participant reported as being 97 years of age. There were 42 denture wearers and 38 non-denture wearers. 52 of the 80 subjects reported taking medications on a weekly basis, of which 23 were taking medications with associated side effects of dry mouth or altered taste (Medications DMAT) (The Royal Pharmaceutical Society, 2019). Participants were asked to provide a list of any medications which they were taking at the time of the study. This list was then cross referenced with the British National Formulary (The Royal Pharmaceutical Society, 2019) to determine which medications have common or very common side effects of dry mouth or altered taste. All procedures were approved by the UCD Human Research Ethics Committee (Ref. No. LS-17-50).

**Table 3.1** Participant demographics for the full study cohort, the 65-74 year olds, and the over 75 year olds.

	Full study cohort (n=80)	65-74 year olds (n=51)	75+ year olds (n=29)
Number of females/males	45/35	26/25	19/10
Age (mean $\pm$ SD, range)	73.7 $\pm$ 7.9 (65-97)	68.5 $\pm$ 2.6 (65-74)	82.3 $\pm$ 6.7 (75-97)
Number of subjects taking medications (at least weekly)	52	30	22
Number of subjects taking medications where dry mouth or altered taste (Medications DMAT) are reported as a common/very common side effect (The Royal Pharmaceutical Society, 2019)	23	16	7
Number of subjects with dentures	42	22	20
Number of subjects to report suffering from hypertension	26	14	12
Number of subjects to report suffering from hyper/hypothyroidism	7	5	2
Number of subjects to report suffering from oral /gum disease	3	2	1
Number of subjects suffering from frequent colds	6	6	0
Number of smokers	4	4	0

### 3.2.3 Experimental Sessions

The overall study design was previously described in Chapter 2 (Section 2.2.5). Briefly, the study was conducted over two different days with panellists consuming one of the two ONS (200 mL) in each session. The panellists were instructed not to eat for two hours prior to each sensory session. The ONS was divided into five cups with panellists allocated three minutes to evaluate each cup. The sensory evaluation session is summarised in Figure 3.1. The terms used for the CATA questionnaire for the ideal ONS (CATA-I) were the same 30 attributes comprising the CATA questionnaire (Table 2.1). Liking was rated on a 9-point hedonic scale and appetite measures (hunger, fullness, thirst, and desire to consume more ONS) were rated on 100 mm Visual Analogue Scales (VAS).



**Figure 3.1** Schematic diagram of the sensory evaluation session.

### 3.2.4 Data Analysis

An appetite score (rated at each sip) was calculated from the ratings listed above, similarly to Perrigue, Monsivais and Drewnowski (2009); (Appetite score = [desire to eat + hunger + (100 - fullness)]/3). To examine influences on appetite, a mixed model ANOVA with age as the dependent variable, and sip and ONS as the independent

variables was conducted. 'Dentures' and 'medications' were added as covariates in a second model.

To examine attribute selection in the two age groups, the over 75 year olds (n = 29) and a random selection of the same number, n = 29, from 65-74 year olds, were compared. Separately, the group of non-denture wearers (n = 38) was compared to a random selection of denture wearers (n = 38), and the group reporting medications DMAT (n = 23) was compared to a random selection (n = 23) of individuals taking no medications. These were examined in a mixed model ANOVA with age, denture status, or medication status as the dependent variable and sip and ONS as the independent variables. Contingency tables were used to summarise the selection frequency of each CATA and CATA-I attribute. Differences in attribute selection frequencies were examined using Fishers exact test. A Cochran's Q test was used to determine the significant differences in attribute selection frequency between each sip within the different cohorts (data not shown).

Liking for the ONS was analysed using a mixed model ANOVA. The penalty-lift analysis for the CATA data for both ONS was completed for each of the study cohorts according to Meyners, Castura and Carr (2013). The ONS were compared with the ideal ONS for the full cohort of individuals aged over 65 years as per Meyners, Castura and Carr (2013). The differences in the proportion of elicitations between the ONS and ideal ONS were plotted along with the confidence interval of the elicitation ratio (ratio of positive answers for a given attribute) to illustrate the differences between the ONS and the ideal ONS (Meyners, Castura and Carr 2013). This alongside the penalty-lift analysis were completed using XLSTAT (Addinsoft, France). Statistical analysis was conducted using IBM®SPSS® (version 24.0 for Windows) (IBM Corp., USA).

### **3.3 Results**

#### **3.3.1 Appetite**

Appetite scores at each sip for both ONS in the 65 to 74 year olds and the over 75 year olds are shown in Table 3.2. Appetite scores decreased with each successive sip for both age cohorts and ONS and were significantly different ( $p \leq 0.05$ ) between the two age cohorts, with the older group reporting lower appetite scores than the

younger group. There were significant effects for sip number ( $p \leq 0.001$ ) and a significant interaction for sip by ONS by age ( $p \leq 0.05$ ).

The mixed model ANOVA with dentures, and medications DMAT added as covariates, showed that while these variables influence the relationship between age and appetite, this was not to the extent that it changed the significance of the above reported result. The significant effect for sip number remained. A significant interaction existed for ONS by dentures ( $p \leq 0.05$ ), but no other significant interactions were recorded.

**Table 3.2** Mean ratings ( $\pm$  standard deviation) for appetite at each sip for ONS 1 and ONS 2 in both 65-74 year olds and over 75 year olds.

		Baseline	Sip 1	Sip 2	Sip 3	Sip 4	Sip 5	Endpoint
ONS 1	65-74	51 $\pm$ 16 <sup>aw</sup>	46 $\pm$ 14 <sup>abw</sup>	45 $\pm$ 12 <sup>abw</sup>	42 $\pm$ 13 <sup>abw</sup>	42 $\pm$ 14 <sup>abw</sup>	37 $\pm$ 17 <sup>bw</sup>	38 $\pm$ 14 <sup>bw</sup>
	Over 75	44 $\pm$ 18 <sup>cw</sup>	41 $\pm$ 16 <sup>cdw</sup>	39 $\pm$ 14 <sup>cdw</sup>	38 $\pm$ 14 <sup>cdw</sup>	35 $\pm$ 13 <sup>cdw</sup>	32 $\pm$ 15 <sup>cdw</sup>	29 $\pm$ 17 <sup>dx</sup>
ONS 2	65-74	48 $\pm$ 17 <sup>ay</sup>	44 $\pm$ 12 <sup>aby</sup>	42 $\pm$ 12 <sup>aby</sup>	40 $\pm$ 13 <sup>aby</sup>	39 $\pm$ 13 <sup>aby</sup>	38 $\pm$ 13 <sup>aby</sup>	37 $\pm$ 16 <sup>by</sup>
	Over 75	44 $\pm$ 18 <sup>cy</sup>	42 $\pm$ 15 <sup>cdy</sup>	38 $\pm$ 18 <sup>cdey</sup>	31 $\pm$ 18 <sup>defz</sup>	25 $\pm$ 16 <sup>efz</sup>	24 $\pm$ 15 <sup>fz</sup>	26 $\pm$ 20 <sup>efz</sup>

Different superscript letters denote significant differences in attribute selection frequency: (a, b) between each sip for 65-74 year olds, (c, d, e, f) between each sip for the over 75 year olds, (w, x) between the 65-74 year olds and over 75 year olds within the sips for ONS 1, and (y, z) between the 65-74 year olds and over 75 year olds within the sips for ONS 2.

### 3.3.2 CATA Profiling

#### 3.3.2.1 Number of attributes selected

Differences in the number of attributes selected by the 65 to 74 and over 75 year olds, the denture and non-denture wearers, and the individuals taking medications DMAT and those not taking medications, were not significant based on ANOVA analysis (data not shown).

#### 3.3.2.2 Attribute selection frequency

The data for attributes selected which are presented in Tables 3.3, 3.4, and 3.5 represent the attribute selection frequency for sip 5 only. These tables exclude attributes selected by < 20 % of participants.

### **3.3.2.2.1 Age**

The attribute selection frequency for the 65 to 74 year olds and the over 75 year olds for ONS 1 and ONS 2 at sip 5 are presented in Table 3.3. The most frequently selected attributes chosen to describe ONS 1 by the 65 to 74 year olds were 'Milky' and 'Sweet' and by the over 75 year olds were 'Creamy' and 'Smooth'. For ONS 2 on the other hand the most frequently selected attributes chosen by the 65 to 74 year olds were 'Creamy', 'Smooth', and 'Sweet' and by the over 75 year olds were 'Creamy', 'Custard-like', 'Smooth', 'Sweet', and 'Vanilla'.

The Fishers exact test (Chi squared) revealed significant differences ( $p \leq 0.05$ ) at sip 5 between the 65 to 74 year olds and the over 75 year olds in the selection of 'Creamy' for ONS 1 with the over 75 year olds selecting this attribute significantly more to describe this ONS. For ONS 2 a significant difference ( $p \leq 0.05$ ) in the selection of 'Chocolate' was observed between the two age cohorts with the over 75 year olds again selecting this attribute significantly more than the 65 to 74 year olds. Other significant differences in attribute selection frequency at different sip levels included 'Watery' which was selected significantly more at sip 4 for ONS 1 by the 65 to 74 year olds.

Significant differences ( $p \leq 0.05$ ) in the selection of three attributes between the two ONS were observed in the 65 to 74 year olds. This cohort selected the attribute 'Watery' significantly more for ONS 1 and 'Creamy' and 'Thick' significantly more to describe ONS 2. Like the 65 to 74 year olds, the over 75 year olds selected the attribute 'Thick' significantly more often ( $p \leq 0.01$ ) to describe ONS 2, however, no other significant differences in discriminating attributes were observed for this age cohort.

Cochran's Q test determined that there was a statistically significant difference ( $p \leq 0.005$ ) in the proportion of 65 to 74 year olds who selected 'Aftertaste' over the five sips for ONS 1, with this attribute being selected significantly more at sip 4 than at sip 2. Whereas, for the over 75 year olds there was a significant difference ( $p \leq 0.05$ ) in the selection of 'Chocolate' across the five sips for ONS 2, with this attribute increasing with increasing consumption volume.

**Table 3.3** Frequency of selection of CATA terms for 65 to 74 year olds and over 75 year olds at sip 5 for both ONS.

	ONS 1		ONS 2	
	65-74s %	Over 75s %	65-74s %	Over 75s %
Airy <sup>ns</sup>	13.8 <sup>aw</sup>	20.7 <sup>ay</sup>	0.0 <sup>cw</sup>	17.2 <sup>cy</sup>
Aftertaste <sup>ns</sup>	44.8 <sup>aw</sup>	24.1 <sup>ay</sup>	27.6 <sup>cw</sup>	48.3 <sup>cy</sup>
Caramel <sup>ns</sup>	37.9 <sup>aw</sup>	37.9 <sup>ay</sup>	37.9 <sup>cw</sup>	34.5 <sup>cy</sup>
Chocolate	6.9 <sup>aw</sup>	24.1 <sup>ay</sup>	0.0 <sup>cw</sup>	20.7 <sup>dy</sup>
Coffee <sup>ns</sup>	13.8 <sup>aw</sup>	6.9 <sup>ay</sup>	10.3 <sup>cw</sup>	24.1 <sup>cy</sup>
Creamy	41.4 <sup>aw</sup>	75.9 <sup>by</sup>	72.4 <sup>cx</sup>	93.1 <sup>cy</sup>
Custard-like <sup>ns</sup>	27.6 <sup>aw</sup>	27.6 <sup>ay</sup>	48.3 <sup>cw</sup>	51.7 <sup>cy</sup>
Hazelnut <sup>ns</sup>	6.9 <sup>aw</sup>	13.8 <sup>ay</sup>	20.7 <sup>cw</sup>	20.7 <sup>cy</sup>
Milky <sup>ns</sup>	62.1 <sup>aw</sup>	48.3 <sup>ay</sup>	41.4 <sup>cw</sup>	48.3 <sup>cy</sup>
Mouthcoating <sup>ns</sup>	20.7 <sup>aw</sup>	34.5 <sup>ay</sup>	31.0 <sup>cw</sup>	48.3 <sup>cy</sup>
Runny <sup>ns</sup>	34.5 <sup>aw</sup>	24.1 <sup>ay</sup>	10.3 <sup>cw</sup>	13.8 <sup>cy</sup>
Silky <sup>ns</sup>	37.9 <sup>aw</sup>	37.9 <sup>ay</sup>	37.9 <sup>cw</sup>	44.8 <sup>cy</sup>
Soft <sup>ns</sup>	24.1 <sup>aw</sup>	41.4 <sup>ay</sup>	41.4 <sup>cw</sup>	48.3 <sup>cy</sup>
Smooth <sup>ns</sup>	34.5 <sup>aw</sup>	55.2 <sup>ay</sup>	62.1 <sup>cw</sup>	55.2 <sup>cy</sup>
Sweet <sup>ns</sup>	51.7 <sup>aw</sup>	48.3 <sup>ay</sup>	58.6 <sup>cw</sup>	69.0 <sup>cy</sup>
Thick	6.9 <sup>aw</sup>	10.3 <sup>ay</sup>	41.4 <sup>cx</sup>	44.8 <sup>cz</sup>
Vanilla <sup>ns</sup>	48.3 <sup>aw</sup>	48.3 <sup>ay</sup>	48.3 <sup>cw</sup>	58.6 <sup>cy</sup>
Viscous <sup>ns</sup>	3.4 <sup>aw</sup>	6.9 <sup>ay</sup>	10.3 <sup>cw</sup>	24.1 <sup>cy</sup>
Watery	31.0 <sup>aw</sup>	13.8 <sup>ay</sup>	6.9 <sup>cx</sup>	10.3 <sup>cy</sup>

Different superscript letters denote significant differences in attribute selection frequency at sip 5 for: (a, b) ONS 1 between the 65-74s and over 75s, (c, d) ONS 2 between the 65-74s and over 75s, (w, x) between ONS 1 and ONS 2 in the 65-74s, and (y, z) between ONS 1 and ONS 2 in the over 75s, (ns) no significant difference. Differences in attribute selection frequencies were examined using Fishers exact test.

### 3.3.2.2.2 Dentures

The most frequently selected attributes chosen by the denture wearers to describe ONS 1 were 'Milky' and 'Vanilla'. 'Milky' was also a frequently selected attribute by the non-denture wearers to describe ONS 1 as was 'Sweet' (Table 3.4). For ONS 2

the attributes 'Creamy', 'Custard-like', 'Silky', 'Soft', 'Smooth', and 'Sweet' were chosen most frequently by the denture wearers. 'Creamy', 'Smooth', and 'Sweet' were also frequently selected attributes for the non-denture wearers to describe ONS 2, as was the attribute 'Vanilla'.

The Fishers exact test (Chi squared) revealed no significant differences in attribute selection frequency between the two cohorts for ONS 1 at sip 5. However, significant differences were observed at sips 3 and 4 in the selection of 'Mouthcoating' and 'Artificial' respectively, both of which were selected significantly more ( $p \leq 0.05$ ) by non-denture wearers. For ONS 2 a significant difference ( $p \leq 0.05$ ) in the selection of 'Silky' was observed at sip 5 between the denture wearers and the non-denture wearers. With the denture wearers selecting this attribute significantly more to describe this ONS.

Significant differences were observed in the selection of four sensory attributes between the two ONS for the denture wearers. The attributes 'Runny' and 'Watery' were selected significantly more ( $p \leq 0.05$ ) to describe ONS 1 than ONS 2 by the denture wearers while the attributes 'Custard-like' and 'Thick' were selected significantly more ( $p \leq 0.01$ ) by this cohort to describe ONS 2. Similarly, the non-denture wearers selected the attribute 'Runny' significantly more ( $p \leq 0.05$ ) to describe ONS 1 than ONS 2, and the attribute 'Thick' significantly more ( $p \leq 0.01$ ) to describe ONS 2 than ONS 1. In addition to this the non-denture wearers also selected 'Creamy' significantly more ( $p \leq 0.01$ ) to describe ONS 2.

A Cochran's Q test revealed significant differences in the frequency of selection of several attributes across the five sips for both cohorts. For ONS 1, the selection of the attribute 'Mouthcoating' was significantly different across the five sips ( $p \leq 0.05$ ) for the denture wearers, with selections increasing significantly from sip 3 to sip 4. For the non-denture wearers, there were significant differences ( $p \leq 0.05$ ) in the proportion of individuals who selected 'Aftertaste' and 'Silky' over the five sips for ONS 1, with 'Aftertaste' increasing and 'Silky' decreasing from sip 1 to sip 5. For ONS 2 for denture wearers significant differences existed ( $p \leq 0.05$ ) for 'Chocolate' between sip 1 and sip 2, and 'Silky' between sip 2 and sip 5, with selection frequency increasing significantly for both attributes. For non-denture wearers, no significant differences were observed across the five sips for ONS 2.

**Table 3.4** Frequency of selection of CATA terms for denture wearers and non-denture wearers at sip 5 for both ONS.

	ONS 1		ONS 2	
	Dentures %	No Dentures %	Dentures %	No Dentures %
Aftertaste <sup>ns</sup>	21.1 <sup>aw</sup>	42.1 <sup>ay</sup>	36.8 <sup>cw</sup>	39.5 <sup>cy</sup>
Caramel <sup>ns</sup>	34.2 <sup>aw</sup>	36.8 <sup>ay</sup>	31.6 <sup>cw</sup>	39.5 <sup>cy</sup>
Creamy	47.4 <sup>aw</sup>	47.4 <sup>ay</sup>	65.8 <sup>cw</sup>	78.9 <sup>cz</sup>
Custard-like	21.1 <sup>aw</sup>	26.3 <sup>ay</sup>	55.3 <sup>cx</sup>	42.1 <sup>cy</sup>
Hazelnut <sup>ns</sup>	10.5 <sup>aw</sup>	5.3 <sup>ay</sup>	21.1 <sup>cw</sup>	10.5 <sup>cy</sup>
Milky <sup>ns</sup>	50.0 <sup>aw</sup>	55.3 <sup>ay</sup>	42.1 <sup>cw</sup>	36.8 <sup>cy</sup>
Mouthcoating <sup>ns</sup>	23.7 <sup>aw</sup>	31.6 <sup>ay</sup>	34.2 <sup>cw</sup>	42.1 <sup>cy</sup>
Runny	31.6 <sup>aw</sup>	34.2 <sup>ay</sup>	7.9 <sup>cx</sup>	10.5 <sup>cz</sup>
Silky	34.2 <sup>aw</sup>	36.8 <sup>ay</sup>	57.9 <sup>cw</sup>	28.9 <sup>dy</sup>
Soft <sup>ns</sup>	28.9 <sup>aw</sup>	28.9 <sup>ay</sup>	50.0 <sup>cw</sup>	36.8 <sup>cy</sup>
Smooth <sup>ns</sup>	42.1 <sup>aw</sup>	44.7 <sup>ay</sup>	55.3 <sup>cw</sup>	52.6 <sup>cy</sup>
Sweet <sup>ns</sup>	44.7 <sup>aw</sup>	52.6 <sup>ay</sup>	63.2 <sup>cw</sup>	57.9 <sup>cy</sup>
Thick	7.9 <sup>aw</sup>	10.5 <sup>ay</sup>	47.4 <sup>cx</sup>	47.4 <sup>cz</sup>
Vanilla <sup>ns</sup>	50.0 <sup>aw</sup>	47.4 <sup>ay</sup>	44.7 <sup>cw</sup>	55.3 <sup>cy</sup>
Watery	26.3 <sup>aw</sup>	23.7 <sup>ay</sup>	5.3 <sup>cx</sup>	7.9 <sup>cy</sup>

Different superscript letters denote significant differences in attribute selection frequency at sip 5 for: (a, b) ONS 1 between denture wearers and non-denture wearers, (c, d) ONS 2 between denture wearers and non-denture wearers, (w, x) between ONS 1 and ONS 2 in the denture wearers, and (y, z) between ONS 1 and ONS 2 in non-denture wearers, (ns) no significant difference. Differences in attribute selection frequencies were examined using Fishers exact test.

### 3.3.2.2.3 Medications

Table 3.5 summarises the attribute selection frequencies for individuals taking medications DMAT and the individuals taking no medications for both ONS at sip 5. The most frequently selected attributes to describe ONS 1 by individuals taking medications were 'Aftertaste', 'Creamy', 'Milky', 'Smooth', 'Sweet', and 'Vanilla'. This cohort also selected 'Aftertaste', 'Creamy', and 'Sweet' frequently to describe ONS 2 in addition to 'Soft' and 'Thick'. For those not taking medications, the most frequently selected attribute to describe ONS 1 was 'Creamy', and for ONS 2 were 'Creamy',

'Custard-like', 'Mouthcoating', 'Smooth', and 'Vanilla'. Notably, 'Aftertaste' was selected more often by those prescribed medications DMAT than those without.

The Fishers exact test (Chi squared) revealed a significant difference for ONS 1 at sip 5 between the individuals taking medications DMAT and individuals not taking medications in the selection of the attribute 'Thick' which was used significantly more to describe ONS 1 by the individuals not taking medications ( $p \leq 0.05$ ). Other significant differences in attribute selection frequency at different sip levels for this ONS included 'Sweet' (sip 2), 'Creamy' (sip 3), and 'Aftertaste' (sips 3 and 4) all of which were selected significantly more ( $p \leq 0.05$ ) by the individuals taking medications DMAT. No significant differences in attribute selection frequency existed between the two cohorts for ONS 2 at sip 5. However, the individuals taking no medications selected the attributes 'Chocolate' and 'Coffee' significantly more than the individuals taking medications at sips 2 and 3, respectively.

Significant differences ( $p \leq 0.05$ ) in the selection of three attributes between the two ONS were observed in the cohort of individuals taking medications DMAT. This cohort selected 'Runny' and 'Watery' significantly more for ONS 1 and 'Thick' significantly more to describe ONS 2. In contrast, the individuals not taking medications selected the attribute 'Artificial' significantly more for ONS 2 than ONS 1 with no other significant differences in discriminating attributes observed for this cohort.

Cochran's Q test determined that there were no statistically significant differences in attribute selection frequency across the five sips for ONS 1 or ONS 2 in the cohort of individuals taking medications DMAT. For the individuals taking no medications there was a statistically significant difference ( $p \leq 0.005$ ) in the proportion of individuals who selected 'Thick' over the five sips for ONS 1, with this attribute being selected significantly more at sip 5 than at sip 2 and sip 3. For ONS 2, no significant differences were observed across the five sips for this cohort.

**Table 3.5** Frequency of selection of CATA terms for individuals taking medications which may cause dry mouth or altered taste (medications DMAT) and individuals not taking medications at sip 5 for both ONS.

	ONS 1		ONS 2	
	Medications %	No Medications %	Medications %	No Medications %
Airy <sup>ns</sup>	13.0 <sup>aw</sup>	21.7 <sup>ay</sup>	0.0 <sup>cw</sup>	13.0 <sup>cy</sup>
Aftertaste <sup>ns</sup>	52.2 <sup>aw</sup>	21.7 <sup>ay</sup>	56.5 <sup>cw</sup>	34.8 <sup>cy</sup>
Artificial	13.0 <sup>aw</sup>	0.0 <sup>ay</sup>	13.0 <sup>cw</sup>	26.1 <sup>cz</sup>
Astringent <sup>ns</sup>	4.3 <sup>aw</sup>	8.7 <sup>ay</sup>	8.7 <sup>cw</sup>	21.7 <sup>cy</sup>
Caramel <sup>ns</sup>	47.8 <sup>aw</sup>	26.1 <sup>ay</sup>	30.4 <sup>cw</sup>	30.4 <sup>cy</sup>
Coffee <sup>ns</sup>	8.7 <sup>aw</sup>	13.0 <sup>ay</sup>	8.7 <sup>cw</sup>	26.1 <sup>cy</sup>
Creamy <sup>ns</sup>	60.9 <sup>aw</sup>	52.2 <sup>ay</sup>	82.6 <sup>cw</sup>	69.6 <sup>cy</sup>
Custard-like <sup>ns</sup>	26.1 <sup>aw</sup>	34.8 <sup>ay</sup>	47.8 <sup>cw</sup>	52.2 <sup>cy</sup>
Hazelnut <sup>ns</sup>	8.7 <sup>aw</sup>	8.7 <sup>ay</sup>	17.4 <sup>cw</sup>	26.1 <sup>cy</sup>
Milky <sup>ns</sup>	56.5 <sup>aw</sup>	47.8 <sup>ay</sup>	39.1 <sup>cw</sup>	34.8 <sup>cy</sup>
Mouthcoating <sup>ns</sup>	39.1 <sup>aw</sup>	21.7 <sup>ay</sup>	39.1 <sup>cw</sup>	52.2 <sup>cy</sup>
Runny	34.8 <sup>aw</sup>	30.4 <sup>ay</sup>	4.3 <sup>cx</sup>	8.7 <sup>cy</sup>
Silky <sup>ns</sup>	39.1 <sup>aw</sup>	39.1 <sup>ay</sup>	43.5 <sup>cw</sup>	47.8 <sup>cy</sup>
Soft <sup>ns</sup>	34.8 <sup>aw</sup>	21.7 <sup>ay</sup>	52.2 <sup>cw</sup>	34.8 <sup>cy</sup>
Smooth <sup>ns</sup>	52.2 <sup>aw</sup>	43.5 <sup>ay</sup>	43.5 <sup>cw</sup>	52.2 <sup>cy</sup>
Sweet <sup>ns</sup>	69.6 <sup>aw</sup>	43.5 <sup>ay</sup>	69.6 <sup>cw</sup>	47.8 <sup>cy</sup>
Thick	0.0 <sup>aw</sup>	21.7 <sup>by</sup>	52.2 <sup>cx</sup>	39.1 <sup>cy</sup>
Vanilla <sup>ns</sup>	52.2 <sup>aw</sup>	39.1 <sup>ay</sup>	43.5 <sup>cw</sup>	56.5 <sup>cy</sup>
Viscous <sup>ns</sup>	8.7 <sup>aw</sup>	4.3 <sup>ay</sup>	8.7 <sup>cw</sup>	26.1 <sup>cy</sup>
Watery	21.7 <sup>aw</sup>	26.1 <sup>ay</sup>	0.0 <sup>cx</sup>	8.7 <sup>cy</sup>

Different superscript letters denote significant differences in attribute selection frequency at sip 5 for: (a, b) ONS 1 between the individuals taking medications DMAT and the individuals not taking medications, (c, d) ONS 2 between the individuals taking medications DMAT and the individuals not taking medications, (w, x) between ONS 1 and ONS 2 in individuals taking medications DMAT, and (y, z) between ONS 1 and ONS 2 in the individuals not taking medications, (ns) no significant difference. Differences in attribute selection frequencies were examined using Fishers exact test.

### **3.3.3 Liking**

#### **3.3.3.1 Age**

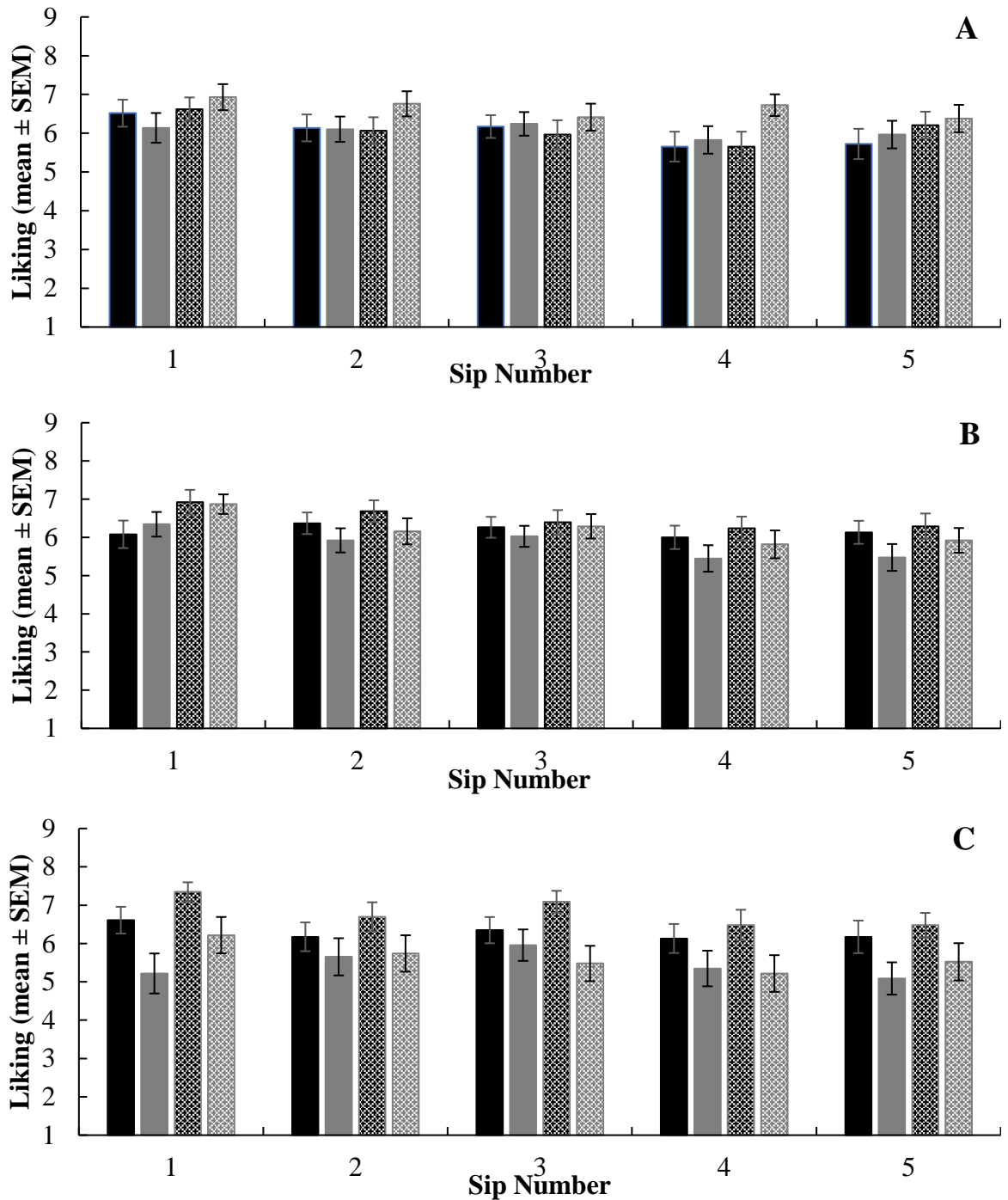
There were no significant differences in the mean liking scores between the two ONS, nor between the two age groups. Both ONS were relatively well-liked, with mean liking scores falling between 5 and 7 (neither like nor dislike - like moderately) on a 9-point hedonic scale for both age cohorts (Figure 3.2A). The mixed model ANOVA showed a significant within subject effect ( $p \leq 0.01$ ) for liking with sip number. There were no significant differences in liking scores between the five sips for either ONS in both age cohorts. There were no significant interactions either between sips and age, ONS and age, sips and ONS, or sips and ONS and age.

#### **3.3.3.2 Dentures**

At sip 5, the denture wearers and non-denture wearers scored both ONS between 5 and 7 (neither like nor dislike – like moderately) on the 9-point scale (Figure 3.2B). The liking scores did not differ significantly between denture wearers and non-denture wearers. However, there were significant within subject effects for liking with sip number ( $p \leq 0.01$ ). Average liking scores were highest at sip 2 and sip 1 for the denture and non-denture wearers respectively for ONS 1. For ONS 2, average liking was highest at sip 1 for both the denture and non-denture wearers alike. However, these differences in liking across the different sips for both cohorts and ONS were not significantly different. No significant interactions were observed for sip and denture status, ONS and denture status, sip and ONS, or sip and ONS and denture status.

#### **3.3.3.3 Medications**

The liking scores for individuals taking medications DMAT were significantly higher than those individuals not taking medications for both ONS ( $p \leq 0.05$ ) (Figure 3.2C). The mixed model ANOVA showed a significant within subject effect ( $p \leq 0.01$ ) for liking with sip number. For ONS 1 sip 1 was the most preferred sip by the individuals taking medications, whereas for the individuals not taking medications sip 3 was most preferred. For ONS 2 sip 1 was the most preferred sip in both cohorts. No significant differences existed for liking across the five sips for either cohort for both ONS.



**Figure 3.2** Mean ratings for liking at each sip (40 mL) for: **(A)** ONS 1 in 65-74 year olds (■) and over 75 year olds (■) and ONS 2 in 65-74 year olds (■) and over 75 year olds (■). **(B)** ONS 1 in denture wearers (■) and non-denture wearers (■) and ONS 2 in denture wearers (■) and non-denture wearers (■). **(C)** ONS 1 in individuals taking medications DMAT (■) and taking no medications (■) and ONS 2 in individuals taking medications DMAT (■) and taking no medications (■). Error bars represent the standard errors of the mean.

### **3.3.4 Penalty-lift analysis**

A penalty-lift analysis was performed to assess the impact that different attributes had on the liking and disliking of the different subject cohorts for both ONS 1 and ONS 2 and results are shown in Figures 3.3 and 3.4, respectively. Only the attributes selected by 20 % of panellists or more were included in the penalty-lift analysis.

#### **3.3.4.1 Age**

For both age groups, most attributes selected for ONS 1 had a positive connotation (Figure 3.3A and 3.3B). The main driver for ONS 1 liking in the 65 to 74 year olds was 'Vanilla'. The attributes 'Custard-like', 'Milky', and 'Silky' were also drivers of liking for ONS 1, although weaker drivers than the 'Vanilla' attribute. For the over 75 year olds, 'Creamy' was the most important driver for ONS 1, followed by 'Aftertaste' and 'Milky'. The attribute 'Runny' was the only real driver of dislike for the 65 to 74 year olds, and there were no notable inhibitors of ONS 1 liking for the over 75 year olds.

Considering ONS 2, most attributes selected by the 65 to 74 year olds had a positive connotation. However, for the over 75 year olds, just 50 % of attributes could be considered positive (Figure 3.4A and 3.4B). Similarly, to ONS 1, 'Custard-like' was a driver of liking for ONS 2 in the younger cohort, and increased liking by 1 point when selected. 'Hazelnut' and 'Aftertaste' also drove ONS 2 liking by 1 point in this cohort. For the over 75 year olds 'Creamy' was again considered the most important driver for ONS 2 liking by 1 point as was 'Coffee'. Unlike ONS 1, there were no notable inhibitors of ONS 2 liking for the 65 to 74 year olds. The attribute 'Viscous' was the main driver for ONS 2 dislike in the over 75 year olds.

#### **3.3.4.2 Dentures**

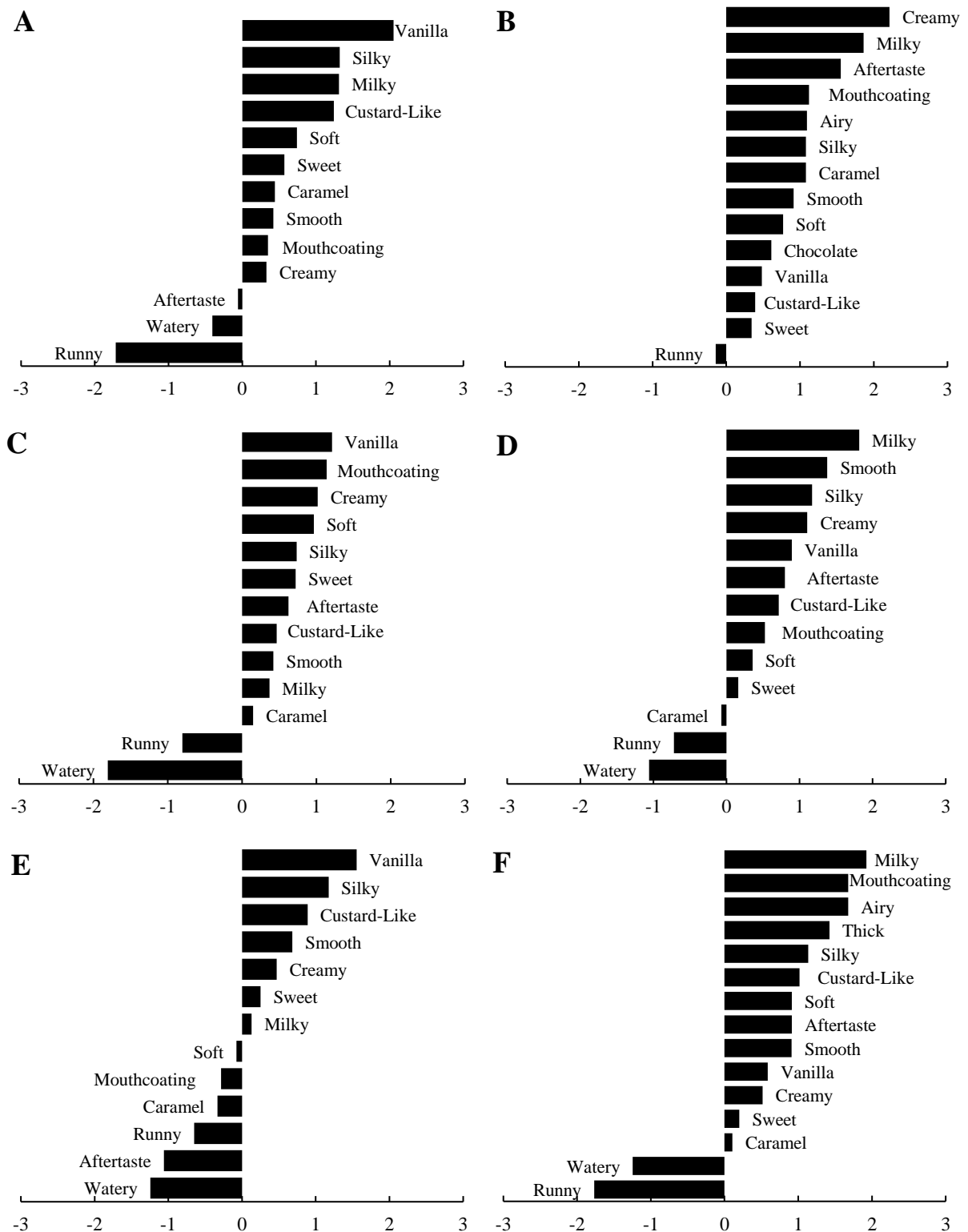
The penalty-lift analysis for denture wearers and non-denture wearers for ONS 1 are displayed in Figure 3.3C and 3.3D, respectively. The main drivers for ONS 1 liking for denture wearers were 'Vanilla', 'Mouthcoating', and 'Creamy' and the main driver for ONS 1 liking in the non-denture wearers was 'Milky' which caused an increase in liking of 1.8 points on average. 'Smooth', 'Silky', and 'Creamy' while not as strong in driving liking as for 'Milky' were also considered drivers of liking for ONS 1 for this cohort. The attribute 'Watery' was the only real driver for dislike of ONS 1 for denture wearers, reducing the liking by 1.8 points on average. This was also a driver of dislike for ONS 1 in the non-denture wearers.

For ONS 2, fewer attributes had a positive connotation for the denture wearers than for ONS 1, however, for the non-denture wearers most attributes for ONS 2 had a positive association (Figure 3.4C and 3.4D). The main driver of liking for ONS 2 both for the denture wearers and non-denture wearers was 'Creamy' with an increase in liking of 1 point and 1.6 points, respectively. 'Soft', 'Milky', and 'Smooth' also drove ONS 2 liking by more than 1 point for the non-denture wearers. The attribute 'Mouthcoating' was the main inhibitor of liking of ONS 2 for denture wearers, by about 0.8 points, whereas, unusually, 'Vanilla' was the only real driver for ONS 2 dislike for the non-denture wearers by 1 point on average.

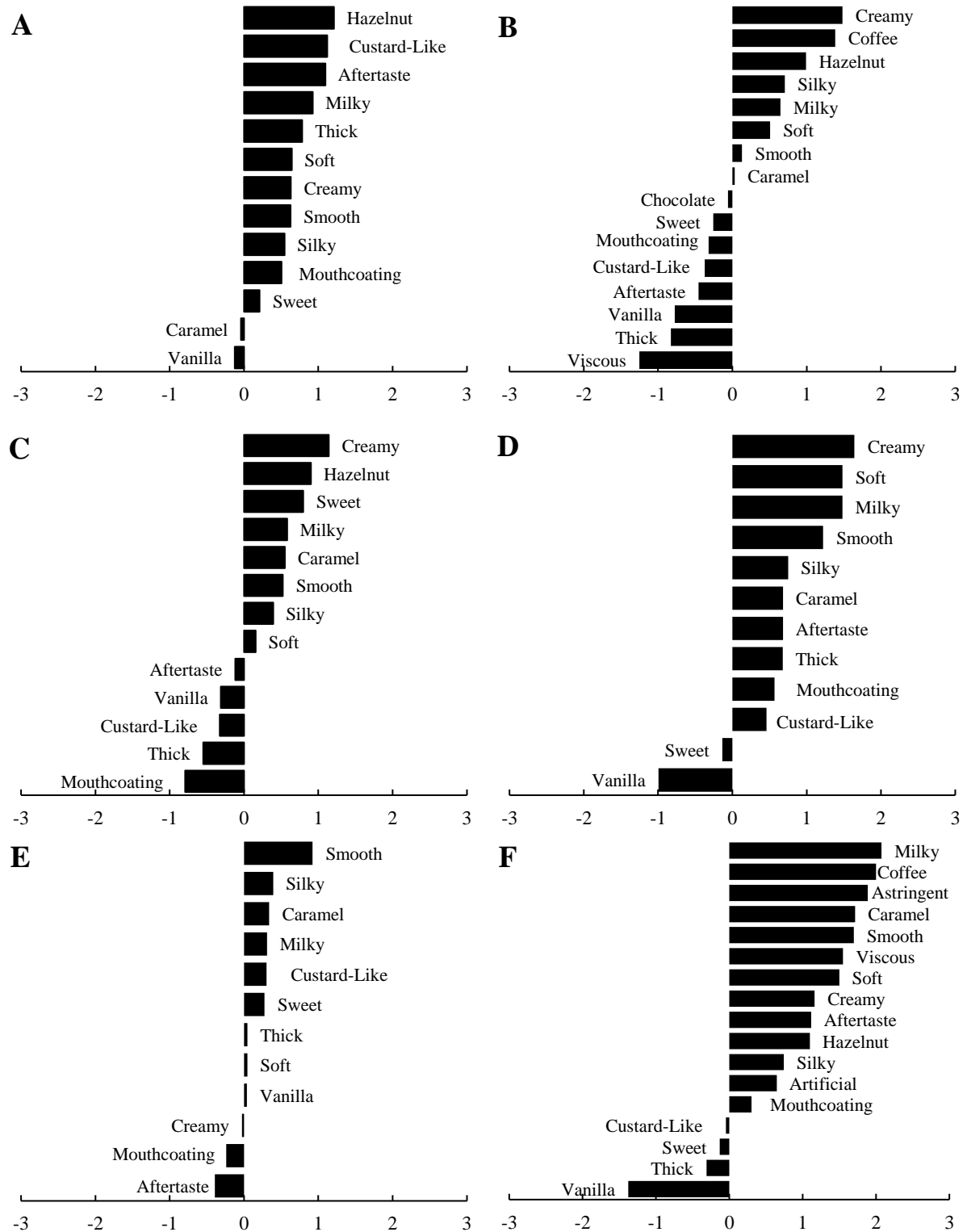
#### **3.3.4.3 Medications**

The drivers of liking and disliking of ONS 1 for the individuals taking medications DMAT and those not taking medications are displayed in Figure 3.3E and Figure 3.3F, respectively. The two main drivers for ONS 1 liking for the individuals taking medications were 'Vanilla' and 'Silky'. On the other hand, for individuals not taking medications, the main driver for ONS 1 liking was 'Milky' which was associated with an increase in liking of almost 2 points when selected compared to when not selected. 'Mouthcoating' and 'Airy' were also important drivers of liking of ONS 1 for this cohort. The attributes 'Watery' and 'Aftertaste' were the drivers for ONS 1 dislike for the individuals taking medications. For the individuals not taking medications 'Runny' and 'Watery' were the inhibitors of liking of ONS 1.

For ONS 2 (Figures 3.4E and 3.4F) 'Smooth' was the driver of liking for the individuals taking medications by 0.9 points on average. For the individuals not taking medications the main drivers of liking were 'Milky' and 'Coffee' which caused an increase in liking of 2 points. There were no notable inhibitors of ONS 2 liking for the individuals taking medications, however, for the individuals not taking medications 'Vanilla' was the main driver for ONS 2 dislike by 1.4 points on average.



**Figure 3.3** Results of the penalty-lift analysis for ONS 1 in individuals **(A)** aged 65-74 years, **(B)** aged over 75 years, **(C)** with dentures, **(D)** with no dentures, **(E)** taking medications DMAT, and **(F)** taking no medications. The values indicate a change in liking when an attribute was selected compared to when it was not selected by panellists at sip 5.



**Figure 3.4** Results of the penalty-lift analysis for ONS 2 in individuals **(A)** aged 65-74 years, **(B)** aged over 75 years, **(C)** with dentures, **(D)** with no dentures, **(E)** taking medications DMAT, and **(F)** taking no medications. The values indicate a change in liking when an attribute was selected compared to when it was not selected by panellists at sip 5.

### 3.3.5 Ideal ONS

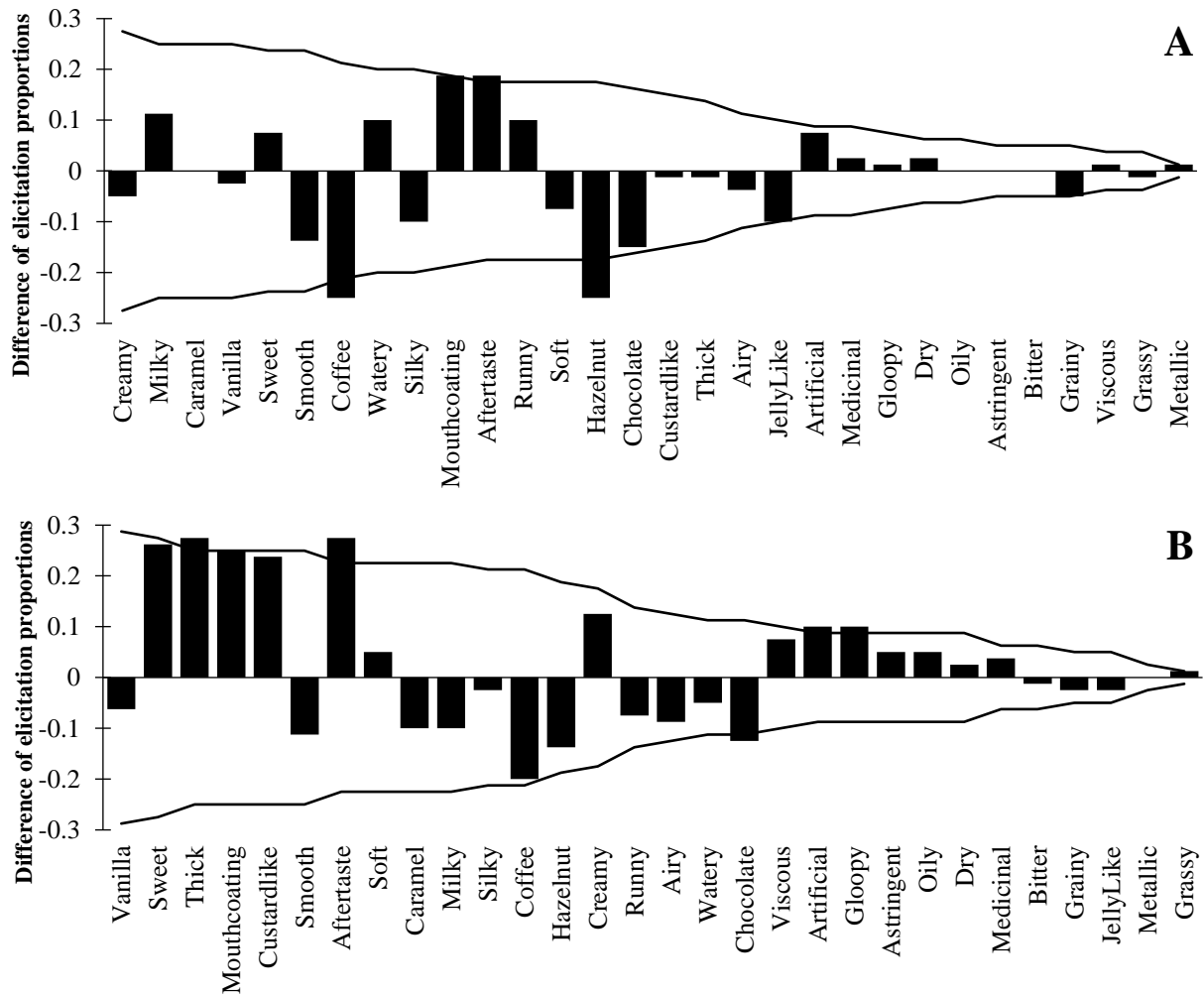
The selection frequency of the attributes used to describe the ideal ONS for the 65 to 74 year olds and the over 75 year olds after tasting both ONS are illustrated in Table 3.6. The most frequently selected attributes which were chosen by more than 50 % of panellists to describe their ideal ONS after tasting ONS 1 were 'Smooth', 'Sweet', and 'Vanilla' for the 65 to 74 year olds and 'Creamy', 'Smooth', and 'Vanilla' for the over 75 year olds. After tasting ONS 2 the most frequently selected ideal attributes for the 65 to 74 year olds were 'Caramel', 'Creamy', 'Smooth', and 'Vanilla' and for the over 75 year olds were 'Creamy', 'Milky', 'Smooth', and 'Vanilla' (Table 3.6). The Fishers exact test (Chi squared) revealed no significant differences between the two age cohorts in the selection of the ideal ONS attributes after tasting either ONS. No significant differences existed in the ideal attributes between the two ONS in both age cohorts.

**Table 3.6** Frequency of selection of the ideal attributes for both age cohorts after tasting both ONS. Superscript letters (ns) denote no significant differences.

	ONS 1		ONS 2	
	65-74s %	Over 75s %	65-74s %	Over 75s %
Airy <sup>ns</sup>	13.8	20.7	17.2	17.2
Aftertaste <sup>ns</sup>	6.9	20.7	6.9	10.3
Caramel <sup>ns</sup>	37.9	41.4	51.7	48.3
Chocolate <sup>ns</sup>	27.6	34.5	13.8	34.5
Coffee <sup>ns</sup>	34.5	24.1	27.6	41.4
Creamy <sup>ns</sup>	41.4	69.0	58.6	65.5
Custard-like <sup>ns</sup>	27.6	31.0	31.0	27.6
Hazelnut <sup>ns</sup>	31.0	41.4	31.0	34.5
Jelly-like <sup>ns</sup>	10.3	20.7	13.8	3.4
Milky <sup>ns</sup>	41.4	44.8	48.3	51.7
Mouthcoating <sup>ns</sup>	6.9	13.8	13.8	20.7
Runny <sup>ns</sup>	27.6	17.2	20.7	20.7
Silky <sup>ns</sup>	44.8	34.5	37.9	44.8
Soft <sup>ns</sup>	37.9	31.0	41.4	41.4
Smooth <sup>ns</sup>	62.1	51.7	55.2	75.9
Sweet <sup>ns</sup>	51.7	41.4	34.5	44.8
Thick <sup>ns</sup>	3.4	20.7	17.2	27.6
Vanilla <sup>ns</sup>	51.7	51.7	58.6	58.6
Watery <sup>ns</sup>	20.7	13.8	17.2	10.3

### **3.3.6 Comparison of products with ideal**

Each individual attribute was compared to the ideal attribute by determining the difference between the proportion of elicitations for the real and ideal ONS for both ONS. Figures 3.5A and 3.5B illustrate the results for ONS 1 and ONS 2 respectively for the full study cohort of individuals aged over 65 years. It is evident from Figure 3.5A that the panellists associated the attributes 'Coffee' and 'Hazelnut' more with their ideal ONS than with ONS 1 which was a vanilla flavoured ONS. In contrast the panellists found ONS 1 to have too much of a 'Mouthcoating' and 'Aftertaste' effect compared to their ideal ONS. For ONS 2 it was apparent that the panellists associated the attribute 'Chocolate' more with their ideal ONS than with this ONS. ONS 2, was judged too 'Thick', 'Artificial', and 'Gloopy' than the ideal ONS. Like ONS 1 the panellists also rated ONS 2 as having too much of an 'Aftertaste' compared to their ideal.



**Figure 3.5** Comparison of the elicitation rates of **(A)** ONS 1 and the Ideal product, and **(B)** ONS 2 and the ideal product. A negative difference corresponds to the attribute not being present enough, while a positive difference corresponds to an attribute being too present. The line represents the 95 % confidence interval of the elicitation ratio.

### 3.4 Discussion

This study investigated the effects of age, denture wearing, and medications on the sensory perception and liking of two ONS within a cohort of community dwelling older adults aged over 65 years. The study used both a low viscosity ONS and a high viscosity ONS to represent a broad viscosity range. This enabled the investigation of whether ONS viscosity impacts on liking, which is a major factor in the uptake and adherence of these supplements. Sensory perception, liking, and appetite were assessed during ONS consumption.

### **3.4.1 Appetite**

For both age groups tested, a total of five sips of ONS (corresponding to 200 mL intake) led to a decline in appetite ratings, and this was observed for both ONS 1 and ONS 2. These results support the findings in Chapter 2 that hunger ratings of over 65 year olds declined with increasing consumption volume of ONS. Given the fact that between 11 and 15 % of community dwelling older adults are reported to experience poor appetite, with this figure increasing further to 19-52 % in hospital and 12-66 % in nursing home settings (Van der Meij *et al.*, 2015), this is an important point to consider. Hospital patients and non-community dwelling older adults are the predominant consumer of ONS on a regular basis. This decline in appetite with increased consumption volume may result in difficulties with ONS adherence and reduce their effectiveness in a cohort already experiencing diminished appetite. This further supports the current strategies adopted by ONS manufacturers to concentrate beverage-style ONS into compact and shot-style modes of delivery (den Boer, Boesveldt and Lawlor, 2019). This approach taken by ONS manufacturers is supported by previous research which showed that lower-volume energy dense ONS are ideal to improve ONS uptake and adherence in individuals who may find it difficult to consume larger volumes (Hubbard *et al.*, 2010; Stange *et al.*, 2013; Lombard *et al.*, 2014).

The present study also observed a reduced appetite throughout the consumption of both ONS in the older age cohort (over 75s) compared to the younger one (65-74s). Causes of poor appetite in older adults are multifactorial and include physiological factors, psychological factors, and other factors such as chronic diseases, inflammation, illness, medication use, and poor oral health (Pilgrim *et al.*, 2015; Van der Meij *et al.*, 2015). These findings clearly illustrate that even within an older adult cohort, a further decline in appetite can be seen with age. This highlights the importance of focusing research efforts on the different segments of the older adult population cohort to meet their individual needs.

### **3.4.2 Sensory perception (CATA profiling)**

It was hypothesised that the over 75 year olds would select fewer sensory attributes than the 65 to 74 year olds to describe both ONS, since the effects of sensory impairment are more likely to be observed in those above 75 years. Particularly in relation to taste and texture, with the number of taste buds decreasing (Feng, Huang

and Wang, 2014; Ogawa *et al.*, 2017), medication use and polypharmacy increasing (Morin *et al.* 2018), and tooth loss rates increasing (Polzer, Schimmel and Biffar, 2010; Sheehan, McGarrigle and O'Connell, 2017) with age, particularly past 75 years. However, no significant differences in attribute selection between the age groups were observed, and those chosen were similar between the two age cohorts.

The majority of the attributes selected did not differ significantly between the two age cohorts. However, for ONS 1 the over 75 year olds selected the attribute 'Creamy' significantly more than the 65 to 74 year olds. Given that previous work suggests that creaminess perception declines with age (Kremer, Mojet and Kroeze, 2005), this was unexpected. It should be noted that the older adults in that study were 68 years old on average whereas the older group here had a mean age of 82 years.

The results also showed that 'Chocolate' was selected significantly more in the older age group for ONS 2 (which was in fact vanilla flavoured) than by the 65 to 74 year olds. This finding agreed with Chapter 2, which showed that the selection of 'Chocolate' as a descriptor for a vanilla flavoured ONS was significantly greater in over 65 versus 18-35 year olds. This is potentially due to age related impairments in sensory perception, and again illustrates the importance for conducting sensory trials with different segments of the older adult population cohort as opposed to just treating all older adults aged over 65 years as one cohort.

Denture wearing appeared to affect texture perception, with non-denture wearers selecting the attributes 'Mouthcoating' and 'Artificial' significantly more than denture wearers for ONS 1 (at sips 3 and 4), and 'Silky' significantly less than the denture wearers to describe ONS 2. Despite this, both groups were equally able to perceive the viscosity differences between the two samples. Dentures have previously been reported to not only limit the movement of foods within the mouth but also to limit the stimuli from reaching the palate papillae (Duffy, Cain and Ferris, 1999; Duffy and Bartoshuk, 2000; Withers, Gosney and Methven, 2013). Therefore, it is quite possible that in this instance the denture wearers were less capable of detecting the build up in 'Mouthcoating' and 'Artificial' sensations with increasing consumption volume as a result of the dentures blocking the top and/or bottom of the palate. Prevalence rates of malnutrition in older adults in nursing homes, can be as high as 66.5 % (Steicher *et al.*, 2017), and this cohort are reported to have higher

prevalence of edentulism than community dwelling older adults (Medeiros *et al.*, 2020). Previous research has highlighted that denture wearers may consider mouthfeel attributes of dairy beverages of greater importance due to the fact that moving them around the mouth may be critical to their enjoyment (Withers, Gosney and Methven, 2013). This highlights the importance of including dentition as a consideration during the development of ONS in this target group.

Medication use is listed as one of the most common causes for taste disturbances and taste disorders in older adults (Schiffman, 2009; Toffanello *et al.*, 2013). This would suggest that individuals taking medications DMAT would select significantly fewer flavour/taste attributes compared to those not on DMAT medications. This was evident here for ONS 2 where the attributes 'Chocolate' and 'Coffee' were selected significantly less by the individuals taking medications DMAT (at sips 2 and 3). Since the average number of prescribed medications has been reported to increase from 3.4 medications in community dwelling older adults to up to 7 medications in assisted living older adults (Schiffman, 2009), this demonstrates a further important consideration in the optimisation of ONS for malnourished, assisted living older adults.

### **3.4.3 Liking**

Neither age nor denture wearing influenced ONS liking. However, individuals taking medications DMAT gave higher liking ratings to the ONS compared with those taking no medications. One possibility is that the ONS may form a mouthcoating, which may be pleasant for individuals suffering from dry mouth, as it has been previously reported that mouthcoating beverages may aid salivation (Stratton and Elia, 2006; Withers, Gosney and Methven, 2013). However, in those on medications DMAT, there was no difference between liking for ONS 2 (the high viscosity ONS) and ONS 1, which might have been expected since viscosity and mouthcoating have been reported to be positively correlated (Aime *et al.*, 2001). It is also possible that both were pleasant due to sufficient mouthcoating. Future research might consider whether there is a maximal level of mouthcoating at which liking does not increase further in this cohort.

### **3.4.4 Drivers of liking of ONS**

The penalty-lift analysis on the CATA data highlighted that similar attributes drove liking for ONS 1 in both age groups, although the extent to which they drove liking

differed slightly. The same was observed for ONS 2, but there were fewer attributes in common for the age groups for this ONS. Of note, 'Creamy' was the most important driver of liking for both ONS in the older group, and viscosity was also important in the older group, with ONS 2 scoring less favourably, and 'Viscous' being the predominant driver of ONS 2 dislike. Viscosity appeared to be less important for the younger cohort, with the attribute 'Viscous' neither driving liking nor disliking of ONS 1 or ONS 2 in this cohort.

Viscosity was also important for denture wearers. The lower viscosity ONS (ONS 1) had similar drivers of liking for denture wearers and non-wearers alike. However, for ONS 2, most of the attributes which drove liking for the non-denture wearers in fact drove disliking for the denture wearers, implying that this level of viscosity was too high for this latter group. This was echoed in the results for mouthcoating, which was a driver of liking for ONS 1, but of dislike for ONS 2 in denture wearers. The apparent viscosity values for ONS 1 were 0.009 Pa.s and 0.177 Pa.s for ONS 2, at a shear rate of  $50.1 \text{ s}^{-1}$ , suggesting that the ideal values for denture wearers may lie towards the middle or lower end of this viscosity range, even though both ONS returned liking ratings to show they were generally acceptable.

Attributes related to sweetness and mouthfeel were important for individuals taking medications DMAT, with this cohort selecting 'Vanilla' and 'Silky' as the predominant drivers of liking for ONS 1, and 'Smooth' as the main driver for ONS 2. Interestingly, unlike the over 75 year olds and the denture wearers, the individuals taking medications DMAT appeared to have more drivers for ONS 1 disliking than for ONS 2. In fact, for ONS 2 it appeared that there were no real drivers of liking or disliking for this study cohort.

### **3.4.5 Practical Implications**

Clear differences in the factors affecting liking can be seen in the different population cohorts examined here, confirming the challenges for ONS manufacturers to meet the opposing needs of older adults. Taking all the above into consideration, the attribute 'Vanilla' may help promote the liking of low viscosity ONS for older adult cohorts. This is further supported by the selection of 'Vanilla' (amongst other attributes) as an ideal ONS attribute after tasting both samples in this study. However, this is only advisable for lower viscosity ONS as 'Vanilla' acted as a driver of disliking for ONS 2 for everyone here, aside from the individuals taking

medications DMAT, where it was considered a very weak driver for liking. Providing a wider range of flavours, including 'Coffee', 'Hazelnut', or 'Chocolate' for ONS is also supported by the present results.

From a texture and mouthfeel perspective, achieving perceptions of 'Creamy' and 'Smooth' should help to improve acceptability, while perceptions associated with a thinner mouthfeel such as 'Watery' and 'Runny' should generally be avoided, although the ideal viscosity range for the older group and for those with dentition issues is likely to fall between the ranges used here, since the more viscous ONS (0.177 Pa.s at a shear rate of 50.1 s<sup>-1</sup>) was less liked by these individuals.

As a final remark it should also be noted that while the results here generally support the current approach taken by ONS manufacturers to concentrate products into compact and shot-style ONS, this process may increase thickness (den Boer, Boesveldt and Lawlor, 2019), and care should be taken to ensure the final viscosity falls within a desirable range.

#### **3.4.6 Limitations and strengths**

In addition to providing important insights for ONS manufacturers on the factors which may affect ONS uptake and adherence in different older adult population cohorts this study also advances sensory science methodology for older adults. There were no reported differences in the number of attributes selected to describe the ONS by the young-old and the old-old adult cohorts and 28 out of the 30 attributes for ONS 1 and 29 out of the 30 attributes for ONS 2 were statistically similar between the two age cohorts. Therefore, this study suggests that adults 75+ years are equally capable of using the CATA technique to evaluate ONS as those aged 65 to 74 years. Further work may be required with the (85+ years), to determine whether this sensory methodology is appropriate for use in this cohort as numbers in this age bracket were low in the current study.

It is worth noting that the appetite score used in this study specifically asked participants to rate 'desire to consume more ONS', rather than simply 'desire to eat.' However, this is both a limitation and a strength of this study as it means that the appetite data in this study are specific to the samples being consumed.

The participants in this study were screened for the absence or presence of dentures. Details regarding the level of palate covering provided from the denture plate were not supplied. This was a limitation of this study and future research should

obtain information regarding palate covering to give more in depth insights on the effects that this may have on perception.

Finally, the cohort used in this study were aged over 65 years to get as close to the age range of ONS consumers, however, this cohort predominantly comprised healthy, community dwelling older adults (not undernourished older adults). Therefore, future research should extend this study further to include a patient group of undernourished older adults. By including a patient cohort this would provide important insight on whether these results are mimicked in a cohort of ONS consumers or whether a patient cohort would exhibit different perceptions and liking of the ONS.

### **3.5 Conclusion**

This study highlights the importance of conducting sensory evaluations with different segments of the older adult population cohort, considering dentition and medications, as opposed to a one-size-fits-all approach. This was evidenced by the differences in appetite ratings, the differences in some dominant attribute selections, and the variation in the drivers of liking and disliking between the young-old and the old-old adult cohorts in this study. Denture wearing influenced the texture perception of ONS, while medications with side effects of dry mouth or altered taste appeared to impact flavour perception of the high viscosity ONS. Increasing perceptions of 'Vanilla' and avoiding perception of a thin or 'Watery/Runny' mouthfeel while maintaining 'Creamy' perceptions, may improve acceptability and thus adherence. Taken together, this study supports the current strategies of low volume, compact, energy dense ONS. However, it is important to consider the effects that this may have on ONS viscosity. Finally, this study advances sensory science methodology by justifying the CATA methodology for use in different older adult cohorts. Further research should extend this study further to include a patient cohort of undernourished older adults.

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## **Chapter 4**

**Measuring the effectiveness of the Temporal Dominance of Sensations technique to investigate the differences in dynamic texture perception of oral nutritional supplements between older and younger adults.**

## **Chapter 4: Measuring the effectiveness of the Temporal Dominance of Sensations technique to investigate the differences in dynamic texture perception of oral nutritional supplements between older and younger adults**

### **4.1 Introduction**

The Temporal Dominance of Sensations (TDS) technique has been used increasingly to assess the dynamic sensory perception of food and beverages (Zorn *et al.*, 2014; Schlich *et al.*, 2017; Rizo *et al.*, 2019). This method is advantageous as it supplies important information on the sequence of attribute perceptions throughout the consumption of a food product, from initial intake to swallowing (Meyners, 2011; Pineau *et al.*, 2012; Pineau and Schlich, 2015). Given these benefits the TDS method has been used in over 180 publications (Based on a search of Web of Science™ database using the term “Temporal Dominance of Sensations”). However, many of these sensory studies use convenience cohorts of relatively narrow age and demographic profiles, with only limited use in older adults aged over 65 years.

The TDS technique was first successfully validated for use with older adults by Hutchings *et al.* (2014a) who reported that clear TDS curves were generated by both old and young adults and that intrasubject variability in the TDS sequence did not differ between the two age groups. Since then, the TDS methodology has only been used in a handful of research studies with older adults, with many of these studies focusing predominantly on the evaluation of both solid and semi-solid foods (Hutchings *et al.*, 2014a, Hutchings *et al.*, 2014b; Aguayo-Mendoza *et al.*, 2020), except for one study by Thomas *et al.* (2018) who used liquid products. Liquid products are likely to be more difficult for participants to undertake a TDS task than solid products, therefore, it is of interest to see how older adults manage these products with TDS. This is particularly relevant, given the importance of some beverage products such as Oral Nutritional Supplements (ONS) in alleviating undernutrition and thus enhancing the health of older adults globally.

ONS are dietary food products specifically designed to counteract undernutrition by delivering essential macro/micronutrients and calories in small food portions (Lochs *et al.*, 2006; Stratton and Elia, 2010; British Association of Parenteral and Enteral Nutrition, 2016). While ONS, coupled with dietary counselling, have been

shown to successfully manage undernutrition (Agarwal *et al.*, 2013), poor adherence to ONS has been reported in both community and non-community dwelling older adults (Gosney, 2003; McMurdo *et al.*, 2009; Özçağlı, Stelling and Stanford, 2012). This is partly attributed to their undesirable sensory properties including, but not limited to, their sweetness, texture, mouthfeel, and aftertaste (Gosney, 2003; Rahemtulla, *et al.*, 2005; Methven *et al.*, 2010; Nieuwenhuizen *et al.*, 2010). To improve the uptake and adherence to ONS in older adults, understanding their temporal sensory profiles through TDS evaluations is vital.

To the best of the author's knowledge only one study to date appears to have used the TDS methodology with ONS in an older adult cohort. This study combined the TDS method with 'liking' to develop a novel sensory method known as "Alternated Temporal Drivers of Liking" (A-TDL) (Thomas *et al.*, 2018). The findings stated that the TDS method was simple to use, instinctive, and the task appeared to be understandable by older adults (Thomas *et al.*, 2018). While this study provides important insights on the dynamic perception and drivers of liking of ONS and on the use of TDS for the evaluation of liquid products with older adults, very few other studies have been conducted in this field.

Previous research (Hutchings *et al.*, 2014a; Hutchings *et al.*, 2014b; Aguayo-Mendoza *et al.*, 2020) has clearly illustrated the effectiveness of the TDS technique in evaluating the dynamic texture perception of solid and semi-solid foods in older adult cohorts. However, no study to the best of the author's knowledge has applied the TDS technique to evaluate the dynamic texture perception of liquid products. Recognising that both texture and mouthfeel have been reported as drivers for reduced liking of ONS in older adults (Gosney, 2003; Methven *et al.*, 2010; den Boer, Boesveldt and Lawlor, 2019), there is a need to understand the dynamic texture perception and preferences of these beverage products in older adults. This would not only be of benefit from an academic point of view but would also provide important information for manufacturers to promote enjoyment and nutrient intake in older adults. The aim of this study was therefore two-fold. The research sought to advance sensory science methodology for older cohorts by applying the TDS methodology with both younger and older adults to assess if this technique is suitable for dynamic sensory evaluations of beverages, and to further expand the knowledge of how texture perception differs with age. In addition to this the study was designed

to deepen the understanding of how older adults perceive ONS and how ONS liking is impacted by viscosity. Four ONS of differing viscosities were used, ranging from a low viscosity supplement (0.009 Pa.s at shear rate 50.1 s<sup>-1</sup>) to a high viscosity supplement (0.177 Pa.s at shear rate 50.1 s<sup>-1</sup>) to allow for investigation of textural perception.

## **4.2 Materials and Methods**

### **4.2.1 Samples**

Two ready-to-drink beverage-style ONS (Fresenius Kabi, Bad Homburg vor der Höhe, Germany) were selected for use in this study based on their previous use in Chapter 2 and Chapter 3, and on their apparent viscosity, with these ONS representing the lower and upper ends of the viscosity range of beverage-style ONS. Throughout this chapter these supplements will continue to be referred to as ONS 1 (low viscosity; 0.009 Pa.s at shear rate 50.1 s<sup>-1</sup>) and ONS 4 (high viscosity; 0.177 Pa.s at shear rate 50.1 s Pa.s<sup>-1</sup>). To achieve a range of supplements with thickness levels that lie between those of ONS 1 and ONS 4, varying quantities of a commercial starch-based thickener (Thick and Easy™, Fresenius Kabi, Runcorn, United Kingdom) were added to ONS 1.

ONS 1 and ONS 4 were evaluated for their apparent viscosity alongside the ONS with added thickener (Section 4.2.2). Based on the results for apparent viscosity, two ONS with added thickener were selected for use in the TDS evaluation in addition to ONS 1 and ONS 4. These additional supplements are referred to as ONS 2 (ONS 1 + 0.5 % w/w thickener) and ONS 3 (ONS 1 + 2.1 % w/w thickener). ONS 2 and ONS 3 were prepared by adding the desired quantity of thickener to ONS 1 under constant stirring for 10 minutes at 21 °C using a laboratory stirrer (IKA RCT basic, IKA® Werke, GmbH and Co. KG, Germany), 15 minutes prior to being served to the participants.

All four ONS were vanilla flavoured, ready-to-drink beverage-style ONS containing essential vitamins and minerals. ONS 1, 2, and 3 were identically flavoured supplements with similar nutritional profiles (moderate energy protein drinks). ONS 4 however, had a significantly different nutritional profile (high energy protein drink) and while it was also a vanilla flavoured supplement its flavour profile cannot be considered identical to that of ONS 1, 2, and 3. As this study was

predominantly focused on the dynamic perception of the four ONS the nutritional content was not standardised across the four ONS.

#### **4.2.2 Rheological Analysis**

The rheology of the ONS was measured using a Physica MCR 301 Rheometer (Anton Paar, Graz, Austria). The rheometer was fitted with a cone and plate geometry (diameter: 50 mm, cone angle: 2 °) and the temperature was set and maintained at room temperature (21 °C) throughout the analysis. All measurements were conducted in triplicate. Prior to analysis the samples were stirred at 21 °C for 10 minutes using a laboratory stirrer (IKA RCT basic, IKA® Werke, GmbH and Co. KG, Germany). The sample was loaded onto the plate and allowed to equilibrate two minutes prior to analysis. Shear stress values were measured at shear rates from 1 to 1000 s<sup>-1</sup> with a ramp of 120 seconds.

#### **4.2.3 Participants**

A total of 70 volunteers were selected for this study: 35 young adults (15 men and 20 women, aged 18-35 years, mean age 25.1 ± 3.7 years) and 35 community dwelling older adults (15 men and 20 women, aged 65+ years, mean age 71.6 ± 5.2 years). Panellists were recruited through word-of-mouth, and poster advertisements, and were fluent English speakers who were computer literate. Each panellist signed a written informed consent agreement before participating in the experiment. This sensory project was reviewed and approved by the UCD Human Research Ethics Committee (Ref. No. LS-17-50).

Table 4.1 summarises the differences between the two age cohorts. The number of subjects taking medications where dry mouth and altered taste were reported as a common or very common side effect (The Royal Pharmaceutical Society, 2019) was greater in the older adult cohort. Likewise, the number of subjects with at least one missing tooth, one artificial tooth, and suffering from a dry mouth was also higher in the older cohort. This reflects the different oral status between the two age cohorts.

**Table 4.1** Participant demographics for older and younger subjects.

	Older subjects ( <i>n</i> =35)	Younger subjects ( <i>n</i> =35)
Number of males/females	15/20	15/20
Age (mean $\pm$ SD, range)	71.6 $\pm$ 5.2 (65-84)	25.1 $\pm$ 3.7 (18-34)
Number of subjects taking medications (at least weekly)	22	3
Number of subjects taking medications where dry mouth is reported as a common/very common side effect (The Royal Pharmaceutical Society, 2019)	6	1
Number of subjects taking medications where altered taste is reported as a common/very common side effect (The Royal Pharmaceutical Society, 2019)	6	1
Number of subjects to report suffering from hypertension	10	0
Number of subjects to report suffering from hyper/hypothyroidism	2	0
Number of subjects with at least 1 missing tooth	20	2
Number of subjects with dentures or false teeth	11	0
Number of subjects to report suffering from dry mouth	6	0

#### 4.2.4 Term generation

A list of 12 sensory attributes (Table 4.2) was created based on the important drivers of liking and disliking from Chapters 2 and 3 and from previous sensory studies similar in nature to this (Thomas *et al.*, 2016; Thomas *et al.*, 2018). The attribute

order on the TDS questionnaire was randomised between subjects but not within subjects.

**Table 4.2** Sensory attributes used in the TDS task.

Texture/Mouthfeel	Taste/Flavour
Creamy	Aftertaste
Mouthcoating	Caramel
Soft	Milky
Silky	Sweet
Smooth	Vanilla
Thick	
Watery	

#### **4.2.5 Training**

Each participant received one training session to prepare them for use of the TDS technique. The training sessions were conducted on a one-to-one basis prior to the TDS session, with each participant receiving an identical training session. First the purpose and background of the study and concept of TDS was explained to the participants followed by an explanation of the 12 attributes. Reference foods were not given alongside the attributes as the aim of this study was to investigate the natural differences in perception between the two age cohorts. Providing training using reference foods has the possibility of diluting this effect. Finally, to ensure that each participant was competent in the use of the TDS technique, they had the opportunity to practice the TDS procedure several times prior to the study. Each participant was encouraged to ask questions throughout the training session.

#### **4.2.6 Experimental session**

The TDS session took place over one 30-minute session in a sensory laboratory at room temperature (21 °C) under white lighting in accordance with ISO 8589 (ISO-Standard, 2007). Over the course of the sensory session the four different ONS samples were evaluated (ONS 1, 2, 3 and 4). For each ONS a total of 45 mL was consumed over three sips (15 mL each). The ONS were presented at room temperature in 30 mL clear plastic cups. Each TDS evaluation lasted 120 seconds and was conducted using RedJade software (RedJade Software Solutions, LLC, Curion, Chicago). The panellists were instructed to begin the evaluation process by

pouring the first sip of the ONS into their mouth, swallow at their free will, and select the start button. Swallowing was not controlled for; however, this is both a strength and limitation of this study as it means the supplements were consumed in a real life manner. Panellists were prompted to select whichever attribute from the list of 12 attributes they felt was dominant at any given time throughout the tasting. The panellists were given 40 seconds to evaluate each sip and were allowed to choose more than one dominant attribute over the evaluation period. After 120 seconds the timer was stopped, and the panellists were prompted to rate their overall liking of the ONS on a 9-point hedonic scale. On completion of this task the panellists were given a 60-second break, over which they were instructed to consume water and a water cracker to cleanse their palate before repeating the evaluation procedure again with the next ONS.

#### **4.2.7 Data Analysis**

A one-way ANOVA and Tukey's pairwise comparisons were used to determine significant differences between the apparent viscosities of the four ONS. Overall liking was analysed using a mixed model ANOVA with age group as the between subject factor, and ONS as the within subject repeated measures, to determine the significant differences between age groups and ONS.

To investigate the behaviour of the TDS technique, a mixed model ANOVA was applied with ONS as the within subject repeated measures. This analysis was undertaken to assess the significant differences between the age group and the ONS in relation to the number of selections made, the number of attributes used, the time taken to first select an attribute, and the average dominance durations. The same approach was taken to investigate the differences in attributes (dominance durations) among the ONS and age cohorts.

For the TDS data analysis, TDS curves (Appendix 3) were constructed by computing the dominance rate of the attributes at each time point (Pineau *et al.*, 2009). To assist the interpretation of the TDS curves a 'chance level' and a 'significance level' were added as two lines to the TDS graphs. The 'chance level' is defined by Pineau *et al.* (2009) as the dominance rate that an attribute can obtain by chance ( $P_0 = 1/\text{number of attributes}$ ). Whereas the 'significance level' refers to the minimum value that should be reached to consider the dominance rate as significantly higher than the 'chance level' (Pineau *et al.*, 2009; Albert *et al.*, 2012; Di

Monaco *et al.*, 2014). The significance level is calculated from the confidence interval of a binomial proportion based on normal approximation (equation 1) (Pineau *et al.*, 2009).

$$\text{Equation 1: } P_s = P_0 + 1.645 \sqrt{\frac{P_0(1-P_0)}{n}}$$

$P_s$  = the lowest significant proportion value ( $\alpha = 0.05$ ) at any point in time for a TDS curve

$n$  = number of subjects x number of replications

$P_0$  = chance level

TDS difference curves (Pineau *et al.*, 2009) were also produced, to compare the two age cohorts. The difference curves were drawn by calculating the differences in dominance rates of older adults and younger adults for each of the products. The differences were only plotted when significantly different from zero (Pineau *et al.*, 2009; Pineau and Schlich, 2015). For the grouped difference curves the plot was obtained by treating the four ONS as replicates of the same product and then comparing perception of this product between older and younger adults as described above.

Successive sips of the same product by age group were mapped using a trajectory map. This trajectory map was established by conducting a covariance Principal Component Analysis (PCA) on the TDS data. The PCA was representative of  $4 \times 2 \times 3 = 24$  observations corresponding to product by age cohort by sip for each of the 12 attributes (variables) being the average (over panellists) of attribute dominance durations. Sensory trajectories are shown on the map by linking the three sips of the same products by age group with the third sip being represented by the end of the trajectory arrow.

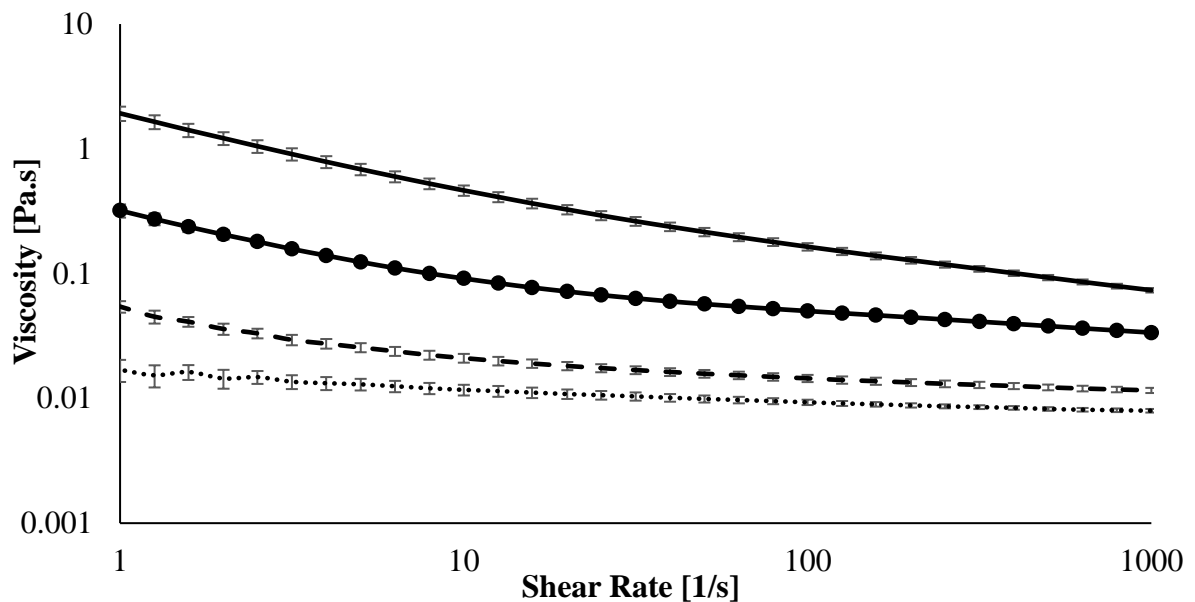
PCA of dominance durations by ONS within the age groups was also completed. For this PCA analysis dominance durations from 0 seconds to 120 seconds were summed. Confidence ellipses of the product means were drawn by projecting individual dominance durations as supplementary data.

TDS data was collected with RedJade software (RedJade Software Solutions, LLC, Curion, Chicago). Data analysis was performed using TimeSens© (INRA, Dijon, France), SAS® 9.4 (SAS Institute Inc., Cary, North Carolina, USA), and IBM®SPSS® (version 24.0 for Windows) (IBM Corp., USA).

## 4.3 Results

### 4.3.1 Rheology

Figure 4.1 shows the viscosity-shear rate curves of the four ONS chosen for use in the TDS session (ONS 1, 2, 3, and 4). The viscous behaviour of ONS 2, 3, and 4 was evidently pseudoplastic with a decrease in viscosity on shearing. In contrast, ONS 1 exhibited lower viscosity and Newtonian characteristics. Significant differences ( $p \leq 0.01$ ) existed between the apparent viscosities of the different ONS at a shear rate of  $50.1 \text{ s}^{-1}$  except for ONS 1 and ONS 2 where the apparent viscosities were not statistically significantly different ( $p \geq 0.05$ ). A shear rate of  $50.1 \text{ s}^{-1}$  was chosen, as a shear rate of  $50 \text{ s}^{-1}$  has been reported as a typical oral shear rate (Withers, Gosney and Methven, 2013).



**Figure 4.1** The viscosity as a function of shear rate ( $\text{s}^{-1}$ ) of ONS 1 (•••), ONS 2 (---), ONS 3 (-•-), and ONS 4 (—). Error bars represent standard deviation.

### 4.3.2 TDS behaviour

Table 4.3 outlines the data from the behavioural analysis for the products, the age cohorts, and the products\*age cohort. It summarises: (1) the average number of selections made, (2) the average number of attributes selected (out of 12 attributes), (3) the average time taken by both age cohorts to select the first attribute during the tasting sequence, and (4) the average time for which an attribute was selected as dominant (average dominance duration).

#### **4.3.2.1 The number of selections made**

The number of attribute selections made during the tasting sequence of the ONS were significantly different between the two age cohorts ( $p \leq 0.01$ ). The younger adults made a significantly greater number of selections throughout the tasting sequence than the older adults (7.5 clicks vs. 3.9 clicks). In addition, there was a product effect for the number of selections made for the two high viscosity products (ONS 3 and ONS 4), with these products involving more selections in both groups than the two less viscous products (ONS 1 and ONS 2). No significant interactions were found between group and product for the number of selections made throughout the tasting sequence.

#### **4.3.2.2 The number of attributes used**

The number of attributes used varied significantly ( $p \leq 0.05$ ) between the different age cohorts with the younger cohort using a greater number of attributes (4.1) than the older cohort (2.8), to a significant degree. No product effects were observed for the number of attributes used. However, there was a slight interaction, albeit not significant ( $p = 0.0739$ ), for product by group. This expresses the fact that the two high viscosity products (ONS 3 and ONS 4) generated more attributes in the younger group than the two lower viscosity products (ONS 1 and ONS 2). This was not the case with the older adults.

#### **4.3.2.3 Time taken to first select an attribute**

Based on the results of the mixed model ANOVA it was evident that the time taken for panellists to select their first dominant attribute during the tasting sequence varied significantly ( $p \leq 0.01$ ) between the two age cohorts. The older adults waited for 22 seconds on average before giving their first dominance while it was 13 seconds for the younger adults. No significant product effects or age\*product interactions were observed for the onset of first attribute selection.

#### **4.3.2.4 Average Dominance Duration**

The average dominance duration was longer in the older cohort (30 seconds) than the younger cohort (24 seconds), however, this difference was not significant ( $p = 0.0643$ ). No significant product effect or age\*product interactions existed for average dominance duration.

**Table 4.3** Differences between the ONS and between the two age cohorts in the TDS behaviour. When a factor is significant the largest value or those making the interactions are highlighted.

	ONS 1	ONS 2	ONS 3	ONS 4	Older adults	Younger adults
<i>n</i>	70	70	70	70	140	140
No. of selections made	5.57	5.24	5.84	6.10	3.92	7.46
No. of attributes used	3.29	3.36	3.54	3.63	2.79	4.11
Time to first attribute selection (s)	18.04	17.50	18.71	14.75	21.76	12.74
Average Dominance Duration	28.11	25.98	25.75	27.45	29.96	23.68

### 4.3.3 TDS Difference Curves

Figure 4.2 illustrates the TDS difference curves between older adults and younger adults for the four ONS. The attributes which lie above the horizontal line represent a significantly ( $p \leq 0.1$ ) higher dominance rate for the younger adult cohort, whereas the attributes that lie below the line represent a significantly ( $p \leq 0.1$ ) higher dominance rate for the older adults.

#### 4.3.3.1 ONS 1

For the lowest viscosity ONS (ONS 1) no significant differences in dominant attributes were observed between the age cohorts for sip 1. Towards the middle stage of the tasting sequence (middle of second sip) the younger adults perceived this supplement with more 'Aftertaste' and 'Silky' than the older adults. Whereas, at

the final stages of the tasting sequence (end of sip 3) the older adults more often perceived ONS 1 as 'Smooth' than the younger adults.

#### **4.3.3.2 ONS 2**

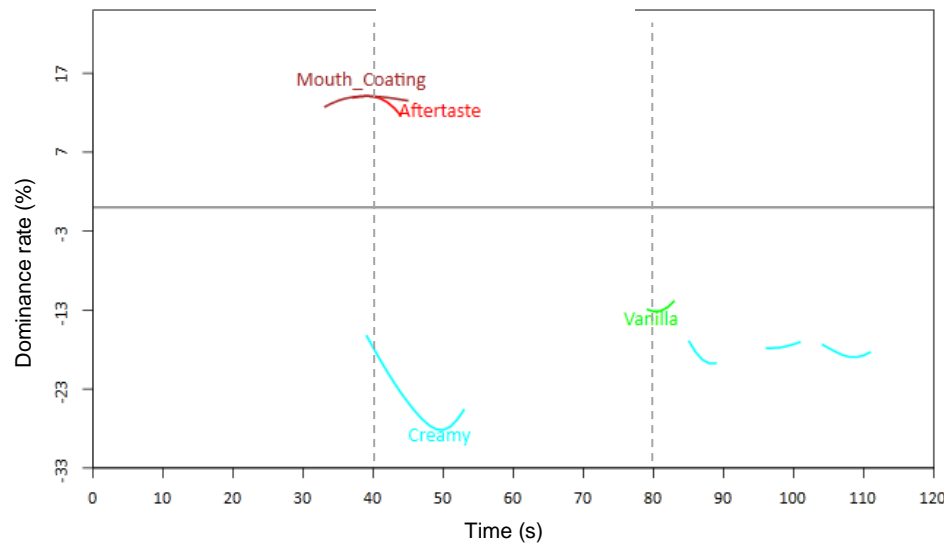
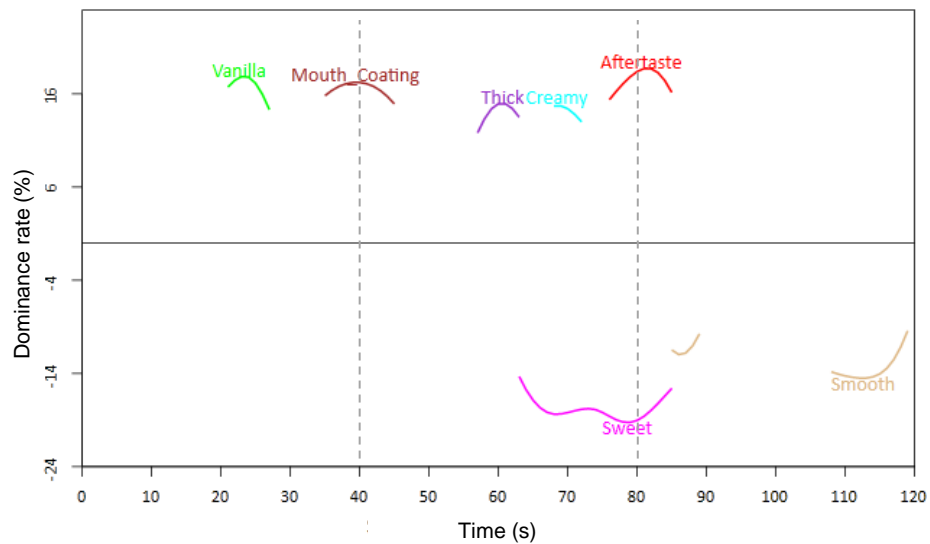
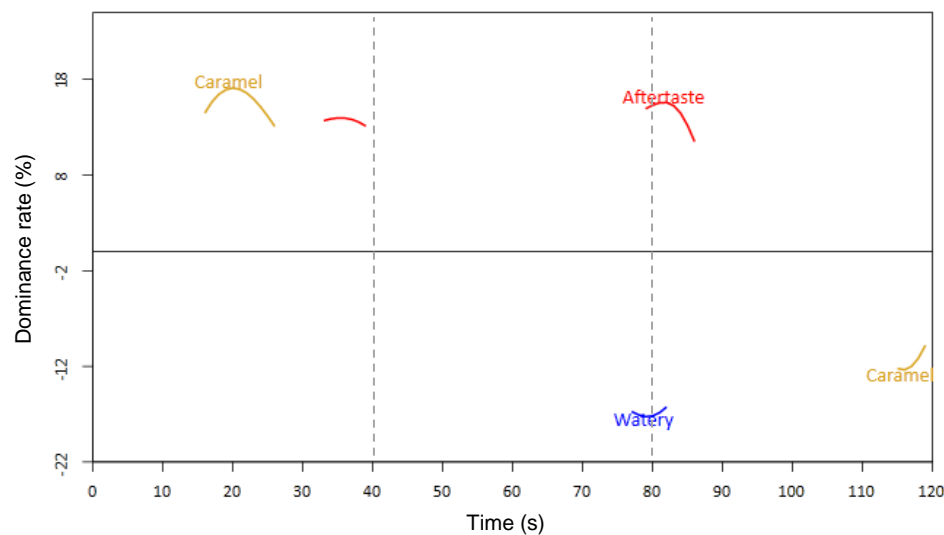
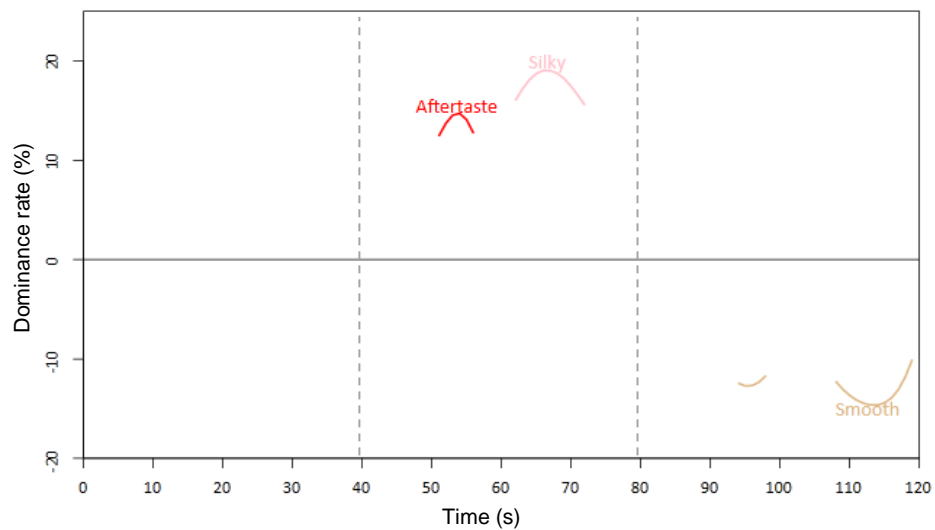
Considering ONS 2, a few differences were observed between the two age cohorts for several attributes. The younger adults perceived significantly more 'Caramel' in the first sip than the older adults and towards the end of the first sip they observed 'Aftertaste' significantly more than the older adults, however, this was only for a short period of time. 'Aftertaste' was again significantly higher in dominance for the younger cohort at the beginning of the third sip. The older adults in comparison perceived this supplement with more 'Watery' (end of sip 2/start of sip 3) and 'Caramel' (end of sip 3) than the younger adults.

#### **4.3.3.3 ONS 3**

The younger adults more often perceived ONS 3 as 'Vanilla' (sip 1), 'Mouthcoating' (end of sip 1/start of sip 2), 'Thick' (sip 2), 'Creamy' (sip 2), and 'Aftertaste' (sip 3) than the older adults. Whereas 'Sweet' and 'Smooth' were significantly higher in dominance rates for the older adults than for the younger adults, at sip 2 and sip 3 respectively.

#### **4.3.3.4 ONS 4**

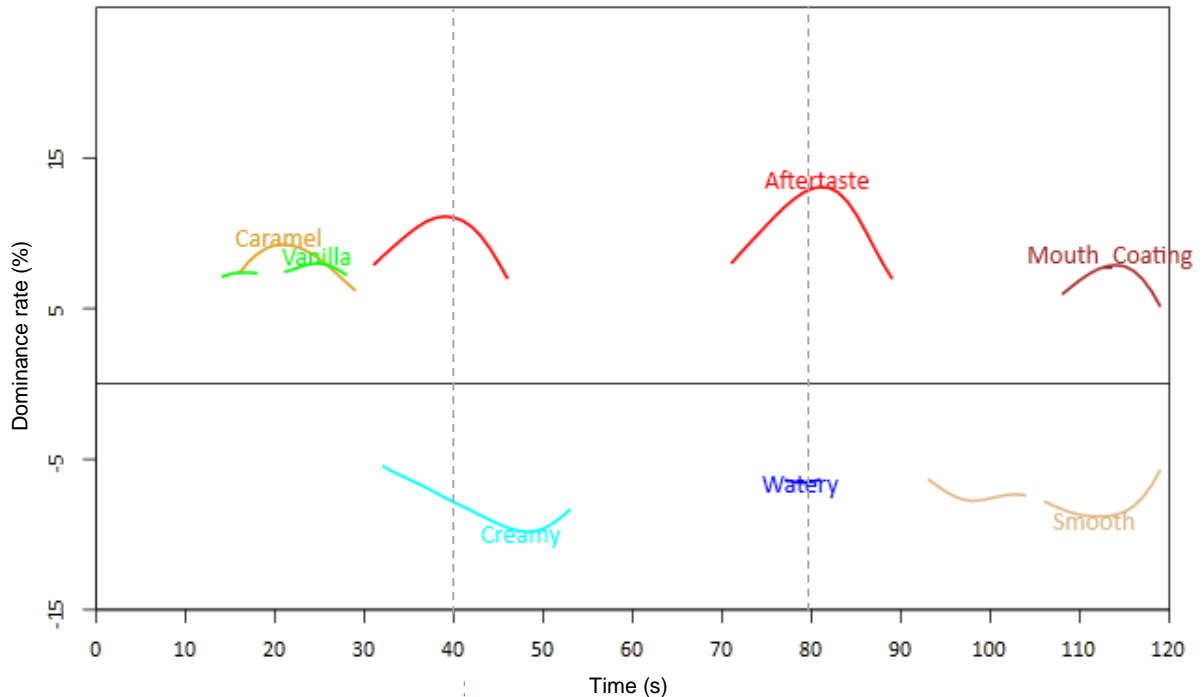
For the highest viscosity ONS (ONS 4) the younger adults more often perceived this as 'Mouthcoating' and 'Aftertaste' from the end of sip 1 into the start of sip 2. In contrast the attributes 'Creamy' (sip 2 and sip 3) and 'Vanilla' (sip 3) were significantly higher in dominance for the older cohort than for the younger cohort for this supplement.



**Figure 4.2.** TDS Difference Curves between older adults and younger adults for (A) ONS 1, (B) ONS 2, (C) ONS 3, and (D) ONS 4. Sip 1 = 0 – 40 s, Sip 2 = 41 – 80 s, Sip 3 = 81 – 120 s.

#### 4.3.4 Grouped Difference Curves

The TDS differences curves comparing older adults and younger adults, where the four ONS were treated as replicates of the same product (140 panellists instead of 35 in both age cohorts) are shown in Figure 4.3. Like Figure 4.2 the top half of the plot represents the younger adults with the bottom half representing the older adults. In the early stage of the tasting sequence (sip 1) 'Caramel' and 'Vanilla' were significantly higher in dominance for the younger cohort than for the older cohort. Moving into the second sip significant differences were drawn for 'Aftertaste' and 'Creamy' for the younger and older adults respectively. Finally, in the later stages of the tasting sequence (sip 3) the younger adults more often perceived the attributes 'Aftertaste' and 'Mouthcoating' whereas the older adults more often perceived 'Watery' and 'Smooth'.



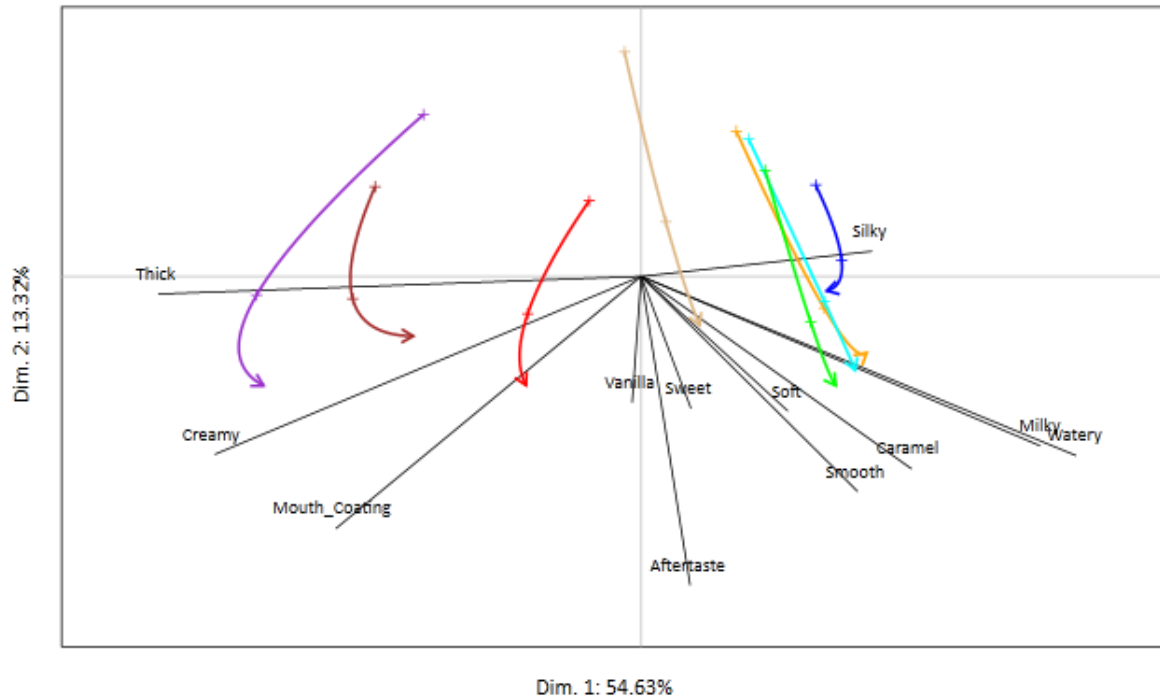
**Figure 4.3** TDS Difference Curves comparing the difference in perception between younger and older adults considering that the four ONS were treated as replicates of the same product. Sip 1 = 0 – 40 s, Sip 2 = 41 – 80 s, Sip 3 = 81 – 120 s. The attributes which lie above the horizontal line represent a significantly ( $p \leq 0.1$ ) higher dominance rate for the younger adult cohort, whereas the attributes that lie below the line represent a significantly ( $p \leq 0.1$ ) higher dominance rate for the older adults.

### 4.3.5 Sensory Trajectory

The PCA biplot (Figure 4.4) summarises the main characteristics of the four ONS for both age cohorts over the tasting sequence (from sip 1 to sip 3). The successive sips for each product in each age cohort are joined by a trajectory, with the third sip being represented by the end of the trajectory arrow. Each attribute is represented by a line with smaller lines meaning that the attribute does not bring a lot of differences between the products.

Axis 1 which explains 55 % of the variability is a thickness axis, going from the high viscosity 'Thick' ONS (ONS 4) to the more 'Silky', 'Milky', and 'Watery' ONS (ONS 1 and ONS 2), this was valid for both age cohorts. The trajectories of the four ONS are perpendicular to this axis, meaning that this main effect is true for each of the three sips. Very little differences existed between the two age cohorts for ONS 1 and ONS 2. These supplements were characterised by an increase in 'Silkiness' from the beginning of the tasting sequence to the middle of the tasting sequence (sip 2) with this turning to 'Milky', 'Watery', and 'Caramel' towards the end of the tasting sequence. For the two high viscosity supplements (ONS 3 and ONS 4) clear differences were observed between the two age groups. Sensory trajectories for ONS 3 in younger adults started close to 'Thick', moved to 'Creamy', and finished toward 'Mouthcoating' and 'Aftertaste'. Whereas, for the older adults this ONS was characterised by 'Silky' at the beginning of the tasting sequence and then in the later stages by 'Caramel', 'Soft', and 'Smooth'. Finally, ONS 4 was characterised by an increase in 'Thickness' in the early stages of the tasting sequence for both age cohorts and finished towards 'Creamy' and 'Mouthcoating' for the older adults and 'Vanilla', 'Creamy', and 'Mouthcoating' in the younger adults.

Axis 2 which explains 13 % of the variability is a dominance duration gradient of every attribute, except for 'Thick' and 'Silky'. It is evident from this axis that the dominance duration of the sensory attributes increased with increasing sips for each of the four ONS. Sip 1 had the lowest dominance durations particularly for the older adult cohort as illustrated by the higher position of older adults first sips in comparison to the younger adults first sips. Sip 2 is located closer to sip 3 than the first sip, but still in the direction of an increase of dominance durations of product characteristic attributes.



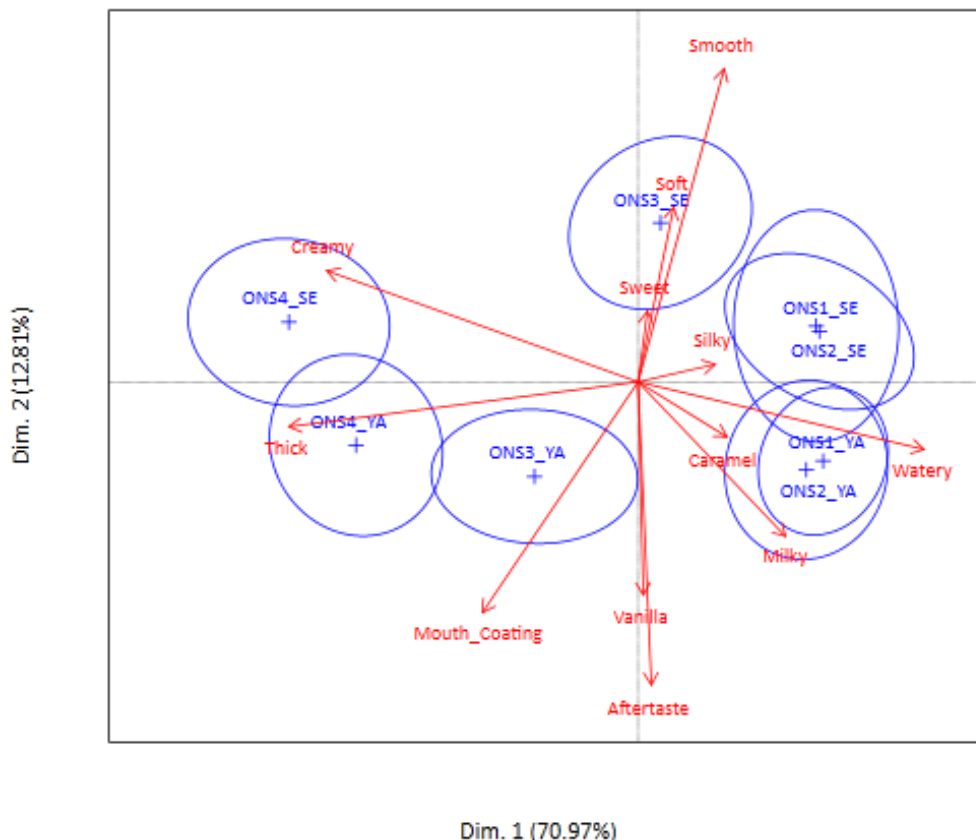
**Figure 4.4** Principal Component Analysis. Biplot representing the sensory trajectories over the tasting sequence of ONS 1 in younger adults (■) and older adults (◐), ONS 2 in younger adults (■) and older adults (◐), ONS 3 in younger adults (■) and older adults (◐), and ONS 4 in younger adults (■) and older adults (◐). The successive sips for each product in each age cohort are joined by a trajectory, sips 1 and 2 are represented by (+) with sip 3 being represented by the end of the trajectory arrow.

#### 4.3.6 Product Map

Figure 4.5 illustrates the results of the PCA analysis of dominance durations for the full tasting sequence (sips are summed). The sensory structure of Figure 4.5 is similar in nature to that of Figure 4.4. The confidence ellipses of the product means are also depicted in this plot. Axis 1 which explains 71 % of the variability is the opposition between 'Watery' and 'Creamy'/'Thickness'. Axis 2 on the other hand is the opposition between 'Smoothness' and 'Aftertaste'/'Mouthcoating'. Note that all four ONS are located on the positive side of axis 2 in older adults but the negative side in younger adults.

Within each of the two age cohorts the low viscosity supplements (ONS 1 and ONS 2) did not appear to be perceived differently. This is clearly demonstrated by the overlapping ellipses for these two products in both age cohorts. Some differences were however observed between the two age groups for these low viscosity

supplements. The younger adults had longer durations of 'Aftertaste' and 'Mouthcoating' for both ONS, while the older adults had longer durations of 'Smooth' and 'Soft'. As the ellipses for both cohorts do however interact, this can only be considered a minor difference between the two cohorts. Unlike ONS 1 and ONS 2 large differences existed between the two age cohorts in the perception of ONS 3. The older adults had notably longer durations of 'Smooth', 'Soft', and 'Sweet' (albeit to a lower extent). The younger adults on the other hand had longer durations of 'Mouthcoating' for this product. ONS 4 (the highest viscosity ONS) was perceived differently to the other ONS by both age cohorts, with this product being noticeably 'Creamier' and 'Thicker' than the other ONS. Like ONS 1 and ONS 2, slight differences were observed between the cohorts for this ONS along axis 2 opposing 'Mouthcoating' to 'Smoothness'. This product was also associated with longer durations of 'Creamy' in older adults and more 'Thickness' in younger adults. This PCA biplot represents a descriptive approach, ANOVA model (Table 4.4) will be fitted (Section 4.3.7) to assess the significance of these dominance duration differences.



**Figure 4.5** Principal component analysis of dominance durations by ONS within the older adults (SE) and younger adults (YA). The confidence ellipses of the product means are depicted by blue outlines.

#### 4.3.7 Dominance durations of attributes

Table 4.4 shows the average dominance durations for each of the 12 sensory attributes for the products and the age cohorts. The results from the mixed model ANOVA of dominance duration revealed that older adults differed significantly to the younger adults in relation to the selection of 'Aftertaste', 'Mouthcoating', 'Smooth', and 'Vanilla'. There were longer durations of 'Smooth' in the older adult cohort than the younger adults, whereas the younger adults had longer dominances of 'Aftertaste', 'Mouthcoating', and 'Vanilla'. In addition to this, there was a product effect for several attributes: 'Creamy', 'Milky', 'Mouthcoating', 'Thick', and 'Watery'. The two low viscosity products (ONS 1 and ONS 2) had longer dominances of 'Milky' and 'Watery' than the high viscosity ONS (ONS 3 and ONS 4), whereas the high viscosity ONS involved longer dominance durations of 'Creamy', 'Mouthcoating', and 'Thick' than the lower viscosity products.

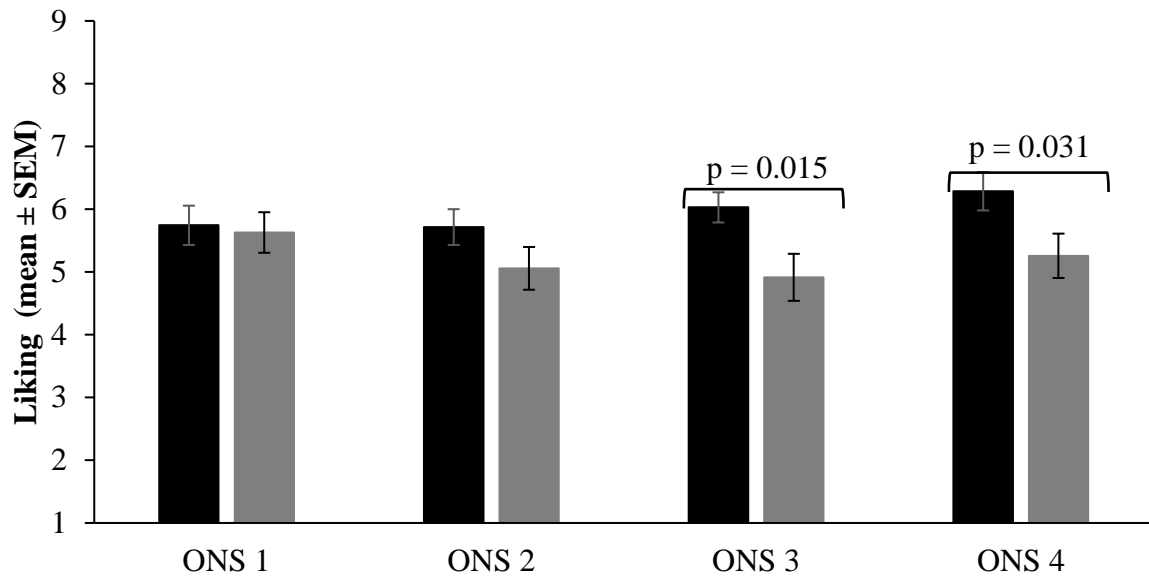
Significant group by product interactions were observed for 'Creamy', 'Silky', and 'Soft'. For 'Creamy' this attribute had significantly longer dominances for ONS 4 in the older adult cohort than for the other three supplements. While this attribute was also selected most for ONS 4 by the younger adults, this was not to a significant degree. In relation to 'Silky' for the young adults ONS 1 had much longer durations of dominance than the other three supplements (13 seconds vs. 3 seconds), whereas with the senior adults there were some differences in dominance rates across the four ONS for 'Silky', however, these were not of significance. The 'Soft' attribute had significantly longer durations of dominance for ONS 3 in the older adult cohort than for the other three ONS while for the younger cohort no significant differences were observed for 'Softness' across the three ONS.

**Table 4.4** Differences in dominance durations between the ONS and between the two age cohorts. When a factor is significant the largest value or those making the interactions are highlighted.

	ONS 1	ONS 2	ONS 3	ONS 4	Older adults	Younger adults
N	70	70	70	70	140	140
Aftertaste	10.46	9.53	8.67	8.84	6.14	12.61
Caramel	10.76	12.60	6.29	6.36	9.03	8.97
Creamy	3.17	6.78	12.15	23.01	13.04	9.51
Milky	12.71	10.88	6.11	2.53	6.99	9.13
Mouthcoating	4.76	4.97	7.19	14.34	5.25	10.38
Silky	8.01	5.83	5.86	2.69	5.31	5.88
Smooth	10.36	9.16	9.28	5.08	11.68	5.26
Soft	2.86	4.66	5.87	2.16	5.05	2.72
Sweet	11.77	6.71	10.30	9.58	9.52	9.66
Thick	0.53	0.39	9.85	21.65	7.10	9.10
Vanilla	8.98	10.89	10.75	8.73	7.50	12.18
Watery	16.03	20.11	8.97	0.28	11.63	11.06

#### 4.3.8 Liking

Average liking scores for both age cohorts and all four ONS are displayed in Figure 4.6. All four of the ONS in both age cohorts scored between 5 and 6 (neither like nor dislike - like slightly) on a 9-point hedonic scale for liking. The overall liking scores were significantly different between the two age cohorts ( $p \leq 0.05$ ) for the two high viscosity supplements (ONS 3 and ONS 4) with the older cohort on average liking both supplements significantly more than the younger cohort.



**Figure 4.6** Mean ratings for liking for both older (■) and younger (■) adults for all four ONS with error bars representing the standard errors of the means.

## 4.4 Discussion

This study applied the TDS methodology to investigate the differences in dynamic perception of ONS between younger and community dwelling older adults. Four ONS of varying viscosities ranging from low viscosity to high viscosity were used in this study. This allowed us to investigate the textural perception and whether the viscosity profiles of ONS impact on liking.

### 4.4.1 The influence of age on TDS behavior

This study demonstrated that age affected the performance and behaviour of the panellists when completing the TDS task. This was apparent across all four of the behavioural variables. The older adults used significantly fewer attributes, made significantly fewer attribute selections/clicks, took longer to make their first attribute selection, and had longer dominance durations for the sensory attributes than the younger adults throughout the 120 second evaluation period. These findings agree with Hutchings *et al.* (2014a), who showed that older subjects made fewer selections, used fewer attributes, and spent a longer period selecting an attribute before deciding on an alternative dominant attribute when evaluating the dynamic texture perception of different nut types.

While the above results show clear differences in how both age cohorts behaved when using the TDS task, it does not mean that the older adults are

incapable of using the TDS task. Previous studies using different sensory techniques have highlighted that older adults perceive less sensory attributes than younger adults. Roininen *et al.* (2003) demonstrated using sorting and laddering interview techniques with younger adults (23-40 years) and older adults (60+ years) that older adults identified fewer textural attributes than younger adults when describing food textures. Furthermore, Chapter 2 found using check-all-that-apply methodology in a younger (18-35 years) and older (65+ years) adult cohort that older adults selected fewer flavour/taste attributes than younger adults when evaluating ONS. The selection of fewer sensory attributes by older adult cohorts are perhaps due to age related impairments in sensory perception rather than the inability of older adults to perform the sensory task. This age-related impairment in sensory perception of foods can be due to both physiological (Doets and Kremer, 2016; Field and Duizer, 2016) and non-physiological changes (Boyce and Shone, 2006; Imoscopi *et al.*, 2012; Field and Duizer, 2016). The subject screenings in this study directly reflect these changes, with the number of individuals with at least one missing tooth, dentures, or false teeth, and suffering from dry mouth significantly higher in the older adult cohort than in their younger counterparts. The number of adults taking medications was also higher in the older adult cohort in comparison to the younger adults. Therefore, it is likely that these factors may have contributed in part to these differences in panel performance with age, as evidenced in Chapter 3.

Another important observation in relation to the panel performance is that older adults are more likely to have slower reaction times than younger adults (Fozard *et al.*, 1994; Deary and Der, 2005). This may have directly contributed to the delay in the selection of the first attribute and the longer dominance durations in the older cohort. This point was also previously raised by Hutchings *et al.* (2014a) to explain the differences in TDS behaviour of older and younger adults when evaluating the texture perception of nuts. Older adults also have an increased incidence of cognitive decline which can lead to issues with memory, attention capacity, problem solving, and reasoning (Maitre, Symoneaux and Sulmont-Rossé, 2015). However, this was unlikely to be an issue of concern with the older cohort in this study given that this cohort were community dwelling independent living older adults (mean age 71.6 years). Future studies should consider a focus on the oldest-old adults (85+ years) and non-community dwelling older cohorts and include a cognitive pre-screening

such as The Mini Mental Scale Examination (MMSE) which is considered an effective means of evaluating the mental status of older adults (Cheah *et al.*, 2011).

#### **4.4.2 Sensory perception (Temporal Dominance of Sensations)**

With regards to the dynamic sensory perception of the ONS, TDS curves with distinct peaks were generated by both age cohorts (Appendix 3). Some similarities in significantly dominant texture attributes were apparent between the two age cohorts. Both age cohorts found ONS 1 to be 'Watery' and 'Milky', ONS 2 to be 'Watery' and 'Smooth', and ONS 4 to be 'Thick', 'Creamy', and 'Mouthcoating'. This suggests that both age cohorts were aware of the textural differences between the ONS. This agrees with the findings of Chapter 2 where it was observed that community dwelling older adults could perceive the textural differences between two commercial ONS of differing viscosities, and with the findings of Withers, Gosney and Methven (2013) who reported that younger and older adults were able to perceive differences in 'Mouthcoating' and 'Thickness' of milk samples. Considering the older adults generated TDS curves with distinct peaks and considering the similarities in some dominant texture attributes between the two age cohorts it is clear that the older adults in this study were equally capable as the younger adults of using the TDS methodology to effectively evaluate the dynamic texture perception of ONS.

While similarities can be seen between the two age cohorts for several sensory descriptors some differences in dominance durations were observed between the two cohorts for a number of sensory attributes. For the two low viscosity supplements (ONS 1 and ONS 2) a few short significances were present between the two cohorts namely 'Smoother' in older adults particularly towards the end of the third sip for ONS 1, and with more 'Aftertaste' for both supplements in younger adults (sips 2 and 3). However, these significances may be too short to be meaningful. In contrast, for the two high viscosity products (ONS 3 and ONS 4) more differences in perception were apparent between the younger and older adults with these significances being longer and more pronounced. The older adults perceived ONS 3 as 'Sweeter' than the younger adults at the middle to late stages of the tasting sequence despite previous research demonstrating that both younger and older adults rated the sweetness intensity of ONS similarly (Kennedy *et al.*, 2010). The older adults also perceived this supplement as 'Smoother' than the younger adults. For the highest viscosity ONS (ONS 4) the older adults more often referred to this supplement as 'Creamy' than the

younger adults which is an interesting observation given that previous research suggests that creaminess perception declines with age (Kremer, Mojet and Kroeze, 2005). A significant interaction was also seen between ONS type and age group for 'Creamy'. The selection of this descriptor was significantly greater for ONS 4 in the older cohort than for the other three ONS while this was not the case for the younger adults. These are positive findings for the high viscosity supplement as Chapter 2 previously noted 'Creamy' as one of the main promoters of liking of a high viscosity ONS by older adults. Creaminess was also previously identified by both 65 to 74 year olds and over 75 year olds as an ideal attribute for ONS (Chapter 3).

Dominance rates were a dynamic process for each of the four ONS during the tasting sequence for both age cohorts. Very little differences in sensory trajectories were apparent between the two age cohorts for ONS 1 and ONS 2. Some differences in sensory trajectories were observed between the cohorts for ONS 4, however, the most notable differences were apparent for ONS 3. Sensory trajectories for this ONS in the younger adult cohort were characterised by an increase in 'Thickness' from the beginning of the tasting sequence towards the second sip, before moving to 'Creamy', and finishing toward 'Mouthcoating' and 'Aftertaste'. Whereas, for the older adults this ONS was characterised by 'Silky' at the beginning of the tasting sequence and then in the later stages by 'Caramel', 'Soft', and 'Smooth'. These findings clearly illustrate that lower viscosity ONS induce very little differences in dynamic perception between older and younger adults. In addition to this within the two age cohorts ONS 1 and ONS 2 did not appear to be perceived differently. High viscosity ONS on the other hand bring out much more differences in dynamic sensory perception between older and younger adults. The ability to obtain information on the sensory trajectories through the analysis of TDS data clearly offers important insight on the attribute perceptions throughout the tasting sequence of a product, yet few studies using TDS report the sensory trajectories. To the best of the author's knowledge no TDS study comparing older and younger adults has presented the sensory trajectories in this manner.

An interesting observation in relation to the sensory trajectories is that most changes in perception occurred in the later stages of the tasting sequence, with much lower attribute dominance durations in both cohorts at sip 1. This is potentially due to the fact that as the panellists placed the first sip of ONS in their mouth there

was a natural delay while they made their first attribute selection. This observation was particularly evident in the older adult cohort as demonstrated by the lowest dominance durations of older adults during the first sip compared to the younger adults. This likely links back to the previous point relating to slower reaction times (Section 4.4.1) and issues with attention capacity, problem solving and reasoning that are commonly linked with ageing. This is an important point of consideration for future TDS studies with older adult cohorts. Perhaps older adults may require longer evaluation times when using TDS than younger adults, more research on this is warranted.

As a final observation it was interesting to note that both age cohorts differentiated between ONS 3 and ONS 4, yet ONS 1 and ONS 2 were perceived similarly. This may relate back to the fact that ONS 4 had a significantly different ingredient and nutritional profile (high energy protein drink) compared to that of ONS 1, 2, and 3 (moderate energy protein drinks). In addition to this the ONS were thickened differently, with ONS 4 the commercially thickened ONS containing modified maize starch (E1442) and carrageenan (E407) as thickeners, while ONS 2 and 3 were thickened in the laboratory with the addition of a commercial thickener (modified maize starch (E1442) and maltodextrin) to ONS 1. This highlights that while viscosity plays an important role in the sensory profiles of ONS, how the viscosity is altered from a compositional perspective is also an important factor.

#### **4.4.3 Liking**

Similarly, to the results in Chapter 2, both the older and younger adult cohorts in this study scored the four ONS between 'neither like nor dislike' and 'like slightly', which indicated that both age cohorts in this study found the ONS tolerable. The similarities between these studies are likely due to the ONS used, with two of the four ONS matching those used in Chapter 2. It is important to note that while these findings are consistent with those of Chapter 2, they differ from other published studies including the work of Gosney *et al.* (2003) who reported a general dislike of ONS. This discrepancy may be due to the small volume of ONS consumed in this study, with panellists only consuming 45 mL of each ONS during the TDS evaluation. Previous research has highlighted a decrease in ONS liking with increased consumption volume (Methven *et al.*, 2010; Thomas *et al.*, 2016; Thomas *et al.*, 2018). Therefore,

it is possible that with increased consumption volume of these four ONS the liking responses may differ.

Viscosity did not appear to impact on liking for either age cohort. However, the liking responses were significantly different between the two age cohorts for the two high viscosity supplements (ONS 3 and ONS 4). The older adults liked these high viscosity supplements significantly more than the younger adults. The increased liking scores for these supplements may be because the older adults perceived ONS 3 as having higher dominances of 'Sweetness' and 'Smoothness', and ONS 4 as having higher dominances of 'Creaminess' compared to the younger adults who perceived these supplements as 'Mouthcoating' with an 'Aftertaste'. This is supported by Chapter 2 where 'Creaminess' was reported as the main promoter of liking of a high viscosity ONS by older adults while 'Aftertaste' was a driver of disliking for the same high viscosity ONS for younger adults.

While the above findings demonstrate that both older and younger adults found the four ONS of varying viscosities equally appealing further work with larger consumption volumes is warranted to truly understand the effects of texture modification on ONS perception, liking, and thus uptake in older adults. Future studies should also consider whether there is a maximal viscosity at which the ONS no longer remain appealing to older adults.

#### **4.4.4 Practical implications**

The results of this study propose that the use of the TDS technique for the dynamic sensory evaluation of liquid products with older adults can be justified. The older adults like the younger adults generated clear TDS curves, they also were aware of and were capable of using the technique to evaluate the textural differences in the ONS. The panel behaviour was different between the two age cohorts; however, this is likely due to the natural differences in perception between these age groups as opposed to their ability to use this sensory technique. It would be beneficial for future studies to establish the optimum TDS evaluation time and to look at the repeatability and the reproducibility of this method as this will offer further insights on the use of this technique with older adults and whether it is a true reflection of dominance rather than cognition and reaction time.

The justification of the TDS technique for use with beverage products in older adults is highly beneficial as this method is a rapid technique which does not require

intense training, allows panellists to score several attributes along tasting, and supplies information on the sensory trajectories of attributes from initial intake to swallowing (Di Monaco *et al.*, 2014; Pineau and Schlich, 2015).

It is important to note that while ONS 2 and ONS 3 were formulated using the same ONS (ONS 1) with the addition of a commercial thickener, the composition of ONS 4 differed as this was a pre-thickened commercial ONS. The differences in composition of the ONS, the thickening agents used, and the type and quantity of ingredients used, may have had an impact on the perception of the ONS in this study. This was an unavoidable limitation of this study, however, there is scope for future research to use only ONS with the same composition to further investigate the dynamic perception of ONS.

Finally, it must be noted that while the cohort in this study were aged over 65 years, these individuals were community dwelling older adults and were predominantly healthy. Therefore, this study does not represent a patient cohort of ONS consumers. Future work should extend this study to include a cohort of ONS consumers. It is also worth noting that the oldest-old population of older adults (aged 85+ years) may struggle with the TDS task and indeed with any sensory task involving the use of a computer. Therefore, there may be an age cut-off point at which older adults can no longer effectively use this methodology, this is another worthy point of consideration for future investigations.

## **4.5 Conclusion**

This study demonstrates that the TDS methodology is an appropriate technique for evaluating the dynamic sensory perception of liquid products with older adults. The older adults generated clear TDS curves and effectively used the TDS task to discriminate between four ONS of varying viscosities. The study provided greater insight into the differences in dynamic perception of ONS products between older and younger adults. While low viscosity ONS induced very little differences in perception between the two age cohorts clear differences in dynamic perception were apparent for high viscosity ONS. Older adults preferred the higher viscosity supplements to the younger adults; however, they had no preference amongst the four supplements. Larger consumption volumes are needed to draw further insight on the effects of ONS viscosity on liking and thus uptake in older adults. Future work should also be conducted with a patient cohort and should identify whether there is

an age limit at which the TDS technique is no longer appropriate for use with older adults.

## 4.6 References

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## **Chapter 5**

**An investigation of the factors influencing  
thirst perception during the consumption of oral  
nutritional supplements in older adults**

## **Chapter 5: An investigation of the factors influencing thirst perception during the consumption of oral nutritional supplements in older adults**

### **5.1 Introduction**

Oral Nutritional Supplements (ONS) combined with dietary counselling have been proven to be beneficial in improving nutritional status and alleviating undernutrition in older adults (Agarwal *et al.*, 2013). However, adherence to ONS has previously been reported to be as low as 37 % (Gosney, 2003). This reduced adherence may be due to their undesirable sensory properties such as sweetness, texture, mouthfeel, and build-up of aftertaste with consumption volume (Gosney, 2003; Rahemtulla, *et al.*, 2005; Methven *et al.*, 2010; Nieuwenhuizen *et al.*, 2010). The findings from Chapter 2 and that of Thomas *et al.* (2018) remarked that the sensation of thirst increases with ONS consumption, yet this remains vastly under researched.

Thirst is a sensation experienced by individuals that results in a desire to drink (Leiper, 2013). The sensation of thirst can be influenced by several factors, from a physiological perspective it is mainly caused by a decline in fluid volume and an increase in the concentration of osmotically active particles (osmolality) (Di Bartola, 2006; Kohlmeier, 2015; Stanhewicz and Kenney, 2015). An increase in concentration of solutes such as sodium, glucose, and other small particles can all increase osmolality, causing thirst (Kohlmeier, 2015). Additional factors such as taste, habit, nutrients, and dryness of the mouth or throat can contribute to increased thirst sensation (Igbokwe and Obika, 2008; Leiper, 2013). Older adults have an increased tendency to suffer from diminished thirst sensation (Schlanger, Lynch Bailey and Sands, 2010; Morley, 2015; Picetti *et al.*, 2017) attributed to factors including but not limited to; hormonal changes, reduced physical activity, physical limitations, functional decline, and cognitive impairment (El-Sharkawy, 2014; Hooper *et al.*, 2016). Older adults may also have a reduced desire to consume fluids to control continence (Hooper *et al.*, 2016). Urinary incontinence in older adults is a common phenomenon, with up to 30 % of community dwelling older adults affected by this issue (Aguilar-Navarro *et al.*, 2012). Causes of urinary incontinence in older adults include commonly prescribed medications such as diuretics and an age-related decline in muscle volume leading to a smaller fluid reserve (Hooper *et al.*, 2016).

Given the diminished thirst sensation and reduced desire to consume fluids with age, the observed increase in thirst with ONS consumption may have a direct impact on adherence to ONS as individuals may not wish to finish the full volume of ONS. To improve ONS adherence it is important to gain a deeper understanding of the factors that are driving this increase in thirst.

A possible driver for thirst with ONS consumption may be their viscosity. Chapter 2 demonstrated that a high viscosity ONS contributed to significantly higher thirst levels than a low viscosity ONS in older and younger adults. Although the ONS used in Chapter 2 differed not only in terms of viscosity but also in terms of energy density and protein content so it cannot be said for certain that this increase in thirst is solely related to viscosity. As recommended in Chapter 2 (Section 2.4) future studies should adjust the texture of the same ONS using low calorie thickeners to adjust the viscosity without affecting the nutritional profile. den Boer, Boesveldt and Lawlor (2019) adopted this approach and found that the desire to drink was higher after the consumption of a high viscosity ONS compared to a low viscosity ONS using a trained panel (aged 22-55 years). One explanation for this was that individuals had an increased desire to drink during and after the consumption of high viscosity ONS as a means of getting rid of unpleasant mouthcoating sensations (den Boer, Boesveldt and Lawlor, 2019). By lowering the viscosity of ONS this may lessen the mouthcoating effects of ONS possibly reducing the desire to drink during and after ONS consumption. However, more research on this topic needs to be undertaken before the association between ONS viscosity and thirst in older adults is better understood.

Another factor which may impact on thirst profiles during ONS consumption is the protein content and type of protein present in ONS. ONS are rich in protein with a typical serving containing between 10 and 20 g of protein, this predominantly stems from dairy proteins (Stratton and Elia, 2010; Withers *et al.*, 2014). Whey protein-based beverages have previously been reported to exhibit unpleasant mouthfeel properties such as astringency, chalkiness, thickness, and mouth-drying (Lee and Vickers, 2008; Bull *et al.*, 2017; Norton, Lignou and Methven, 2021). In addition to this whey proteins have been reported to adhere to the oral cavity which corresponds to an increase in dryness sensation (Withers *et al.*, 2013; Celebioglu, Lee and Chronakis, 2020; Norton *et al.*, 2020a). Casein may also play a role in the drying

sensation experienced during the consumption of ONS (Withers *et al.*, 2014). Mouth-drying caused by both whey and casein may be an important contributor to increased thirst perception during ONS consumption as Thomas *et al.* (2016) previously reported the attribute dry as a temporal driver of thirst for ONS. However, no study to the best of the author's knowledge has investigated the effects of protein content on thirst profiles during ONS consumption in older adults.

The sweetness intensity of an ONS may also have a direct effect on thirst during ONS consumption. Withers *et al.* (2014) reported that increased sweetness caused by the addition of 3 % w/w sucrose increased the build-up of mouth-drying, a finding which was also observed when profiling a range of ONS with a trained panel where the ONS with the highest sweetness level was reported to be the most astringent. This build-up of mouth-drying would likely have a direct effect on thirst perception. However, another research study by den Boer, Boesveldt and Lawlor (2019) which used 0.005 g/100 g of sucralose to increase the sweetness of ONS reported that sweetness level did not influence the desire to drink. Therefore, while sweetness may affect mouth-drying and thus influence thirst during ONS consumption this may be dependent on the source of the sweetness as opposed to just sweetness in general. The type of sweetener used may impact the osmolality of these beverages, which in itself may contribute to increased thirst. It is also quite possible that increasing the sweetness with the likes of sucrose may also increase ONS viscosity which itself is a contributor to mouthcoating and possibly thirst. Finally, the thirst observed with ONS of increased sweetness may reflect an individual's desire to consume water to get rid of unpleasant flavours or aftertastes resulting from the sweetness of the drinks. As previously mentioned, one contributing factor for thirst is taste (Igbokwe and Obika, 2008; Leiper, 2013). It is clear that the effects of ONS sweetness on thirst may be complex and more research is warranted to draw better conclusions on this matter. Therefore, the sweetness of the ONS and the contributing factors to thirst may be complex and requires more research.

Recognising the importance in improving ONS adherence in undernourished older adults, it is evident that there remains a gap in the literature when it comes to the drivers of thirst during ONS consumption. Given the diminished thirst sensitivity in older adults it is important to address this gap. This chapter hypothesises that thirst experienced with ONS consumption will be impacted by (1) physico-chemical

properties of ONS, and (2) physiological and non-physiological factors in older adults (such as age, gender, dental status, medication status, and salivary flow). This hypothesis was tested through the following objectives: (1) to establish whether the protein content and type, sweetness levels, viscosity profiles, or osmolality of ONS impact thirst, mouthdrying, taste in mouth and prospective water consumption in community dwelling older adults, and (2) to advance the understanding of how older adults perceive ONS by testing if individual differences such as age, gender, dental status, medication status, and salivary flow can influence thirst with ONS consumption.

## **5.2 Materials and Methods**

### **5.2.1 Sample Preparation**

The samples were prepared by adding varying quantities of proteins, thickener, and sweetener to a commercial ONS. The ONS used for this was the same as ONS 1 in Chapter 2, 3, and 4 (a low viscosity, moderate energy, and protein, vanilla flavoured, ready-to-drink beverage-style ONS which contained many essential vitamins and minerals. The protein samples were prepared a maximum of 18 hours before the sensory test. The sweetness and viscosity samples were prepared on the day of the sensory test. All samples were stored at 4 °C and were allowed to come up to room temperature for 30 minutes prior to the sensory test.

Table 5.1 summarises the formulations of each of the samples used in this study. The energy (kcal), protein, carbohydrates, and fat were all calculated using back of pack nutrition labelling. The total nitrogen content of the control ONS and the protein powders was measured in the laboratory to confirm the back of pack labelling. This was measured using the Kjeldahl method with a conversion factor of 6.38 for crude protein (IDF, 2014). The mineral analysis of the samples was completed by Eurofins (Eurofins Food Testing Ireland Ltd., Finglas, Dublin, Ireland).

**Table 5.1** Nutritional composition, mineral profile, and osmolality of the control ONS, the ONS with varying quantities of sucralose, protein, and thickener. Superscript letters denote any significant differences in the osmolality of the ONS.

	Control ONS	ONS + 0.0096 %w/v Sucralose	ONS + 0.025 %w/v Sucralose	ONS + 0.0566 %w/v Sucralose	ONS + 2.5 %w/w WPI	ONS + 5 %w/w WPI	ONS + 5 %w/w MPI	ONS + 0.5 %w/w thickener	ONS + 2.1 %w/w thickener	ONS + 4.1 %w/w thickener
<b>Nutritional Composition (per 200 mL)</b>										
Energy (kcal)	200	200	200	200	221.4	242.82	242.94	204.2	216.8	233.6
Protein (g)	7.6	7.6	7.6	7.6	12.62	17.65	17.5	7.605	7.62	7.64
Carbohydrates (g)	27.6	27.6	27.6	27.6	27.67	27.74	27.66	28.65	31.8	35.9
Fat (g)	6.8	6.8	6.8	6.8	6.86	6.92	7.03	6.8	6.805	6.81
<b>Mineral Profile (per 200mL)</b>										
Calcium (g)	0.12	0.12	0.12	0.12	0.15	0.18	0.34	0.12	0.12	0.12
Chloride (g)	0.21	0.21	0.21	0.21	0.22	0.22	0.22	0.21	0.21	0.21
Magnesium (g)	0.035	0.035	0.035	0.035	0.040	0.045	0.044	0.035	0.035	0.035
Phosphorous (g)	0.083	0.083	0.083	0.083	0.097	0.110	0.212	0.083	0.083	0.083
Sodium (g)	0.12	0.12	0.12	0.12	0.127	0.135	0.127	0.122	0.128	0.136
<b>Osmolality (mOsmol/kg)</b>										
Osmolality (mOsmol/kg)	360 ± 10 <sup>a</sup>	350 ± 9 <sup>a</sup>	370 ± 20 <sup>a</sup>	360 ± 10 <sup>a</sup>	380 ± 10 <sup>ab</sup>	410 ± 4 <sup>b</sup>	400 ± 20 <sup>b</sup>	360 ± 10 <sup>a</sup>	360 ± 10 <sup>a</sup>	360 ± 10 <sup>a</sup>

### **5.2.1.1 Protein samples**

Three protein enriched ONS were prepared, one Milk Protein Isolate (MPI) enriched ONS (5 % w/w), and two Whey Protein Isolate (WPI) enriched ONS (2.5 % w/w and 5 % w/w). The MPI powder was kindly gifted by Kerry Foods (Kerry Ingredients and Flavours Ltd., Naas, Co. Kildare, Ireland) while the WPI powder was gifted by Carbery Group (Carbery, Ballineen, Co. Cork, Ireland). For the MPI enriched ONS, 5 % w/w MPI was added gradually to the ONS under constant shearing at 4000 rpm using a Silverson L4RT High Shear Mixer (Silverson Machines Inc., Massachusetts, United States). The temperature was set and maintained at 50 °C while the MPI was added. Once fully solubilised the ONS was cooled and left to hydrate overnight at 4 °C. The WPI enriched ONS were prepared using the same conditions as the MPI ONS, however, the temperature was set and maintained at room temperature (21 °C) throughout the shearing process. These samples were also left to hydrate overnight at 4 °C.

### **5.2.1.2 Viscosity samples**

To achieve a range of ONS with different viscosities varying quantities (0.5 % w/w, 2.1 % w/w, 4.1 % w/w) of a commercial starch-based thickener (Thick and Easy™, Fresenius Kabi, Runcorn, United Kingdom) were added to the ONS at room temperature (21 °C) under constant stirring for 15 minutes using a laboratory stirrer (IKA RCT basic, IKA® Werke, GmbH and Co. KG, Germany).

### **5.2.1.3 Sweetness samples**

The ONS with different sweetness levels were prepared by adding varying quantities (0.0096 % w/v, 0.0245 % w/v, and 0.0566 % w/v) of sucralose (Bulk™, Colchester, United Kingdom) to the commercial ONS at room temperature under constant stirring for 15 minutes using a laboratory stirrer (IKA RCT basic, IKA® Werke, GmbH and Co. KG, Germany). The concentrations of sucralose added were equivalent in sweetness intensity to 5 % w/v, 7 % w/v, and 11 % w/v sucrose concentrations according to the data provided by Wee, Tan and Forde (2018).

A pilot trial was conducted with a panel of 10 researchers from the UCD Institute of Food and Health (3 men and 7 women, mean age 27.2 ± 4.7 years) to ensure that the differences in sweetness intensity were detectable across the different ONS. The panellists underwent one hour of training where they: (1) familiarised themselves with the general Labelled Magnitude Scale (gLMS), (2) used

the gLMS to rate the intensity of ten imagined sensations, and (3) were asked to rate the intensity of sweet (146 mmol/L Sucrose), salty (86 mmol/L NaCl), sour (9 mmol/L Citric Acid), and bitter (4.1 mmol/L Caffeine) solutions (Sigma-Aldrich, Arklow, Ireland). For the sensory evaluation itself the panellists were asked to rate the sweetness intensity of five ONS of varying sweetness concentrations (0 %, 0.0096 %, 0.0245 %, 0.0387 %, and 0.0566 % w/v sucralose). The panellists were also asked to rate their liking using a generalized Degree of Liking scale (gDOL) and their desire to consume more of the ONS using a 100 mm Visual Analogue Scales (VAS).

### **5.2.2 Rheological Analyses**

The viscosity of each of the ONS was measured using a Physica MCR 301 Rheometer (Anton Paar, Graz, Austria). The rheometer was fitted with a cone and plate geometry (diameter: 50 mm, cone angle: 2 °) and the temperature was set and maintained at room temperature (21 °C) throughout the analysis. All measurements were conducted in triplicate. Shear stress values were measured at shear rates from 1 to 1000 s<sup>-1</sup> with a ramp of 120 seconds.

### **5.2.3 Osmolality**

Osmolality was measured using an automatic cryoscopic osmometer (OSMOMAT 030, Gonotech, Berlin, Germany). The osmometer was zeroed prior to use with 50 µL of deionised water. 50 µL of sample was then transferred into Eppendorf tubes, taking care not to cause bubble formation. A thermistor probe was immersed in the sample. The sample temperature was reduced by means of a peltier cooling system, and freezing point depression was measured. This value was then converted by the instrument to a reading of Osmolality (Osmol/kg).

### **5.2.4 Participants**

A total of 72 community dwelling older adults were selected for this study (27 men and 45 women, aged 65+ years, mean age 71 ± 4 years). Panellists were recruited through word-of-mouth and poster advertisements and were fluent English speakers that were computer literate. Each panellist signed a written informed consent agreement before participating in the experiment. This sensory project was reviewed and approved by the UCD Human Research Ethics Committee (Ref. No. LS-19-80).

Table 5.2 illustrates a breakdown of the participant demographics within the full study cohort. Briefly, of the 72 participants, 83 % were aged between 65 and 74 years and 17 % were aged 75+ years. 81 % of participants took medications at least

on a weekly basis, with 24 of these individuals taking medications where dry mouth is reported as a common/very common side effect and 13 where altered taste is reported as a common/very common side effect. 19 of the 72 subjects wore either full or partial dentures.

**Table 5.2** Participant demographics for the full study cohort.

	Full study cohort (n=72)	%
Age (years), mean $\pm$ SD (range)	71 $\pm$ 4 (65-81)	-
Subjects aged 65-74 years	60	83
Subjects aged 75+ years	12	17
Number of males/females	27/45	37/63
Estimated BMI (kg/m <sup>2</sup> ), mean $\pm$ SD	27 $\pm$ 4	-
Underweight, BMI <18.5	1	1
Healthy Weight, BMI = 18.5-25	30	42
Overweight, BMI = 25-30	27	38
Obese, BMI $\geq$ 30	14	19
Subjects taking medications (at least weekly)	58	81
Subjects taking medications where dry mouth is reported as a common/very common side effect (The Royal Pharmaceutical Society, 2019)	24	33
Salivary flow rate (g/min), mean $\pm$ SD	0.46 $\pm$ 0.05	-
Subjects with high salivary flow rates (0.77-2.18 g/min)	9	12
Subjects with medium salivary flow rates (0.53-0.77 g/min)	12	17
Subjects with low salivary flow rates (0.04-0.53 g/min)	51	71
Number of subjects to report suffering from dry mouth	4	6
Number of subjects taking medications where altered taste is reported as a common/very common side effect (The Royal Pharmaceutical Society, 2019)	13	18
Number of subjects to report suffering from hypertension	17	24
Number of subjects to report suffering from hyper/hypothyroidism	6	8
Number of subjects to report suffering oral/gum disease	2	3
Number of subjects to report suffering from diabetes	4	6
Number of subjects with full dentures	5	7
Number of subjects with partial dentures	14	19
Number of subjects to report difficulty swallowing	1	1

### **5.2.5 Water Consumption Questionnaire**

Each panellist completed a detailed pre-screening questionnaire on the first day of the study. This pre-screening questionnaire included several questions relating to their water consumption. Panellists were asked; (1) “how many glasses of water (240 mL) do you consume per day?” (1 – 3 glasses, 4 – 6 glasses, 7 – 9 glasses, 9+ glasses), (2) “how long do you feel you can go without drinking water” (< 1 hour, 1 - 3 hours, 4 - 6 hours, 7+ hours), (3) “how often do you feel thirsty during the day?” (always, often, occasionally, almost never, never), (4) “do you regularly need to remind yourself to drink water?” (yes, no), (5) “do you find it challenging to drink an adequate amount of water?” (yes, no), (6) “what beverage do you consume when you feel thirsty?”, and (7) “are there any times you would deliberately restrict your fluid intake?”.

### **5.2.6 Experimental Session**

The experimental sessions took place over three 30-minute sensory sessions, over three different days with panellists consuming all the protein enriched ONS on one day, all the viscosity ONS on one day, and all the sweetness ONS on one day. The order in which the sensory sessions were completed was randomised between the panellists. Each participant completed all three sensory sessions at the same time of day. The subjects were asked not to drink tea or coffee on the day of the study, they were also instructed not to eat for two hours prior to the sensory session and were asked to drink one glass of water (240 mL) one hour before the sensory session. Panellists were not allowed to consume water at any stage during the sensory session. Prior to beginning the sensory evaluation, baseline measurements for hunger, desire to eat, and thirst were measured using 100 mm VAS.

In each session panellists consumed four different ONS, the control ONS (with no proteins, thickener, sweetener added) and the three other ONS with varying quantities of either proteins, thickener, or sweetener. Salivary flow (Section 5.2.7) was measured before consumption of the first ONS on each of the three visits. For each ONS panellists were given two minutes to consume three 10 mL sips (40 seconds per sip). After consuming all three sips the panellists were asked to complete the sensory questionnaire. On the questionnaire they were instructed to record their liking of the ONS using a 9-point hedonic scale. They were then asked using 100 mm VAS “How thirsty do you feel right now?” (not thirsty at all – extremely

thirsty), “How dry does your mouth feel right now?” (not dry at all – extremely dry), “How pleasant would it be to drink some water right now?” (not pleasant at all – extremely pleasant), and “How would you describe the taste in your mouth right now” (normal – extremely unpleasant). Once they were happy with their responses the panellists were then asked to evaluate their hunger, fullness, and desire to eat using 100 mm VAS. Panellists were then given a five minute break where they were asked to rinse and spit with warm water. The panellists were instructed not to swallow the water at all during this five minute break. Once the enforced five minute break was finished the panellists repeated the evaluation process again with the next ONS. The evaluation process was repeated for all four ONS and was the same for each of the three sessions.

### **5.2.7 Salivary Flow**

The unstimulated saliva was collected over a period of five minutes. For this the panellists were presented with a pre-weighed clear plastic container (60 mL) and were asked to allow the saliva to pool in their mouth and any time they felt the urge to swallow to instead spit the saliva into the collection container (Norton *et al.*, 2020a).

### **5.2.8 Data analysis**

A one-way analysis of variance (ANOVA) and Tukey’s pairwise comparisons were used on the full data set to determine significant differences in apparent viscosities, osmolality, liking, thirst, mouth-drying, water consumption, and taste in mouth between each of the ONS.

The full data set was segregated into different groups to allow for further analysis: age (over 75 years vs. a random selection of the same number of 65-74 years), gender (males vs. a random selection of the same number of females), dentures (full/partial denture wearers vs. a random selection of the same number of non-denture wearers), medications which cause dry mouth or altered taste (Medications DMAT) (medications DMAT vs. a random selection of individuals taking no medications), salivary flow (high/med salivary flow vs. a random selection of the same number of individuals with low salivary flow), and finally reminder to drink (individuals who don’t regularly have to remind themselves to drink vs. a random selection of the same number of individuals who regularly need to remind themselves to drink). Overall liking, appetite, thirst, mouth-drying, water consumption, and taste in mouth were analysed for each of the different groups using a mixed model ANOVA

with the subject group as the between subject factor, and ONS as the within subject repeated measure.

An appetite score was calculated from the ratings for 'desire to eat', 'hunger' and 'fullness' similarly to Perrigue, Monsivais and Drewnowski (2009); (Appetite score = [desire to eat + hunger + (100 - fullness)]/3). Differences in appetite ratings after tasting each of the ONS were also analysed using a one-way analysis of variance (ANOVA) and Tukey's pairwise comparisons.

## 5.3 Results

### 5.3.1 Rheology

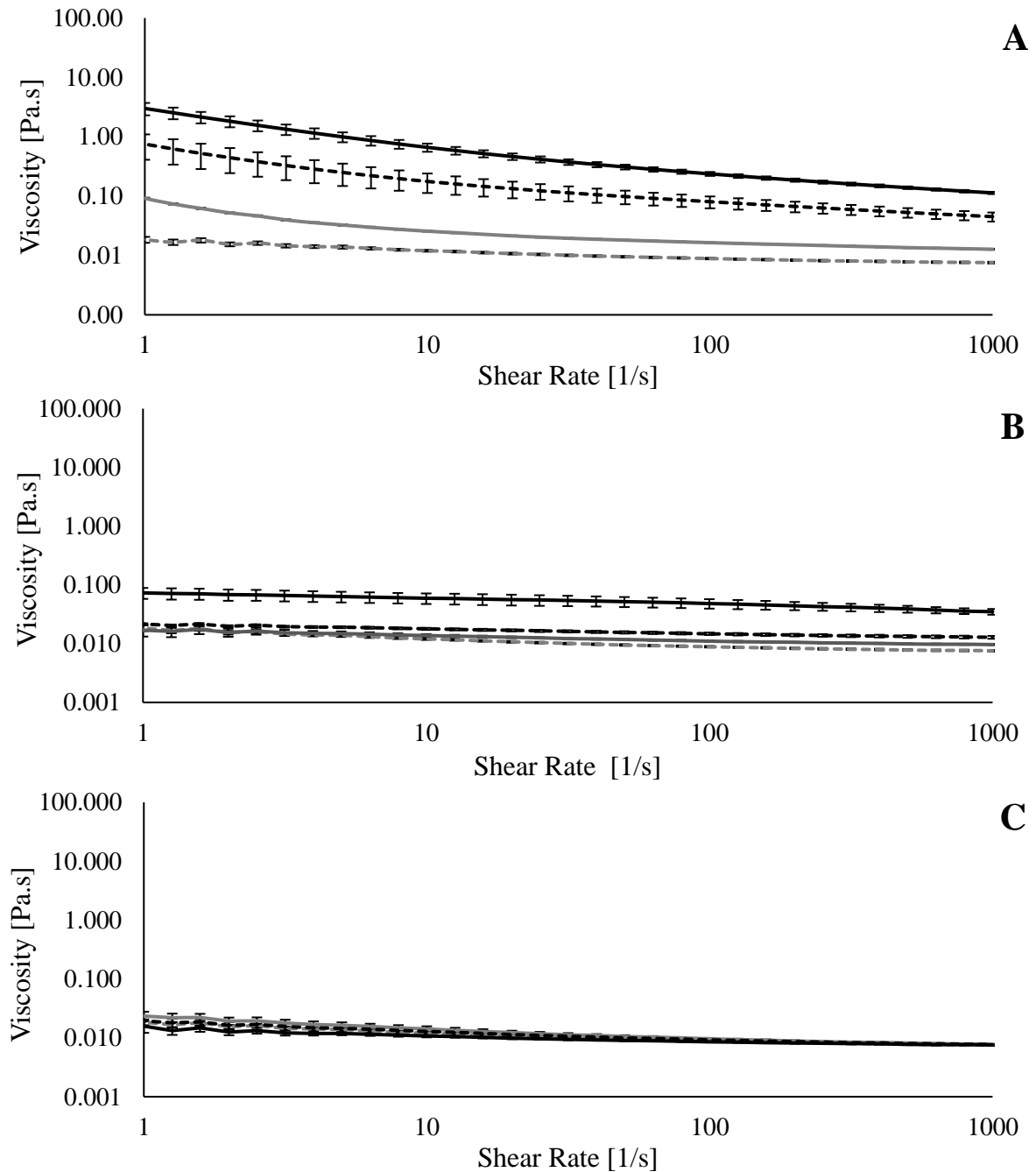
Figure 5.1 shows the flow rate curves for each of the ONS. For the thickened ONS viscosity increased with an increase in concentration of thickener (Figure 5.1A). The viscous behaviour of the ONS with 0.5 % w/w, 2.1 % w/w, and 4.1 % w/w thickener was evidently pseudoplastic with a decrease in viscosity on shearing. In contrast, the control ONS exhibited lower viscosity and Newtonian characteristics. Significant differences ( $p \leq 0.01$ ) existed between the apparent viscosities of the different ONS at a shear rate of  $50.1 \text{ s}^{-1}$  except for the control ONS and the ONS with 0.5 % w/w thickener where the apparent viscosities were not statistically significantly different ( $p \geq 0.05$ ).

Unlike the thickened beverages each of the protein enriched ONS had Newtonian characteristics (Figure 5.1B). The apparent viscosities of the ONS with 2.5 % and 5 % w/w WPI were not statistically significantly different to each other ( $p \geq 0.05$ ), or to the control ONS. The apparent viscosity of the ONS with 5 % w/w MPI on the other hand was significantly higher than the control ONS, the ONS with 2.5 % w/w WPI, and the ONS with 5 % w/w WPI.

In relation to the sweetened ONS (Figure 5.1C) each of these ONS displayed lower viscosity and Newtonian characteristics. At a shear rate of  $50.1 \text{ s}^{-1}$  the apparent viscosities of the sweetened ONS were not statistically significantly different ( $p \geq 0.05$ ) to each other.

In addition to the differences observed within the different formulations of ONS, some significant differences in apparent viscosities were also apparent between the different ONS. The ONS with 2.1 % w/w and 4.1 % w/w thickener differed significantly ( $p \leq 0.01$ ) to each of the sweetened ONS and to each of the protein

enriched ONS. Furthermore, the ONS with 5 % w/w MPI differed significantly ( $p \leq 0.01$ ) to the sweetened ONS and the thickened ONS.



**Figure 5.1** Flow curves of **(A)** The thickened ONS: control (---), 0.5 % w/w thickener (—), 2.1 % w/w thickener (---), and 4.1 % w/w thickener (—), **(B)** The protein enriched ONS: control (---), 2.5 % w/w WPI (—), 5 % w/w WPI (---), and 5 % w/w MPI (—), and **(C)** The sweetened ONS: control (---), 0.0096 % w/v Sucralose (—), 0.0245 % w/v Sucralose (---), and ONS + 0.0566 % w/v Sucralose (—). Error bars represent the standard deviation.

### 5.3.2 Osmolality

Table 5.1 shows the average value of osmolality for each ONS. Beverages with an osmolality of 270 – 330 mOsmol/kg are considered isotonic beverages, any osmolality value below this level is considered hypotonic (<270 mOsmol/kg) with anything above this considered hypertonic (>330 mOsmol/kg) (European Commission, 2001; European Food Safety Authority, 2001). As each of the ONS in this study have an osmolality value greater than 330 mOsmol/kg they were therefore classified as hypertonic beverages. Significant differences existed in the osmolality of the ONS, with the 5 % w/w WPI and 5 % w/w MPI ONS having significantly higher values of osmolality than the control ONS, sweetness ONS, viscosity ONS, and the 2.5 % w/w WPI ONS.

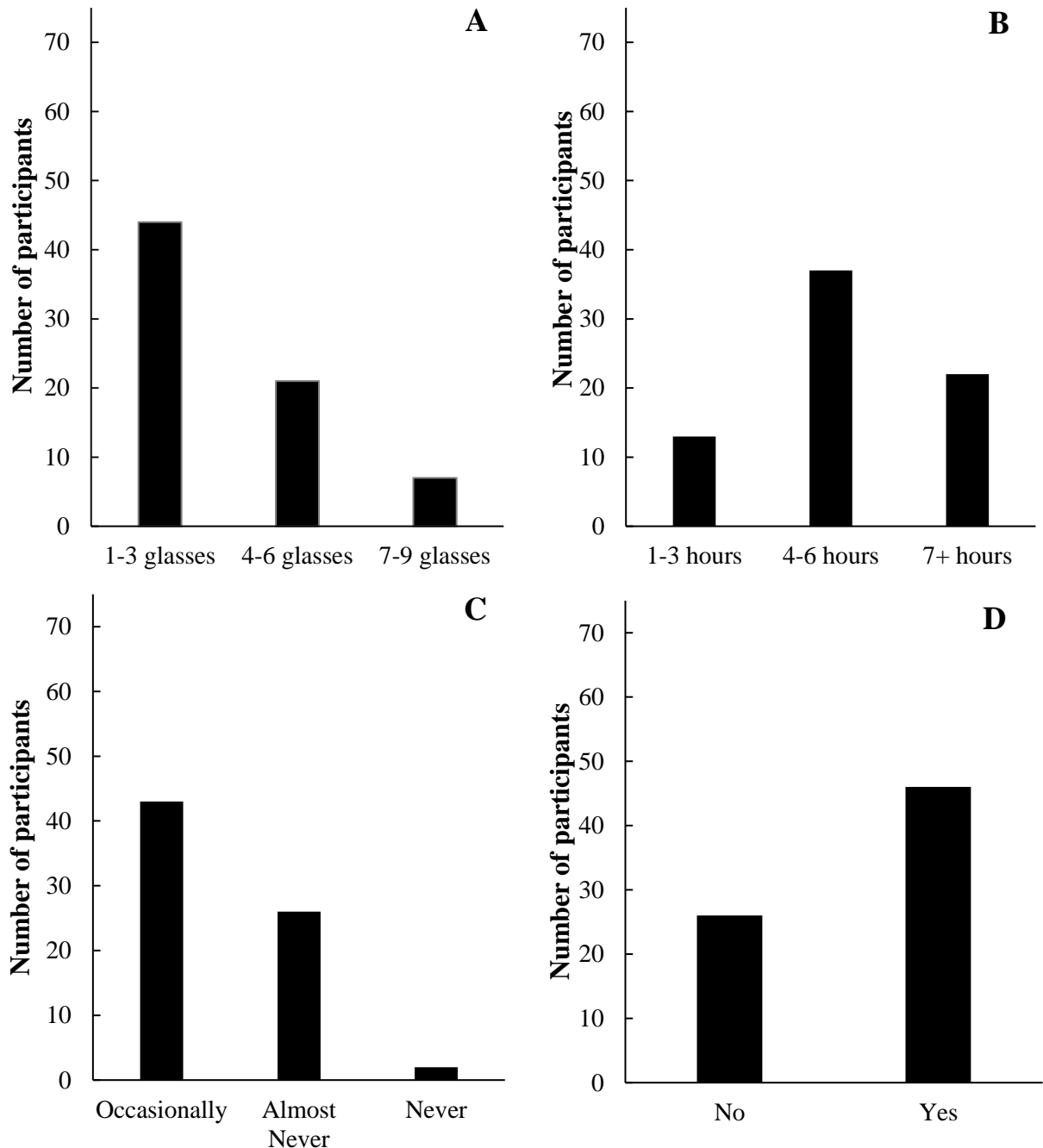
For comparison purposes the osmolality of a range of ONS with concentrations of sucrose (5 % w/v, 7 % w/v, 11 % w/v) equivalent in sweetness intensity to the sucralose enriched ONS used in this study was also measured (data not shown). The osmolality of these ONS ranged from  $599 \pm 17$  mOsmol/kg (5 % w/v sucrose) to  $976 \pm 7$  mOsmol/kg (11 % w/v sucrose). These ONS had significantly higher values of osmolality than the sucralose enriched ONS, the control ONS, the protein ONS, and the viscosity ONS.

### 5.3.3 Water Consumption Questionnaire

Figure 5.2 illustrates the results of the water consumption pre-screening questionnaire. In relation to the amount of water consumed per day (Figure 5.2A), 44 out of the 72 panellists (61 %) consumed on average 1-3 glasses (240 - 720 mL) while 21 individuals (29 %) consumed 4-6 glasses (960 mL – 1440 mL), and only 7 individuals (10 %) consumed 7-9 glasses (1980 mL – 2160 mL) per day. Just over half of the study cohort felt they could go 4 to 6 hours without drinking water while a further 31 % felt they could go for 7 hours or longer without drinking water on any given day (Figure 5.2B). None of the panellists always or often felt thirsty with most either occasionally feeling thirsty (43 panellists) or almost never feeling thirsty (26 panellists) (Figure 5.2C). 64 % of panellists regularly needed to remind themselves to drink water (Figure 5.2D), while 42 % of panellists find it challenging to drink an adequate amount of water (data not shown).

In addition to the data displayed in Figure 5.2 the beverages which the panellists would typically consume when thirsty were; water (54 %), tea (35 %),

coffee (7 %), and sweet beverages including carbonated beverages, sugar free beverages, and cordial (4 %). While the most reported times where panellists restricted their fluid intake was either before bed or when out of their home with limited access to toilet facilities (data not shown).



**Figure 5.2** Results of the water consumption pre-screening questionnaire: **(A)** How many glasses of water (240 mL) would you consume per day? **(B)** How long do you feel you can go without drinking water?, **(C)** How often do you feel thirsty during the day?, **(D)** Do you regularly need to remind yourself to drink?

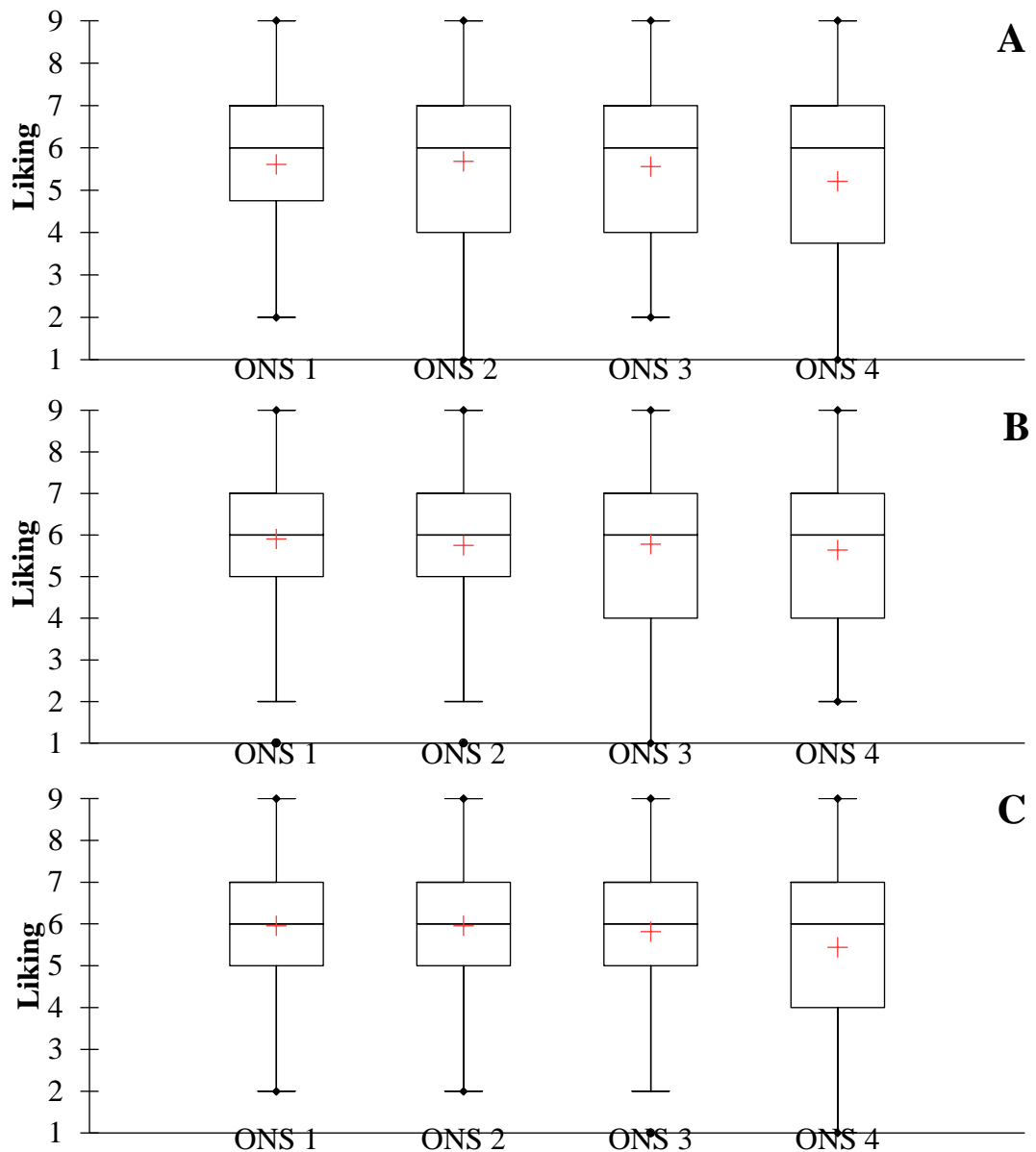
### 5.3.4 Salivary Flow Rates

The salivary flow rates (Table 5.2) were separated into three groups; high salivary flow (0.77-2.18 g/min), medium salivary flow (0.53-0.77 g/min), and low salivary flow (0.04-0.53 g/min) consistent with the research of Norton *et al.* (2020a) and Norton *et al.* (2020b). The values used by Norton *et al.* (2020a) and Norton *et al.* (2020b) were expressed as mL/min rather than g/min (as reported in this case), however, unstimulated whole salivary flow rate expressed as g/min has been reported to be nearly equivalent to mL/min (Foglio-Bonda *et al.*, 2017). It is clear from Table 5.2 that most of the study cohort (71 %) had low salivary flow rates. Gender influenced salivary flow rates with male panellists having significantly ( $p \leq 0.05$ ) higher salivary flow rates compared with female panellists. Age (65-74 years vs. 75+ years) had no effect on salivary flow rate. A difference in salivary flow rates (albeit not significant;  $p = 0.059$ ) was observed between the individuals who regularly need to remind themselves to drink (mean  $\pm$  SE:  $0.37 \pm 0.08$  g/min) and those who do not have to remind themselves to drink (mean  $\pm$  SE:  $0.60 \pm 0.09$  g/min).

### 5.3.5 Liking

The liking scores for the sweetened ONS, protein enriched ONS, and thickened ONS are shown in Figures 5.3A, 5.3B, and 5.3C respectively. Each ONS scored between 5 and 6 (neither like nor dislike - like slightly) on a 9-point hedonic scale for liking. The ONS with the highest level of sweetener had the lowest liking ratings of the sweetened ONS. For the protein enriched ONS the ONS with 5 % MPI was liked the least, while the thickest ONS had the lowest liking of the thickened ONS. These differences in liking were not statistically significantly different.

The mixed model ANOVA showed a significant difference in liking with age ( $p \leq 0.05$ ) for the thickened ONS, where the liking scores for the individuals aged 65 to 74 years were significantly higher than those aged over 75 years for these ONS. A significant difference was also observed in the liking of the sweetened ONS between males and females, the male panellists liked these ONS significantly more (data not shown).



**Figure 5.3** Box-plots for liking for **(A)** The sweetened ONS; Control (ONS 1), 0.0096 % Sucralose (ONS 2), 0.025 % Sucralose (ONS 3), 0.0566 % Sucralose (ONS 4) **(B)** The protein enriched ONS; Control (ONS 1), 2.5 % WPI (ONS 2), 5 % WPI (ONS 3), 5 % MPI (ONS 4), and **(C)** The thickened ONS; Control (ONS 1), 0.5 % Thickener (ONS 2), 2.1 % Thickener (ONS 3), 4.1 % Thickener (ONS 4). Lower and upper box boundaries represent the 1st and 3rd quartiles, respectively. The line inside the box represents the median. The cross (+) represents the mean. Upper and lower whiskers represent the min. and max. values of the dataset excluding outliers while the points above and below the whiskers illustrate the min. and max. points of the dataset.

### **5.3.6 Thirst**

Average thirst ratings after consuming the ONS are shown in Figure 5.4A. The thirst ratings for each of the ONS lay between 27 and 33 mm on a 100 mm VAS (0 = not thirsty at all, 100 = extremely thirsty). The lowest thirst rating reported was for the ONS with 0.5 % w/w thickener, while the sweetest ONS (ONS + 0.057 % sucralose) had the highest thirst rating post consumption. There were no significant differences in thirst within the sweetness ONS, protein ONS, or viscosity ONS and no significant differences between the ONS. In addition to this the differences in baseline thirst measurements and thirst ratings post consumption were not statistically significantly different.

There were a number of significant differences ( $p \leq 0.05$ ) in thirst across the different subgroups. After consuming the sweetened ONS the non-denture wearers reported significantly higher thirst for these samples compared to the denture wearers. Significant differences in thirst scores were also observed between those who reported that they regularly need to remind themselves to drink and those who do not, where thirst was significantly higher in those who regularly need to remind themselves to drink after consuming the protein ONS. The individuals taking no medications had higher thirst ratings after consuming the sweetness ONS than the individuals taking medications DMAT.

### **5.3.7 Mouth-drying**

The VAS ratings for mouth-drying for each of the ONS were assessed (Figure 5.4B). The mouth-drying scores across each of the ONS ranged between 28 and 32 mm on a 100 mm VAS (0 = not dry at all, 100 = extremely dry). The ONS with the highest mouth-drying rating was that with 5 % w/w MPI (32 mm) while the sweetness control ONS had the lowest rating (28 mm). There were no statistically significant differences in mouth-drying ratings within the sweetness ONS, protein ONS, viscosity ONS or between any of the ONS. No other differences in mouth-drying were apparent between the subgroups.

### **5.3.8 Pleasantness to consume water**

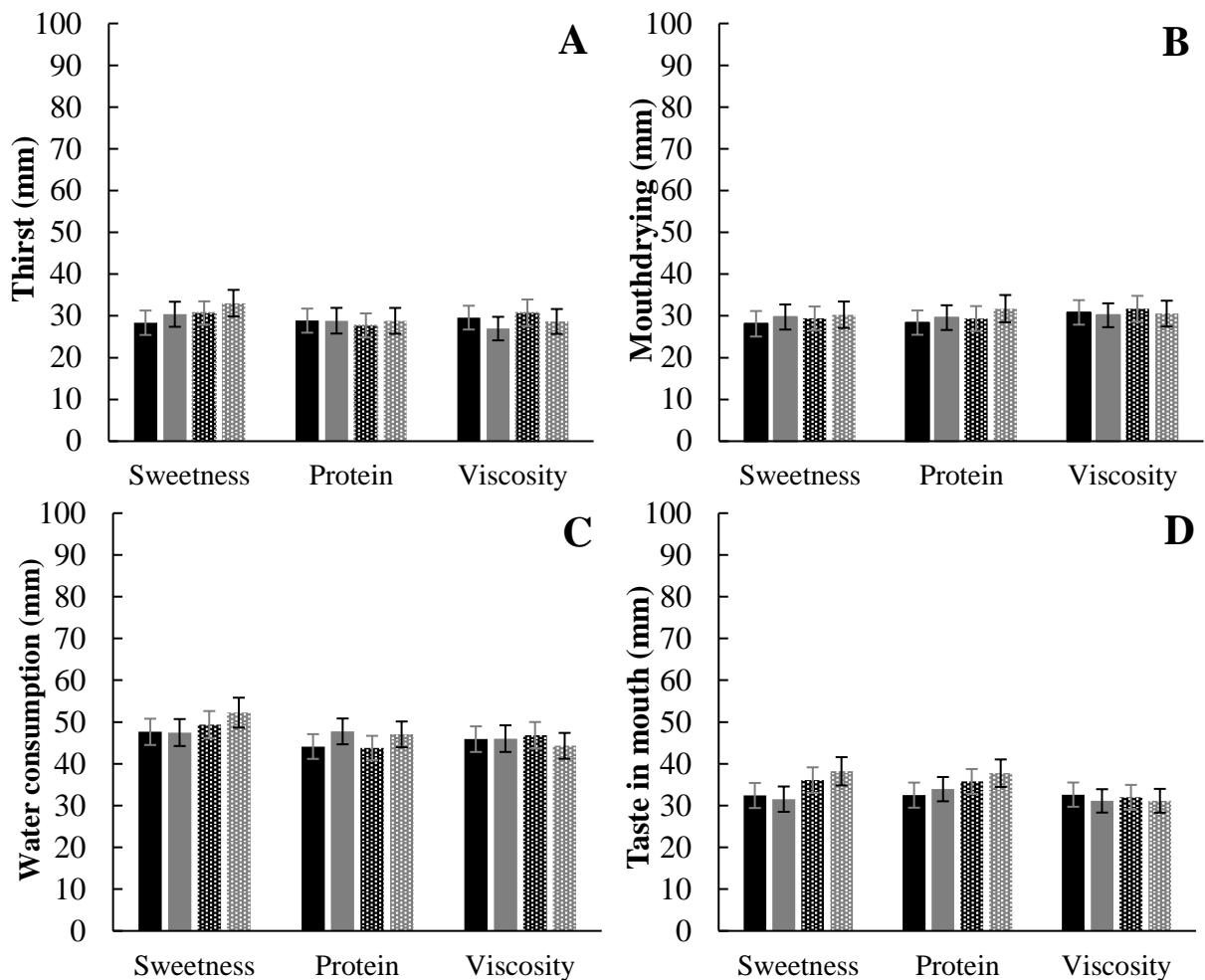
Figure 5.4C illustrates the results of the panellist's response to how pleasant it would be to drink some water after tasting the ONS (0 = not pleasant at all, 100 = extremely pleasant). The average VAS pleasantness ratings for each of the ONS lay between 44 and 52 mm, with the lowest rating for the 5 % WPI ONS and the highest rating for

the sweetest ONS (0.057 % w/v sucralose). Despite the differences in ratings across some of the ONS these were not of statistical significance.

Several differences in pleasantness ratings were apparent from the mixed model ANOVA. There were significant differences between male and female panellists with the female panellists having higher ratings for pleasantness to consume water after tasting the protein ONS and the sweetness ONS than the male panellists. The non-denture wearers had significantly higher ratings than the denture wearers after tasting the sweetness ONS. While the panellists who regularly need to remind themselves to drink had higher ratings of pleasantness to consume water after consuming the protein ONS than those who do not regularly need to remind themselves.

### **5.3.9 Taste in mouth**

Average ratings for taste in mouth after consuming the ONS are shown in Figure 5.4D. Each ONS scored between 31 and 38 mm on a 100 mm VAS (0 = normal, 100 = extremely unpleasant). There were no statistically significant differences in taste in mouth ratings within the sweetness ONS, protein ONS, viscosity ONS or between any of the ONS. Some significant differences were however observed between the different subgroups of panellists. Female panellists had significantly higher ratings for taste in mouth after consuming the thickened ONS than male panellists.

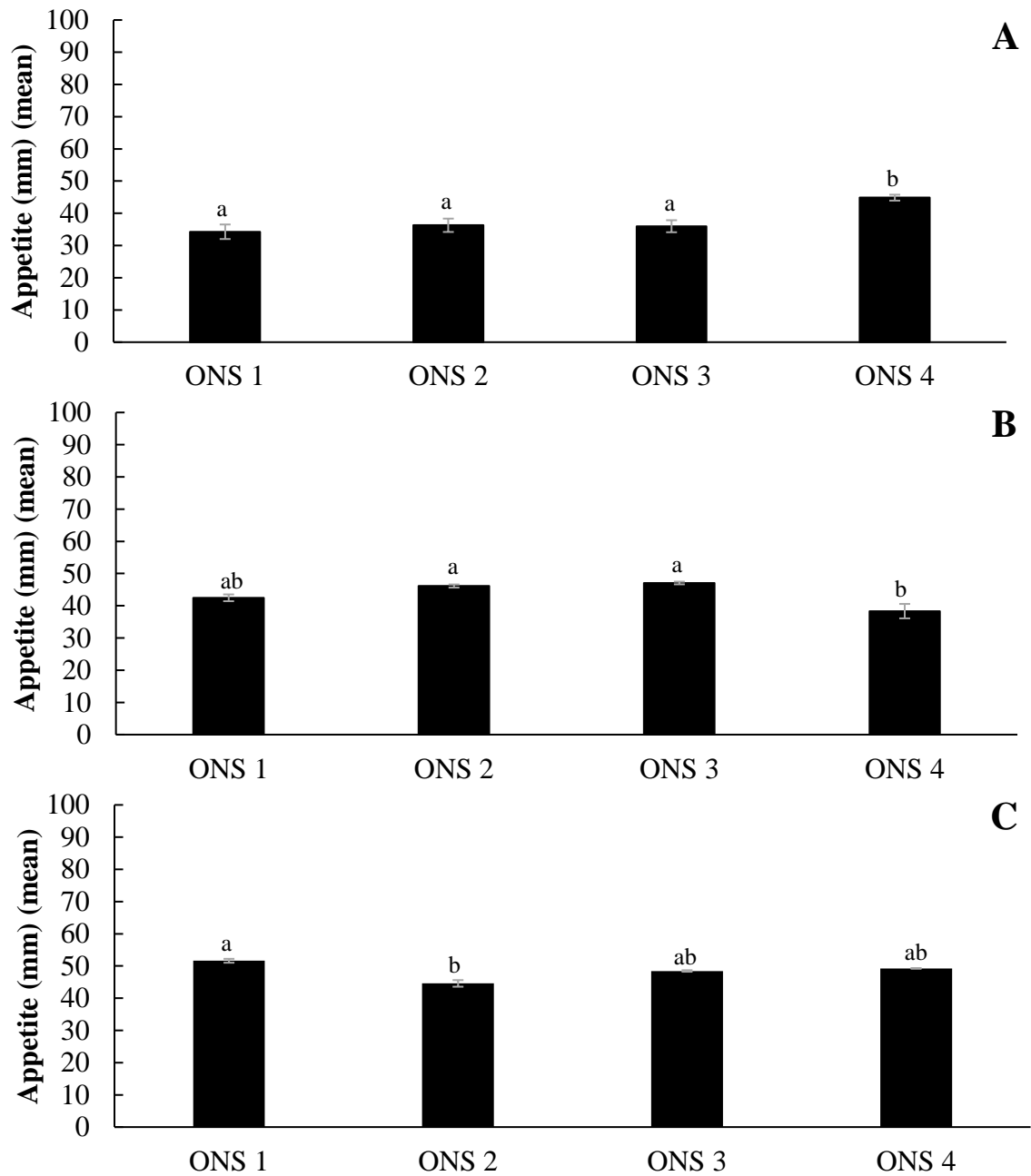


**Figure 5.4** Results for (A) Thirst (B) Mouth drying (C) Water consumption, and (D) Taste in mouth for the ONS sweetness samples; Control (■), 0.0096 % Sucralose (■), 0.025 % Sucralose (■), 0.0566 % Sucralose (■), the protein samples; Control (■), 2.5 % WPI (■), 5 % WPI (■), 5 % MPI (■), and the viscosity samples; Control (■), 0.5 % Thickener (■), 2.1 % Thickener (■), 4.1 % Thickener (■). Values are expressed as mean  $\pm$  standard error of the mean.

### 5.3.10 Appetite

The VAS ratings for appetite for each of the ONS are shown in Figure 5.5. As the nutritional profiles of the sweetness, protein, and thickened ONS are different (Table 5.1) no comparisons are made on the appetite ratings between the supplements. Within the supplements several statistically significant differences were observed. For the sweetness ONS the sweetest ONS (ONS + 0.057 % sucralose) had significantly higher appetite scores than for the other three ONS. Whereas within the protein ONS the ONS with 5 % w/w MPI had significantly lower rating than those with 2.5 % w/w and 5 % w/w WPI. In relation to the ONS of varying thickness levels the appetite

ratings for the ONS with 0.5 % w/w thickener were significantly lower than the control ONS.



**Figure 5.5** Mean ratings for appetite for **(A)** ONS with varying sweetness'; Control (ONS 1), 0.0096 % Sucralose (ONS 2), 0.025 % Sucralose (ONS 3), 0.0566 % Sucralose (ONS 4) **(B)** ONS with varying proteins; Control (ONS 1), 2.5 % WPI (ONS 2), 5 % WPI (ONS 3), 5 % MPI (ONS 4), and **(C)** ONS with varying viscosities; Control (ONS 1), 0.5 % Thickener (ONS 2), 2.1 % Thickener (ONS 3), 4.1 % Thickener (ONS 4). Values are expressed as mean  $\pm$  standard error of the mean. Significant differences ( $p \leq 0.05$ ) are denoted by different letters.

## 5.4 Discussion

This research study aimed to identify possible factors contributing to the increase in thirst during ONS consumption in older adult cohorts observed in Chapter 2 and in a previous study by Thomas *et al.* (2018). It assessed whether the composition of ONS such as their protein content and type, sweetness levels, or thickness affect thirst, mouth-drying, the pleasantness to consume water, and the taste in mouth. In addition to this the study cohort was segmented into different subgroups to see if factors such as age, dentures, medication status, gender, or salivary flow rate have an impact on thirst. Finally, the osmolality of the ONS was measured to look at whether this may be a possible factor influencing thirst. Liking and appetite ratings were also recorded in this study.

The thirst levels for the study cohort both before and after consumption of the ONS were low (between 25 and 30 mm on a 100 mm VAS) demonstrating that these adults may have been suffering from diminished thirst sensation which is commonly associated with ageing (Schlanger, Lynch Bailey and Sands 2010; Morley, 2015; Picetti *et al.*, 2017). This is further supported by the results of the water consumption questionnaire where the majority of the cohort reported the need to remind themselves regularly to drink water and only occasionally or almost never felt thirsty. As a result of the diminished thirst sensation likely experienced by a significant portion of this study cohort most of the older adults reported to only consume 240 – 720 mL of water daily. These are important points for consideration as it is likely that individuals suffering from diminished thirst will have little desire to consume beverages such as ONS and will struggle to finish large quantities of ONS. The subject cohort in this study were community dwelling older adults and were not undernourished older adults (typical ONS consumers). However, it is likely that similar results will be evident in an undernourished adult, but further research is needed to draw evidence-based insights. The current strategies adopted by ONS manufacturers to concentrate ONS into smaller volumes such as compact or shot-style ONS may make these supplements more appealing to individuals with lower thirst. However, it is important to consider the effects that this approach may have on the viscosity profiles. Concentrating the ONS will result in an increase in solids which may increase the viscosity of ONS and possibly impact thirst.

Previous research investigating the effects of increased sweetness on the ability to suppress mouth-drying in protein fortified beverages, found that not only was the addition of 3 % w/w sucrose not effective in reducing mouth-drying it in fact led to an increase in the build-up of mouth-drying (Withers *et al.*, 2014). This finding was also observed when profiling a range of ONS with a trained panel where the sweetest ONS was reported to be the most astringent (Withers *et al.*, 2014). The results in this chapter demonstrated that the addition of 0.0096 %, 0.025 %, or 0.0566 % w/v sucralose which are equivalent in sweetness intensity to 5 %, 7 %, and 11 % w/v sucrose did not cause any significant increase in thirst, mouth-drying, taste in mouth, or the pleasantness for water consumption. Similarly, den Boer, Boesveldt and Lawlor (2019) reported that the addition of 0.005 % w/w sucralose to ONS did not influence the desire to drink. It must be noted that this is not a like for like comparison as the results from Withers *et al.* (2014) are based on sucrose whereas the present findings and those of den Boer, Boesveldt and Lawlor (2019) are based on sucralose. Therefore, it is probable that the increase in mouth-drying reported by Withers *et al.* (2014) which we hypothesised would impact thirst is related to the type of sweetener used as opposed to the sweetness intensity *per se*. The addition of sucrose to ONS causes a significant increase in osmolality. This is clearly evidenced by the above findings (Section 5.3.2) comparing the osmolality of ONS with varying quantities of sucralose to ONS with equi-sweet concentrations of sucrose. The ONS enriched with sucrose were significantly higher in terms of osmolality compared to their sucralose counterparts. This increase in osmolality may lead to an increase in thirst (Maughan, 2001). Sucrose addition is also likely to alter texture, viscosity, and the nutritional composition of ONS, which may also contribute to mouthcoating thus driving thirst. In this study, sucralose was selected to minimise the impact on viscosity and nutritional composition of the ONS. Hence any differences observed should solely relate to sweetness. Further studies comparing thirst, mouth-drying, mouthcoating, and pleasantness to consume water after the consumption of ONS with sucralose and ONS with equi-sweet sucrose concentrations would be worthwhile.

Viscosity profiles in this study did not influence thirst ratings. These findings agree with previous research by den Boer, Boesveldt and Lawlor (2019) who reported no effect of ONS viscosity on perceived thirst. However, while den Boer,

Boesveldt and Lawlor (2019) found no effect on thirst *per se*, they did however report that the desire to drink was greater following thicker ONS consumption. The present findings found no differences in the panellists desire to drink water across the viscosity samples. The differences in findings between the studies may be due in part to the differences in the quantity of ONS consumed. The volumes consumed by panellists in the research conducted by den Boer, Boesveldt and Lawlor (2019) were significantly larger than those consumed in this present study. Ideally larger quantities of ONS would have been given in this study, however, as four ONS were being evaluated in each session the older adults may have struggled with larger consumption volumes. This is certainly an area for further research, and it is recommended that future studies extend this research to include larger consumption volumes.

The protein type and content of ONS did not have a significant impact on mouth-drying, thirst, or the desire to consume water after consumption. Further studies would be worthwhile, perhaps employing a paired comparison method which may draw more effective conclusions on this matter. Norton, Lignou and Methven (2021) also suggested their research should be extended to include an older adult cohort using a more sensitive discrimination test such as two-alternative forced choice (2-AFC).

Some differences in thirst were observed when different subgroups of panellists were compared. The non-denture wearers reported higher thirst after consuming the sweetened ONS than the denture wearers. Dentures have previously been reported to limit food movement in the mouth and limit stimuli from reaching the palate papillae (Duffy, Cain and Ferris, 1999, Duffy and Bartoshuk, 2000, Withers, Gosney and Methven, 2013), therefore, it is possible that the denture wearers were not able to perceive the sweetness of the ONS to the same extent as those with no dentures. The non-denture wearers also had higher ratings for pleasantness to consume water after drinking the sweetened ONS than the denture wearers. It is likely that this is directly correlated with their higher ratings for thirst after the consumption of these ONS. Medication status also influenced thirst and pleasantness to consume water after the consumption of the sweetened ONS. The individuals taking no medications reported higher thirst and higher pleasantness to consume water after consuming these supplements than those taking medications DMAT. Medications are a common

contributor to taste disorders and disturbances in older adults (Schiffman, 2009, Toffanello *et al.*, 2013), suggesting that individuals taking medications DMAT similarly to those with dentures may be less capable of perceiving the sweetness of these ONS and therefore did not have as strong an urge to drink water to remove the sweet sensations experienced. Based on these findings it could be hypothesised that dentures and medications DMAT reduce the impact of sweetness and consequently these cohorts do not have as strong an urge to consume water or as strong a feeling of thirst following ONS consumption.

Gender affected the ratings for pleasantness to consume water after the consumption of the sweetness ONS and the protein ONS although it did not appear to influence thirst. The female panellists had higher ratings for pleasantness to consume water after the consumption of these ONS. Several factors may have contributed to these findings. Firstly, the female panellists in this study had significantly lower salivary flow rates than the male panellists meaning they are possibly more susceptible to mouth-dryness which has previously been reported as an essential integrant of thirst and a signal to initiate drinking (Igokwe and Obika, 2008; Leiper, 2013). The female panellists also liked the sweetness ONS significantly less than the male panellists and therefore might have had a greater desire to consume water after consuming those ONS to get rid of any unpleasant aftertastes. No differences in liking were observed between male and female panellists for the protein beverages.

A final observation between the different subgroups was that the individuals who reported a regular need to remind themselves to drink water were significantly thirstier and had higher ratings for pleasantness to consume water after consuming the protein beverages than those who do not regularly need to remind themselves to drink water. It is probable that these panellists were suffering from diminished thirst sensation considering they need to remind themselves to drink on a regular basis. In addition, the individuals who regularly need to remind themselves to drink had significantly lower salivary flow rates than those who do not. It is likely that these individuals due to their low salivary flow rates were suffering from dry mouth. Previous research has highlighted both whey and casein proteins elicit mouth-drying characteristics in ONS and milk-based beverages (Withers *et al.*, 2014). It is therefore conceivable that the protein enriched ONS may contribute to mouthdrying

on consumption which will be more pronounced in individuals who have low salivary flow rates and are likely already experiencing dry mouth. As dryness of the mouth or throat are contributing factors to increased thirst sensation this may explain why this cohort of older adults were significantly thirstier and had higher ratings for prospective water consumption after consuming the protein beverages than those who do not regularly need to remind themselves to drink water (Igbokwe and Obika, 2008; Leiper, 2013).

Liking ratings were measured in this study to determine whether the ONS were liked or disliked and whether any ratings of dislike might have been reflected in the taste in mouth ratings or in individuals' ratings for pleasantness to consume water after drinking the ONS. There were no observed significant differences in liking between any of the ONS in this study. The average liking ratings from this study cohort lay between 'neither like nor dislike' and 'like slightly' meaning the panellists found each of the ONS tolerable. These results differ to those from other research groups including the work of Gosney *et al.* (2003) who reported a general dislike of ONS. This discrepancy may be due to the small volumes of ONS consumed in this study. Although it must be noted that while these findings differ to some previous reports, they are however in agreement with the findings from Chapter 2 which reported that older adults scored ONS between 'neither like nor dislike' or 'like moderately' and that consumption volume did not cause any significant differences in liking among older adults. The similarities between these studies are likely due to the ONS used, with the control ONS which also formed the base of all ONS in this study matching ONS 1 used in Chapter 2.

In relation to the osmolality, each of the ONS in this study were considered hypertonic meaning that they had an osmolality value greater than 330 mOsmol/kg (European Commission, 2001; European Food Safety Authority, 2001). This is likely due to their high levels of minerals and carbohydrates. The 5 % MPI and 5 % WPI samples had significantly higher osmolality compared with the other ONS which may be attributed to their different mineral profiles. The hypertonic nature of the ONS in this study is beneficial from a nutritional point of view, as high carbohydrate concentrations will lead to slow absorption and delayed gastric emptying thus increasing the amount of carbohydrate and energy delivery (Maughan, 2001). However, hypertonic drinks with osmolality greater than plasma osmolality (270 – 295

mOsmol/kg) (Leiper, 2013) will result in a net secretion of water from the bloodstream into the intestine, which can cause dehydration, this may in turn lead to an increase in thirst (Maughan, 2001). This is a possible link to why ONS can cause increased thirst with increasing consumption volume, yet this is the first study to the best of the author's knowledge that investigated the osmolality of ONS. Further research in this area would be beneficial.

Finally, from an appetite perspective it was interesting to note that the sweetest ONS contributed to significantly higher appetite ratings compared with the control ONS and the other sweetened ONS. These findings were somewhat surprising as den Boer, Boesveldt and Lawlor (2019) previously reported that the sweetness level of ONS did not influence hunger, fullness, desire to eat, or prospective consumption after consuming ONS. This difference between the studies may be attributed in part to the differences in sweetener concentration; den Boer, Boesveldt and Lawlor (2019) used 0.005 % w/w sucralose compared to 0.0566 % w/v (0.054 % w/w) sucralose in the current study. The findings of den Boer, Boesveldt and Lawlor (2019) were also representative of a much younger population (mean age 30 years) than that used in this study.

Differences in appetite ratings were evident across the ONS with differing protein types. Appetite ratings were significantly lower after consuming the MPI enriched ONS than after consuming the ONS with added WPI. The differences in appetite rating between the ONS with 2.5 % WPI and the MPI enriched ONS may in part be attributed to the differences in nutritional composition between these two ONS. Although, this does not account for the differences between the 5 % WPI and the 5 % MPI beverages as these ONS had similar protein content and calories. It must also be noted that the control beverage had significantly lower calorie and protein levels to the MPI drink, yet these ONS did not differ in terms of appetite ratings. Taking this into consideration it may be that the differences in appetite between the WPI and MPI enriched ONS are related to the differences in the type of proteins added, comparing whey protein enriched ONS (WPI) to a predominantly casein enriched ONS (MPI). Although if this were the case it would likely be the WPI enriched ONS that would contribute to lower appetite after ONS consumption, which is contrary to our findings. Previous research has highlighted that the absorption and digestion rates of whey and casein differ, with whey protein being rapidly absorbed

while casein is absorbed more slowly (Boirie *et al.*, 1997; Bendsten *et al.*, 2013). This may be due in part to the protein structures of whey and casein, comparing the micellar structure of casein (stabilized by  $\kappa$ -casein) which coagulates in the acidic environment of the stomach, delaying gastric emptying, to the globular whey proteins which are soluble in the stomach and thus reach the upper intestine at a quicker rate (Mahé *et al.*, 1996; Bendsten *et al.*, 2013). The difference in absorption rates may therefore impact satiety, with previous research reporting the “rapid absorbing” whey to be more satiating in the short term while the “slower absorbing” casein is more satiating in the long term (Bendtsen *et al.*, 2013).

The differences in appetite scores between the MPI and WPI enriched ONS may relate to the viscosity differences between the ONS. The ONS with 5 % MPI which contributed to lower appetite ratings post consumption had significantly higher apparent viscosity than both ONS with WPI. Previous studies have reported that thicker products have a greater tendency to be consumed at a slower rate (Viskaal-van Dongen, Kok and de Graaf, 2011; den Boer, Boesveldt and Lawlor, 2019) which leads to higher/longer orosensory stimulation and higher/longer transit time through the oral cavity (Zijlstra *et al.*, 2008; den Boer, Boesveldt and Lawlor, 2019), both of which trigger a satiety response (Chambers, 2016). In addition, a study comparing the satiating effects of two high protein drinks with similar energy content, but different thickness and creaminess levels found that the drink with lower thickness and creaminess was less satiating than the high thickness and creaminess drink (Bertenshaw, Lluch and Yeomans, 2013). As the WPI enriched ONS were significantly less thick than the MPI enriched ONS this may explain the contrasting appetite ratings after consumption of these ONS. However, this explanation conflicts with findings of no significant differences in appetite between the MPI enriched ONS and the control ONS despite the higher viscosity of the MPI ONS. It is evident that more research is warranted to further elicit the understanding of factors affecting appetite across the protein enriched ONS.

## **5.5 Conclusion**

This study highlights a gap in the literature in relation to the drivers of thirst with ONS consumption. Most of the study cohort had low salivary flow rates and were experiencing diminished thirst, this was reflected in the low baseline thirst ratings and

the thirst ratings after consuming each of the ONS. While no differences in thirst were observed between the different protein, sweetness, or viscosity ONS in this study, this may be due to the low consumption volumes and the sensory methodology used. Further work including larger consumption volumes and alternative sensory methodology such as 2-AFC would be worthwhile. Dentures, medication status, and gender all influenced thirst and the pleasantness to consume water after consuming ONS. This highlights the heterogeneity of the older adult population. Finally, the osmolality of ONS was found to be hypertonic, which may contribute to the thirst experienced with increased consumption volume. Further research should extend this study to include a patient cohort of undernourished older adults.

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## **Chapter 6**

### **General Discussion**

## **Chapter 6: General Discussion**

Oral Nutritional Supplements (ONS) coupled with dietary counselling have been shown to successfully manage undernutrition in older adults, although, this can only be achieved if the full prescribed amount is consumed. This, however, is often not the case and poor adherence to ONS has been reported in both community and non-community dwelling older adults. In recent years the scientific community has been actively seeking to understand the factors for reduced ONS adherence, yet it is still necessary to improve the knowledge on this. Most of the research in this field to date has focused on the flavour profiles of ONS paying particular attention to their sweetness levels. Among some of the factors yet to be investigated in detail are the increased thirst and satiating affects associated with ONS consumption, the drivers of liking and disliking of ONS, and the texture profiles of ONS. Completing sensory evaluations of ONS products with older adults will provide important insight on their sensory profiles, liking, and thus adherence. However, the effective application of different sensory techniques to evaluate the sensory perception of foods with older adults remains a largely under researched area. For this reason, the aims of this thesis were to advance sensory science methodology for older adults by utilising different sensory techniques to understand in as much detail as possible the perception and liking of ONS with the aim of improving adherence.

The research from this thesis makes several contributions to the current literature on ONS. First, Chapters 2 and 3 highlighted that increased ONS consumption volume led to a decline in appetite in older adults with Chapter 3 further demonstrating that the reduced appetite was more prevalent in individuals aged over 75 years than those aged 65 to 74 years. This is an important point of consideration for ONS manufacturers as this may result in difficulties with ONS adherence, reducing their effectiveness in a cohort already experiencing diminished appetite. For this reason, the research from this thesis supports current strategies adopted by ONS manufacturers to concentrate beverage-style ONS into compact and shot-style modes of delivery (den Boer, Boesveldt and Lawlor, 2019). Compacting ONS so that individuals are consuming smaller volumes is supported by previous research which demonstrated that doubling the consumption volume of a beverage without changing the energy content, caused a significant reduction in pleasantness ratings and increased sensory-specific satiety, while doubling the energy content of the beverage

without changing the consumption volume had no effect (Bell, Roe and Rolls, 2003). Therefore, the consumption volume of a food or beverage is important as it may impact the termination of eating/consumption (Bell, Roe and Rolls, 2003). It is however important for ONS manufacturers to consider the effects that this approach of compacting ONS into low volume drinks has on the viscosity profiles of ONS as this will increase thickness which may be reason for decreased intake (den Boer, Boesveldt and Lawlor, 2019). A final point worth noting here is that the volume of ONS consumed by panellists in Chapters 2 and 3 was controlled and panellists had no choice but to consume the full serving (200 mL). This does not represent a real life setting and a future study adopting a free choice approach with check-all-that-apply methodology would be very interesting not only from a research point of view but also from a manufacturer's perspective.

Another important outcome of the research from Chapter 2 is the identification that thirst increased with increased consumption volume of ONS. Similar findings were also reported by Thomas *et al.* (2018), who found that the consumption of ten sips of ONS in an older adult population group strongly increased thirst rating. This finding may have important implications for ONS adherence given that older adults are more likely to experience diminished thirst sensation and a reduced desire to consume fluids to control continence (Schlanger, Lynch Bailey and Sands 2010; Morley, 2015; Hooper *et al.*, 2016; Picetti *et al.*, 2017). This inspired the research work conducted in Chapter 5 which was one of the first studies of its kind to focus in detail on what causes this increased thirst with ONS consumption. This was specifically investigated from an ONS compositional point of view, focusing on the protein type and content, sweetness, and viscosity profiles of ONS. The findings from this chapter indicated no significant differences in thirst, mouth-drying, taste in mouth, and pleasantness for water consumption after consuming the ONS varying in protein type and content, sweetness, and viscosity. Although, it is probable that this may be due to the fact that the Visual Analogue Scales (VAS) used in this study may lack the sensitivity to describe changes across the different ONS. Future research should therefore extend this approach by comparing these results with a control method such as paired comparison which may draw more effective conclusions on this matter. Although it may be difficult to extend this testing approach with discrimination testing such as 2-AFC as the participant will need to consume enough volume before

they can complete the discrimination test, which may not be feasible. The thirst element caused by ONS consumption remains a significant knowledge gap worth addressing. Therefore, this research is still worthy of future investigations, particularly relating to the effects of protein type and protein content of ONS as there is strong evidence in the literature relating these factors to mouth-drying (Withers *et al.*, 2014; Norton, Lignou and Methven, 2021) which would likely impact thirst and the desire to consume water after ONS consumption.

The results from Chapter 2 and Chapter 5 highlight the importance of conducting sensory evaluations with different segments of the older adult population cohort, considering dentition and medications as opposed to a one-size-fits-all approach. This was evidenced by the fact that dentures influenced mouthfeel and texture perception of ONS while medication status impacted flavour perception. In addition to this, differences in some dominant attribute selections, and variation in the drivers of liking and disliking between 65 to 74 year olds and over 75 year olds were evident (Chapter 2). Dentures, medication status, and gender also influenced thirst and the pleasantness to consume water after consuming ONS (Chapter 5). This research clearly demonstrates the differences in the perception and factors affecting liking between the different older adult cohorts, validating the challenges for ONS manufacturers to meet the opposing needs of older adults. Perhaps from a manufacturing point of view a more tailored approach designing ONS products for these different subgroups may improve adherence, although this may not be feasible. It is unfortunate that the research in this thesis did not include a patient cohort of undernourished older adults. While the study cohorts were aged over 65 years to get as close to the age range of ONS consumers the results cannot be extrapolated to a patient cohort. Considerably more work will need to be done to draw insights on whether the findings in this thesis are representative of a cohort of ONS consumers.

From an ONS manufacturers point of view the data obtained in Chapters 2 and 3 contribute a clear understanding of the drivers of liking and disliking of ONS. From a flavour perspective achieving perceptions of Vanilla should help to improve liking and acceptability of ONS in older adult cohorts given this was selected as an important driver for liking by older adults and as an ideal ONS attribute. This, however, is only advisable for low viscosity ONS as Vanilla acted as a driver of disliking for high viscosity ONS for every cohort of older adults, except for individuals

taking medications with side effects of dry mouth and altered taste. Providing a greater variety of flavours, including 'Coffee', 'Hazelnut', or 'Chocolate' for ONS is also supported by the results from Chapter 3. From a texture and mouthfeel perspective, increasing perceptions of 'Creamy' and 'Smooth' may improve acceptability, while perceptions associated with a thinner mouthfeel such as 'Watery' and 'Runny' should generally be avoided. It is however important to note that the findings from Chapters 2 and 3 are based on CATA data and as a result are representative of the point where these attributes are recognised and associated with the product. While Chapter 4 demonstrated no differences in older adults liking across four ONS of varying viscosities, the ideal viscosity range for over 75 year olds and for those with dentition issues is likely to fall below 0.177 Pa.s at a shear rate of  $50.1 \text{ s}^{-1}$  as ONS at this viscosity were less liked by these individuals (Chapter 3). It is recommended that future research is undertaken to investigate the links between ONS viscosity and adherence and whether there is a maximal viscosity at which the ONS no longer remain appealing to older adults. Although if this research is to be completed care should be taken to ensure that the study is conducted via unbiased tests so that any results obtained relate solely to the viscosity of the ONS. Increasing the viscosity of ONS will influence a number of related factors such as the nutritional profile and energy density, the satiety, and the expected satiety (Zijlstra *et al.*, 2008; McCrickerd *et al.*, 2012). It is important for future investigations to manipulate the viscosity of these beverages while controlling for factors such as energy density, satiating effects, and even flavour/off-note profiles, so that only the viscosity of the supplements is being assessed. One approach to this would be to increase the viscosity through the addition of low calorie thickeners to a neutral flavoured ONS, and to adopt an approach similar to den Boer, Boesveldt and Lawlor (2019) who added a non-thickening fibre to the low viscosity supplements to control for possible satiating effects of fibres. Care should also be taken to control for any expected satiating effects.

It is clear from the above findings that the research completed in this thesis offers much understanding on the perception and liking of ONS which has the potential application to improve adherence globally. In addition to this the research completed in this thesis was also undertaken with the aim of advancing sensory science methodology for older adults. It is well established that sensory evaluations

with older adult cohorts remains a largely under researched field of sensory science due to the different challenges that are associated with this group (Methven, Jimenez-Pranteda and Lawlor, 2016). For this reason, several questions remain unanswered at present as to which sensory methods are appropriate for use with older adult cohorts. The use of specific sensory techniques such as Check-All-That-Apply (CATA), and Temporal Dominance of Sensations (TDS) remain underutilised with older adults particularly for the evaluation of beverage products. These methods can evidently provide in depth insight on older adults' perception of foods. Therefore, the implementation and furthermore the justification of these techniques provided by this thesis makes a significant contribution to the field of sensory science with older adults. To advance this research even further it would be interesting to next investigate the repeatability of these sensory techniques with older adults.

## **6.1 Conclusion**

The present thesis was designed to understand the factors influencing ONS perception, liking and thus adherence, while also advancing sensory science methodology for older adults by investigating the effectiveness of the CATA and TDS techniques for sensory evaluations of ONS products with this cohort. The research has shown that decreased texture perception of ONS is evident in older adult cohorts with this being more notable in ONS with high viscosities. Attributes such as 'Watery' and 'Runny' should be avoided for ONS as these drive disliking in older cohorts. The current research highlights the importance of conducting sensory evaluations with different segments of the older adult population as opposed to a one-size-fits all approach. Accordingly, this must be taken into consideration for effective food design strategies for the elderly. Older adults' sensation of hunger decreased with consumption volume while thirst sensations increased significantly with increasing consumption volume of ONS. This research therefore supports the current strategies of low volume, compact, energy dense ONS. However, the effects that concentrating these ONS may have on their viscosity must be considered, some ingredients may be better suited to these approaches such as WPI (Whey Protein Isolate) compared with MPI (Milk Protein Isolate). Finally, the use of both CATA and TDS to date remain largely under-utilised methodologies for sensory evaluations in older adults. Therefore, the results of this thesis add a significant contribution to sensory research in older adults indicating that the implementation of these sensory techniques is

justified for use in older adult cohorts with beverages products. The most important limitation of this thesis lies in the fact that the older adult study cohorts used in this thesis were not representative of a patient cohort of typical ONS consumers.

## 6.2 References

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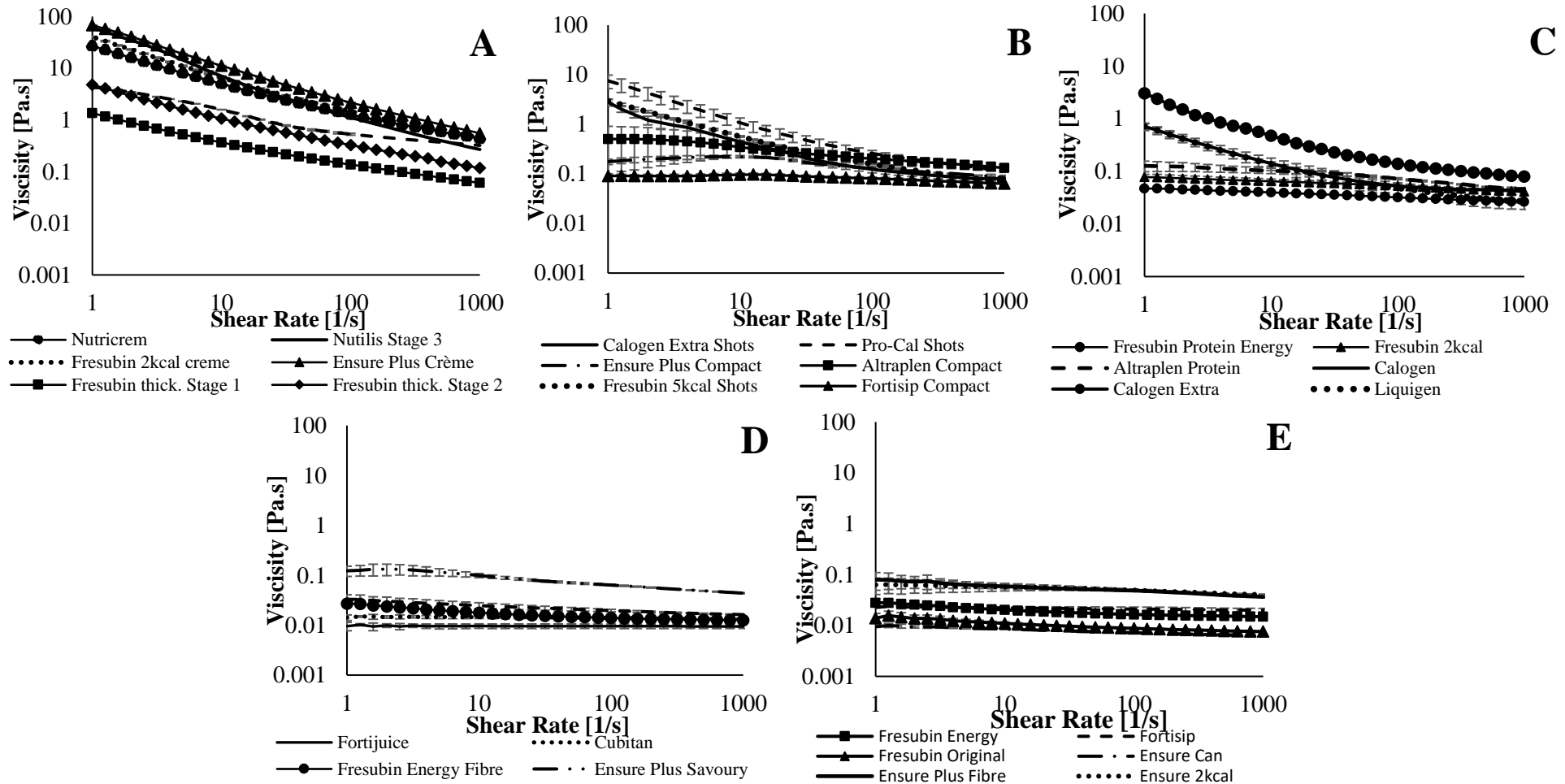
## **Appendices**

## Appendix 1

**Table A.1** Nutritional Composition of ONS 1 and ONS 2 used in Chapter 2 and 3

Nutritional Composition	Fresubin Original (ONS 1) Per 100 mL	Fresubin Thickened Level 2 (ONS 2) Per 100 mL
Energy (kcal)	100	150
Protein (g)	3.8	10
Carbohydrate (g)	13.8	12
of which sugars	3.5	7.3
of which lactose	≤0.03	≤0.7
Fat (g)	3.4	6.7
of which saturated fatty acids (g)	0.3	0.5
of which monounsaturated fatty acids (g)	2.2	5
of which polyunsaturated fatty acids (g)	0.9	1.2
Fibre (g)	0	0.83
Salt (g)	0.19	0.13
Water (mL)	84	79
Osmolarity (mosmol/L)	330	430
Osmolality (mosmol/kgH <sub>2</sub> O)	380	550

## Appendix 2



**Figure A.2.** The viscosity of 30 ONS (semi-solid and thickened supplements (A), compact and shot style supplements (B), and beverage style supplements (C, D, E) as a function of shear rate ( $s^{-1}$ ). Error bars represent standard deviation

## Appendix 3

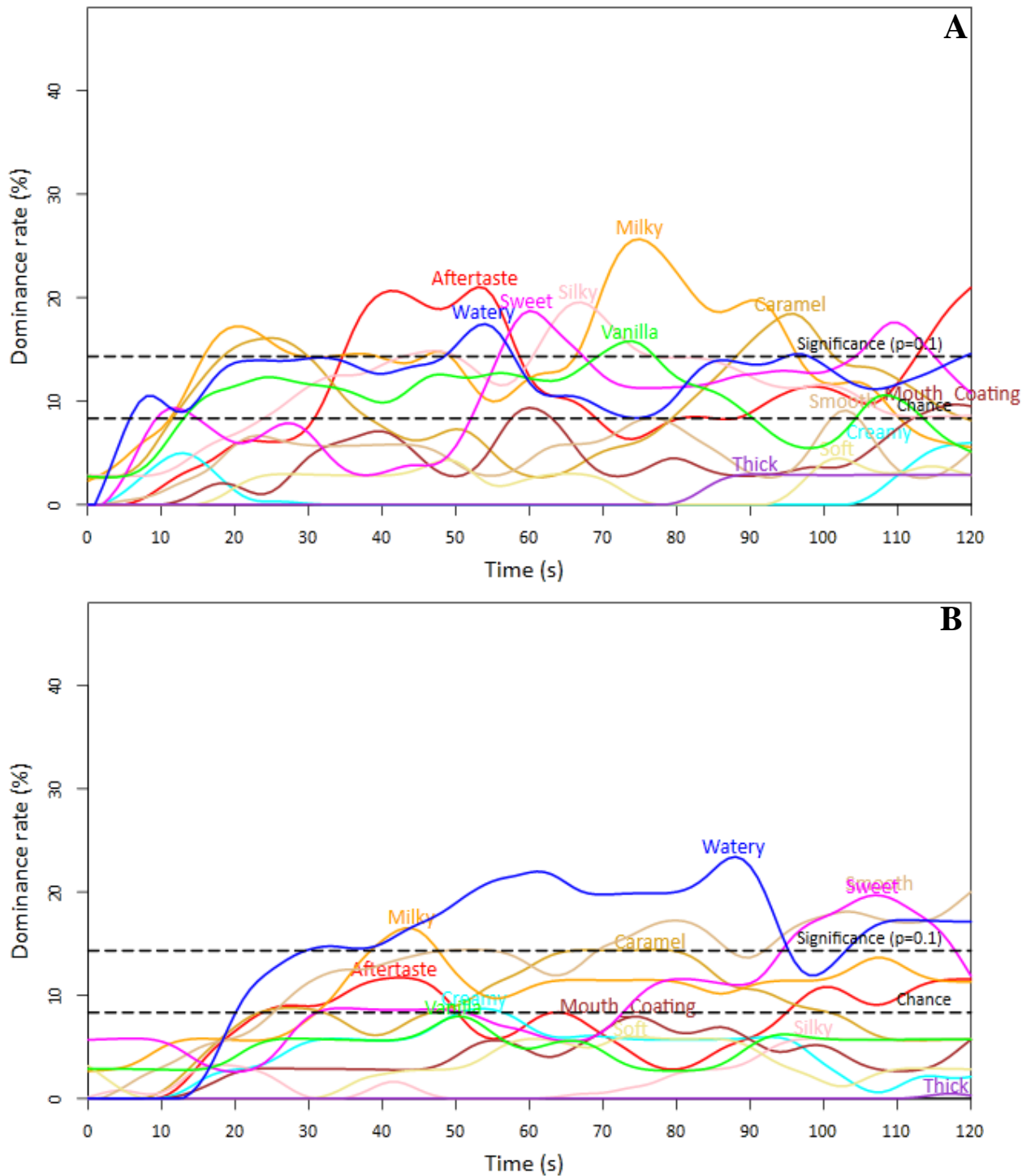
**Table A.3** Definitions of attributes used in Chapters 2 and 3.

<i>Attribute</i>	<i>Definition</i>
Airy	Light, pillowy texture, bubbles
Aftertaste	Taste remaining in the mouth
Artificial	Made or produced by humans rather than occurring naturally
Astringent	Puckering or tingling sensation on the surface and/or edges of the tongue or mouth
Bitter	Basic bitter taste, tart, sharp
Caramel	Flavour associated with caramel; sweet, nutty, buttery, creamy
Chocolate	Characteristic flavour of chocolate bars
Coffee	Characteristic flavour associated with freshly brewed coffee
Creamy	Characteristic flavour associated with fresh cream
Custard-like	Characteristic mouthfeel/texture/consistency associated with custard
Dry	Reduction in the free fluids in the mouth
Gloopy	Messy, sticky, coating surfaces in mouth
Grainy	Rough texture containing small hard particles
Grassy	Flavour associated with cut grass
Hazelnut	Characteristic flavour associated with hazelnut; nutty, toasted, musty, earthy
Jelly-like	Semisolid, elastic consistency
Medicinal	Flavour associated with medicine; plastic, pharmaceutical, chemical
Metallic	Taste associated with metal/rust
Milky	Characteristic flavour associated with fresh full-fat milk
Mouthcoating	A filming layer coating the palate
Oily	Sensation in mouth similar to oil, an immiscible liquid in the mouth

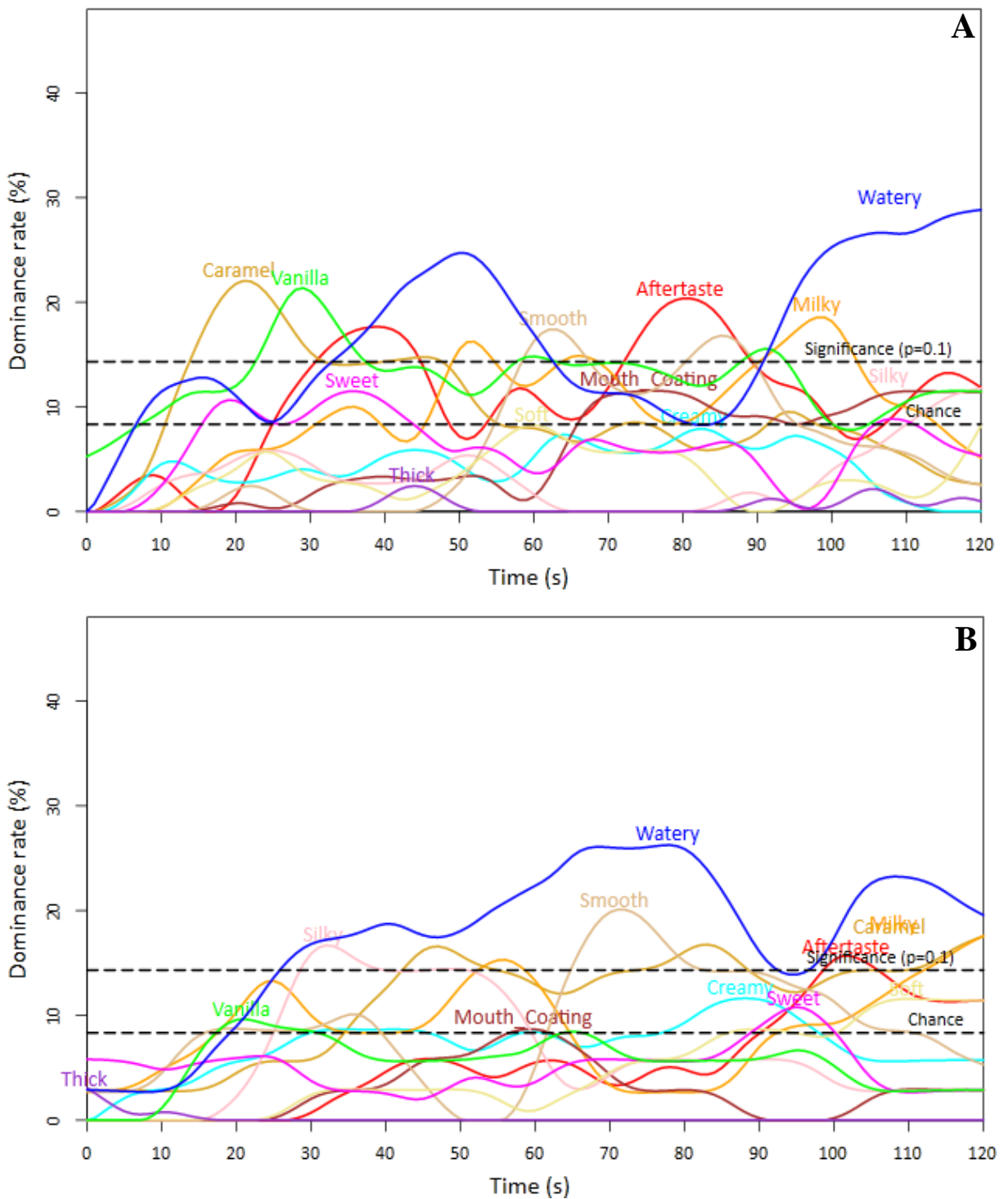
**Table A.3 continued.** Definitions of attributes used in Chapters 2 and 3.

<i>Attribute</i>	<i>Definition</i>
Runny	Fluid like consistency
Silky	The slippery sensation while a product is being moved from front to back of mouth
Soft	Easy to move around mouth/manipulate and swallow
Smooth	Absence of lumps/particulates
Sweet	Flavour associated with table sugar
Thick	Effort required to drink through straw resistance to flow across the tongue
Vanilla	Flavour associated with vanilla beans
Viscous	Consistency between solid and liquid. Force required to move the product across the tongue
Watery	Texture/Mouthfeel associated with a thin water like fluid

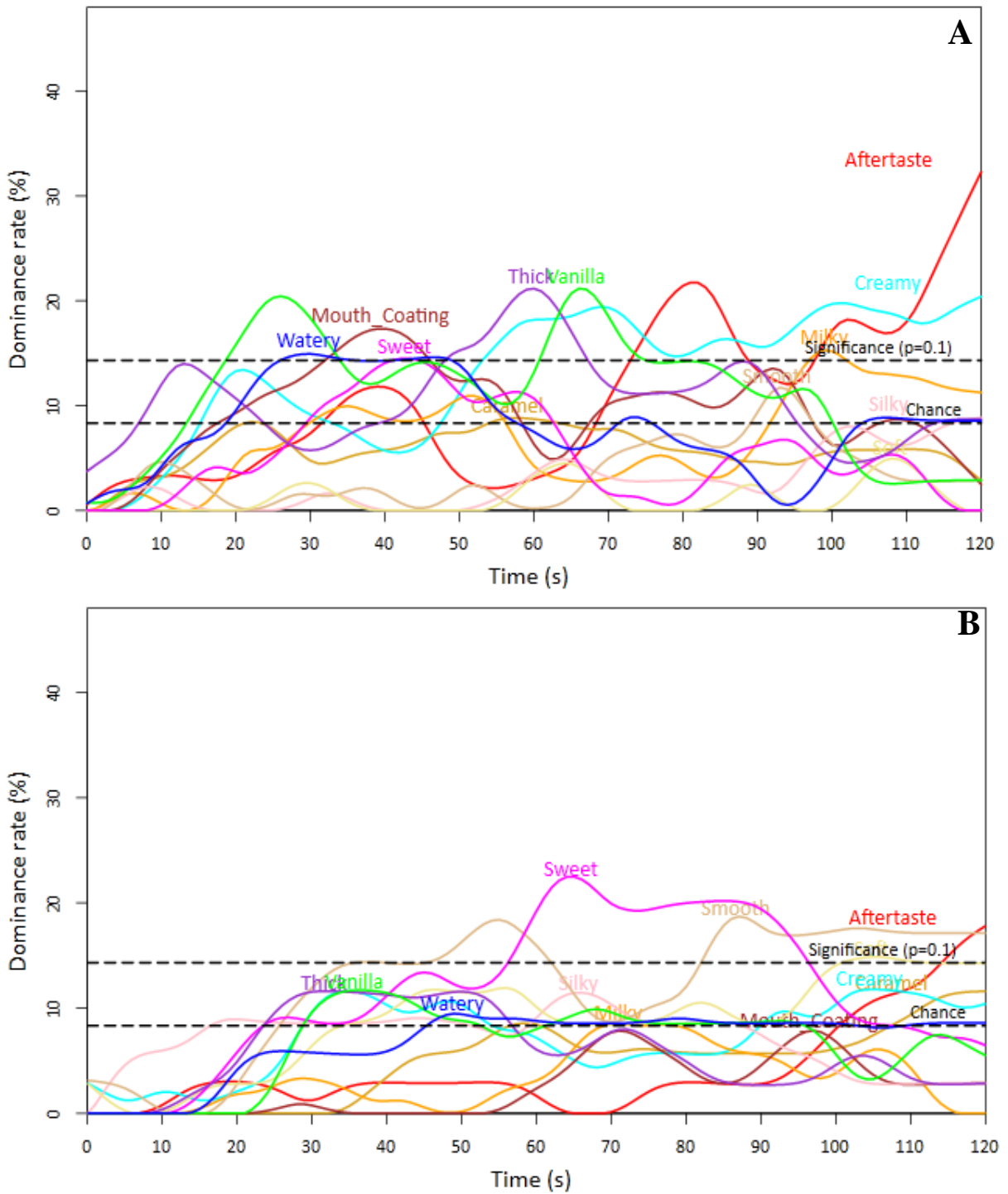
## Appendix 4



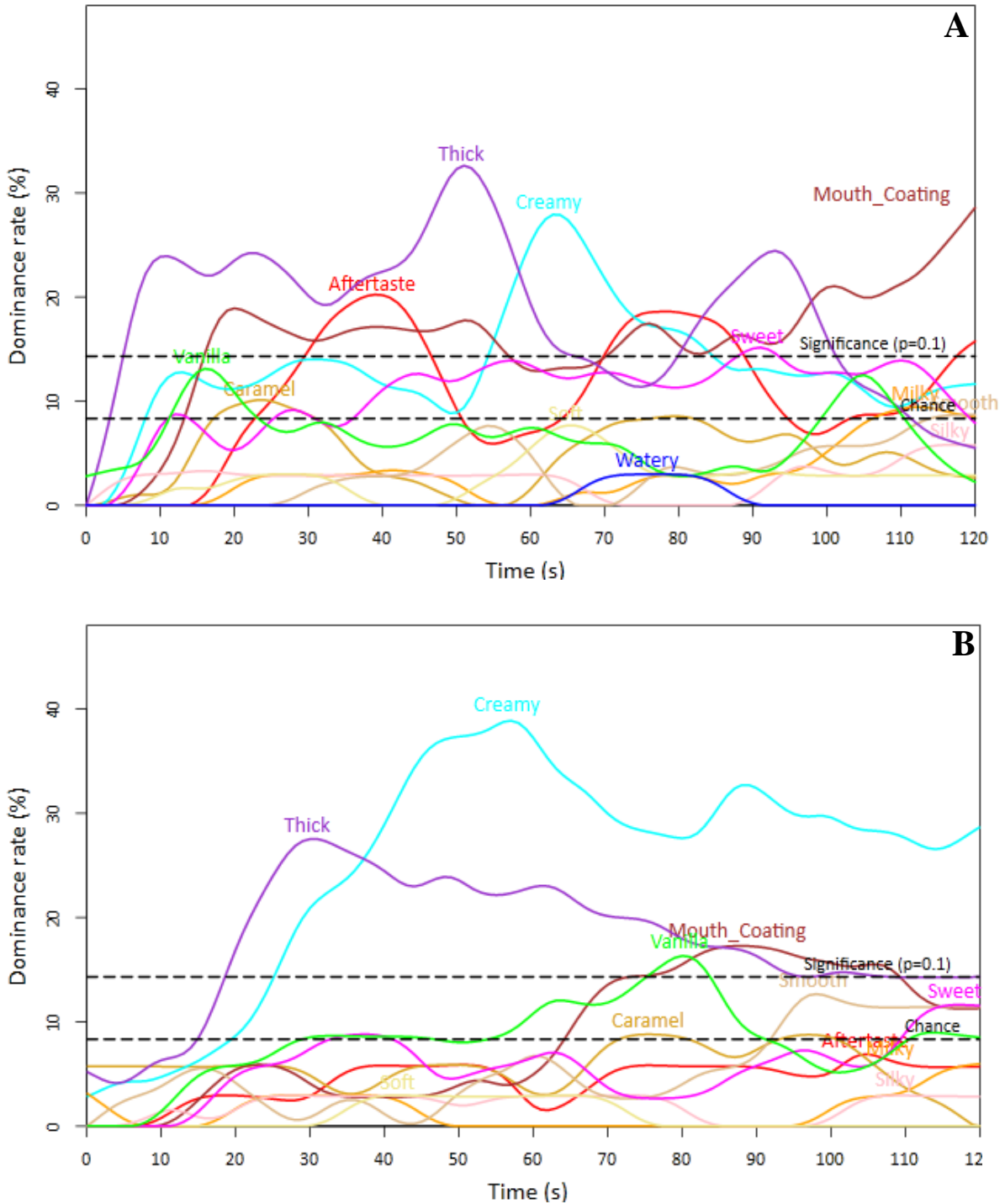
**Figure A.4.1** Temporal Dominance of Sensations (TDS) curves showing the dominance rates of each attribute for ONS 1 in **(A)** Younger adults and **(B)** Older adults.



**Figure A.4.2** Temporal Dominance of Sensations (TDS) curves showing the dominance rates of each attribute for ONS 2 in **(A)** Younger adults and **(B)** Older adults



**Figure A.4.3** Temporal Dominance of Sensations (TDS) curves showing the dominance rates of each attribute for ONS 3 in **(A)** Younger adults and **(B)** Older adults



**Figure A.4.4** Temporal Dominance of Sensations (TDS) curves showing the dominance rates of each attribute for ONS 4 in **(A)** Younger adults and **(B)** Older adults