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Individual variation in mouthfeel sensitivity: investigating influences of whey protein content, consumer age, food format and fat addition

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Abstract

Individual sensitivity to whey protein derived mouthdrying can vary with protein level and age; however, to date no thresholds for this have been established. Additionally, previous research suggests that increasing fat in whey protein solid models can enhance lubrication and suppress mouthdrying, but this needs testing in older adults. Here, a trained sensory panel (*n* = 10) determined a mouthdrying detection threshold (MDT) in whey protein beverages (WPB). To compare sensitivity between younger and older adults (*n* = 116; 18-30; 65+): (1) WPB just-noticeable difference (JND) thresholds were established and (2) liking and perception of whey protein fortified beverages and scones were rated. The trained panel detected mouthdrying at all protein levels (0.14% to 10.0% w/v) with the MDT being established between 0.41% (50% discriminators) and 1.37% (Best Estimate Threshold, BET) w/v protein. The JND mouthdrying threshold was significantly lower (*p* = 0.02) in older adults compared with younger adults (0.75% versus 0.90% w/v protein; BET). Increasing protein levels in WPBs significantly increased mouthdrying and reduced liking and easiness to consume (utilising rating scales). Whey protein fortified scones with cream topping significantly increased liking, easiness to consume, sweetness, moistness and rate of clearance, and reduced mouthdrying and chewiness. Older adults perceived WPBs as significantly easier to consume and the scones significantly chewier than younger adults. Age-related mouthfeel effects and individual differences in mouthdrying sensitivity are key factors for product design.

Keywords: whey protein fortified products; mouthdrying; mouthfeel; sensitivity; ageing

1. Introduction

Ageing is commonly associated with negative consequences, such as changes in smell, taste, vision, appetite and oral health, which are relevant to sensory perception (SACN, 2021). However, balanced nutrition can help to alleviate and/or modulate these issues (Pout, 2014; SACN, 2021). More specifically, maintaining protein intake can help prevent age-related muscle and functional decline (Bauer et al., 2013; Deutz et al., 2014). In addition, there is growing evidence that older adults have increased protein needs (such as 1.0-1.2 g/kg/d) in order to counterbalance age-related protein metabolism changes compared with younger adults (Bauer et al., 2013; Deutz et al., 2014). To achieve such intake, products are often fortified with whey protein, due to its beneficial nutritional and functional properties (Madureira, Pereira, Gomes, Pintado & Malcata, 2017). Moreover, whey proteins are recognised as being key to enhancing protein intake within an ageing population, since they can modulate muscle synthesis and protein gain (Dangin et al., 2003; Pennings et al., 2011).

There are, however, sensorial issues linked with whey protein fortified products which can subsequently impact product consumption and compliance (Norton, Lignou & Methven, 2021a). Such issues typically relate to mouthdrying, a textural defect (Lemieux & Simard, 1994) associated with whey protein. Mouthdrying and/or dry/harder texture can typically be perceived by trained sensory panels and/or consumers across a range of whey fortified matrices and/or oral nutritional supplements (ONS) (Sano, Egashira, Kinekawa & Kitabatake, 2005; Methven et al., 2010; Kelly et al., 2010; Childs & Drake, 2010; Ye, Zheng, Ye & Singh, 2012; Withers, Gosney & Methven, 2013; Thomas, van der Stelt, Prokop, Lawlor & Schlich, 2016; Wendin, Hoglund, Andersson & Rothenberg, 2017; Song, Perez-Cueto, & Bredie, 2018; Norton, Lignou, Bull, Gosney & Methven, 2020a; Norton, Lignou, Bull, Gosney

& Methven, 2020b). Mouthdrying also intensifies with repeated consumption, product heating time and/or age, subsequently negatively impacting liking (Methven et al., 2010; Withers et al., 2013; Thomas et al., 2016; Thomas, van der Stelt, Schlich & Lawlor, 2018; Bull et al., 2017). Additionally, previous work has suggested some foods (such as nut butters and seed pastes) are associated with hard-to-swallow behaviour that may be influenced by hydration from saliva (Rosenthal & Yilmaz, 2015). There may be a similar relationship between mouthdrying and easiness to swallow in protein fortified products. Indeed, whey protein fortified beverages and cakes have been found to be mouthdrying and less easy to consume (Norton et al., 2020b; 2021b); however, the extent of such impact is yet to be fully established.

Potential mouthdrying mitigation strategies using trained sensory panels have had varying success in reducing perceived mouthdrying (Withers, Lewis, Gosney & Methven, 2014; Norton, Lignou, Faka, Rodriguez-Garcia & Methven, 2021c). Recently, increasing lubrication via fat (using a cream topping) significantly suppressed mouthdrying in scones fortified with whey protein (Norton et al., 2021c). However, this needs further investigation using naïve consumers of differing ages to understand conclusively the effectiveness of this proposed strategy. Accordingly, defining the causes of whey protein derived mouthdrying has been the focus of research in this field, alongside investigating successful mitigation strategies. Most studies to date have, however, quantified whey protein derived mouthdrying using trained sensory panels and/or consumers, without considering differences in individual sensitivity.

As noted in our recent review, the extent of age-related changes in mouthfeel perception could be product and attribute related; however, this needs further proof

(Norton et al., 2021a). Individuals typically differ in sensitivity to sensory stimuli (Methven, Allen, Withers & Gosney, 2012; Doty & Kamath, 2014; Engelen, 2018) and such differences could influence mouthdrying perception. Previously, determining whether mouthdrying sensitivity increases with age has resulted in differing results depending on the specific test used. For example, older adults were better at detecting mouthdrying than younger adults using discrimination testing (two-alternative forced choice, 2-AFC) in dairy beverages (Withers et al., 2013). However, when utilising rating scales (0-100) (visual analogue scale, VAS or generalised Labelled Magnitude Scale, gLMS), no significant differences were found between age groups relating to mouthdrying from whey protein fortified beverages, cakes and biscuits (Norton et al., 2020a; 2020b). Accordingly, to address such inconsistencies, research using more sensitive discrimination tests is suggested (Norton et al., 2021a; Norton, Lignou & Methven, 2021b). Methven, Jimenez-Pranteda and Lawlor (2016) highlighted the simplicity and suitability of 2-AFC tests for older adults, which can also be used to determine thresholds such as just-noticeable difference (JND). JND refers to the intensity required to elicit a perceptual change (Lawless & Heymann, 2010). In addition, JND tests have previously been utilised to establish differences in texture sensitivity between age groups (Kremer, Bult, Mojet & Kroeze, 2007; Withers et al., 2013).

Detection thresholds aim to determine the minimum intensity of a stimulus required to cause a perceptual response and can be either product or individual focused (Lawless & Heymann, 2010). However, to date there have been limited whey protein beverage (WPB) threshold related studies and no defined whey protein derived mouthdrying thresholds have been published. Previous studies have typically used one of the following: (a) no set ratio progression between protein levels; (b) scales (0-5-, 0-7- and

0-15-point scales) rather than alternative forced choice tests (2-AFC or 3-AFC); or (c) focused on taste and orthonasal aroma, rather than mouthfeel due to possible confounding factors associated with model WPBs (Sano et al., 2005; Kelly et al., 2010; Childs & Drake, 2010; Ye et al., 2012). Since WPBs are associated with mouthdrying at a range of different protein concentrations (Sano et al., 2005; Kelly et al., 2010; Ye et al., 2012) defining a threshold could have useful product implications.

Whey protein derived mouthdrying studies have often investigated the causes rather than the extent of individual differences in sensitivity to such mouthdrying. This study hypothesises that: (a) a mouthdrying detection threshold (MDT) for whey protein derived mouthdrying can be established; (b) there will be individual differences in mouthdrying thresholds; (c) sensitivity to mouthfeel differences will increase with age, regardless of the food model; (d) the intensity of mouthdrying will increase with protein concentration in WPBs; and (e) consumers of varying age will perceive that adding a cream topping to a whey protein fortified scone will suppress mouthdrying. In order to test these hypotheses this paper uses: (1) whey beverages to evaluate mouthdrying thresholds via sensory panels and/or younger and older adults and (2) whey protein fortified scones (with and without cream topping) to assess liking and perception by younger and older adults.

2. Materials and methods

2.1. Study outline

This study consisted of two stages, as summarised in Figure 1. Stage one utilised the trained sensory panel at the Sensory Science Centre (University of Reading) (*n* = 10; 9 female and 1 male) to determine a mouthdrying detection threshold (MDT) for whey protein. Stage two involved 116 healthy volunteers (Table 1) varying in age: (a) 58 younger adults (18-30 years, 25.4 ± 3.2 years) and (b) 58 older adults (over 65 years, 69.5 ± 3.9 years) to investigate the influence of age on perception. Based on the primary outcome (2-AFC mouthdrying sensitivity) power calculations (alpha = 0.05, power = 0.9 and delta = 0.80) were carried out using the results from previous work (Withers et al., 2013) concluding a sample size of 49 (Ennis & Jesionka, 2011) was sufficient for testing within each age group. All volunteers were recruited from the surrounding Reading area (UK) and the study was a single blinded randomised crossover trial involving a one-day study at home. The study was performed as an at home study due to ongoing COVID-19 restrictions, conforming with social distancing and COVID-19 guidelines, as well as applicable risk assessments. All volunteers had the study fully explained, provided written consent and were informed that data would be anonymous and remain confidential, as well as there being a right to withdraw. In addition, all volunteers were screened in accordance with the inclusion criteria (meeting age requirements, healthy, no COVID-19 symptoms or not having had COVID-19 within the past month, minimal medication, non-smokers and not having had diabetes, food intolerances and allergies, cancer, oral surgery or a stroke). The University of Reading Research Ethics Committee (UREC) provided a favourable opinion for conduct (UREC 20/35) and the study was recorded as NCT04869722 on the clinical trials database (www.clinicaltrials.gov).

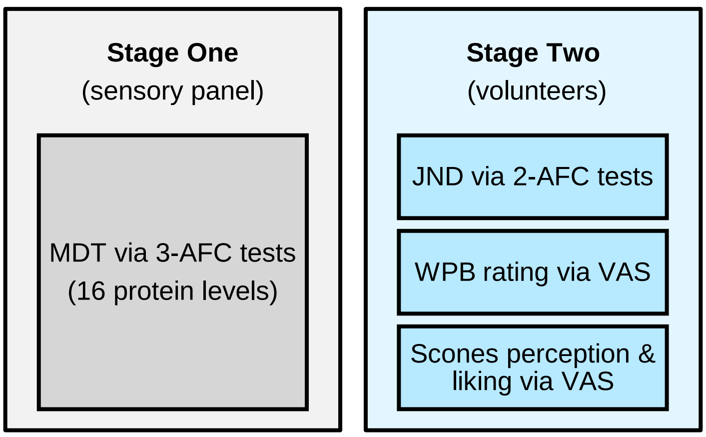


Figure 1. Study outline (MDT: mouthdrying detection threshold; 3-AFC: three-alternative forced choice; JND: just-noticeable difference; 2-AFC: two-alternative forced choice; WPB: whey protein beverage; VAS: visual analogue scale).

Table 1. Overview of volunteer's biological sex and medication (*n* and % represent number and percentage in each contributing group) (Stage 2: at home study).

	Biological Sex				Medication			
	Male		Female		Yes		No	
	n	%	*n*	%	*n*	%	*n*	%
Younger Adults (*n* = 58)	22	38	36	62	2	3	56	97
Older Adults (*n* = 58)	29	50	29	50	17	29	41	71

2.2. Materials

All study materials are described in Table 2.

Table 2. Overview of main study materials.

Product Description	Key Feature	Supplier
Volactose® Taw Whey Permeate (WPe)	89% lactose	Volac (Royston, UK)
Volactive® UltraWhey Sugar Free WPC (SF-WPC)	86% protein	Volac (Royston, UK)
Volactive® UltraWhey 80 Instant (WPC)	81% protein	Volac (Royston, UK)
Volactose® Edible Lactose (Lactose)	99% lactose	Volac (Royston, UK)
Nestle Resource Thicken Up Clear[1] (Hydrocolloid)	n/a	NutriDrinks (London, UK)
Rodda's Clotted Cream (Cream topping)	64% fat	Sainsbury's (Reading, UK)

WPe: whey permeate; SF-WPC: sugar-free whey protein concentrate; WPC: whey protein concentrate; n/a: not applicable. All other ingredients referred to in the study models below were purchased at Sainsbury's (Reading, UK). [1]Thicken Up Clear is a thickener comprising of xanthan gum with maltodextrin and was used to modify model viscosity as outlined in Section 2.3.

2.3. Study models preparation

2.3.1. Mouthdrying detection threshold (MDT) models

The control beverage was a whey permeate beverage (WPeB; 4.0% w/v, WPe powder in deionised water) considered a suitable non-protein whey control and a beverage well utilised in our previous work (Norton et al., 2020a; 2021b). The protein beverage consisted of 16 different protein levels (WPB, 0.14% to 10.0% w/v, SF-WPC powder in deionised water) based on ×1.33 progression, with the aim of representing a full spectrum of protein levels (up to 10.0% w/v) to establish a MDT for whey protein. Lactose was added to all protein levels to match the level found in the control beverage (in all beverages the lactose level was considered below the average lactose taste recognition threshold (4.19% w/v) (Belitz, Grosch & Schieberle, 2004)).

2.3.2. Mouthdrying just-noticeable difference (JND) models

The formulations for JND thresholds were designed following the results of the MDT as mouthdrying was detectable at low protein levels (Section 3.1). Accordingly, six beverages were developed where the control beverage (WPB, 0.33% w/v, SF-WPC powder in deionised water) was considered a detectable mouthdrying sample based on the MDT results. Five additional protein levels (WPB, 0.41% to 1.00% w/v, SF-WPC powder in deionised water) were utilised using a ×1.25 progression (MDT results and initial testing within our laboratory concluded that a narrower progression than 1.33 was needed) to determine the level of increase in protein concentration required to cause a detectable difference in mouthdrying. All beverages were matched on lactose content as with the MDT model.

2.3.3 Whey protein beverages (WPB) rating models

Four different protein levels were selected (1.81%, 3.20%, 5.56% and 10.0% w/v; SF-WPC powder in deionised water) from the original 16 MDT levels. This was to cover a range of protein levels from below and up to a typical WPB and to determine whether younger and older adults found increasing protein levels resulted in increased mouthdrying from these samples.

All model beverages are outlined in Table 3 and were stirred (Stuart™ SM5 Bibby Fascia, UK) for 90-min at room temperature (19.2 ± 1.5 °C), as described in our previous work (Norton et al., 2020a; 2021b; 2021c). Viscosity increased linearly with increasing hydrocolloid concentration at a shear rate of 50 s^{-1} (Figure S.1). The levels of hydrocolloid used in each model (Table 3) were optimised to minimise viscosity differences between beverages (Figures S.2).

Table 3. Summary of mouthdrying detection threshold (MDT), just-noticeable difference (JND) and whey protein beverage (WPB) rating models.

Subset	Beverage¤	**Formulations** (per 100 mL)					**Composition** (per 100 mL)			
		Water (mL)	WPe (g)	SF-WPC (g)	Lactose (g)	Hydrocolloid (g)	Energy (kcal)	Fat (g)	Carbohydrate (g)	Protein (g)
MDT control	**WPeB**	**96.0**	**4.0**	**-**	**-**	**0.150**	**14.7**	**0.008**	**3.65**	**0.10**
MDT: WPBs varying in protein levels	0.14%	96.0	-	0.138	3.56	0.146	0.58	0.02	3.65	0.12
	0.18%	96.0	-	0.184	3.56	0.145	0.77	0.02	3.65	0.16
	0.25%	96.0	-	0.245	3.56	0.145	1.02	0.03	3.65	0.21
	0.33%	96.0	-	0.326	3.56	0.144	1.36	0.04	3.65	0.28
	0.43%	96.0	-	0.434	3.56	0.143	1.81	0.05	3.65	0.37
	0.58%	96.0	-	0.577	3.56	0.142	2.40	0.06	3.65	0.50
	0.77%	96.0	-	0.767	3.56	0.140	3.19	0.08	3.65	0.66
	1.02%	95.0	-	1.021	3.56	0.138	4.25	0.10	3.65	0.88
	1.36%	95.0	-	1.358	3.56	0.135	5.65	0.13	3.65	1.17
	1.81%[1]	95.0	-	1.807	3.56	0.131	7.51	0.17	3.65	1.56
	2.40%	94.0	-	2.403	3.56	0.124	10.0	0.23	3.65	2.07
	3.20%[2]	93.0	-	3.196	3.56	0.117	13.3	0.30	3.65	2.75
	4.25%	92.0	-	4.251	3.56	0.107	17.7	0.40	3.65	3.66
	5.56%[3]	91.0	-	5.563	3.56	0.093	23.5	0.53	3.65	4.87
	7.52%	89.0	-	7.519	3.56	0.074	31.3	0.71	3.65	6.47
	10.0%[4]	86.0	-	10.00	3.56	0.042	41.6	0.95	3.64	8.60
JND control	**0.33%**	**96.0**	**-**	**0.326**	**3.56**	**0.144**	**1.36**	**0.04**	**3.65**	**0.28**
JND: WPBs varying in protein levels	0.42%	96.0	-	0.408	3.56	0.143	1.70	0.05	3.65	0.35
	0.51%	96.0	-	0.509	3.56	0.142	2.12	0.06	3.65	0.44
	0.64%	96.0	-	0.637	3.56	0.141	2.65	0.08	3.65	0.55
	0.80%	96.0	-	0.796	3.56	0.139	3.31	0.10	3.65	0.68
	1.00%	95.0	-	0.995	3.56	0.138	4.14	0.10	3.65	0.85

¤Beverage levels expressed as % w/v. Subscript numbers (1-4) denote models utilised in whey protein beverage (WPB) rating. Acronyms: whey permeate beverage (WPeB); whey permeate powder (WPe); sugar-free whey protein concentrate (SF-WPC). Data based on ingredients technical sheets. Dash (-) notes not applicable. Hydrocolloid (thicken up clear) was a xanthan gum with maltodextrin thickener. Bold notes the control beverage for MDT and JND respectively.

2.3.4. Scone models

Whey protein fortified scones (30.0 g; 4.5 g protein per scone) with cream topping (8.0 g clotted cream providing 5.0 g fat and total fat level 9.0 g per scone) and without cream topping (total fat level 3.9 g per scone), were used as described in our previous work (Norton et al., 2021c). In brief, the dry ingredients were added and mixed (Kenwood Titanium Major KMM020, Hampshire, UK) followed by wet ingredients (low speed, 2 to 10-min). Scones were formed (diameter: 4.5 cm cutter and 1.0 cm thickness), brushed with mixture (eggs and milk), baked (12-min at 200 °C in a pre-heated oven (Altas Salva, London, UK)), individually packaged (polypropylene pouches), frozen at -18 °C until consumption and underwent microbiological clearance testing (SGS analytics, Northumberland, UK).

2.4. Stage one: mouthdrying detection threshold (MDT)

The trained sensory panel used a series of three-alternative forced choice (3-AFC) tests to determine a MDT for whey protein; testing complied with the International Organisation for Standardisation (ISO) 13301:2018 (ISO, 2018). COVID-19 restrictions (February to March 2021) resulted in all sessions being carried out at panellists' homes; however, they conformed to COVID-19 guidelines and appropriate risk assessments. All sessions were completed remotely via Microsoft Teams (Version 1.3.00.28778, Washington, USA) individually on iPads (Apple, London, UK) with Compusense Cloud Software (Version 21.0.7713.26683, Compusense, Ontario, Canada) in a quiet and aroma free location. The panellists were provided with samples (10 mL) (coded with a random three-digit number) in paper cups (113 mL) with sip lids (to mask any potential differences between samples) and tasted in a fixed ascending order, with each level allocated in a random sequential balanced order. Panellists completed a series of training sessions (3 × 30-min) to become familiar with the term mouthdrying (defined as the drying sensation in the mouth during or after consumption of a product (and persists/builds for up to 30-s post swallow)) and were presented with three samples (two WPeBs and one WPB). Panellists were asked which sample was more mouthdrying and this procedure was repeated in triplicate for all 16 levels in different sessions. Panellists had an enforced 1-min break between levels and used water (~ 40 °C, warm, filtered) for palate cleansing.

2.5. Stage two: at home tasting study

All tasting was carried out at volunteers' homes due to COVID-19 restrictions (April and May 2021) in a quiet and aroma free location. Tasting was completed on the same day (within 2-h) as they received the samples (all adhering to COVID-19 guidelines and risk assessments) and volunteers refrained from food or drink for 30-min prior to the test; volunteers recorded all results in paper booklets. For all tasks, volunteers were provided with detailed consumption instructions. All beverages were presented in paper cups with sip lids as outlined in Section 2.4. Volunteers were asked to consume: (a) all of the provided WPB and (b) break each scone in half and consume two bites from the middle. In addition, all volunteers were provided with definitions for all perception attributes as summarised in Figure S.3.

2.5.1. Mouthdrying just-noticeable difference (JND)

Volunteers were provided with a series of five 2-AFC tests (with 1-min break in-between) to determine which sample was more mouthdrying within each pair (conforming with ISO 5495:2005) as summarised in Figure 2. All tasting was evaluated in a fixed ascending order with each pair allocated in a random sequential balanced order. The rationale for using 2-AFC tests (two samples: one control and one WPB) relates to 3-AFC (three samples: two controls and one WPB) can lead to fatigue (due to number of samples) and/or confusion (especially within a home setting). Accordingly, the 2-AFC test was used with volunteers since they were untrained, and it had better suitability for the older adults.

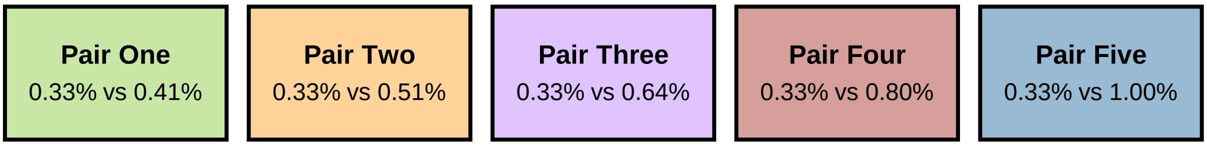


Figure 2. Overview of mouthdrying just-noticeable difference (JND) pairs (0.33% w/v protein denotes the control beverage and 0.41% to 1.00% w/v represents increasing protein levels within the WPB).

2.5.2. Whey protein beverages (WPB) rating

Volunteers were provided with four WPBs, differing in protein levels (1.81%, 3.20%, 5.56% and 10.0% w/v), in a random sequential balanced order (with 45-s break between samples). Volunteers rated all WPBs on visual analogue scales (VAS; 10 cm lines on paper, scale 0-100) for the following attributes: liking (dislike extremely to like extremely), easiness to consume (drink and swallow; very difficult to very easy), mouthdrying (not mouthdrying to very mouthdrying), appropriateness of flavour level (Just-About-Right, JAR) (five category labels; much too weak to much too strong) and added any comments relating to each sample. All volunteers completed a familiarisation exercise on how to use the VAS by non-food related questions (Norton et al., 2020b).

2.5.3. Scones perception and liking

Volunteers were provided with two scones (with and without cream topping) in a random sequential balanced order (with 45-s break between samples). Volunteers rated scones on VAS for the following attributes: appearance liking (dislike extremely to like extremely), liking (dislike extremely to like extremely), easiness to consume (eat and swallow; very difficult to very easy), sweetness (not sweet to very sweet), moistness (not moist to very moist), mouthdrying (not mouthdrying to very mouthdrying), chewiness (not chewy to very chewy), rate of clearance (slow to fast), appropriateness of flavour level (Just-About-Right, JAR) (five category labels; much too weak to much too strong), added any comments relating to each sample and noted how often they consumed protein fortified products. To finish, volunteers completed a single 2-AFC test to determine which sample was more mouthdrying.

2.6. Statistical analysis

MDT analysis was completed in R-package sensR (Christensen & Brockhoff, 2018) using binomial and beta-binomial models obtaining for all 16 individual protein levels to establish: (a) proportion of correct responses (Pc; correct responses/number of total response); (b) proportion of discriminators ($Pd = \frac{P_c - P_g}{1 - P_g}$) (Jesionka, Rousseau & Ennis, 2014); and (c) significance of sample (*p* value). The Thurstonian model was also used to transform the number of correct responses into an estimate (d-prime) of the underlying sensory difference. To capture any potential panellist variability (gamma - overdispersion) in the data (due to replication), the beta-binomial model was applied if there was a significant overdispersion, whilst if there was a non-significant result, the binomial model was utilised (Ennis & Bi, 1998; Liggett & Delwiche, 2005). Accordingly, all data were checked for overdispersion and for all WPBs the binomial model was sufficient (apart from two levels: WPB 1.80% and 3.20% w/v, where the overdispersion was significant and the beta-binomial model was used). However, it should be noted that the d-prime values from both models were very similar, supporting no strong overdispersion in our data. Linear regression was fitted to determine a detection threshold (i.e. the overall 50% discriminator level) where the proportion of discriminators was plotted against the protein level natural logarithm (ln(protein%))

(ISO, 2018) in XLSTAT (version 2020.1.3, Addinsoft, New York, USA). Additionally, analysis was carried out using the Best Estimate Threshold (BET) approach (as described below) to determine both individual panellist and group sensitivity.

The BET method utilised the individual thresholds from MDT or JND by calculating the geometric mean of (a) the concentration at which the individual correctly identified the WPB as more mouthdrying (with all subsequent levels deemed as mouthdrying) and (b) the highest concentration where the WPB was incorrectly identified as more mouthdrying (Lawless 2010; Lawless & Heymann, 2010). If an individual incorrectly identified the highest provided WPB level as mouthdrying; therefore, it was assumed that their individual threshold was equal to or greater than the next protein concentration presented based on the relevant subset progression (Lawless 2010; Lawless & Heymann, 2010). For example, equal to or greater than (a) MDT: 13.3% (×1.33) and (b) JND: 1.11% (×1.25) (w/v) protein and progression respectively. The group thresholds were calculated from the individual geometric means (MDT: panellists and JND: within an age group) (Lawless 2010; Lawless & Heymann, 2010).

JND data (using the BET approach to false positives (Lawless; 2010; Lawless & Heymann, 2010)) was also used to determine the: (a) proportion of correct responses; (b) proportion of discriminators (Jesionka et al., 2014); and (c) d-prime values using Thurstonian modelling in XLSTAT. Subsequent age group analysis was conducted in XLSTAT using a Mann-Whitney test due to non-normally distributed data (as defined by lack of normality of residuals $p < 0.05$).

WPB and scones ratings (VAS; 0-100) were analysed in SAS® software (version 9.4, Cary, NC, USA) by linear mixed models (suitable for unbalanced data (Torrico et al., 2018)) as follows: (a) explanatory variables: age, sample, sex, medication and volunteer code (random effect); (b) dependent variables: liking, perception and JAR scores; (c) post hoc analysis (if the model demonstrated a significant value) applied Bonferroni and (d) data denotes least square means (LSM) estimates. JAR data (0-100) was converted into category data (three levels: (1) too little (less than 45); (2) JAR (within 10% of midpoint (45-55)); and (3) too much (more than 55)) to relate perception of optimum flavour intensity to liking data. The resulting penalty analysis was then completed in XLSTAT, as noted in our previous work (Norton et al., 2021b). Scone mouthdrying 2-AFC results were analysed by Binomial expansion and Thurstonian modelling (*p* values, power and d-prime) in V-power (Ennis & Jesionka, 2011). A chi-square test on contingency tables was used to determine associations between age and categorical data (medication and protein consumption) in XLSTAT. For all analyses $p < 0.05$ was used to reflect sample significance.

3. Results

3.1. Mouthdrying detection threshold (MDT)

Significant mouthdrying was detected at all protein levels tested compared with the whey permeate control (WPeB) and the d-prime generally increased with increasing protein content as outlined in Table 4. The detection threshold for whey protein (defined as 50% discriminators level) was estimated at 0.41% w/v protein using the fitted regression model utilising all protein levels (Figure S.4). However, the lowest individual protein level at which the proportion of discriminators reached 50% was 0.33% w/v (Table 4). The alternative BET approach resulted in a higher calculated mean detection threshold (1.37% w/v protein) and demonstrated the panellists individual range (0.12% to 5.92% w/v protein).

Table 4. Overview of mouthdrying detection threshold as identified by trained panel (*n* = 10).

Protein Level¤	Correct[1] (n)	Pc[2]	Pd[3]	Significance of sample (*p* value)[4]	d-prime[5]
0.14%	17	0.57	0.35	0.007	0.77
0.18%	16	0.53	0.30	0.02	0.67
0.25%	16	0.53	0.30	0.02	0.67
0.33%	20	0.67	0.50	<0.0001	1.12
0.43%	21	0.70	0.55	<0.0001	1.24
0.58%	24	0.80	0.70	<0.0001	1.65
0.77%	22	0.73	0.60	<0.0001	1.37
1.02%	24	0.80	0.70	<0.0001	1.65
1.36%	26	0.87	0.80	<0.0001	2.01
1.81%#	20	0.68	0.52	0.04	1.16
2.40%	25	0.83	0.75	<0.0001	1.82
3.20%#	24	0.80	0.70	0.009	1.66
4.25%	26	0.87	0.80	<0.0001	2.01
5.56%	26	0.87	0.80	<0.0001	2.01
7.52%	29	0.97	0.95	<0.0001	2.96
10.0%	26	0.87	0.80	<0.0001	2.01

¤Protein levels expressed as % w/v; [1] refers to number of correct responses out of 30 (all data was collected in triplicate); [2] demonstrates the proportion of correct responses; [3] denotes the proportion of discriminators; [4] reflects the *p* value as defined by Binomial or beta-binomial model; [5] expresses the d-prime as defined by Thurstonian modelling and # within the column highlights where the overdispersion was significant and data are reported as adjusted values from Beta-Binomial model.

3.2. Mouthdrying just-noticeable difference (JND)

The JND testing concluded a greater difference between WPBs resulted in more volunteers detecting differences in mouthdrying (Figure 3). At 1.00% w/v protein (including all lower subsequent protein levels) the proportion of correct responses was 0.64 and the proportion of discriminators only reached 0.26; hence, a JND threshold (based on the 50% discrimination method) could not be established. Indeed, the maximum d-prime was 0.50 and at lower protein levels a d-prime was not possible to calculate as the guessing probability was higher than the number of correct responses. However, JND thresholds could be estimated using the BET approach, and this method concluded an age-related difference where older adults had a significantly lower ($p = 0.02$) average JND threshold compared with younger adults (geometric mean: 0.75 ± 0.04% versus 0.90 ± 0.03% w/v protein respectively).

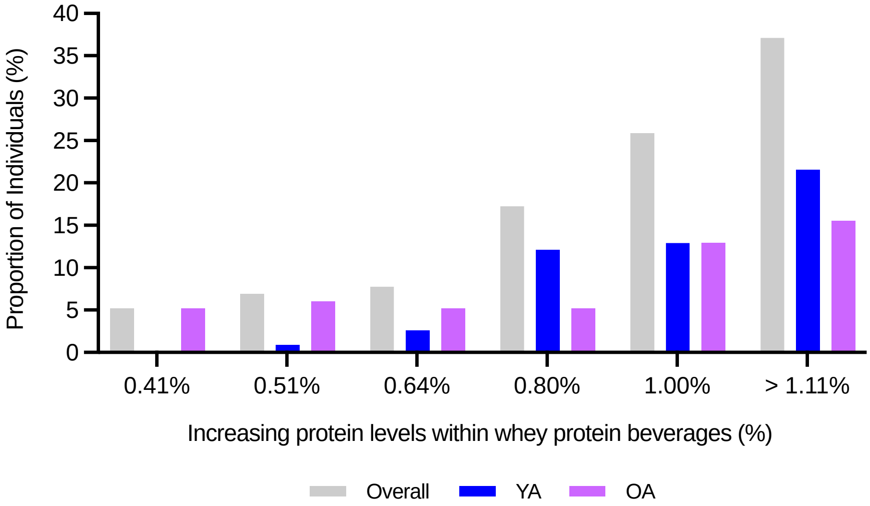
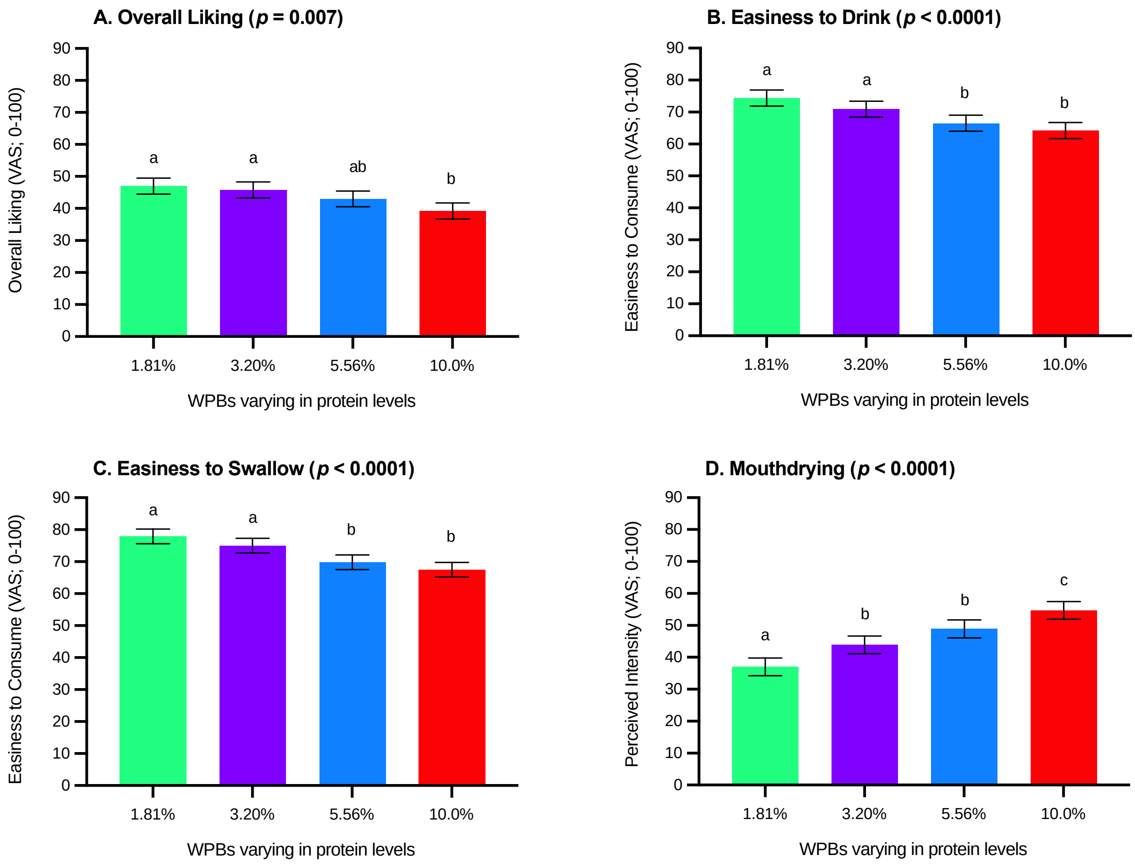


Figure 3. Just-noticeable difference (JND) mouthdrying thresholds frequency distribution (*n* = 116; younger adult (YA): *n* = 58; older adult (OA): *n* = 58) for each corresponding protein level (% w/v). Control was 0.33% w/v protein with increasing protein levels 0.41% to 1.00% w/v and > 1.11% w/v denotes individuals are above JND threshold.

3.3. Whey protein beverages (WPB) rating

Increasing protein from 1.81% to 10.0% (w/v) resulted in significantly increased mouthdrying, as well as significantly reduced liking and easiness to consume (Figure 4). Age had no significant effect on either liking or mouthdrying; however, older adults rated WPBs as significantly easier to consume compared with younger adults (Table 5). Flavour intensity became significantly closer to optimum (Just-About-Right; 50 on 0-100 scale) with increasing protein levels; age had no significant influence on JAR flavour ratings (Table 6). The impact of flavour intensity on subsequent liking was revealed by penalty analysis. For example, lower protein levels resulted in more individuals perceiving the WPBs as 'too low' in flavour, impacting liking, compared with 'too much' flavour. However, at higher protein levels both 'too little' and 'too much' flavour resulted in reduction in WPB liking. Older adults found the 10.0% (w/v) WPB having both 'too little' and 'too much' flavour which led to a reduction in liking whereas the younger adults only reported 'too much' flavour having an effect (Table 6). Other factors (such as sex and medication) had no significant effect on WPB ratings (Figure

S.5). Comments were provided relating to the WPBs with 245 comments recorded (32% positive and 68% negative) as described in Figure 5.



Figures 4A-4D. Mean whey protein beverage (WPB) ratings (**A**: Overall liking; **B**: Easiness to Drink; **C:** Easiness to Swallow; and **D**: Mouthdrying) (± standard error) (*n* = 116; VAS: visual analogue scale 0-100) differing in protein levels (% w/v). Differing letters highlights sample significance from multiple comparisons.

There was a significant association (*p* < 0.0001) between medication and age, highlighting more older adults take medication than younger adults (Table 1). However, medication use had no significant effect on WPB ratings or perception and liking of scones (Section 3.4).

Table 5. Influence of age (YA: younger adult *n* = 58 and OA: older adult *n* = 58) on rating (± standard error) of differing protein levels (% w/v) in whey protein beverages (WPB).

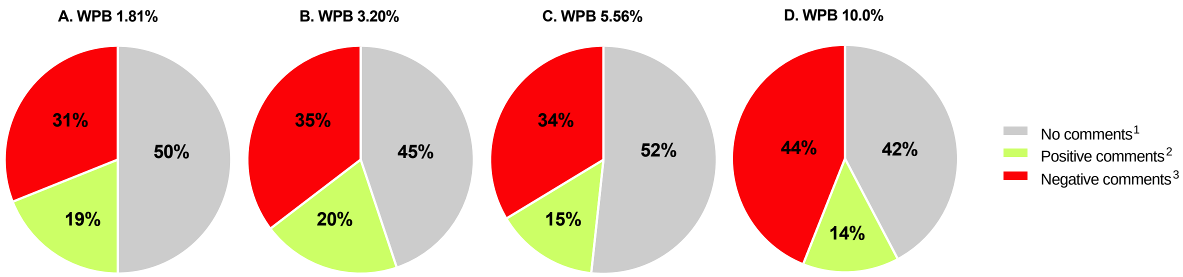
	1.81%		**3.20%**		**5.56%**		**10.0%**	
	Younger Adults (*n* = 58)	Older Adults (*n* = 58)	Younger Adults (*n* = 58)	Older Adults (*n* = 58)	Younger Adults (*n* = 58)	Older Adults (*n* = 58)	Younger Adults (*n* = 58)	Older Adults (*n* = 58)
Liking	47.9 ± 3.5	46.2 ± 3.1	43.8 ± 3.5	47.9 ± 3.1	45.9 ± 3.5	40.2 ± 3.1	37.8 ± 3.5	40.5 ± 3.1
Easiness to drink	68.8 ± 3.5^{aA}	80.0 ± 2.9^{bA}	62.4± 3.5^{aAB}	79.3 ± 2.9^{bA}	61.5 ± 3.5^{aAB}	71.4 ± 2.9^{bAB}	57.2 ± 3.5^{aAB}	71.2 ± 2.9^{bAB}
Easiness to swallow	74.3 ± 3.2^{A}	81.7 ± 2.7^{A}	68.6 ± 3.2^{aA}	81.4 ± 2.7^{bA}	66.4 ± 3.2^{AB}	73.1 ± 2.7^{B}	61.8 ± 3.2^{aB}	73.2 ± 2.7^{bB}
Mouthdrying	35.7 ± 4.0	38.3 ± 3.4	40.7 ± 4.0	47.1 ± 3.4	47.7 ± 4.0	50.1 ± 3.4	54.9 ± 4.0	54.7 ± 3.4

Significant differences between samples and age are noted by differing small letters (YA vs OA within sample) and capital letters (within age group across WPBs) respectively; no letter reflects no significance.

Table 6. Just-About-Right (JAR) flavour mean ratings (± standard error) and effect on liking (penalty analysis) by overall and age for whey protein beverages (WPB; % w/v) and scones.

	Overall (*n* = 116)		**Age**		**Penalty Analysis**							
					Too Little (YA)		Too Much (YA)		Too Little (OA)		Too Much (OA)	
		Significance of sample (*p* value)	Younger Adults (*n* = 58)	Older Adults (*n* = 58)	Mean Drop	Frequency (%)	Mean Drop	Frequency (%)	Mean Drop	Frequency (%)	Mean Drop	Frequency (%)
WPBs												
1.81%	39.6 ± 2.3^{a}	**<0.0001**	37.6 ± 3.3	41.5 ± 2.7	17.0#	59%	30.3†	14%	11.7#	53%	9.8†	17%
3.20%	42.3 ± 2.3^{a}		41.4 ± 3.3	43.1 ± 2.7	20.0#	55%	24.3#	21%	9.9†	38%	11.0†	12%
5.56%	43.2 ± 2.3^{ab}		41.2 ± 3.3	45.2 ± 2.7	18.3#	52%	9.3	21%	2.9	43%	13.1	26%
10.0%	52.3 ± 2.3^{c}		51.9 ± 3.3	52.7 ± 2.7	3.7	36%	18.1#	40%	18.0#	33%	36.3#	35%
Scones												
Protein Scone	42.8 ± 1.6	**0.0009**	43.4 ± 2.3	42.2 ± 1.8	15.7#	41%	10.7†	9%	16.3#	45%	26.0†	8%
Protein Scone + cream topping	46.6 ± 1.6		46.5 ± 2.3	46.8 ± 1.8	26.5#	31%	-2.9†	10%	19.6#	28%	18.8†	14%

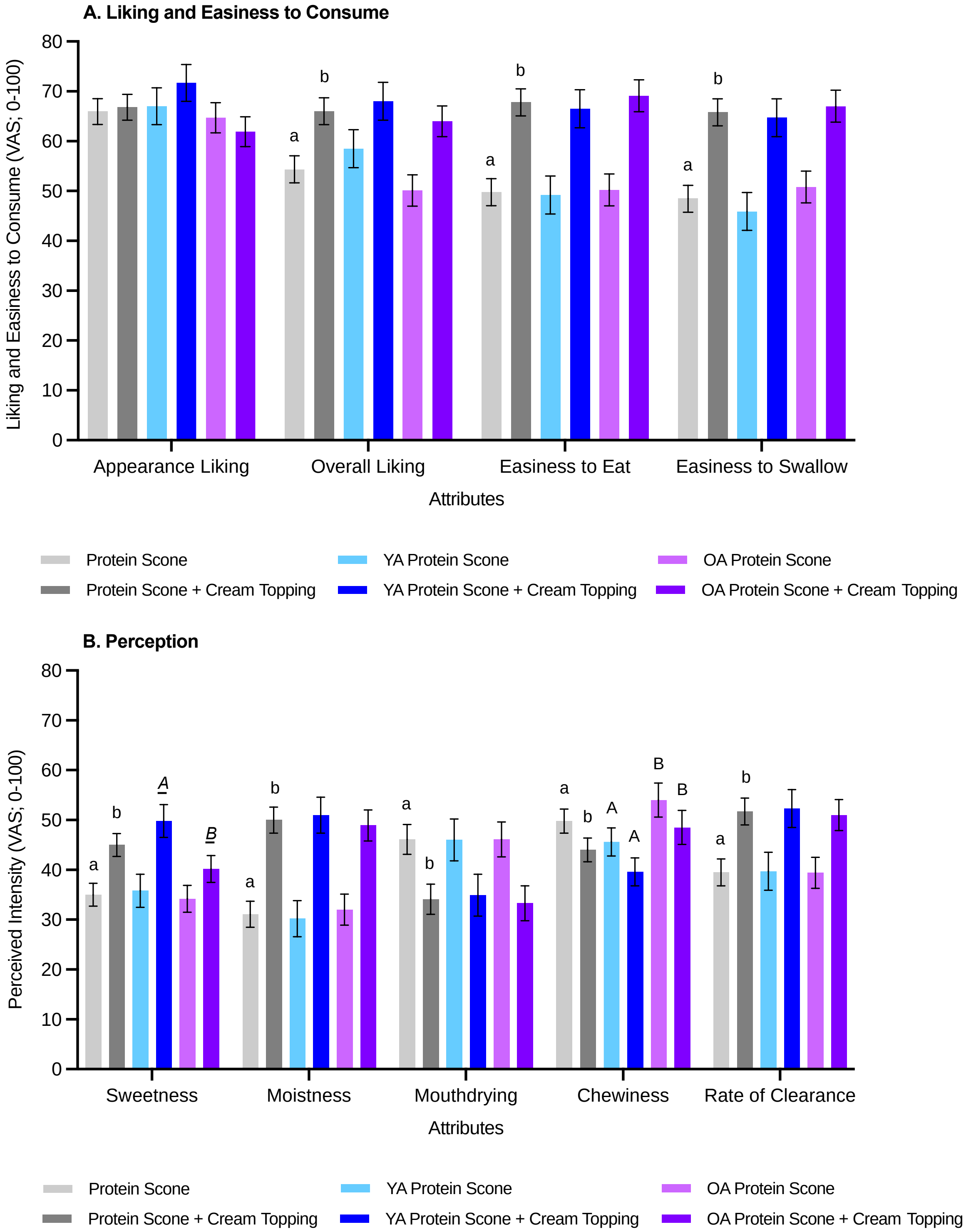
Differing letters within WPBs overall column denotes within sample significance; no letter reflects no significance. # indicates significance difference from penalty analysis within each sample and age group; † denotes lower than group threshold (20%); frequency (%) represents percentage within too little or too much group.



Figures 5A-5D. Percentage overview of volunteer comments relating to whey protein beverages (**A**: WPB 1.81%; **B**: WPB 3.20%; **C**: WPB 5.56%; and **D**: WPB 10.0%) differing in protein levels (% w/v). [1]Refers to volunteers that did not provide any comments; [2] volunteers who provided positive (or neutral) comments (such as great, preferred, tasty, nice, smooth, creamy, easy to consume, OK and pleasant); [3]volunteers who provided negative comments (namely gritty, dislike, bland, horrible, unpleasant, mouthdrying, powdery, aftertaste, sickly, tacky, weak and watery).

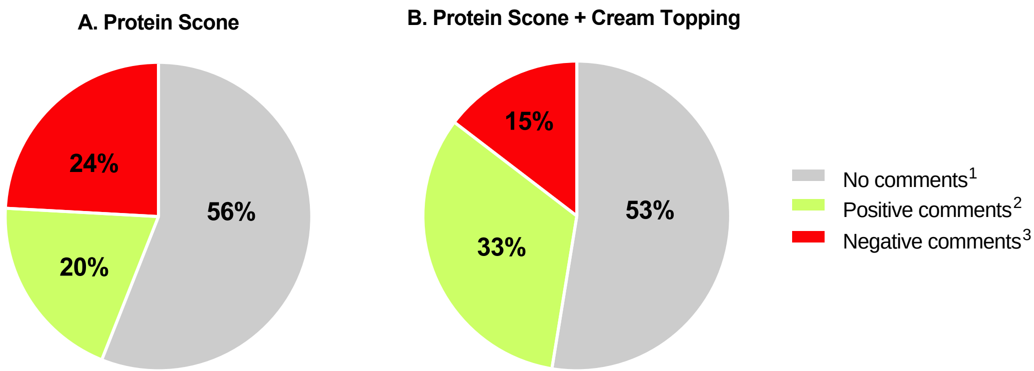
3.4. Scones perception and liking

Scones fortified with whey protein and added cream topping significantly increased liking, easiness to consume, sweetness, moistness and rate of clearance, as well as significantly reduced mouthdrying and chewiness compared with the scone without cream topping (Figure 6). Older adults perceived scones as significantly chewier compared with younger adults; however, age had no significant effect on the remaining attributes (Figure 6). It should be noted there was a significant interaction between sample and age (p = 0.04) for sweetness; older adults perceived scones with cream topping less sweet (p = 0.01) than younger adults. The use of cream topping resulted in a scone closer to optimum flavour (JAR) than a scone without cream topping (Table 6). The penalty analysis highlighted that 'too little' flavour significantly related to lower liking for both scones (with and without cream topping); this trend was supported by both age groups (Table 6). Sex significantly altered sweetness perception, where males perceived scones to be significantly sweeter (p = 0.005) than females. However, all remaining additional factors (such as sex and medication) had no significant influence on scone perception and liking (Figure S.6).



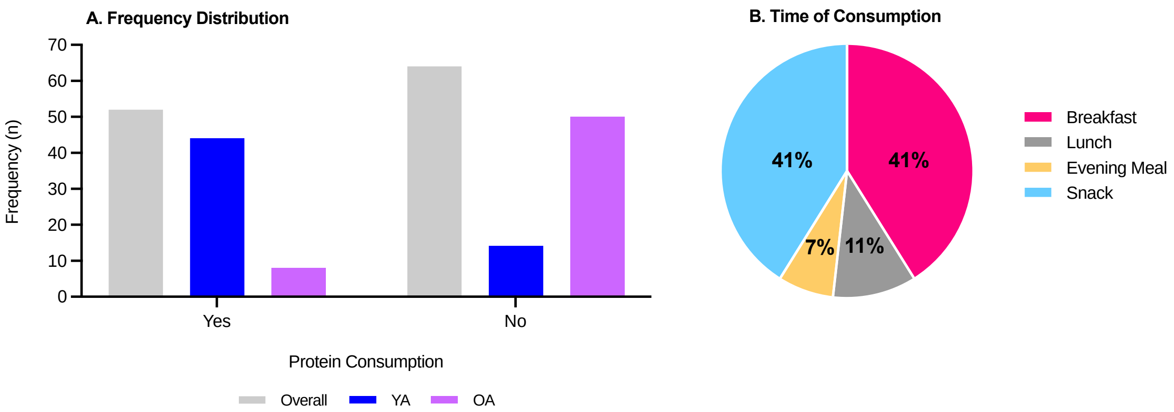
Figures 6A and 6B. Volunteers' (*n* = 116) ratings of scones with and without cream topping (**A**) liking and easiness to consume and (**B**) perception by overall and age (YA: younger adults (*n* = 58); OA: older adults (*n* = 58)) (visual analogue scales; VAS 0-100). Data denotes means ± standard error. Significant differences between samples and age are noted by differing small letters and capital letters respectively. Differing capital letters in *italics* (sweetness) indicate a significant pairwise comparison between age groups for protein scone + cream topping (via a significant sample by age interaction (p = 0.04); however, age overall did not reach significance (p = 0.09)).

Volunteers provided 106 comments, where scones with cream topping had a greater number of positive comments (69%) compared with scones without cream topping (45%) as summarised in Figure 7. The mouthdrying discrimination test (2-AFC) supported the rating results, demonstrating that adding a cream topping to scones significantly reduced mouthdrying ($p < 0.0001$; power: 1.00) compared with scones without cream topping; however, the effect size may be considered relatively small (d-prime: 0.74). The proportion of individuals who identified the scone with cream as the less mouthdrying sample was 70%.



Figures 7A and 7B. Percentage overview of volunteer comments relating to whey protein fortified scones (**A**: Protein Scone and **B**: Protein Scone + Cream Topping). [1]Refers to volunteers that did not provide any comments; [2] volunteers who provided positive (or neutral) comments (such as nice taste, delicious, easy to consume, enjoyed, good flavour, OK, sweetness, nice, soft, light, tasty, pleasant, palatable, better with cream); [3]volunteers who provided negative comments (namely sweetness, dry, tasteless, bitter, weak, grainy, dense, chewy, heavy, claggy, unpleasant, horrid, disappointing, rather messy with cream).

Volunteers' protein fortified products consumption habits were categorised into two groups: "yes, I consume protein fortified foods and/or beverages (less than once per month to once a day)" and "no, I do not eat/drink protein foods and/or beverages". There was a significant association ($p < 0.0001$) between protein fortified product consumption and age, where older adults infrequently consume protein fortified products compared with younger adults (Figure 8).



Figures 8A and 8B. Overview of volunteers protein fortified consumption habits **(A)** frequency distribution (*n* = 116; younger adult (YA): *n* = 58; older adult (OA): *n* = 58) and **(B)** volunteers that consume protein fortified products (n = 52/116) time of consumption.

4. Discussion

4.1. Mouthdrying detection threshold (MDT)

The MDT demonstrated mouthdrying was detectable in all WPBs compared with the control (WPeB). The estimated whey protein detection threshold was 0.41% w/v protein and these levels are considerably lower than most commercial WPBs. The resulting threshold was analysed using binomial and beta-binomial models (suitable for a trained panel often, having a small sample size with replicated results) for all 16 individual protein levels and subsequently fitted into a linear regression to obtain a 50% discriminator level. However, the BET method resulted in a higher estimated threshold most likely due to this method being considered less accurate, which can lead to individual thresholds potentially being over-estimated (especially if individuals fail to correctly identify the highest protein level) (ISO, 2018). Therefore, regardless of the statistical approach, mouthdrying was detectable at low protein levels by a trained panel. In addition, confounding factors were minimised as the control (WPeB) was matched with all protein levels in terms of sweetness and viscosity. There were relatively small fat differences in samples (0.008% to 0.95% w/v); however, such small differences in fat are unlikely to contribute to mouthdrying (Norton et al., 2021c). Furthermore, all samples were presented in sealed cups with sip lids to mask any visual differences. Previous work in this area has used a range of low pH WPB models (β-lactoglobulin, lactoferrin, whey protein isolate (WPI), process whey protein (PWP) and acidic process whey protein (aPWP)) (Sano et al., 2005; Kelly et al., 2010; Ye et al., 2012). These studies have utilised rating scales (0-5-, 0-7- and 0-15-point scales) and used no ratio set progression between protein levels; however, they have also demonstrated that mouthdrying can be detected at low protein levels (less than 3.0% protein). They focused on low pH WPB, whereas our study used a neutral pH WPB. This could suggest that mouthdrying is detectable at low protein levels regardless of potential differences in mechanism between low and neutral pH systems (Sano et al., 2005; Kelly et al., 2010; Ye et al., 2012; Norton et al., 2021b). Mouthdrying can be detectable at low levels using: lactoferrin (0.05%) (Ye et al., 2012), aPWP (0.07%), PWP (0.10%), (Sano et al., 2005), WPI (0.15%) and β-lactoglobulin (0.25-3.0%) (Kelly et al., 2010; Ye et al., 2012) (all in low pH WPBs; % w/v or wt/wt). These levels are comparable to the 0.41% (w/v) demonstrated in our study using a neutral pH WPB (SF-WPC). The accuracy and/or differences in detectable protein levels could depend on the: (1) specific sensory test used (rating scales versus discrimination testing); (2) increments in protein level; and/or (3) protein type. It is also likely that once mouthdrying is detected individuals will subsequently find it more difficult to detect the differences between levels since such effects can build with repeated sips (Methven et al., 2010). This supports Kelly et al. (2010) that noted mouthdrying plateaus at higher levels (4.0-13.0% wt/wt protein). All these findings have important product implications since on-the-market WPBs are typically between 6.0-10.0% w/v protein, which is considerably higher than the 'lowest' detectable mouthdrying WPB.

4.2. Mouthdrying just-noticeable difference (JND)

The JND testing demonstrated individuals differ in mouthdrying thresholds; however, most individuals (over 70%) could tolerate a 1.00% w/v increase in protein level without registering an increase in mouthdrying. However, older adults were more sensitive to WPB mouthdrying compared with younger adults. This supports previous mouthdrying research in dairy beverages which also used discrimination testing; therefore, highlighting the enhanced discriminating abilities of older adults compared with younger adults (Withers et al., 2013). It is suggested that older adults are more sensitive to mouthdrying due to potential age-related effects, such as increased protein retention (Norton et al., 2020a), reduced saliva flow (Vandenberghe-Descamps et al., 2016) and/or a dry mouth (Thomson, 2016).

This study was limited by the number of samples that could be provided within the JND subset; accordingly, at the 50% discriminators level the JND threshold was unable to be established. Therefore, subsequent testing with less tight protein progression would be recommended to determine a more accurate threshold than estimated by the BET method for those considered above threshold. However, as alluded to in a review on sensory methods for older adults, providing a balance between the number of samples versus sample fatigue is a key issue within older adults (Methven et al., 2016). In addition, the tight progression (i.e. ×1.25) between samples could have led to samples being considered too similar; therefore, resulting in less than 50% of individuals detecting a difference at each level. As noted within the MDT subset, once mouthdrying is detected, it is less easy to detect any increase in mouthdrying or difference between samples. This could be the reason why individuals found it challenging to select correctly the more mouthdrying WPB within all five pairs, despite the increasing protein content. Therefore, future work could focus on determining an exact JND threshold for whey protein derived mouthdrying and to achieve this both optimising protein level progression and the number of samples is needed. It should also be noted that our study was unable to collect saliva samples (due to the ongoing COVID-19 pandemic) and differences in saliva flow have recently been correlated with mouthdrying build up in ONS (Lester et al., 2021). Therefore, such differences in mouthdrying sensitivity may relate to saliva flow groups; however, this needs further proof in older adult populations and using balanced saliva flow groupings. The individual differences in mouthdrying sensitivity could impact product compliance and understanding them could assist in providing product suitability for the ageing population. Our study also supports the use of 2-AFC tests as providing useful mouthdrying results in both a home setting (as per this current study) and a sensory laboratory (Withers et al., 2013; Norton et al., 2021b).

4.3. Whey protein beverages (WPB) rating

Increased protein levels in WPBs correlated with negative effects such as reduced liking and easiness to consume as well as increased mouthdrying. However, flavour intensity was closer to JAR with increased protein levels which may suggest WPBs, especially those with lower protein content, were perceived to lack flavour. This would be expected since the WPBs used in our study had no added flavour and accordingly adding flavour would be suggested in order to mask the associated undesirable whey related flavours which were more prevalent at the higher protein levels. This could also imply that texture related attributes (mouthdrying) had a greater effect than flavour related attributes on liking. However, it should be noted that our consumers may not have been able to separate clearly their subjective scoring between flavour and mouthfeel. Previous work, investigating differing protein levels in WPBs, has typically focused on low pH WPBs (as alluded to in Section 4.1). This demonstrated that increasing protein levels (0.01-5.0% w/v or wt/wt) in different WPBs models resulted in higher mouthdrying (Sano et al., 2005; Kelly et al., 2010; Ye et al., 2012) which subsequently plateaued at higher levels (4.0-13.0% wt/wt) (Kelly et al., 2010). These findings generally support our work in neutral WPBs which show that increasing protein levels increases mouthdrying.

Age-related effects were present between age groups, where older adults perceived all WPBs as easier to drink and swallow compared with younger adults. This is a relatively positive result, as it supports their suitability for an ageing population, despite the associated negative sensory attributes. This may be because the WPBs had a suitable thickness, perhaps perceived as neither too thin nor too thick; therefore, easily consumed (viscosity: 4.20-4.96 mPa·s, thicker than water but less viscous than above 50 mPa·s beverages). In addition, older adults may have considered the WPBs easier to drink due to altered sensory acuity compared with younger counterparts (Smith, Logemann, Burghardt, Zecker & Rademaker, 2006; Methven et al., 2012). For example, less acute flavour perception might increase tolerance for any off-flavour related notes. No additional age-related significant differences were present; however, such differences could have been suppressed due to the following: (a) all sensory evaluation was conducted using single sips (10 mL) to maintain adherence in a home setting; therefore, negative attributes (such as mouthdrying) could not build up over consumption (mouthdrying is suggested to build with repeated consumption) and (b) all testing was carried out using VAS (0-100) which may lack test sensitivity compared with discrimination testing. It is noteworthy that in our current study we recruited healthy community based older adults (aged 65 years or over); however, the group age average was 69.5 years which is towards the lower end of this age group. Future work using different older adult populations (such as 65-74 years and over 75 years) is recommended, as was recently done by Regan, Feeney, Hutchings, O'Neill and O'Riordan (2021), as the effects are likely to intensify with increased age. JND testing (Section 4.2) via 2-AFC tests demonstrated that older adults are more sensitive to mouthdrying; however, when WPBs were presented monadically using VAS (0-100) significant differences were not present. Such findings might imply the effect size is relatively small, but where such differences may be relevant then short simple sensitive discrimination tests (such as a 2-AFC) are recommended to investigate age-related mouthdrying.

4.4. Scones perception and liking

Consumers of differing ages found adding cream topping to whey protein fortified scones to have a positive effect. For example, increasing liking and easiness to consume as well as reducing mouthdrying. This supported our previous work involving a trained sensory panel and concluded that increasing fat (via cream topping), hence increasing lubrication, is an effective strategy to suppress perceived mouthdrying in a whey protein solid food model. Moreover, future work should focus on methods to increase lubrication (without the need to add cream), ensuring a sufficient effect size and investigating subsequent effects on food bolus within such products. Rosenthal and Yilmaz (2015) found that when hard-to-swallow foods (such as nut butters) are manipulated in the mouth, moisture is removed from the saliva in order to hydrate the food. Additional hydration or lubrication can reduce the hard-to-swallow phenomenon. Such findings were demonstrated in our study by adding cream topping to whey protein fortified scones, which subsequently increased easiness to consume. This suggests a broader approach to increasing protein hydration and in-mouth lubrication should be investigated.

Within the context of older adults, energy dense toppings (such as milk, cream, butter), which can be easily added to products, are often used to moisten food bolus (Cichero, 2016) and is a well utilised strategy within clinical settings to promote food intake (BAPEN, 2016). It should be noted that the cream topping was well received by the volunteers, as supported by their liking scores. Similarly in cream cheese (enriched with whey protein), added butter improved flavour and increased liking (Song et al., 2018). Furthermore, using 'familiar' foods has previously been considered a viable means of enhancing protein intake within an ageing population (Morilla-Herrera et al., 2016; Beelen de Roos & de Groot, 2017; Mills, Wilcox, Ibrahim & Roberts, 2018). Clotted cream fits this remit well and makes a whey protein solid food matrix more palatable.

Age-related differences between age groups were noted where older adults perceived scones as chewier than younger adults. This suggests that within whey protein fortified foods texture sensitivity can increase with age. Currently, the extent of such effects in whey protein fortified foods are relatively unknown since age-related differences were unable to reach significance in whey protein fortified cakes and biscuits (Norton et al., 2020b). However, in other food models, such as nuts, older adults noted hardness as a more dominant sensation (Hutchings, Foster, Grigor, Bronlund & Morgenstern, 2014) and had increased brittleness preference (Miyagi & Ogaki, 2014) compared with younger adults. Vandenberghe-Descamps, Laboure, Septier, Feron and Sulmont-Rosse (2018) developed an oral comfort questionnaire for an ageing population during food consumption. Products such as ground beef and protein enriched milk roll were perceived as 'less comfortable' and were associated with negative terms (i.e. hard/firm, dry, doughy and difficult to chew, swallow and humidify) (Vandenberghe-Descamps et al., 2018). Bolus properties also alter with age. For example, older adults have a more degraded bolus and perceived dryness as a more dominant attribute (during the latter stages of consumption only) as result of increased consumption time post sausage consumption than younger adults (Aguayo-Mendoza, Martinez-Almaguer, Pigueras-Fiszman & Stieger, 2020). It is likely that the reduced saliva flow and/or dental status in older adults leads to poor oral clearance (Turner & Ship, 2007; Razak et al., 2014; Vandenberghe-Descamps et al., 2016) or alternatively increased protein retention within the oral cavity (Norton et al., 2020a) resulting in foods being perceived as chewier or harder. Interestingly, no other significant age-related effects were present in our study. This highlights the challenges of sensory testing with older adults when researching age-related differences. In addition, texture sensitivity with age may be attribute, product and segment (age or population) based (Song, Giacalone, Johansen, Frost & Bredie, 2016; Norton et al., 2021a).

5. Conclusion

Mouthdrying was detectable regardless of the protein level and a MDT was estimated at 0.41% w/v protein. JND testing noted many naïve consumers could tolerate at least a 0.67% w/v increase in protein content without detecting an increase in mouthdrying; correspondingly, this led to the JND threshold being unable to reach 50% discriminators. However, older adults were more sensitive to mouthdrying than younger adults. Such findings are important since previous research has not typically focused on individual differences and could be key to ensure that whey protein products meet the needs of the consumer. Similarly, at higher protein levels (more relevant to commercial products) increasing protein content within WPBs increased mouthdrying and reduced liking. Accordingly, this work demonstrated that mouthdrying was clearly present in WPBs whatever the protein level. Therefore, future work should focus on proposed causes and methods to suppress mouthdrying, whilst taking account of individual differences, to maximise the benefits and encourage protein intake, especially in an ageing population. Scones with cream topping successfully improved palatability of whey protein fortified models, suppressed mouthdrying and increased liking in consumers of both age groups. This resulted from enhanced lubrication via fat; however, future work should focus on improved methods to increase lubrication within whey protein fortified foods. In addition, since older adults found the whey protein fortified scones chewier this also emphasises the importance of protein products being formulated to meet the needs of older consumers to enhance protein intake.

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