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# The impact of varying key sensory attributes on consumer perception of beer body

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ABSTRACT

Beer body remains a poorly defined term, and although technical brewing experts currently describe it as the fullness of flavour and mouthfeel, little is known regarding the impact of different sensory factors on its perception. Previous studies have linked consumer understanding of beer body with viscosity (e.g. thickness, smoothness), alcohol warmth and flavour intensity. Therefore, modifications to these attributes in a base beer were explored. A commercial 0.05 % lager beer was used as the beer base, with ethanol additions at two levels to yield 2.8 and 4.5 % alcohol by volume (ABV), resulting in three levels in total for ethanol. Viscosity, bitterness and hoppy aroma were each increased to perceivably different levels by the addition of carboxymethyl cellulose (CMC), *iso*-α-acids, and hop oil extract, respectively, resulting in two levels for each (with addition and without). Beer samples (n = 18) were evaluated by naive UK beer consumers (n = 100) for overall liking, the intensity of perceived body and consumer-derived attributes using the Rate-All-That-Apply (RATA) technique. A 4-way ANOVA revealed significant positive effects of all four variables ($p < 0.05$) on body intensity ratings and significant impacts of ethanol, bitterness and aroma on overall liking. Correlation of RATA data with overall beer body ratings showed positive correlations with sensory attributes; smooth, overall flavour, overall aftertaste, hoppy flavour and negatively correlated with watery mouthfeel. Furthermore, cluster analysis was conducted on the body intensity ratings revealing three distinct consumer clusters based on the variables. This research suggests that beer consumers are not a homogenous group when it comes to body perception, and they place different levels of importance on different variables and their associated sensory attributes.

## 1. Introduction

Body, palate fullness, and mouthfeel are sensory attributes widely used in the literature to describe beer. Technical experts and consumers frequently use body as an umbrella term to describe multiple mouthfeel characteristics in alcoholic beverages (Gawel et al., 2007; Krebs et al., 2021; Niimi et al., 2017; Ramsey et al., 2018; Runnebaum et al., 2011; Sugrue & Dando, 2018). Mouthfeel is a complex sensory characteristic elicited by interactions between haptic, tactile, trigeminal sensations and temperature-induced impressions in the mouth that relate to the physical or chemical properties of a stimulus (DIN 10950-1 - Sensorische Prüfung - Teil 1: Begriffe, 1999; DIN EN ISO – 5492 Sensorische Analyse - Vokabular, 2009; British Standards, 2020; Sarkar et al., 2019). Pioneering work by Clapperton (1974), Meilgaard et al. (1979), and Langstaff et al. (1991), Langstaff and Lewis (1993a) explored terms used to describe beer mouthfeel, aroma and flavour and made important contributions to the beer terminology wheel. As a result of those studies, the modality of texture/mouthfeel was divided into three main categories, namely: carbonation (sting, bubble size, foam volume and total carbon dioxide), fullness (density and viscosity), and after-feel (oily mouth-coating, astringency and stickiness). However, a later modification proposed by Schmelzle (2009) suggested that mouthfeel should be added as a category of texture for benefit of the consumer and defined it by tingly, warming, astringent and pungent attributes, with two further categories, including body (viscosity and density) and foam (volume and structure), implying that body is a one-dimensional characteristic of texture (Schmelzle, 2009). Interestingly, the term fullness was replaced with the term body to describe density and viscosity. Throughout the

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literature, these terms often appear to be used interchangeably, or as an aspect of each other, e.g. body and watery used as bipolar scale anchors for the rating of beer palate fullness (Brown & Clapperton, 1978). The American Society of Brewing Chemists (ASBC, 2011) has expanded the technical definition of beer body to include flavour, defining beer body as *'fullness of flavour and mouthfeel'*. Furthermore, the definition includes descriptors resulting from Clappertons' work, namely thick, satiating, characterless and watery (Clapperton et al., 1976); however, reference standards for those sensory terms are not provided, making sensory panel training on these attributes difficult. Previously, concerns were also raised about the interpretation of body in wine research (Gawel et al., 2007; Laguna et al., 2017; Vidal et al., 2015). In wine, the term body is used within red and white wine mouthfeel wheels to define weight, distinct from viscosity, yet the same reference standard (carboxymethyl cellulose, CMC) is proposed for both body and viscosity evaluation (Pickering & Demiglio, 2008). The majority of research to date exploring mouthfeel characteristics in alcoholic beverages and texture perception in general have focused on attributes, definitions and techniques for use with a trained panel. However, there is little research exploring consumer vocabulary and perception. In a previous exploratory study by the current author (Ivanova et al., 2021), consumer perception of beer body was investigated qualitatively, and consumers were found to understand beer body as a multi-sensory term of flavour (intensity, complexity), texture (smoothness, creaminess, thickness, alcohol warming, mouth-coating, astringency and carbonation), as well as other multi-faceted sensory concepts, such as complexity, balance, quality, preference and satiety. It was clear that olfactory, gustatory and haptic sensory perceptions overlapped when discussing beer body with consumers, suggesting that beer body is not a one-dimensional sensory characteristic, which agrees with previously conducted consumer research in wine (Niimi et al., 2017).

Other studies that included beer body in their lexicons investigated the influence of ethanol concentration on sensory attributes, including body (Ramsey et al., 2018) and the effect of macromolecular distribution, including polysaccharides, proteins and protein–polyphenol complexes on palate fullness (Krebs et al., 2021). Ramsey et al. (2018) presented beer body in their consumer-defined lexicon as a *'feeling of thickness/ fullness as beer is moved around the mouth'* and reported that sweetness, beer body and alcohol warming sensations were cited more frequently as the ethanol concentrations increased, suggesting that ethanol is an important contributor to beer body perception. Krebs et al. (2021) reported that original gravity was the highest influencing factor affecting the perception of palate fullness, as well as other parameters such as viscosity, total nitrogen content, and ß-glucan concentration.

The individual components that contribute to body in beer are not fully understood. Dextrins, polypeptides and ß-glucans (Kato et al., 2021; Krebs et al., 2019, 2021; Langstaff et al., 1991; Langstaff & Lewis, 1993b; Ragot et al., 1989) have been separately explored in the context of mouthfeel evaluation with trained sensory panels, and each of the individual components was found to affect beer fullness. The previous study that explored consumer perception of beer body (Ivanova et al., 2021) revealed that basic tastes and certain flavours were also admissible as drivers of body perception, including bitterness, malty, and hoppy flavours that have not been reported previously and require further investigation. However, there was some disagreement regarding drivers of body perception, suggesting that consumers may attribute different factors to body perception, which could be based on their past experiences. Studies exploring consumer body perception in alcoholic beverages are beginning to gain traction (Niimi et al., 2017) as body is a desirable attribute for reduced-alcohol beverages that consumers currently perceive as flavourless, empty, unbalanced and lower quality (Chrysochou, 2014; Shemilt et al., 2017). Reduced-alcohol beer is one of the fastest-growing segments within the market, with health consciousness and wellness trends identified among the major drivers of change in alcohol consumption (Ledovskikh, 2017). In order to develop low-alcohol beers that are acceptable to consumers, thereby lowering the risk of long-term health conditions associated with alcohol overconsumption and reducing caloric intake from the regular-alcohol beer counterparts, the perception of beer body and the factors contributing to and varying its perception must be understood. Furthermore, by exploring the consumer perception of body in beer, it is hoped that this will have cross category application to research in other low alcohol products such as wines, where industry are working hard on finding solutions, and more generally to the human perception of texture.

This study adopted an experimental design investigating the impact of four key variables on consumers' perception of beer body and hedonic response. To manipulate beer composition: ethanol was varied to explore the impact of different alcohol levels; carboxymethyl cellulose (CMC) was added as a viscosity enhancer; *iso*-α-acids were included to investigate the impact of bitterness, and hop oil extract was used to enhance the hoppy aroma.

The proposed hypothesis was that increasing alcohol, viscosity, bitterness and beer-related aroma intensity would increase perceived body intensity in beer. Previous research reported by Ivanova et al., (2021) suggested body perception is a multi-dimensional sensation, and body perception could be driven by different sensory factors, including taste and mouthfeel attributes but this has yet to be investigated using a systematic approach. Furthermore, this study provided an opportunity to gain further insights into a consumer definition of body and explore to what extent different factors drive consumers' perceptions of beer body.

## 2. Materials & methods

Ethical approval was granted from the University of Nottingham's Medical Ethics Committee (Ref. number: 256–1903). Informed consent was collected from all participants prior to study commencement. An appropriate inconvenience allowance was offered to the participants on study completion.

### *2.1. Participants*

Regular beer consumers from the UK who consumed beer at least once a week (n = 100: 40 men, 60 women; aged 18–71 (mean age: 30)) were invited through an established consumer database at the Sensory Science Centre (University of Nottingham, UK) to participate in this study. Exclusion criteria included being under the UK legal drinking age (18 + ), having any medical (including potential pregnancy), religious, allergy or lifestyle reasons that prevent participants from alcohol consumption or any oral sensory impairment.

### *2.2. Beer samples*

Prior to sample development, instrumental analysis of a collection of beer samples was conducted to establish realistic levels that could be applied within the consequential sample design (see supplementary S1). A design space varying in four compositional factors: ethanol (EtOH: 0.5 %, 2.8 % and 4.5 % alcohol by volume (ABV)), carboxymethyl cellulose (CMC: 'low' and 'high'), *iso*-α-acids (IαA: 0 and 60 μL/L), and hop oil extract (HopOE: 0 and 280 μL/L). 'Low' corresponded to the viscosity of the samples prior to the modification with CMC (1.7 ± 0.03 mPa·s) and 'high' to 0.16 % CMC concentration (3.5 ± 0.06 mPa·s) was created resulting in 18 samples, (including one experimental replicate), which are detailed in Table 1. Levels of addition were chosen to be perceivably different from the untreated control and tested with a sub-set of naïve assessors (n = 12) using Triangle tests (data not shown). Instrumental analysis showed that ethanol and CMC additions resulted in an significant increase in measured alcohol levels and instrumental viscosity (see supplementary S1 and Table S1).

#### *2.2.1. Preparation of experimental beer samples*

To create samples with the various compositional factors detailed in Table 1, a 0.05 % ABV commercial lager beer (Leça do Balio, Portugal)

**Table 1**
Experimental design based on four compositional factors (ethanol (EtOH, E), viscosity (CMC, V), bitterness (IαA, B) and aroma (HopOE, A) at different levels).

| **Experimental design** | | | | | |
|---|---|---|---|---|---|
| **Sample Number** | **EtOH (%)** | **CMC** | **IαA (μL/L)** | **HopOE (μL/L)** | **Sample Code** |
| | **E** (Ethanol) | **V** (Viscosity) | **B** (Bitterness) | **A** (Aroma) | |
| 1 | 0.05 | Low | 0 | 0 | $E_0V_0B_0A_0$ |
| 2 | 0.05 | Low | 0 | 280 | $E_0V_0B_0A_1$ Rep$^1$ |
| 3 | 0.05 | Low | 0 | 280 | $E_0V_0B_0A_1$ Rep$^2$ |
| 4 | 0.05 | Low | 60 | 0 | $E_0V_0B_1A_0$ |
| 5 | 0.05 | High | 0 | 280 | $E_0V_1B_0A_1$ |
| 6 | 0.05 | High | 60 | 280 | $E_0V_1B_1A_1$ |
| 7 | 0.05 | High | 60 | 0 | $E_0V_1B_1A_0$ |
| 8 | 2.8 | Low | 0 | 280 | $E_1V_0B_0A_1$ |
| 9 | 2.8 | Low | 60 | 0 | $E_1V_0B_1A_0$ |
| 10 | 2.8 | Low | 60 | 280 | $E_1V_0B_1A_1$ |
| 11 | 2.8 | High | 0 | 0 | $E_1V_1B_0A_0$ |
| 12 | 2.8 | High | 60 | 280 | $E_1V_1B_1A_1$ |
| 13 | 4.5 | Low | 0 | 280 | $E_2V_0B_0A_1$ |
| 14 | 4.5 | Low | 60 | 0 | $E_2V_0B_1A_0$ |
| 15 | 4.5 | Low | 60 | 280 | $E_2V_0B_1A_1$ |
| 16 | 4.5 | High | 0 | 0 | $E_2V_1B_0A_0$ |
| 17 | 4.5 | High | 0 | 280 | $E_2V_1B_0A_1$ |
| 18 | 4.5 | High | 60 | 280 | $E_2V_1B_1A_1$ |

Sample 1 shows an unmodified sample ('base'); Samples 2 and 3 show the 2 experimental replicates, and Samples 12 and 18 show samples with all compositional factors modified in various combinations ('extreme').
**Samples codes:** Ethanol (E, $E_0$ = 0.05 % (Low); $E_1$ = 2.8 % (Medium); $E_2$ = 4.5 % (High) v/v), viscosity (V, $V_0$ = no addition (Low); $V_1$ = addition (High) of CMC), bitterness (B, $B_0$ = no addition (Low); $B_1$ = addition (High) of *iso*-α-acids) and aroma additive (A, $A_0$ = base beer (Original), no addition; $A_1$ = addition of hop oil extract (Hoppy)).

with a mild, neutral flavour profile was used as a base beer to prepare samples with manipulated ethanol (EtOH), carboxymethyl cellulose (CMC), *iso*-α-acids (IαA), and hop oil extract (HopOE) composition. Firstly, the viscosity of the samples was adjusted by adding 80 mL of 1 % wt aqueous CMC (sodium salt, low viscosity, Sigma-Aldrich, Dorset, UK) stock solution prepared in advance or 80 mL of Evian still water (Danone, Paris, France) to 370 mL base beer to achieve 'high' (0.16 %, 3.5 ± 0.06 mPa·s) or 'low' viscosity (0 %, 1.7 ± 0.03 mPa·s) samples, respectively. For 0.5, 2.8 and 4.5 % ethanol samples, 0, 12.6 and 20.5 mL of 96 % food-grade ethanol (VWR International, Lutterworth, UK) and 30, 17.4 and 9.5 mL of Evian still water (Danone, Paris, France) were added, respectively, to 470 mL of base beer/water ('low' viscosity samples) or base beer/CMC ('high' viscosity samples) mixture. Furthermore, 30 μL *iso*-α-acid product (IsoHop®, BarthHaas GmbH & Co, Nurnberg, Germany, density: 1000–1200 kg/m$^3$, pH: 7.5–10.5, 30 % *w/v*) was added to 500 mL base beer/water/ethanol or base beer/water/water mixtures to achieve ~ 42 International Bitterness Units (IBUs) in samples with intensified bitterness. The base beer bitterness unit level was determined under the ASBC method Beer-23A (ASBC Method of Analysis., 2011) to be at ~ 12 IBUs. Lastly, for samples with modified aroma, 140 μL of 5 % hop oil extract (Totally Natural Solutions, Kent, UK) dissolved in propylene glycol (Fisher Scientific, Loughborough, UK) was added to the final sample mixtures. An equivalent volume of propylene glycol was added to samples with base levels of bitterness (~12 IBUs) and aroma (0 μL/L hop oil extract) to ensure consistency amongst samples. When the desired concentrations of all compositional factors were obtained, samples were degassed completely by sonication and mixed on a roller mixer for at least 6 h at room temperature to aid solubilisation. All samples were then refrigerated (5 ± 1 °C) before recarbonation.

*2.2.1.1. Re-carbonation of experimental beer samples.* After sample preparation, a batch carbonation system manufactured in-house (Medical Engineering Unit, University of Nottingham, UK) was used to recarbonate the experimental beer samples. The well-mixed, degassed samples were aliquoted into 1 L Duran Pressure Plus + bottles (Scientific Laboratory Supplies Limited, Nottingham, UK) in duplicate. External plastic meshing was used to protect bottles from accidental breakage when pressure was applied. The caps were tightly secured by placing a silicone sealing ring (RS Components, Corby, UK) inside the cap to prevent any gas leakage. Bottle caps (Fisher Scientific, Loughborough, UK) were modified in-house with a one-way connecting valve (RS Components, Corby, UK), which fitted to the coupling connector (RS Components, Corby, UK) upon initiation of $CO_2$ delivery. The one-way connecting valve ensured a steady flow until the desired level of $CO_2$ (controlled by the batch carbonator system) was achieved upon connecting to the coupling connector and isolation of the $CO_2$ flow upon disconnection (controlled by a shut-off valve). Two pressure gauges fitted on the batch carbonator system allowed close monitoring of the pressure delivered to and dispersed inside each bottle. To speed up the dispersion of $CO_2$ into the sample mixture, the bottle was disconnected and gently shaken. The steps were repeated as required until the equilibrium was achieved. Once $CO_2$ flow was isolated from the sample bottle, the bottles' correct pressure (2.5 volumes or 5 g/L) was confirmed, and the sample bottle was disconnected from the carbonator system. The samples were then stored overnight in the cold room (4 ± 2 °C), with sensory evaluation commencing the next day. All samples maintained a fixed $CO_2$ level (2.5 volumes or 5 g/L) selected as a representative carbonation level found in draught lager style beer (Briggs et al., 2004). Prior to each sensory session, samples were tested for pressure level to ensure no gas leakage had occurred overnight.

### 2.3. *Sensory evaluation*

Eligible consumers (n = 100) participated in three evaluation sessions (45 min each) held over six weeks at the Sensory Science Centre, Sutton Bonington Campus, University of Nottingham, UK. All sessions were performed in the ISO standard (ISO 8589:2007) isolated sensory booths with controlled temperature (23 ± 1 °C) and airflow conditions. At the beginning of the first session, a short presentation (10 min) was given to participants to explain the session protocol and to provide an opportunity to ask questions. All 18 experimental samples were evaluated across three sessions, i.e., 6 samples per session, presented in a randomised order. Each sample was served in two aliquots (each labelled with a random 3-digit code), which were dispersed from the pressurised bottle upon request to account for the loss of carbonation during evaluations.

All samples were served at 5 ± 1 °C (standard lager drinking temperature for consumers in the UK) (Dorado, et al., 2016) and presented monadically, following a blocked, randomised, balanced design according to the William Latin Square. No more than 1 unit of alcohol (8 g) was consumed in any one test session. Consumers were given a forced 1-min break between samples and a 2-min break after the first aliquot set to minimise fatigue and carryover effect. Unsalted crackers (Rakusens, Leeds, UK) and Evian still water (Danone, Paris, France) were provided for palate cleansing. The test was designed, and data was captured using Compusense© Cloud software (Guelph, Ontario, Canada). For the first aliquot (20 mL), consumers evaluated overall liking using a 9-point hedonic scale (Peryam, 1998) to measure consumer acceptability, after which they were asked to define beer body with an open-ended question. Once the first aliquot of all six beer samples presented in the session had been evaluated for overall liking, a fresh aliquot of the same 6 samples (30 mL), each labelled with a different random 3-digit code, was presented, again in a randomised order. Consumers were instructed to take a sip (~10 mL) and rate their perceived body intensity for each sample on a 7-point scale (1 = 'extremely low', 7 = 'extremely high').

Finally, consumers evaluated 11 consumer-generated sensory attributes (Table 2) using Rate-All-That-Apply (RATA) (Ares et al., 2014) with a 'not selected' option (equated to 0 for data analysis) with the remaining 20 mL. The attributes were randomised within the modality-specific block for each consumer, with 'overall aroma' always appearing first and 'overall flavour' and 'overall aftertaste' appearing last to ensure consistent sample evaluation. Consumers were asked to rate the intensities of the applicable attributes using a 7-point scale (1 = 'extremely low', 7 = 'extremely high') using the RATA question format (Ares et al., 2014).

Consumer-generated sensory attributes were developed with a subset of 10 naïve consumers who participated in a dedicated attribute generation session prior to the main test (Table 2). During the attribute generation session, naïve consumers were presented with a sub-set of 5 samples chosen from the design space to ensure the similarities and differences between the samples were apparent. Consumers were then asked to evaluate beer samples and record all attributes they perceived in each sample. All descriptive terms generated were then listed and grouped by modality, including aroma, flavour, mouthfeel, texture and aftertaste. The sensory attributes for analysis were selected based on the frequency of mention and relevance to the research question.

### 2.4. Data analysis

#### 2.4.1. Open-ended question

The responses to the open-ended question were analysed with content analysis and word frequency queries using qualitative data analysis software (nVivo®, SQR International Pty Ltd.). All responses were considered valid and were used for data analysis. Pre-processing of the collected raw text responses began with data cleaning, which included correcting the typing and orthographic mistakes and removing extra spaces, punctuation, and numeric digits. The raw text was then converted to lowercase. The matrix of content codes was developed manually from the raw text based on the principles of quantitative content coding (Krippendorff, 2010) and in line with the descriptive approach to thematic analysis (Braun et al., 2019). The codes were further grouped into categories, and the frequency of mention was calculated.

#### 2.4.2. Effects of modified factors on hedonic and body intensity responses

All the independent variables were treated as qualitative factors and four-way ANOVA with interaction was applied to examine the effect of ethanol, viscosity, bitterness and aroma on body intensity and hedonic responses. The independent variables included ethanol at three levels and viscosity, bitterness and aroma at two levels and were partitioned into main effect and two-way interactions, three-way and four-way interactions. Four- and three-way interactions were not found significant due to the complex model fit, therefore, only main effect and second-order interactions were considered. Judge effects were explored within the ANOVA model but no model improvement was found. A subsequent post-hoc test (Fisher's Least Significant Difference (LSD)) was performed to compare all possible pairs of means with a predetermined significance level of $p < 0.05$.

**Table 2**
Consumer-generated discriminating attributes and their definitions.

| Attribute | Definition |
|---|---|
| *Basic Taste* | |
| Bitter Taste | Taste on the tongue associated with caffeine or bitter beer |
| Sweet Taste | Taste on the tongue associated with sugar/ sucrose |
| Overall Aftertaste | Perception of taste 15 s after swallowing |
| *Flavour Attributes* | |
| Malty/ Biscuity Flavour | Sweet, nutty, malty cereal, biscuit-like flavour |
| Hoppy Flavour | Fresh hop flavour, including herbal, grassy, flowery and earthy notes |
| Acidic/ Citrus Fruit Flavour | The flavour associated with citrus fruits/ acids |
| Overall Flavour | The overall flavour associated with beer |
| *Mouthfeel Attributes* | |
| Watery/ Thin Mouthfeel | Absence of texture, water-like |
| Astringent/ Dry Mouthfeel | Causing dryness in the mouth and on the tongue |
| Creamy/ Smooth/ Mouth-coating | The feeling of texture, coating sensation in the mouth |
| *Aroma Attributes* | |
| Overall Aroma | Overall aroma associated with beer |

#### 2.4.3. Consumer clustering based on body rating

To assess whether patterns of body rating varied across consumers, a cluster analysis using k-means with 'Trace W' as the clustering criterion, pooled within the covariance matrix, as a classification criterion was performed. To determine the appropriate number of clusters the clustering algorithm (k-means clustering) was computed for different values of k (1–10). For each k, the total within-cluster sum of squares (WSS) was calculated and the curve of WSS was plotted according to the number of clusters k. K-means clustering algorithm was run multiple times (k^100) to minimise the chances of local minima. To help identify the factor driving each cluster, one-way ANOVAs with body intensity as dependent variable and all samples as independent variables, followed by a post-hoc test (Fisher's LSD) were subsequently applied to examine differences between samples within each cluster.

#### 2.4.4. Comparison of sample discrimination based on RATA analysed with parametric methods

PCA was conducted for the experimental beer sample set (n = 18) with mean consumer RATA responses for 11 attributes and supplementary quantitative variables, including overall hedonic score, overall body intensity rating, consumer clusters and instrumental measurements (ABV% and dynamic viscosity) to increase the interpretation quality. Furthermore, modified factors (ethanol, viscosity, bitterness and aroma) were added as supplementary qualitative variables.

All data apart from the open-ended question were analysed using XLSTAT (XLStat 19.3.2, Addinsoft, New York, USA).

## 3. Results

### 3.1. The consumer definition of body in beer

The consumer definition of beer body was explored via consumer responses to the open-ended question during their first sensory session. Content analysis revealed 32 different content codes from the words that consumers used to describe beer body, namely, texture, thickness, silkiness and viscosity, smoothness, flavour and intensity of flavour, aroma, taste (including bitterness), aftertaste, heaviness and weight, mouthfeel, fullness, balance/ whole experience, mouth-coating, sensation, strength, complexity, density, satiety, carbonation and foaminess, lightness, ease of drinking, caloric density, appearance, volume and richness. It also included certain flavours mentioned in association with beer body, including hoppy, citrus, caramel, and earthy. Furthermore, content codes and attributes were collated into 10 categories, with mouthfeel having the highest percentage of mentions, followed by flavour, viscosity and intensity (Table 3).

### 3.2. Effect of modified factors on hedonic and body intensity responses

Four-way ANOVA (with interaction) revealed a significant impact of ethanol, bitterness and aroma on overall liking ($p < 0.001$). Hedonic response was positively driven by the addition of ethanol ($p < 0.001$), with higher alcohol beers scoring significantly higher in overall liking (Fig. 1A). Interestingly, viscosity levels did not have a significant effect ($p > 0.05$) on the hedonic response. Furthermore, beers with higher bitterness or enhanced hoppy aroma scored lower in overall liking, indicating bitterness and hoppy aroma were negative drivers of overall liking (Fig. 1B and 1C). A significant two-way interaction between ethanol and bitterness levels was found. Consumer liking scores were significantly higher ($p < 0.05$) for samples with lower bitterness level

**Table 3**
Categories identified in the open-ended question in which beer consumers (n = 100) were asked to define body of beer in their own words, and the percentage of mentioned responses within each category.

| Category | Examples | Percentage of mention *(%)* |
|---|---|---|
| Mouthfeel | mouth, feel, feeling, feels, mouthfeel, sensation | 87 |
| Flavour | taste, flavour, flavours, aftertaste | 80 |
| Viscosity | thick, thickness, thin, viscosity, texture, watery, wateriness | 40 |
| Intensity | intense, intensity, strength | 26 |
| Fullness | full, fullness | 20 |
| Depth | deep, depth | 16 |
| Heaviness | heaviness, heavy, weight | 15 |
| Mouth-coating | coated, coating, coat, coats | 7 |
| Balance | balance, whole, combination, combined | 5 |
| Complexity | complex, complexity | 5 |

(no addition of *iso*-α-acids) at both low and medium alcohol levels; however, at the higher alcohol level, bitterness level did not have a significant effect on overall sample liking (Fig. 1D) indicating that bitterness levels should be kept lower in low alcohol beers in order to optimise consumer liking.

A significant two-way interaction between bitterness level and aroma was also found (Fig. 1E, $p < 0.05$), where the negative effect of hop oil extract addition is higher when bitterness is high (added *iso*-α-acids) in contrast to when it is low (no hop oil extract added). This indicates that if bitterness is kept low in low alcohol beers then the hop aroma should be matched in intensity in order to optimise liking. No significant three-way or four-way interactions were found ($p > 0.05$).

The majority of the beer samples were perceived by consumers as acceptable (scoring 5 and above on the 9-point hedonic scale), with only three samples ($E_0V_1B_1A_1$, $E_1V_0B_1A_1$, $E_1V_1B_1A_1$) receiving a mean liking score of less than 5 (Supplementary Table 2).

For body intensity, four-way ANOVA with interaction revealed statistically significant differences for ethanol, viscosity, bitterness levels at $p < 0.001$ (Fig. 2A, 2B and 2C) and aroma at $p < 0.05$ (Fig. 2D), with each positively contributing to body intensity ratings. Beer samples that included all four modified factors ($E_2V_1B_1A_1$ and $E_1V_1B_1A_1$) scored highest in body intensity (Supplementary Table 2).

Moreover, there was a significant two-way interaction between the ethanol and bitterness levels (Fig. 2E, $p < 0.001$), where there was a positive effect of bitterness on body intensity perception, but only when ethanol is at the low or medium level. These results indicate that bitterness level should be carefully considered in a low alcohol beer because whilst bitterness may negatively contribute to liking, it can positively contribute to body perception. Whilst not significant ($p = 0.08$), a similar two-way interaction trend was observed between ethanol and viscosity, where higher ethanol induced greater body intensity at low viscosity but not at higher viscosity (Fig. 2F). There were no significant three-way or four-way interactions ($p > 0.05$). Overall, results showed strong evidence for accepting the hypothesis that ethanol, viscosity, bitterness and aroma positively contribute to consumers' perception of body in beer.

### 3.3. Consumer clustering on beer body perception

Cluster analysis (k-means) was performed on body intensity scores to explore if different groups of consumers had different drivers of body perception, as suggested by previous research (Ivanova et al., 2021). Subsequently, three consumer clusters were identified. To help identify the trends driving each cluster, one-way ANOVAs with body intensity as a dependent variable and all samples as independent variables, followed by a post-hoc test (Fisher's LSD) were applied to each of the clusters (Fig. 3). Within cluster 1 ($n = 34$) there was a trend of greater body intensity ratings for samples with higher viscosity (V1, mean body score 4.8) compared to those with low viscosity (V0, mean body score 3.8), and this cluster was therefore named the Viscosity Driven Cluster (Fig. 3A). Cluster 2 ($n = 34$) perceived samples with modified bitterness (B1) as higher in body (mean body score 5.1) compared to samples with low bitterness (B0, mean body score 4.3). Furthermore, there was a trend that all samples with both modified bitterness and aroma (…B1A1) were perceived to have greater body intensity than those with only modified bitterness (…B1A0), so this cluster was named the Flavour Driven Cluster (Fig. 3B). The trend for cluster 3 ($n = 32$) was not as clear as for the other clusters because this cluster provided lower overall body intensity ratings. However, there did appear to be a modest trend in relation to ethanol addition where the majority of samples with 4.5 % ABV (E2) were perceived to have greater body (mean score 4.1) than those with no alcohol addition (E0, mean score 3.7) and, after consultation with the PCA (see section 3.4 and Fig. 4) was named the Alcohol Driven Cluster due to correlations with higher alcohol. Basic demographic information (e.g. age, gender) was collected but no trends based on clustering solutions were found.

### 3.4. Effects of modified factors on sensory properties and body perception

Significant differences were found between samples for all sensory attributes evaluated using the RATA method (ANOVA, $p < 0.0001$). PCA resulted in 78.2 % of the variation in the data being explained in the first two dimensions. A bi-plot of the beer samples shows the scores and loadings from the PCA of the sensory data (Fig. 4).

The first dimension (F1, 46.3 %) distinguished beer samples on the right-hand side with intense overall flavour (OverallF), hoppy flavour (HoppyF), overall aroma (OverallA), aftertaste (OverallAf), bitter taste (BitterT) and astringent mouthfeel (AstringentMF) from those perceived as sweet (SweetT) on the left-hand side of the bi-plot. The second dimension (F2, 31.9 %) distinguished beer samples in the top half of the bi-plot perceived as smooth (SmoothMF) and malty (MaltyF) from those perceived to be watery (WateryMF) in the bottom half of the bi-plot.

Overall liking (**Overall Liking**) was positively correlated with sweet taste (SweetT, 0.625) and malty flavour (MaltyF, 0.549), and negatively correlated with bitter taste (BitterT, (-0.627)), overall aroma (OverallA, (-0.616)), hoppy flavour (HoppyF, (-0.538)) and astringent mouthfeel (AstringentMF, (-0.533)).

According to the Pearson correlation matrix ($p < 0.05$), overall beer body rating (**Body**) was positively correlated with sensory attributes, including smooth (SmoothMF, 0.796), overall flavour (OverallF, 0.785), overall aftertaste (OverallAf, 0.662), hoppy flavour (HoppyF, 0.627) and negatively correlated with watery mouthfeel (WateryMF, (-0.913)). Furthermore, a weaker yet significant correlation was observed with instrumental measurements of dynamic viscosity (DViscosity, 0.598) and alcohol (ABV%, 0.477).

The Viscosity Driven Cluster was positively correlated with dynamic viscosity (DViscosity, 0.821) and sensory attributes, including smooth mouthfeel (SmoothMF, 0.934) and malty flavour (MaltyF, 0.560), and negatively correlated with watery mouthfeel (WateryMF, (-0.898)). The Flavour Driven Cluster rated samples with more intense overall aftertaste (OverallAf, 0.789), hoppy flavour (HoppyF, 0.754), overall flavour (OverallF, 0.743), bitter taste (BitterT, 0.695) and overall aroma (OverallA, 0.597) as higher in body, and negatively driven by watery mouthfeel (WateryMF, (-0.659)). This cluster also did not significantly correlate with measured alcohol level (ABV%) or dynamic viscosity (DViscosity). Furthermore, the Alcohol Driven Cluster was positively correlated with higher alcohol (ABV%, 0.567), as well as sensory attributes such as overall flavour (OverallF, 0.674). A weaker yet significant positive correlation was also found between aftertaste (OverallAf, 0.501) and hoppy flavour (HoppyF, 0.488).

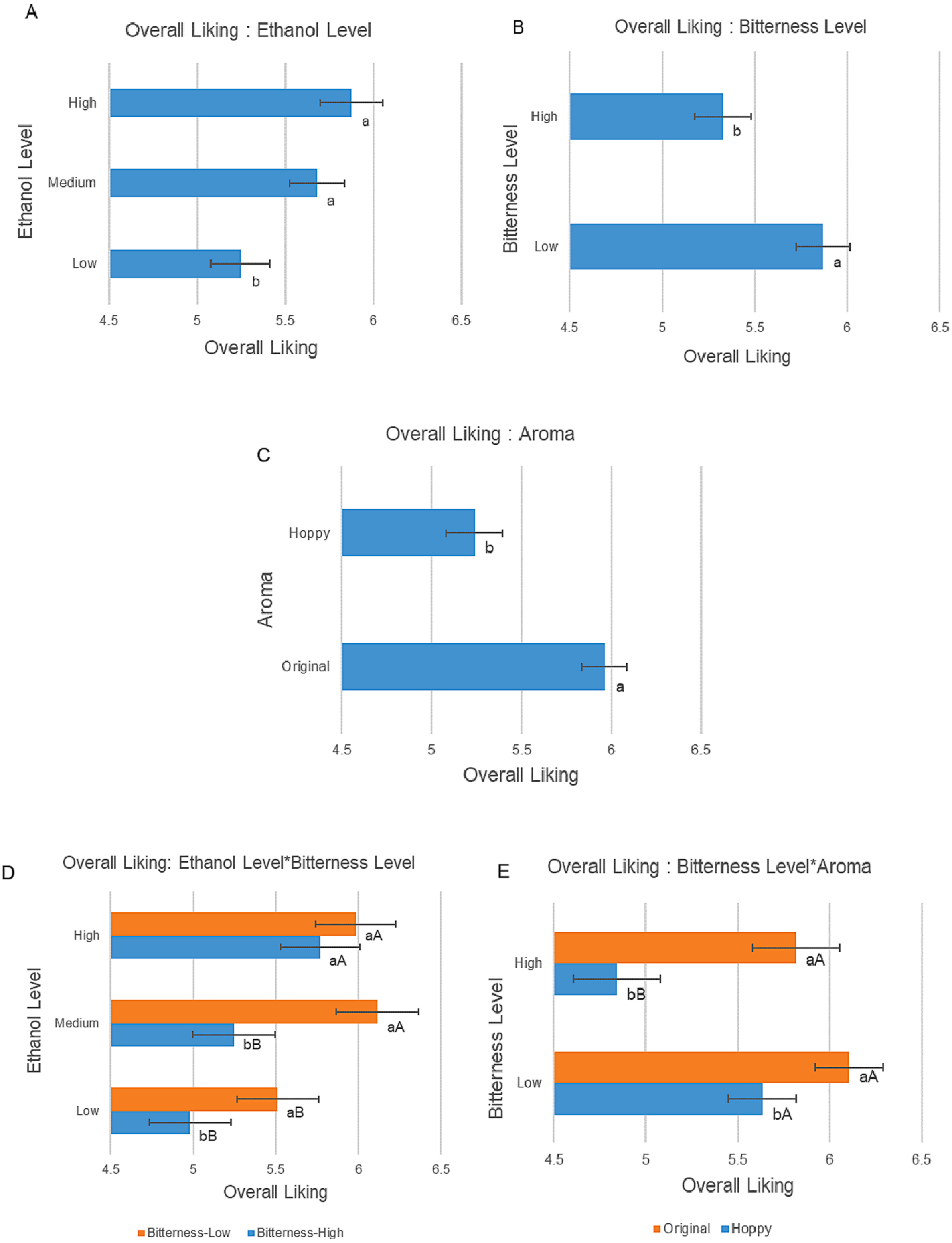

**Fig. 1.** Estimated marginal means of ethanol (A), bitterness (B), aroma (C), ethanol*bitterness (D) and bitterness*aroma (E) interaction and effects on overall liking. Different letters ($^{abAB}$) represent a significant difference between levels of the same compositional factor (lower case) and between levels within the interactions (upper case).

## 4. Discussion

### 4.1. The impact of ethanol

Ethanol was one of the main factors that positively influenced the perception of body and overall liking of the experimental beer samples when the samples were tasted. Yet, interestingly, beer consumers did not mention alcohol or alcohol-related attributes, such as warming or burning, as a defining characteristic of beer body in the open-ended question prior to tasting, supporting earlier findings demonstrated by

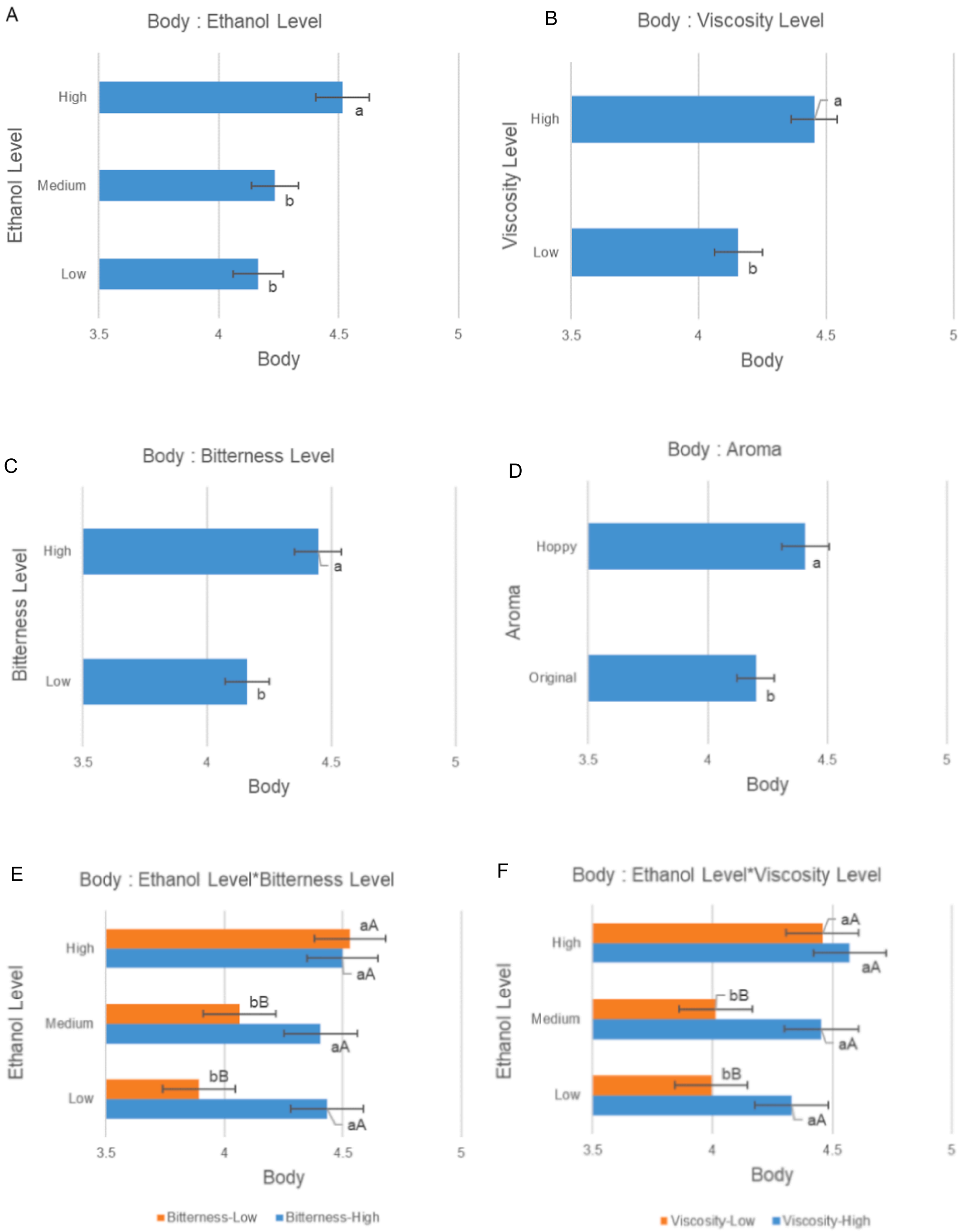

**Fig. 2.** Estimated marginal means of ethanol (A), viscosity (B), bitterness (C), aroma (D), and ethanol*bitterness (E) and ethanol*viscosity (F) interactions and effects on consumer beer body perception. Different letters ($^{abAB}$) represent a significant difference between levels of the same compositional factor (lower case) and between levels within the interactions (upper case).

wine consumers when exploring wine body (Niimi et al., 2017). However, consumers in a previous study mentioned alcohol warming as a contributor to beer body perception in a focus group setting without tasting (Ivanova et al., 2021) but this might be due to the nature of a focus group method as consumers are asked to think deeper than with an opened ended question within a questionnaire. Therefore, it seems that alcohol warming may not be one of the key attributes that all consumers consider when first thinking about body in beer. However, on tasting beers without alcohol, it may appear obvious to some consumers that something is missing, but this is not directly attributed to a warming sensation, or, a mouthfeel sensation, such as smooth mouthfeel as found in the present study (Fig. 4). The impact of alcohol on beer's taste, flavour, and mouthfeel characteristics has been previously researched. Studies have shown ethanol contributes to the perception of warming mouthfeel, sweetness, and complexity of beer flavour (Blanco et al., 2016; Clark et al., 2011a) and enhances alcohol warming sensation and greater perception of fullness/body (defined as *'feeling of thickness/fullness as beer is moved around the mouth'*) (Ramsey et al., 2018). In this study, experimental samples with higher ethanol concentrations (ABV %) were perceived to have a greater body and enhanced overall flavour (OverallF). It is evident from previous research that ethanol plays a key role in aroma partitioning and release in alcoholic beverages. It was

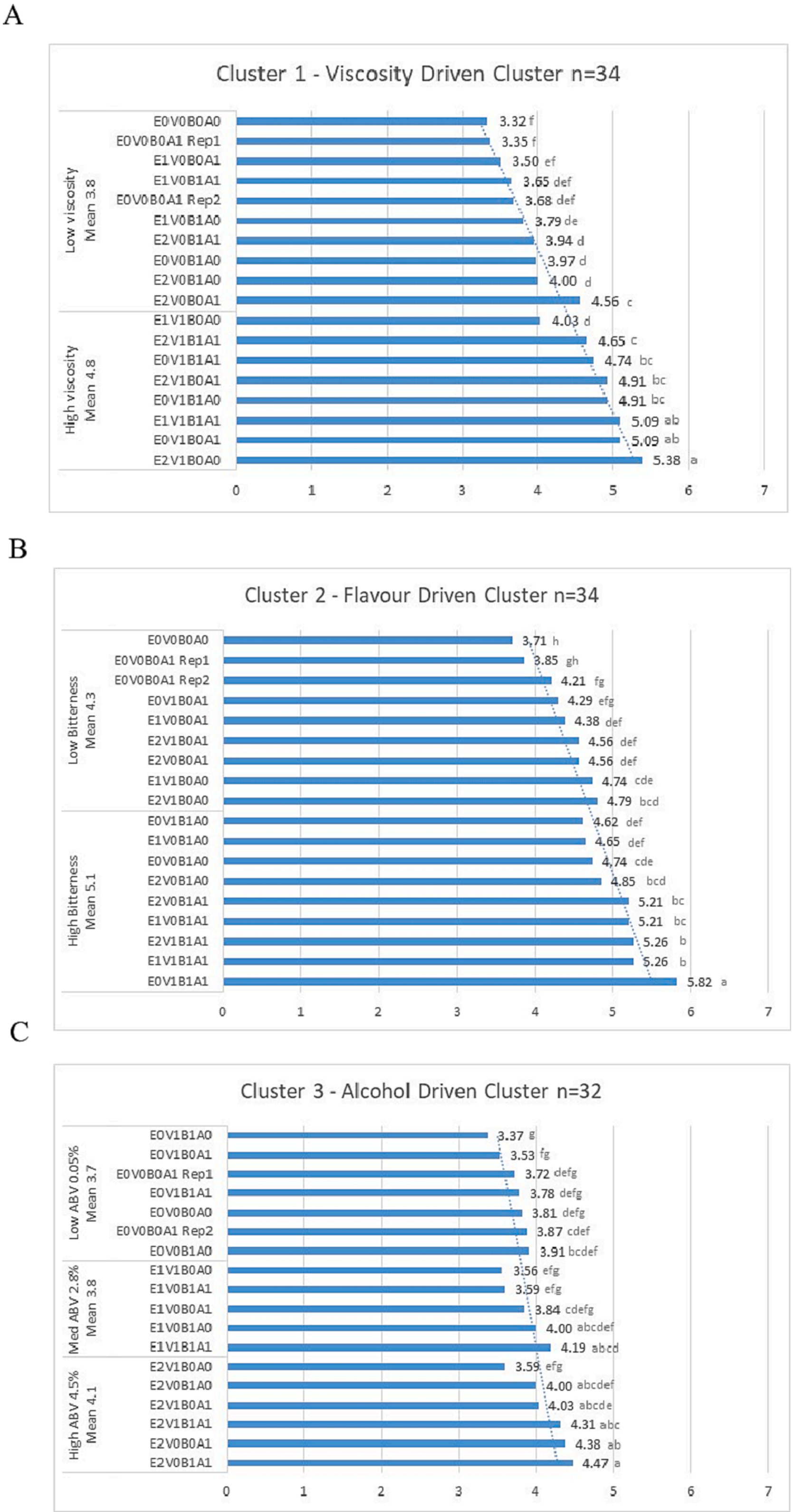

**Fig. 3.** Cluster analysis (k-means) performed on body intensity (7-point scale) yielding three consumer clusters (A: Viscosity Driven cluster (n = 34), B: Flavour Driven cluster (n = 34), C: Alcohol Driven cluster (n = 32)). Samples codes: Ethanol ($E_0$ = 0.05 %; $E_1$ = 2.8 %; $E_2$ = 4.5 % v/v), viscosity ($V_0$ = no addition; $V_1$ = addition of CMC), bitterness ($B_0$ = no addition; $B_1$ = addition of *iso*-α-acids) and aroma ($A_0$ = base beer, no addition; $A_1$ = addition of hop oil extract). The dotted line indicates the trend across individual consumer clusters. Mean body rating is displayed against individual beer samples and means per factor level are displayed to the left of the figure.

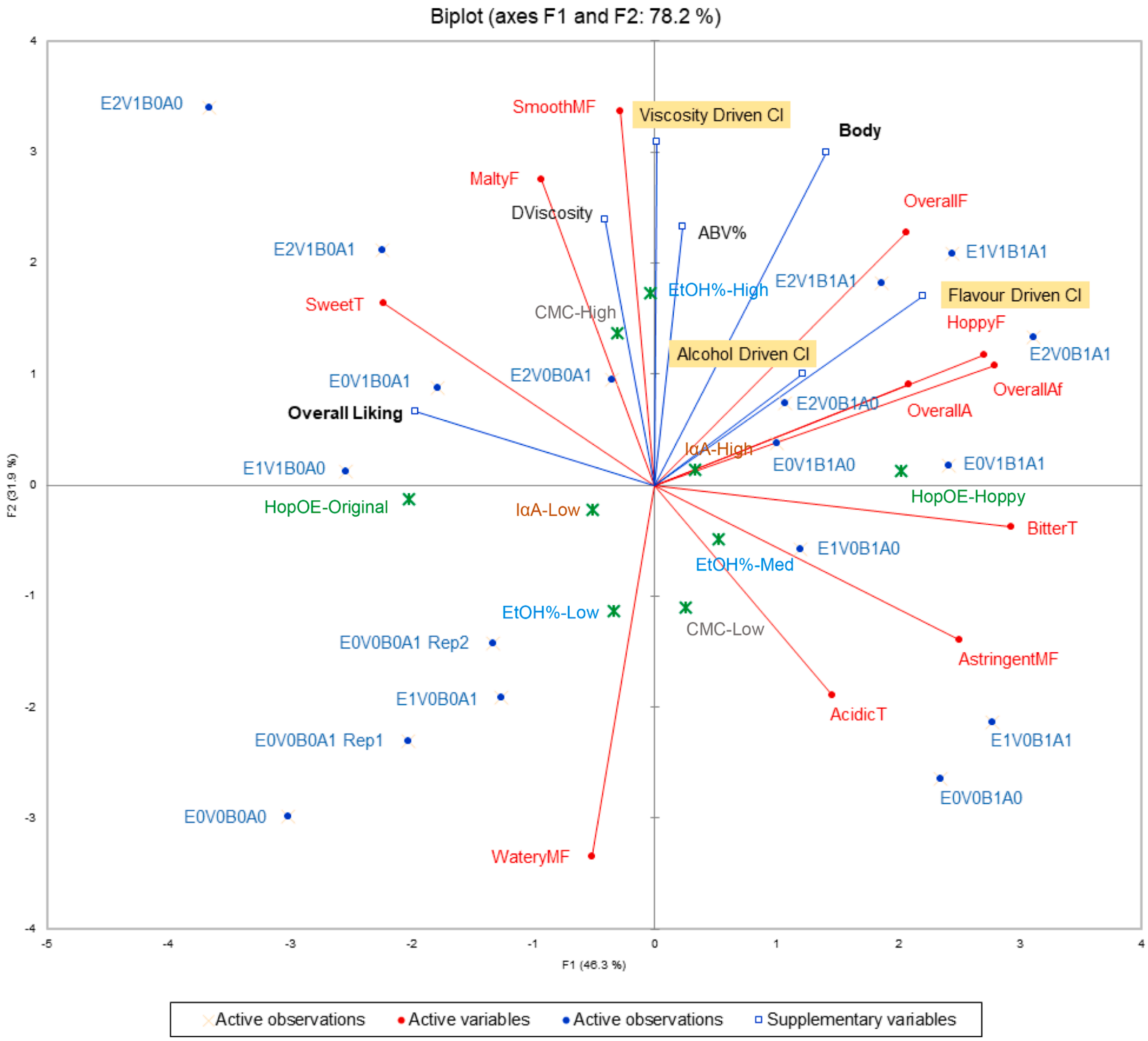

**Fig. 4.** Principal component analysis plot (F1 & F2: 78.2 %) of the sensory attributes that differentiated 18 experimental beer samples by the consumer panel (n = 100) using RATA, overlaid with the supplementary variables (body intensity ratings, overall liking, modified factors, instrumental measurements and consumer clusters) Beer samples (), sensory attributes () and supplementary variables (& ⁎). **Sample codes:** Ethanol (E, $E_0$ = 0.05 %; $E_1$ = 2.8 %; $E_2$ = 4.5 % v/v), viscosity (V, $V_0$ = no addition; $V_1$ = addition of CMC), bitterness (B, $B_0$ = no addition; $B_1$ = addition of *iso*-α-acids) and aroma additive (A, $A_0$ = base beer, no addition; $A_1$ = addition of hop oil extract). **Attributes:** A = Aroma, T = Taste, F = Flavour, MF = Mouthfeel, Af = Aftertaste. **Modified Factors**: E = Ethanol (EtO%-Low, EtO%-Med, EtOH%-High), V = Viscosity (CMC-Low, CMC-High), B = Bitterness (IαA-Low, IαA-High) and A = Aroma (HopOE-Original and HopOE-Hoppy). **Clusters by body:** Cluster 1 = Viscosity Driven, Cluster 2 = Flavour Driven, Cluster 3 = Alcohol Driven.

shown that increasing ethanol concentration in model beer results in an in-breath volatile increase, including ethyl acetate, isoamyl alcohol and phenylethyl alcohol, measured after consumption (Clark et al., 2011a), highlighting that alcohol removal may have a detrimental effect on beer flavour. The increased volatility was attributed to changes in surface tension affecting how the beverage coats the mouth during consumption, thereby resulting in increased volatile release (Clark et al., 2011a) which could explain the increase in perceived overall flavour at higher ethanol levels found in the present study. It should be noted that alcohol removal has a significant, detrimental effect on beer flavour and mouthfeel, showed in de-alcoholised lager beer (0.05 % ABV) exhibiting maltier flavour, with reduced fruitiness, sweetness, fullness/body and alcohol warming sensation (Ramsey et al., 2018), which highlights a more significant impact on the overall flavour, aroma release and mouthfeel profile than effect of ethanol concentration (0.05 – 4.5 ABV) on aroma release. However, it is yet unclear if the effect found instrumentally is capable of an increased sensory effect. Peltz (2015) found that ethanol concentration had a minor effect on hop compounds sensory detection thresholds, whereas Clark et al. (2011b) found ethanol to increase the perceived complexity of beer flavour with a trained sensory panel but not specific flavour attributes.

Furthermore, in contrast with other studies, where ethanol enhanced sweetness perception (Clark et al., 2011b; Ramsey et al., 2018, 2020), sweetness was not correlated to higher ethanol concentration but did contribute to overall liking.

Overall, this study shows that ethanol was one of the strongest factors contributing to body perception when quantitatively measured with consumer panel. The main positive impact of ethanol on beer body intensity at the low bitterness levels, but not at the high bitterness level was observed, suggesting that higher bitterness intensity is required in lower alcohol beers to achieve a similar body intensity response in consumers. However, this should be considered in relation to liking data which indicated that higher bitterness would reduce consumer liking in lower alcohol beers.

### 4.2. The impact of viscosity

In the present study, the thickness of the samples was modified with CMC to increase physical viscosity whilst limiting any impact to taste or flavour properties and was found to be a significant driver for beer body perception. The intensity of the watery attribute (WateryMF) was negatively correlated with beer body (**Body**), in agreement with previous research (Krebs et al., 2021), suggesting that experimental beer samples perceived as less viscous were recognised as being low in body. The samples that were perceived to be watery in this study either had one or none of the factors modified, suggesting that the addition of more of the selected factors influenced consumer perception away from perceiving samples as watery. Terms describing mouthfeel were mentioned by consumers most frequently when qualitatively defining beer body using the open-ended question and the quantitative consumer ratings show a positive correlation between the addition of CMC (CMC-High) and smooth mouthfeel (SmoothMF). However, viscosity was not the only factor impacting perceptions of smooth mouthfeel (SmoothMF); ethanol (EtOH%-High) was also correlated with smooth mouthfeel (SmoothMF), suggesting that it could be an important sensory attribute for overall mouthfeel, despite it being mentioned less than 5 % in relation to consumers definition of beer body in response to the open-ended question. This agrees with previous research where smoothness perception was found to increase with viscosity (thickness) as a function of both suspension viscosity and particle modulus (Shewan et al., 2020) but was not supported by earlier research where decreased smoothness did not affect beer body with a trained panel (Kaneda et al., 2002).

According to the PCA results, beer body ratings were significantly correlated with higher alcohol content (EtOH%-High) and dynamic viscosity (DViscosity). Similarly, a recent study explored macromolecular profiles and palate fullness in lager beers and demonstrated a significant correlation between palate fullness and analytically measured ethanol concentration and viscosity (Krebs et al., 2021). In another study, Krebs et al. (2019) explored non-alcoholic lager beers and showed no significant correlation between viscosity and the sensory perception of palate fullness, suggesting that within the common range of viscosities, the correlation between the thickness of the beer and palate fullness is less apparent. Krebs et al. (2019) noted that sensory attributes that are often mentioned to describe beer, including palate fullness, body and mouthfeel, are currently used indiscriminately due to the absent or inaccurate definition of those terms. Similar interchangeable terminology can be found in the wine literature (Lemos Junior et al., 2019) and requires further investigation. Overall, this study appears to show that whilst samples with greater viscosity were perceived to have more body, the relationship is more complex when other variables are considered, as seen in the PCA. Smooth mouthfeel (SmoothMF) was the term used by consumers to describe greater viscosity in tasted beers, yet this attribute was not correlated with body. However, watery mouthfeel (WateryMF) was negatively correlated.

### 4.3. The impact of bitterness and hoppy aroma

Significant differences were found amongst experimental beer samples containing *iso*-α-acids, where these samples were perceived as greater in overall flavour (OverallF), overall aftertaste (OverallAf), hoppy flavour (HoppyF), bitter taste (BitterT), overall aroma (OverallA) and astringent mouthfeel (AstringentMF). In comparison, samples without the addition of *iso*-α-acids (low in bitterness) were perceived as sweet (SweetT) and malty (MaltyF). Unsurprisingly, the addition of *iso*-α-acids (higher in bitterness) caused a negative effect on the overall liking of the experimental beer samples, which agrees with the previous research (Carvalho et al., 2017). The presence of hop oil extract, with the intension of increasing hoppy aroma in the experimental beer samples also caused a decrease in the overall liking. This notion might be explained by the fact that the majority of the consumers (45 %) in the present study identified as lager drinkers (compared with other beer style preferences: IPA (16 %), pale ale (14 %), craft (13 %)), which might explain a significant drop in their acceptance when consuming beer samples with enhanced bitterness and hoppy aroma as lager beer style beers tend to contain low levels of both.

Perceived bitterness drove body perception for the Flavour Driven cluster. This cluster was also correlated to sensory attributes such as hoppy flavour (HoppyF) and overall flavour intensity (OverallF), suggesting that the addition of *iso*-α-acids may have also contributed to the perception of these attributes. Furthermore, in addition to bitterness, hoppy aroma (addition of hop oil extract) also drove beer body perception, explored with 4-way ANOVA, suggesting that the presence of expected beer flavours may positively influence body intensity and highlighting the importance of congruent flavours. However, it is unclear if this effect is specific to hoppy aroma/flavour, as previous qualitative research (Ivanova et al, 2021) suggested dark fruit (blackberry, cherry, plum), citrus and tropical fruit (lemon, orange, pineapple), roast-associated flavours (chocolate, coffee, caramel, smoke, grain, oak, roasted malt), as well as hoppy, to be important for beer body perception. Similarly, Liguori et al. (2018) explored beers produced by osmotic distillation and reported a strong correlation between beer body and fruity/esters, fruity/citrus, malty, hoppy and alcoholic/solvent flavour attributes. Therefore, various beer flavours may drive body perception depending on the consumer. This study only explored the impact of the generic hoppy aroma; however, further research should examine the impact of a range of flavours on beer body perception.

Furthermore, samples with different bitterness levels (B0: IαA-Low and B1: IαA-High) showed clear separation on the plot, unlike samples with modified hoppy aroma (A0: HOE-Original and A1: HOE-Hoppy). It was previously reported that hop aroma could modify perceived bitterness by taste–aroma interactions (Oladokun et al., 2016). Oladokun et al. (2016) observed that the addition of hop aroma extract caused an increased bitterness intensity perception and demonstrated that the effect was driven by volatile hop aroma compounds stimulating receptors via the retronasal route. In this study, both *iso*-α-acids and hop oil extract drove taste attributes, suggesting that volatile hop aroma may have acted indirectly by enhancing bitterness perception which may have been the cause for the increase in perceived body, despite no significant interaction effect between bitterness and aroma. This is likely to be attributed a taste–aroma interaction (Auvray & Spence, 2008; Small & Prescott, 2005).

### 4.4. The impact of factor interaction

Interaction between two factors can be characterised as an additive, suppressive or synergistic (enhancement) using psychophysical curves (Keast & Breslin, 2003), where, respectively, the effects of combined perceived intensity are equal ($AB = A + B$), lower ($AB > A + B$) or greater ($AB < A + B$) than the intensity of each compound individually.

Whilst ethanol was found to contribute to the body of beer independently, it is interesting that two significant interaction terms were also found (ethanol*viscosity and ethanol*bitterness). This adds further evidence that body is not a simple one-dimensional characteristic but rather a multi-faceted term, where enhancement can be achieved in beers with low and no alcohol. The results highlighted this notion as an experimental beer sample with modified viscosity, bitterness and hoppy aroma, but no alcohol ($E_0V_1B_1A_1$) scored second-highest for body intensity and was not perceived to be significantly different in body from samples with both 2.8 % and 4.5 % ABV ($E_1V_1B_1A_1$ and $E_2V_1B_1A_1$, respectively) (Supplementary Table 2). In support of the present findings, it was previously noted by Liguori et al (2018) that body and the alcoholic/solvent descriptors decreased after the removal of ethanol; however, the addition of hop extract and pectin solution improved the body of the beer samples (Liguori et al., 2018). This highlights that high alcohol content is not a necessity for body perception, assuming that other factors can be modified to compensate.

When exploring significant modified factor interaction effects on the overall beer body ratings, synergistic effects of ethanol and bitterness, as well as ethanol and viscosity, were found. Fig. 4 shows a clear separation of samples with added *iso*-α-acids driving overall body perception, supporting that bitterness is one of the main drivers of beer body (Leskosek-Cukalovic et al., 2010). Similarly, the addition of *iso*-α-acids (high bitterness) to beer samples with different alcohol concentrations increased overall body rating, in contrast with the overall liking score, suggesting that bitterness elicited by *iso*-α-acids may have enhanced effects of ethanol bitterness, similarly to findings of other studies that explored the perception of binary mixtures containing quinine (Thibodeau & Pickering, 2021), in turn enhancing beer body perception through increasing bitterness. Likewise, the addition of CMC (high viscosity) to beer samples with different alcohol concentrations promoted overall body ratings. It was also demonstrated that adjusting the bitterness and viscosity of experimental beer samples at low alcohol concentration (0.05 % ABV) had a similar effect on overall beer body ratings as at higher alcohol concentration (4.5 % ABV). This is supported by the fact that no further increase in body perception was found after the addition of *iso*-α-acids or CMC to beer samples.

It was previously reported that ethanol elicits bitterness (Nolden et al., 2016; Nolden & Hayes, 2015; Small-Kelly & Pickering, 2020), among other tastes and sensations, including astringency (Nolden & Hayes, 2015), warming, irritation or burning (Allen et al., 2014; Clark et al., 2011; Ramsey et al., 2018), suggesting that ethanol is a complex stimulus capable of eliciting multiple taste and chemesthetic sensations. In this study, ethanol addition positively influenced the overall liking of the samples at the higher bitterness level but not at the low bitterness level, suggesting ethanol suppressed perceived bitterness to acceptable levels because bitterness was a negative driver of liking, and sweetness a positive driver. Therefore, ethanol may be capable of supressing undesirable attributes in beer. Furthermore, an interaction effect between bitterness (addition of *iso*-α-acids) and hoppy aroma (addition of hop oil extract) (bitterness level*aroma) was observed when exploring the effects of modified factors on overall liking. Previously the contribution of hoppy aroma to bitterness and mouthfeel was studied in Pilsner beer, and it was reported that hop aromatisation impacted bitterness and enhanced fullness perception (van Opstaele et al., 2010), suggesting a synergistic effect between hop aroma and bitterness for those parameters. It is likely that the perception of bitterness was increased with the addition of hop oil extract due to that synergistic effect, subsequently reducing hedonic response, potentially related to the negative emotions elicited in response to beers with higher bitterness concentration explored previously (Viejo et al., 2020). In this study, the highest liking score was achieved at medium alcohol concentration (2.8 % v/v) with no *iso*-α-acid addition, suggesting that reducing the bitter components in beer would likely increase its palatability through enhancement of the established sweet-like component in the taste of ethanol reported previously (Lemon et al., 2004).

With higher bitterness having a negative effect on overall liking but a positive effect on overall body perception, it is important to consider that improving beer body in the final product by modifying these factors might negatively impact consumer acceptance.

### *4.5. The impact of consumer clustering*

One of the key findings of this study was that three clear consumer clusters were identified based on the perceived beer body intensity ratings. Results revealed that consumers rated body according to different factors present in the samples, including viscosity, flavour (hoppy aroma and bitter taste) and ethanol, suggesting that individual differences within a population for beer body perception are based on different dominant attributes. This highlights the relevance of modified variables explored within this study and provides direction for the brewing industry and new product developers to consider a combinational approach.

The Viscosity Driven consumer cluster asserted the perceived thickness of the beer samples to beer body perception, suggesting that viscosity was important to them when assessing body intensity. Furthermore, the addition of *iso*-α-acids (IαA-High) and hop oil extract (HOE-Hoppy) drove the body perception for the Flavour Driven consumer cluster. It is evident from the results of both the present study and previous research that whilst beers with higher alcohol and viscosity are perceived to have greater beer body, there is a different consumer focus on taste and flavour. It is also important to highlight that, according to the PCA, body perception for both the Flavour Driven cluster (Flavour Driven Cl) and Alcohol Driven cluster (Alcohol Driven Cl) were driven by the flavour attributes, including overall flavour intensity (OverallF), hoppy flavour (HoppyF) and overall aftertaste (OverallAf) of the experimental beer samples. This is not surprising as the addition of ethanol was previously attributed to enhancing flavour intensity, as well as eliciting bitter and sweet tastes when explored with ethanol/water mixtures (Mattes & DiMeglio, 2001; Scinska et al., 2000).

The three-cluster solution revealed different term interpretation patterns based on sensory characteristics, which suggests that beer consumers cannot be seen as a homogenous group when attempting to define and evaluate a multi-sensory attribute such as beer body as they place different levels of importance on different factors and their associated sensory attributes. Therefore, whilst all four factors may be considered important for body in beer, results suggest that reduction or removal of one factor, such as ethanol, can still result in body intensity ratings comparable to their full-strength counterparts, provided the other factors are increased. Despite each individual factor having a positive effect on consumer beer body perception, the acceptability of a manipulated final product will likely depend on the individual consumer clusters. Consumer clusters may also differ depending on the explored beer and beverage market in general, which is acknowledged as a limitation of the study. Furthermore, no trends based on the clustering solutions across available demographic information were identified in this study but future research should explore an in-depth analysis of consumer demographics to investigate trends.

## 5. Conclusion

Previously, beer body was associated with viscosity and density as contributing sub-qualities, as well as palate weight and flow resistance, which suggested that beer body is a uni-modal characteristic of texture. As seen in the present study, viscosity is not the single characteristic that influences beer body, as all four factors explored (ethanol concentration, viscosity, bitterness, and hop aroma) were all important drivers of body perception.

However, with regard to flavour, only certain tastes and aromas may be responsible for creating a fuller-bodied beverage, highlighting the importance of congruence and taste–aroma interactions. Therefore, further work needs to address the impact of different flavour profiles on perceived beer body. This study has made a major contribution towards understanding beer body perception by demonstrating that ethanol, viscosity, bitterness and aroma have the ability to drive beer body ratings, suggesting that factors besides ethanol can contribute significantly to body enhancement. However, new product developers should pay close attention to the fact that despite the explored factors having a positive effect on body perception, not all will promote acceptability. Cluster analysis revealed that consumers are not homogenous when assessing body perception, and they place differing levels of importance on different factors.

The findings obtained only apply to one beer style and consumers selected from the UK. Exploring different beer styles and extending the generalisation of the findings to other consumer and beverage markets will broaden the understanding of the contribution of each modified factor to the perception of beer body.

## CRediT authorship contribution statement

**Natalja Ivanova:** Conceptualization, Methodology, Data curation, Investigation, Formal analysis, Project administration, Visualization, Writing – original draft. **Qian Yang:** Investigation, Supervision, Writing – review & editing. **Susan E.P. Bastian:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Kerry L. Wilkinson:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Trent E. Johnson:** Formal analysis. **Rebecca Ford:** Conceptualization, Methodology, Funding acquisition, Supervision, Writing – review & editing.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

## Acknowledgements

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2023.105004.

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