Using a combined temporal approach to evaluate the influence of ethanol concentration on liking and sensory attributes of Lager beer

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Abstract

A low alcohol beer evoking similar sensory enjoyment as its higher alcohol counterpart is potentially an attractive proposition to breweries for increased sales volumes, as well as consumers due to health and societal reasons. This study aimed to determine the influence of ethanol on the temporal sensory characteristics and liking of beer as perceived by beer consumers. A commercial 0% ethanol concentration lager was spiked with ethanol to different concentrations (0.5%, 2.8%, 5% ethanol). Consumers (n=101) indicated their liking using temporal liking (TL) methodology (rated throughout consumption) and overall liking (rated at the end of consumption). Consumers also denoted the sensory properties perceived using temporal Check-All-That-Apply (TCATA). Overall, liking data divided consumers into 3 clusters with different patterns of liking. As ethanol concentration increased from 0 to 5%, the TL time that best predicted overall liking shifted from 60 sec to 10-20 sec indicating that liking of higher alcohol products was decided earlier on in consumption. Data suggested that in a lower ethanol beer, a liking judgement may not be stabilized until later in the evaluation, while in high ethanol beers, a liking judgement, either positive or negative, stabilised more rapidly. TCATA results revealed different temporal sensory profiles among the different ethanol concentrations. As ethanol concentration increased, the citation of sweetness, fullness/body and alcohol warming sensation increased. However, the relationship between TCATA citations and TL varied among the three clusters highlighting that, in relation to ethanol concentration, different negative and positive sensory drivers of preference exist for different segments of consumers.

1. Introduction

Beer consumers are accustomed to a product that offers a well-defined and complex taste (Blanco, Andres-Iglesias, & Montero, 2016). In addition to these sensory considerations, the increasing interest of consumers regarding health and societal issues has motivated breweries to expand their portfolio of beers with low or no alcohol content products (Rehm, Lachenmeier, Llopis, et al., 2016; SeekingAlpha, 2016). As beer consumers are accustomed to particular attributes, the development of a low alcohol beer that displays a similar sensory profile to its higher alcohol counterpart is an attractive proposition. This would allow consumers to still enjoy the sensory properties of a beer while making responsible drinking choices (Missbach, Majchrzak, Sulzner, et al., 2017).

The challenge remains that sensory attributes in alcohol-free and alcohol-reduced beers differ from those in regular beer. Beers vary in their alcohol content but the majority of beers consumed contain between 3-8% ethanol (Preedy, 2011). Ethanol is an effective olfactory and trigeminal stimulus, contributing to the warming/burning perception of beer (Clark, Hewson, Bealin-Kelly, et al., 2011a; Green, 1987). Ethanol also contributes to the perception of different tastes, predominantly sweetness, bitterness and sourness (Hellekant, Danilova, Roberts, et al., 1997; Martin & Pangborn, 1970; Scinska, Koros, Habrat, et al., 2000). Consuming beer is a multimodal experience and the influence of ethanol on sensory perception and its interactions with the other components in beer has been documented (Clark, et al., 2011a). For example, ethanol interacts with hop acids to suppress a warming sensation at 4.5%, but also interacts with low levels of CO_2 to yield an increased alcohol warming sensation (Clark, et al., 2011a). Furthermore, ethanol has been found to physically influence aroma release in beer during consumption (Clark, Linforth, Bealin-Kelly, et al., 2011b). The influence of ethanol concentration on dynamic headspace recovery of different volatile compounds in ethanol/water solutions using proton transfer reaction mass spectrometry (PTR-MS) with concentrations similar to those found in beer (0, 2.5 and 6.2% v/v) showed that increased ethanol concentration decreased volatile release (Aprea, Biasioli, Mark, et al., 2007). This reported similar findings to Clark, et al. (2011b), again with dynamic headspace, with the change being attributed to an increase in the solubility of aroma compounds (Aprea, et al., 2007; Conner, Birkmyre, Paterson, et al., 1998; Perpete & Collin, 2000). Ethanol clearly has the capability to impact sensory perception of beer. Therefore, an understanding of how ethanol reduction in beer affects consumer perception and acceptance is important (Kaneda, Kobayashi, Watari, et al., 2002; Porretta & Donadini, 2008). Previous studies have reported that consumers can distinguish among beers containing different ethanol concentrations. For example, in one triangle test, consumers could distinguish between an alcohol free (0.5% ethanol) and regular (5% ethanol) beer but interestingly were not able to identify which was of a higher alcoholic strength, suggesting consumers are not necessarily aware of the characteristics associated with ethanol (Lachenmeier, 2014). In another study, consumers were able to distinguish between an alcohol-reduced (3.8% ethanol) and regular beer (5.3% ethanol), with the standard strength beer having more overall appeal than the lower strength (Segal & Stockwell, 2009). However, these studies did not report consumer liking of the products, which is an important piece of information for innovating a commercially successful product.

Beer possesses a highly complex sensory profile (Clark, et al., 2011a) and as with other beverages including wine (Baker, Castura, & Ross, 2016), displays a temporal aspect. In short, beer perception changes over the consumption period, from the moment the beer is placed in the mouth to when the final sensations of that beer, including aftertaste, abate. Particularly, the sensory attributes of beer arising from the presence of ethanol (ethanol warming) and iso-alpha acids (bitter taste) are well documented to have a temporal quality in beer (Arrieta, Rodriguez-Mendez, de Saja, et al., 2010). Thus to better understand consumer perception of a low-alcohol beer, the application of temporal methods is important. Previous testing of the temporal sensory aspects of beer has relied upon the use of time intensity or dominance testing using Temporal Dominance of Sensation (TDS) (Missbach, et al., 2017), and usually with trained panels. Using TDS, differences among three beers based on their ethanol concentration with trained panellists were identified. Beer samples containing <0.5%, 3.4% and 5% ethanol displayed differences in the dominance of astringency and other fermentation-related flavours, with the higher ethanol concentrations showing increased bitterness and astringency (Missbach, et al., 2017). However, it is unclear what impact this might have had on consumer liking.

Understanding the sensory attributes that drive consumer liking of food and beverage products is critical to both the food and beverage industry. In the present study, the impact of ethanol concentration on the perception of beer was investigated with consumers using a combination of methods to evaluate temporal and overall liking and the temporal perception of key sensory attributes. Temporal Check-All-That-Apply (TCATA) methodology (Baker, et al., 2016; Castura, Antúnez, Giménez, et al., 2016a) was chosen over TDS as it does not limit evaluation to just dominant attributes. Previous studies have successfully employed similar methods to determine drivers of liking (Ares, Alcaire, Antúnez, et al., 2017; Thomas, Visalli, Cordelle, et al., 2015); however, no studies have yet examined temporal liking in beer.

The objectives of this study were therefore to i) evaluate the influence of ethanol on consumer liking of lager and perception of its sensory characteristics; ii) determine if particular time points during temporal liking related to overall liking; and iii) investigate the relationship between the temporal sensory profile of beer and temporal liking data identifying critical attributes driving consumer acceptance of beer in relation to ethanol concentration.

2. Methods

2.1 Participants

Consumers (n=101: 53 men, 48 women; aged 19-70 (mean age 32)), who self-reported consumption of beer at least once every two months, participated in this study. Data concerning frequency of consumption and the types of beer consumed was also obtained. Approval from the University of Nottingham Medical Ethics Committee was granted before the study commenced and the subjects were offered an inconvenience allowance to participate.

2.2 Beer samples

A 0% ABV lager style beer (Carlsberg, Northampton, UK) was used as a base beer from which four experimental beer samples (0, 0.5, 2.8 and 5% ethanol) were prepared. These ethanol concentrations were selected to reflect a full ethanol beer (5%), an intermediate ethanol concentration (2.8%), a low ethanol beer (0.5%), and an alcohol free beer (0%). In the United States, an alcohol-free beer is described as having 0% ethanol concentration, a non-alcoholic beer corresponds to a beer containing 0.5% ethanol or less and a lower alcohol beer contains less than 3.5% ethanol. In the United Kingdom, alcohol duty rates are increased when a beer exceeds 2.8% ethanol concentration and so some brewers try to satisfy this target for their lower alcohol beers (Branyik, Silva, Baszczynski, et al., 2012). The above points were considered when selecting the specific concentrations to represent ethanol concentrations of beer commercially available in each of these categories.

To create the 0.5, 2.8 and 5% ethanol samples, 1.7, 9.6 and 17.5 mL of 99.5% food grade ethanol (VWR International, Lutterworth, UK) and 28.3, 20.4 and 12.5mL of still water (Danone, Paris, France) were added, respectively, to 300ml of beer. The 0% ethanol beer also had 30mL of water added to ensure that all samples were treated the same. Commercial bottles of beer (330ml) stored at 4±1°C, were opened as close to sample testing as possible, 30ml was poured out of the bottle, and the relevant ethanol/water solution was added back in after which the bottle was inverted to ensure adequate mixing. Beer samples (30ml) were poured into plastic serving cups and were used within 20 mins of opening. This approach was used to minimise sample handling and limit the decarbonation and volatilisation of the samples.

2.3 Sensory Attributes

Attributes and definitions for beer evaluation were developed in reference to published literature (Langstaff & Lewis, 1993; Martin & Pangborn, 1970; McMahon, Culver, Castura, et al., 2017; Meilgaard, Dalgliesh, & Clapperton, 1979) as well as through the use of a naïve panel of six beer consumers.

2.4 Procedure

All consumers participated in two evaluation sessions over two weeks at the Sensory Science Centre, Sutton Bonington campus, University of Nottingham. Both sessions began with a familiarisation session (15 min) after which consumers evaluated samples in isolated sensory booths (45 min). Consumers evaluated temporal liking (TL) first and overall liking (OL) second to gain an understanding of consumer liking of the product during specific periods of consumption (before swallow and aftertaste) and then an overall score. TL and OL were evaluated in session one and sensory attributes using TCATA in session two. Although not always shown to cause bias (Jaeger, Giacalone, Roigard, et al., 2013) this order was chosen to avoid analysis of sensory attributes influencing liking results as reported in other studies (Earthy, MacFie, & Hedderley, 1997; Popper, Rosenstock, Schraidt, et al., 2004).

2.4.1 Familiarisation Sessions

Previous research has shown that a short familiarisation session (7-10 mins) can result in a small increase in consumer ability to discriminate among samples (Jaeger, Beresford, Hunter, et al., 2017). In session one familiarisation involved the explanation and practice of the evaluation protocol for TL and OL. In session two, the TCATA method was described to the consumers as a relatively new technique, and the importance of checking and unchecking perceived attributes during evaluation was discussed (Castura, Baker, & Ross, 2016b). The attributes (Table 1) were also reviewed to ensure consumers understood them all.

For all in-mouth evaluations, the in-mouth protocol remained the same: consumers were asked to place the sample in the mouth and press the green start button immediately, move the sample around in the mouth and then swallow at 10s when a prompt appeared on-screen. Although not necessarily normal drinking behaviour, this enabled the protocol to be controlled and facilitated comparison between TL and TCATA data. Consumers continued the evaluation up to 60s, at which point it ceased. If nothing was perceived before reaching the end of the evaluation time consumers were told to deselect attributes. Consumers were given a handheld tablet (Apple, Cupertino, California, USA) and practice sample at the end of each familiarisation session so that they could interact with the method and software prior to formal evaluations.

In each session all samples (n=4) were presented monadically under Northern hemisphere lighting using a randomised balanced design according to a Williams Latin Square (Meyners, Castura, & Carr, 2013). Data were captured using Compusense© Cloud software (Guelph, Ontario, Canada). To minimise fatigue and carryover, consumers were given a forced 2 min break between each sample, and were told to take at least 2 sips of water (Evian, Danone, France) during this break to cleanse the palate.

2.4.2 Temporal Liking Measurement

During the first session, consumers used a 15-cm semi-structured line scale, anchored with dislike extremely and like extremely to continuously quantify their current liking. During the 60s evaluation time, consumers were instructed to click on the scale at any point that their perceived liking changed. The total duration of evaluation (60s) was established through preliminary investigations as a duration that was adequate to capture relevant changes in aftertaste perception while minimising fatigue to the consumers. Data was recorded at one data point per second.

2.4.3 Overall Liking Measurement

Within 30s of completing the TL measurement, consumers assessed their overall liking of the sample using a 9-pt hedonic scale ranging from 'dislike extremely' to 'like extremely'.

2.4.4 Temporal evaluation of sensory attributes in mouth using Temporal Check-All-That-Apply (TCATA)

In the second session, consumers assessed the presence of 10 attributes within each sample. Prior to the test, consumers were instructed to familiarise themselves with the position of the attributes on screen, which were presented in a three-column format. The attribute order was randomised across subjects to balance bias associated with list order but was retained for a given panellist (Meyners & Castura, 2016).

2.5 Instrumental Analyses

Instrumental analyses were conducted to record the impact of ethanol concentration on key chemical characteristics. The ethanol content, density and specific gravity were all measured in triplicate across sample bottles prepared as described in section 2.2, using an Anton Paar Alcolyzer and DMA4500 (Graz, Austria). The pH of all samples was determined using a Metler Toledo FiveGo pH meter (Columbus, Ohio, USA) and the titratable acidity (TA) measurements were made using a Metrohm 702 SM Titrino potentiometric titrator (Metrohm UK Ltd, Cheshire, UK) after calibration with pH 4.0 and 7.0 standards. To determine if differences existed between samples, an ANOVA was performed followed by a comparison of means calculated by Tukey's Honest Significant Difference (HSD) post-hoc test (XLStat 19.01, Addinsoft, New York, USA).

2.6 Data Analyses

An α risk of 0.05 was set as the level of significance in all data analyses.

2.6.1 Overall Liking

To determine if differences existed between samples in terms of overall liking a mixed model two-factor ANOVA (sample, panellist), with panellist as a random effect was performed followed by a comparison of means calculated by Tukey's HSD post-hoc test (XLStat 19.01, Addinsoft, New York, USA). To ascertain if liking patterns varied across consumers a cluster analysis (XLStat 19.01, Addinsoft, New York, USA) on overall liking data was performed using agglomerative hierarchical clustering employing a dissimilarity matrix with Euclidean distance and Ward's method in the agglomeration (Desai, Shepard, & Drake, 2013). Further analysis was then performed, with a two-factor ANOVA (as above) to examine differences between samples within each cluster. Cluster membership was further explored according to the demographic variables collected in this study using a Chi square analysis and Fishers exact test (Gellynck, Kühne, Van Bockstaele, et al., 2009).

2.6.2 Temporal Liking

For each product and consumer, six liking scores were extracted from the temporal data i.e. every 10s until 60s. As the cluster analysis discovered 3 different patterns of liking the temporal liking data was assessed taking different clusters into account. For each cluster, a two-factor ANOVA (sample and time point) with liking as the dependent variable was then performed (XLStat 19.01, Addinsoft, New York, USA). Tukey's HSD tests were subsequently used to identify where significant differences occurred between time points and clusters.

2.6.3 Relating Temporal liking to Overall Liking

Liking data were extracted for all time points, however only data relating to 10, 20, 40 and 60s were subsequently further analysed as no differences in liking were found at 30 and 50s. These liking data were modelled against overall liking which had been determined after the 60s evaluation period had ceased (Table 5). In order to determine if particular time points during TL related to overall liking, an ordered probit model was employed (Stata 14.0 (Stata

Corp, College Station, TX, USA)). This model was selected because the dependent variable was an ordered scale, ranging from 1 to 9 (Long, 1997). A separate model was estimated for each consumer cluster at temporal liking times of 10 (swallow), 20, 40 and 60s (end of test) to identify which time point best related to the overall liking.

2.6.4 Analysis of TCATA data

2.6.4.1 Analysis of Average Proportions of Citations

The analysis of the average proportion of citations followed a similar method as McMahon, et al. (2017), with each attribute being assessed as the proportion of the 60s time period in which it was selected (XLStat 19.01, Addinsoft, New York, USA). For example, if malty was checked for a duration of 15s and hoppy for 25s, the average proportion of citations would be 15/60 = 0.25 for malty and 25/60 = 0.42 for hoppy.

2.6.4.2 TCATA Curves

Following a similar procedure as described in Castura, et al. (2016a); and McMahon, et al. (2017), data were exported for each attribute at 0.1s intervals in the form of either '1' or '0' to show presence or absence of this attribute. Proportions of citations were calculated as the percentage of panellists who perceived (or checked) an attribute at any given moment during the evaluation period. For each attribute, TCATA curves (smoothed using the cubic spline function in R (The R Foundation, Vienna, Austria) to reduce noise in the data (McMahon et al., 2017)) were calculated per treatment at each time point (each 0.1 s during the evaluation period). Thicker sections of an attribute line were used to represent segments where the proportion of citations was significantly different in contrast to the other samples. The average proportion of citation of the attribute for the other samples was plotted on the same figure, when significant, using a dotted line enabling visualisation of the direction of the difference i.e. higher or lower citation, and the time periods during which significant differences were observed.

2.6.4.3 Multivariate Analysis of TCATA Attributes

The relationship between beer samples and TCATA attributes was investigated using principal component analysis (PCA) on unfolded data, to create a two-way matrix with sensory attributes in columns and rows corresponding to sample (ethanol concentration) by time point (Castura, et al., 2016a; Castura, et al., 2016b) (Stata 14.0 (Stata Corp, College Station, TX, USA)). PCA plots were constructed to show how attributes were perceived and evolved in relation to treatments (McMahon, et al., 2017).

2.6.5 Relationships between temporal sensory attributes (TCATA) and temporal liking (TL)

To evaluate the contribution of each TCATA attribute to temporal liking, a random effects regression model was used (Stata 14.0 (Stata Corp, College Station, TX, USA)). This analysis was selected so as to compare, by panellist, the evaluation of the same attribute at different points in time. Because the same panellist is evaluating the same attribute at various points in time, the evaluations of that panellist are correlated with each other. A random effects model takes into account this non-independence among the observations. For this model, TL was the dependent variable whilst the TCATA attribute (i.e. astringent, malty, etc.) was used as the independent variable, with z-values showing whether this was a positive or negative association.

3. Results

3.1 Instrumental Analyses

The instrumental analyses confirmed that the planned concentrations of ethanol were achieved. The ANOVA showed that the effect of ethanol concentration was significant (F (3, 11) = 897, $p=<0.0001$) as were associated specific gravity (F (3, 11) =67.8, $p=<0.0001$) and density values (F (3, 11) = 69.1, $p=<0.0001$) (Table 2). Analysis of the pH values of the samples, although close, were significantly affected (F (3, 87) =2.83 p=0.043) with the Tukey test indicating the 0% and 0.5% having a significantly higher pH compared to the 5% ethanol sample (<0.05). The analysis of variance showed that the effect of TA was significant (F (3,11) = 35.8, p=<0.0001), whereby the Tukey test indicated 0% and 5% were significantly different (p<0.05), although still quite close in absolute value (differential= 0.703g/L). Theoretically, this increase in acidity might have increased the citation of the sour attribute in the TCATA for the 5% sample, however this was not found.

3.2 Overall Liking

ANOVA revealed no significant differences (F (3, 403) = 0.426, p =0.735) among the four beer samples in terms of overall liking. However, agglomerative hierarchical clustering analysis was subsequently performed and three clusters of consumers were identified.

Table 3 shows the average overall liking scores of the three consumer clusters. The ANOVA yielded significant differences for the interaction between sample identity and cluster (F (2, 6) = 15.2, p=<0.0001), indicating that the overall liking of the samples varied with the consumer cluster. Statistically, scores for cluster 1 (C1, n=23) showed significant differences for consumers liking (F (3,91) = 15.7, p=<0.0001) with Tukey test indicating that the overall liking was significantly higher for the 5% beer compared to the 0%, 0.5% and 2.8% samples, which were 'disliked slightly' (p<0.05). Cluster 2 (C2, n=50) showed no significant difference in overall liking among the samples (F (3, 199) = 0.913, p=0.436), but rated all samples higher than the other clusters as either 'like slightly' or 'like moderately'. The ANOVA for cluster 3 (C3, n=28) yielded significant differences for consumer liking (F (3,111) = 14.5, p=<0.0001) with the Tukey test revealing that the overall liking for the 0%, 0.5% and 2.8% was significantly higher than for the 5% beer, which was rated as 'dislike very much' (p<0.05). Interestingly consumers in this cluster disliked all beer samples.

Cluster membership was further explored according to the demographic variables collected in this study which included beer consumption patterns, gender, age and types of beer consumed (e.g. ale and non-alcoholic beer) but low cell numbers meant no inference could be made regarding their effect on cluster membership. In addition to this, the familiarity of beer styles (more specifically non-alcoholic beer) over all consumers was studied, but no significant differences were found to suggest that non-alcoholic beer drinkers rated the 0% sample higher, as might be expected.

3.3 Temporal Liking

Because of the different patterns of liking found among consumers in overall liking, subsequent analyses looked at each cluster separately. Figure 1 shows the average temporal liking curves for each sample by cluster. In general, they show that temporal liking of the beer samples in each cluster reflected those results seen in the overall liking (Table 3). The ANOVA showed that the effect of ethanol concentration on liking was significant (F (3, 91) = 15.7, p=<0.0001) for C1, and the Tukey test showed a significantly higher and constant level of liking for 5% ethanol sample over the entire 60s evaluation period ($p<0.05$). Some reduction in liking for the other three samples was evident around and after swallowing. No significant differences were found in liking scores between samples for C2 (F (3, 199) = 0.913, p=0.436) and, visually, the level of liking was generally consistent throughout the evaluation. C3 generally showed consistent dislike for most of the samples throughout the temporal evaluation, as seen with the overall liking data. Again ANOVA showed that there was a significant difference in terms of liking between samples (F (3, 111) = 14.5, p=<0.0001), with the tukey test indicating the 0% sample scoring significantly higher for the duration. This cluster also clearly disliked the 5% sample the most, particularly after swallowing ($p<0.05$). The ANOVA performed to compare liking for each sample within a given cluster at each increasing 10s of the evaluation time highlighted some of these differences between the samples. For C1 and C2, no significant differences were found. However, for C3, a difference was found for the 5% ethanol beer (F (5, 143) = 4.31, p=0.001), with the Tukey test showing a significant decrease in liking when assessed at latter time points (40, 50 and 60s), during the aftertaste, compared to the first point which was in mouth, at 10s ($p<0.05$).

3.4 Relating Temporal Liking to Overall Liking

The relationship between liking at a given time point (determined using TL) and overall liking determined at the end of the test (using a 9-pt hedonic scale) was assessed and although clusters showed similar trends there were differences and hence the data was interrogated by cluster (Table 5).

The ordered probit estimates revealed that the time point from the TL data that best predicted overall liking varied with beer sample and cluster. For 0% ethanol, TL at 60s (the end of the evaluation) best predicted overall liking in both C1 (p=0.015) and C2 (p=0.006). None of the TL evaluations significant predicted overall liking in C3. No significant time point was found for C3. For 0.5% ethanol, TL at 60s again best predicted overall liking in C1 (p=0.049). For C2, overall liking was significantly predicted by liking at both 40 (p=0.001) and 60s (p=0.001). Again, evaluations at none of the time points was a significant predictor of overall liking for C3. For 2.8% ethanol, overall liking for both C1 (p=0.014) and C2 (p=0.009) was significantly predicted by TL at 40s. No significant time point was found for C3. Finally, for 5% ethanol, overall liking for C1 was significantly predicted by evaluations at 10 (p=0.005) and 60s (p=0.041). For C2 (p=0.005) and C3 (p=0.002), overall liking was significantly related to liking at 20s.

To a certain extent, as ethanol content decreased, overall liking was better predicted by temporal liking increasingly later in the consumption process. For cluster 3, who did not really like any beers, it was more difficult to find a temporal point relating to OL except for the 5% beer. In this beer, evaluations early in the consumption process better predicted overall liking.

3.5 Impact of ethanol concentration on temporal perception of sensory attributes (TCATA)

3.5.1 Analysis of Average Citation Rates for Temporal Data

The average proportion of citations of various attributes varied among the beer samples as analysed using Cochran's Q analysis (Table 4). The citation of the mouthfeel attributes of fullness/body and alcohol warming were higher in the 5% ethanol sample compared to the 0, 0.5 and 2.8% ethanol samples ($p<0.05$). In the citation of the sweet attribute, the 5% ethanol sample was higher than the other three samples, with significant differences also observed between the 0 and 2.8% ethanol samples.

3.5.2 TCATA Curves

Differences were observed among the samples in the citation of sensory attributes over time (Figure 2). For the 0% ethanol sample, in general, fewer attributes were cited compared to the other three samples. Between ~14 and 60s, fullness/body was cited significantly less frequently ($p<0.05$) compared to the three other ethanol concentrations, as well as sweet taste and fruity flavour from ~4 to 60s. The warming attribute was cited significantly less often ($p<0.05$) compared to the three other ethanol concentrations at ~26s and ~30s, within the 0% ethanol sample, however, interestingly it was not at zero which may have been expected suggesting other attributes may contribute to its perception in beer.

For the 0.5% ethanol sample, several significant differences in the citations of attributes were found. Compared to the other 3 beer samples, sweetness was cited significantly less frequently ($p<0.05$) from ~4 to 60s and malty flavour from ~20 to 60s. Alcohol warming sensation was also cited significantly less often from ~21 to 60s and bitter taste from ~16 to 20s ($p<0.05$). For the 2.8% ethanol sample, bitter taste was cited significantly less frequently from ~15 to 23s and ~27 to 44s. From ~16 to 24s, malty flavour was perceived less often ($p<0.05$).

For the 5% ethanol sample, attributes were cited more frequently compared to the 0 and 0.5% ethanol samples. Malty flavour was cited less often ($p<0.05$) from ~15 to 60s and bitter from ~16 to 60s. Sour was highlighted as an attribute being cited significantly less ($p<0.05$) from ~30 to 40s and hoppy flavour from ~25 to 37s. Alcohol warming sensation was cited significantly more often ($p<0.05$) in the 5% beer between ~55 and 60s.

As ethanol concentration increased attributes were cited more frequently. The lower ethanol concentration samples were cited significantly less compared to the other samples for sweetness, fullness/body and alcohol warming sensation. For the higher ethanol concentration sample, alcohol warming sensation was cited significantly more often compared to all other samples.

3.5.3 Multivariate Analysis of TCATA Attributes

The ethanol content in the beer clearly influenced the temporal citation of flavour, taste and mouthfeel sensory attributes. The influence of ethanol content described above is clearly visualised through the use of a PCA (Figure 3), showing the multivariate space and the temporal evolution of attributes in the beer samples over the 60s evaluation period. Ethanol concentration is labelled at the 40s evaluation point. The two components accounted for 83.05% variation in the data. PC1 is strongly correlated to bitter (0.934), malty (0.918), hoppy (0.866) and fruity (0.858), whereas, PC2 is strongly correlated with tingly sensation (0.902) and fullness/body (0.758) and negatively correlated with astringent (-0.568). The trajectories for each beer sample start at the top left (t=0) where the citation rate for all attributes is 0. As this biplot is not a continuous loop, it shows that consumers were still perceiving attributes up until the end of the evaluation at 60s. As evaluated by citation frequency, the early onset attributes in the beer samples were tingly, fullness and sweet occurring around~10s. The delayed onset attributes, appearing at ~45s, were identified as astringent and malty and they were more associated with the beer aftertaste.

When comparing the beer samples in their temporal evolution, the 0 and 0.5% ethanol samples displayed similar profiles, as the trajectories show these samples initially described as tingly, evolving to become more sour and ending with being described as having malty and astringent aftertastes. The 2.8% ethanol sample again was initially described as tingly, however there was a more delayed onset of alcohol warming sensation and fruity, finishing with bitter and hoppy aftertastes. The 5% ethanol sample was initially described as tingly, but also displayed delayed onset attributes of fullness, sweet, fruity and warming, with a sour and hoppy aftertaste.

3.6 Relationships between temporal sensory attributes (TCATA) and temporal liking (TL)

The random effects regression analyses highlighted the influence of the TCATA attributes on liking in each cluster. For C1, presence of tingly sensations exerted a significant positive influence on liking for all four samples (Table 6). For 0, 2.8 and 5% ethanol samples, having body also positively influenced liking. A sour note was a significant negative driver of liking ($p<0.001$) for all samples except for the 2.8% ethanol. Alcohol warming sensation was a negative driver of liking for both the 0 ($p=0.033$) and 0.5% ($p<0.0001$), becoming non-significant as the ethanol concentration increased. Presence of a fruity note was a negative driver of liking for the 0 ($p<0.0001$) and 2.8% ($p=0.047$), but positive for the 0.5 ($p<0.0001$) and 5% ($p<0.0001$) ethanol samples. Sweet was a significant negative driver of liking for the 0% ($p<0.0001$), yet when the ethanol concentration increased to 0.5% ($p=0.002$) and 5% ($p<0.0001$), this attribute became a positive driver of liking. Interestingly, bitter was a negative driver of liking for all samples ($p=0.048$ for 0% ethanol; $p<0.0001$ for 0.5% and 2.8% ethanol); however, at 5%, it became a significant positive driver of liking ($p=0.011$).

For C2 (Table 6), the significant positive drivers of liking for samples other than 5% ethanol were the presence of the attributes of malty (p<0.0001) and sweet for 0% ethanol (p=0.003) and 0.5 and 2.8% ethanol (p<0.0001). Other significant positive drivers of liking were presence of alcohol warming sensation for 0% and 5% (p<0.001), as well as 0.5% ethanol (p=0.039). The citation of the fruity attribute positively influenced liking in the 0% ethanol (p=0.004), 2.8% and 5% ethanol samples (p<0.0001). Astringent (p<0.0001) and tingly (p=0.034) sensations were identified as significant positive drivers of liking for the 0% ethanol sample, but then significant negative drivers of liking for all the higher ethanol concentration samples (p<0.0001).

For C3 (Table 6), a sour note exerted a significant positive influence on liking for all beer samples (0% ethanol (p=0.007), 0.5% ethanol (p<0.0001), 2.8% ethanol (p=0.014) and 5% ethanol (p<0.00001). The citation of tingly positively influenced liking for all samples except the 2.8 % ethanol (p<0.0001). Sweet had a positive influence on liking for the 0.5% sample (p<0.0001); however, as the ethanol concentration increased to 5%, this negatively influenced liking (p<0.0001). A similar trend was observed with bitterness, exerting a positive influence on liking for the 0% ethanol (p=0.002) but the liking of 2.8 and 5% ethanol samples was negatively influenced by the presence of bitterness (p<0.0001).

Overall each cluster showed differences in terms of attributes which drove liking and disliking for all samples. C1 seemed to enjoy the mouthfeel attributes of tingly and fullness/body sensations at all ethanol concentrations, with the tastes of sweetness and bitterness seeming to be negative drivers of liking. C2 enjoyed malty and sweet attributes and disliked astringent and tingly sensations when ethanol concentration increased. C3 liked sour and tingly sensations and disliked bitterness as the ethanol concentration increased.

4. Discussion

The market for low alcohol beer is increasing rapidly and so an understanding of the sensory properties that ethanol contributes to a beer is important. Here the impact of ethanol on the temporal sensory signature and temporal, as well as overall liking was investigated. Furthermore, whether a particular time point related to overall liking was explored, as were the temporal sensory drivers of liking.

The instrumental analysis confirmed ethanol concentrations of the beer samples to be in the regions of 0, 0.5, 2.8 and 5%, and showed significant differences among samples in terms of their pH and titratable acidity. As the ethanol concentration in the beer sample increased, the pH decreased and titratable acidity increased. The ranges in values measured were in accordance with typical values expected in beer (pH 4.0 ± 0.2) (Taylor, 1990). Despite ethanol concentration affecting changes in pH and TA, the differences were below the thresholds previously identified for sensory detection in wine (Amerine, 1976) (0.02-0.05% for TA and 0.05 for pH). It is noted that the medium in this latter study was wine and not beer and so these results cannot be applied directly, however no research has been done for beer. Therefore, it can be concluded that these parameters were unlikely to have contributed to a sensory difference across the beer samples.

4.1 The influence of ethanol concentration on liking

In the initial analysis of overall liking of the four beer samples, no significant differences were found. However, with the application of cluster analysis, three consumer clusters were identified and so understanding that there are individual differences within a population for beer liking in relation to ethanol content is key for the brewing industry in the development of new products (Guinard, Uotani, & Schlich, 2001).

While differences in overall liking were found among clusters, no demographic predictors of cluster membership could be identified due to insufficient cell counts for the statistical analysis. The clusters were therefore likely to be a result of the differences in liking of the sensory profile of the samples brought about by the variation in ethanol concentration. C1 consumers preferred the high ethanol beer whilst C3 consumers preferred the low or no ethanol beer samples. C2 was composed of consumers who did not show any preference for the samples. Consumers within this cluster could be described as 'enthusiasts' as their overall liking for all samples was considerably higher than other clusters; a similar group was found in other products such as bread (Gellynck, et al., 2009) and quinoa (Wu, Ross, Morris, et al., 2017).

It is important to note that the number of consumers for C1 and C3 were too low to draw strong conclusions from and so the results for these clusters can only be viewed as trends in the consumer data. Suggestions for future work would be to increase the number of consumers participating, to ensure stronger conclusions can be drawn from the data.

Previous studies have shown that liking is not a static measurement but rather a temporal event (Delarue & Loescher, 2004; Lee & Pangborn, 1986; Taylor & Pangborn, 1990; Veldhuizen, Wuister, & Kroeze, 2006). Consumers were able to perform the task of evaluating their liking over time, supporting previous research (Sudre, Pineau, Loret, et al., 2012; Thomas, et al., 2015). The three consumer clusters created from the overall liking measurements reflected similar patterns of preference as the liking curves generated through TL. It should be noted that measuring OL straight after TL may have introduced some bias and could explain why the clusters followed similar patterns of liking for both liking measurements. Other research has shown similar results in orange lemonades, displaying relatively flat hedonic curves for temporal liking for the whole assessment procedure from ~2.5s to 30s (Veldhuizen, Wuister, et al., 2006). However, in a temporal study of liking of cheese, the most liked products overall were found to be liked significantly less at the beginning of evaluation, but this may be due to the change in product matrix through mastication (Thomas, et al., 2015). Therefore a recommendation for further work would be to investigate the effects of multiple sips of beer on temporal liking as suggested in other literature (Guinard, Pangborn, & Lewis, 1986; Jamieson & Wantling, 2017).

In the current study, the liking of all clusters was shown to be significantly stable throughout the 60s evaluation period. Although the figures show some variability in liking for all products between 0-15s, further analysis at earlier time points (5s and 8s) showed no significant differences in liking between time points ($p>0.05$). This may have been because liking by some consumers was registered as late as 26s into the evaluation period which may not reflect the normal experience for a consumer. Generally, temporal liking was found to be more discriminating than overall liking, with changes seen over the 60s consumption period. In C1, the temporal liking of the most liked sample (5% ethanol concentration) is maintained throughout evaluation, however for the least liked products the liking diminishes after swallowing. This is similar for C3, where the liking of the least liked sample (5% ethanol concentration) diminishes rapidly after swallowing.

4.2 Relating overall liking to temporal liking

The relationship between OL and TL was assessed to see at which time point consumers might base their overall liking. One of the main findings from this study was that OL and TL results gave consistent sample rankings for each cluster. In addition to this, TL evaluations were found to be fairly stable over time for all clusters, although they did highlight a drop in liking for some samples after swallowing. Only two studies to our knowledge (Sudre, et al., 2012; Thomas, et al., 2015) have linked time intensity of liking data or continuous liking with overall liking. In both of these studies, consumers registered their overall liking responses early in the consumption experience. In a study by Thomas, et al. (2015) overall liking was recorded at 17s, with the total consumption experience being 36s, thus describing more of the first impression of the product rather than after swallowing/aftertaste of the product (Sudre, et al., 2012; Thomas, et al., 2015). Interestingly, in the current study, there was not a particular time that best related to liking. It appeared to be dependent on ethanol concentration. As ethanol concentration increased in the beer samples, the time during the temporal evaluation that best related to overall liking shifted. For C1, as ethanol concentration increased from 0% to 5%, the time point that significantly related to overall liking decreased from 60s to 10s.The liking of the most liked sample (5%) in C1 was maintained throughout evaluation, with the lower ethanol concentration products diminishing in liking after swallowing. For C3 the overall liking did not significantly relate to temporal liking for any samples, apart from the 5% sample (at 20s), which was the most disliked product. This suggests that the highly liked and disliked products within each cluster related best to overall liking earlier on into evaluation. It could also have been due to familiarity of the beer, as the 5% sample is assumed to be closer to the consumers' expectations and so could be easier for them to evaluate. In addition, as consumers followed a strict procedure to drink the beer, this likely influenced their overall liking. Looking deeper into the data C1 (who preferred the 5% sample) and C3 (who disliked the 5% sample most) were found to perceive the ethanol related attribute of sweetness at 10s significantly more than C2 and so it could be deduced that these consumers either liked or disliked this respectively, which formed their overall liking score. Finally, the use of TL should be discussed based on the results of this study. TL for consumers appeared to be an easy task, but, not surprisingly, was longer and more cumbersome compared to OL. It gave stable results over time. TL evaluation may be well suited to foods where clear consumption periods can be defined (e.g mastication, swallow, aftertaste) or for drinks with strong aftertastes (e.g bitter tea, coffee, wine) to understand the change in liking over these periods of consumption.

4.3 Influence of ethanol on sensory attributes of beer

4.3.1 TCATA

Overall, the TCATA curves showed a difference in temporal sensory profiles among all beer samples over time. As ethanol concentration in the beer sample increased, the citation of alcohol warming sensation increased, following results from other research in beer (Clark, et al., 2011a). However, interestingly in the current study, alcohol warming sensation was only significantly cited more often during the ~55 to 60s time period in the 5% ethanol beer sample, reflecting its later presentation. This later presentation may have been due to the interaction effect of other factors within the beer, including the presence of carbon dioxide and hop acids, which have both been found to suppress warming sensation (Clark, et al., 2011a).

CO_2 has also been found to interact with ethanol at lower ethanol concentrations (0, 2.25 and 4.5%) to modify warming sensation; this may explain why alcohol warming sensation was still cited at the 0% and 0.5% ethanol levels in the beer samples (Clark, et al., 2011a). It has also been speculated that this could have been due to the irritation from the carbonic acid from the CO_2 (Dessirier, Simons, Carstens, et al., 2000; Simons, Dessirier, Carstens, et al., 1999).

The increase in ethanol concentration was also accompanied by the increased citation of other sensory attributes such as sweetness and fullness/body. Previous studies have found that ethanol enhances the perception of sweetness at ethanol concentrations between 0 and 24% (Clark, et al., 2011a; Martin & Pangborn, 1970). Ethanol (0.3-10%) stimulates sweet-best fibres due to taste-taste mechanisms, as well as activates nerve fibres sensitive to sugar which can be used to explain these differences among samples (Hellekant, et al., 1997; Scinska, et al., 2000). In terms of fullness/body, Langstaff, Guinard, and Lewis (1991) reported that the fullness of commercial beers was moderately correlated with alcohol content with correlation coefficients of 0.41 for density and 0.50 for viscosity.

No significant differences were found in the overall citation rates of flavour attributes malty, hoppy and fruity. Instrumental results using in-vivo atmospheric pressure chemical ionisation mass spectrometry (APCI-MS) by Clark, et al. (2011b) found that as ethanol concentration increased from 0 to 4.5% the in-breath release of ethyl acetate, isoamyl alcohol and phenylethyl alcohol increased. This may suggest an expected increase in citation of related sensory attributes, however this was not the case here, and hence if volatile release was higher in the higher ethanol samples this was not perceivable. The differing results between this study and Clark, et al. (2011b) could have been due to the volatile compounds measured and their correlated sensory attributes (Conner, et al., 1998).

No significant differences were found in the current study in the overall citation rates of astringency, but when looking at the temporal evaluation of this attribute the lower alcohol samples were found to be significantly more astringent towards the end of consumption time, with this attribute being temporally negatively correlated with PC2.

The onset of attributes also differed in that some attributes were cited more frequently earlier in the evaluation time, while others were delayed and thus were cited later in the evaluation time. For all beer samples, tingly sensation was one of the first attributes to appear. Delayed onset attributes which appeared after swallowing included malty flavour, bitterness and hoppy flavour. Work by Missbach, et al. (2017) showed similar results with worty off-flavour being most pronounced between 0 and 30s, with the dominance of malty flavour increasing after swallowing. Bitterness was also found to dominate the flavour profile after swallowing. A study by Vázquez-Araújo, Parker, and Woods (2013) showed a similar time to maximum intensity of both hoppy flavour and bitter taste in commercial lagers. Bitterness was also found to be the attribute which lingered longer, and estery/fruity notes were found to abate first (Vázquez-Araújo, et al., 2013).

4.3.2 Influence of temporal sensory attributes on TL

Acceptance of the beer samples was also contextualized by an examination of the TCATA attributes. Thomas, et al. (2015) found that the dominance of attributes plays a role in consumer liking, however the drivers of liking are mainly through the synergy of several components. The present study supported this earlier finding, showing that all attributes (and not just dominant attributes) were related to ethanol concentration and liking within the three different clusters of consumers.

C1 (who preferred the 5% sample) were found to like tingly and fullness/body attributes, which are both linked to a higher ethanol concentration. In addition, alcohol warming sensation was a significant driver of disliking at the lower concentrations, with the consumers also disliking sourness mostly in the 0% beer. Alcohol has been reported to suppress sourness due to the decrease in the physiological response of the chorda tympani nerve in the presence of a sour stimulus (Martin & Pangborn, 1970). The consumers in C1 in the present study also disliked bitterness until the ethanol concentration reached 5%, when it became a positive driver of liking. Ethanol concentration has been found to have an additive effect on bitter sensation as it intensifies flavour perception (Martin & Pangborn, 1970; Meillon, Viala, Medel, et al., 2010; Missbach, et al., 2017) thus the consumers within this cluster may have perceived this at the higher concentration.

C2 (who liked all samples) liked malty flavour, sweet taste and alcohol warming sensation. Interestingly a study by Porretta and Donadini (2008) showed similar results, with conclusions being drawn that overall flavour preference was highest for a malty flavour beer, which reflects the fact that this was the largest beer consumer cluster. Consumers within C2 disliked astringent and tingly sensations when the ethanol concentration was increased to 0.5%, and ethanol has been found to enhance both of these sensations.

C3 (who disliked the 5% sample most) enjoyed sourness and tingly sensations and disliked alcohol, bitter and sweet attributes perceived within the 5% sample. All these attributes can be related to the added ethanol within the beer and the interactions between the components impacting sensory perception (Clark, et al., 2011a). Conclusions can be drawn from this study that attributes are not only drivers of liking or disliking depending on the ethanol concentrations of beer samples, but that these vary depending on the consumers, as was evident from the clustering. One hypothesis for this is that at different concentrations of ethanol different attributes are enhanced or masked which drive liking/dislike in the different clusters differentially. It is important to note that the balance of the overall profile of attributes is just as important as the particular attributes themselves and so this needs to be considered when developing a new low alcohol beer, to form a favourable product; although this may only be a favourable product to some consumers within a population. It is recognised that one limitation in this study is that the beers were not fully optimised as would happen commercially when changing the ethanol concentration. This may also have had a difference in the integration of the flavour compared to when the beer is brewed to a certain alcohol percentage. The use of dealcoholisation apparatus to develop a base non-alcohol beer which can be adjusted for its chemical composition and to produce samples only varying in ethanol content, may offer improved insights into the effects of ethanol concentration. In addition to this, this study only looked into the effect of ethanol concentration in the context of lager and therefore this does not necessarily apply to other beer styles, which would be an interesting area for future research.

Many papers have looked at combining overall liking data with TCATA, TDS and CATA results (Ares, et al., 2017; Thomas, Chambault, Dreyfuss, et al., 2017; Thomas, et al., 2015), however to the authors' knowledge this is the first paper to combine TCATA data with temporal liking. However the fact that only ten attributes were included could be seen as a limitation as others characteristics may be important but were not included on the list. Using a temporal measure of liking enabled additional insights into which aspect of the product drove liking via the combination of TL and TCATA results and/or at what time of the consumption process.

5. Conclusions

This study evaluated the influence of ethanol on the temporal perception of beer including both the perception of liking and sensory attributes, as well as identified critical attributes that drive consumer acceptance. Overall, it showed that consumers can be clustered to show their liking and disliking of beer samples containing different ethanol levels, including a cluster that liked low/no alcohol beer products similarly to standard beers. A study with larger numbers of consumers would help confirm this.

This study also reported the relationship between temporal liking and overall liking to understand particular time points in products where consumers judge their overall liking, with results showing this was dependent upon the consumer, as well as the ethanol content of the beer sample. In the higher ethanol samples, liking was determined more rapidly compared to the lower alcohol samples. In addition, differences in sensory attributes among beer samples with different ethanol concentrations were described, with a 5% beer having significantly more sweetness, fullness/body and alcohol warming sensation, highlighting the importance and role of ethanol within beer.

This research is important for the brewing industry as it shows the overall sensory experience during consumption of a beer. It provides insight into a broad range of sensory attributes which are altered when ethanol is modified in beer, and highlights which attributes should be targeted by manufacturers when developing new low alcohol products. A new technique giving greater insight into liking was also described to link temporal liking with TCATA results to understand the drivers of liking at certain time points across different products.

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Table 1. TCATA attributes and definitions provided to consumers during familiarisation session.

Flavour and Taste Attributes	**Definition**
Malty Flavour	Smell and taste of malty cereals. Can be related to smell of Ovaltine drink.
Hoppy Flavour	Smell and taste of hops which can be flowery and herbal.
Fruity Flavour	The aroma and taste of fruit characteristics – including banana, apple, pineapple, peach, lemon, orange.
Bitter Taste	Taste stimulated by strong black coffee, beer, red wine or tonic water.
Sweet Taste	Taste stimulated by sugar when experienced in mouth.
Sour Taste	Taste stimulated by acids when experienced in mouth.
Fullness/Body	Feeling of thickness/fullness as beer is moved around in the mouth.
Alcohol Warming Sensation	The feeling of warming which is characteristic of ethanol throughout the mouth.
Tingly Sensation	Perception of irritation such as prickling, stinging and bubbles bursting in mouth from carbonation. The feeling of pins and needles.
Astringent Mouthfeel	The feeling in mouth of roughing, puckering and drying.

Table 2. Mean (3 replicates) chemical profile of the beer samples.

Beer Sample	**Alcohol by volume (ABV%)**	**pH**	**Density (g/cm³)**	**Specific Gravity (SG)**	**Titratable Acidity (g/L)**
0% Ethanol	0.06 ^{d}	4.209 ^{a}	1.019 ^{a}	1.021 ^{a}	0.848 ^{c}
0.5% Ethanol	0.64 ^{c}	4.202 ^{a}	1.018 ^{b}	1.020 ^{b}	1.130 ^{b}
2.8% Ethanol	2.85 ^{b}	4.185 $^{a\,b}$	1.015 ^{c}	1.017 ^{c}	1.260 ^{b}
5% Ethanol	5.25 ^{a}	4.175 ^{b}	1.012 ^{d}	1.014 ^{d}	1.551 ^{a}

^{abcd}*different letters within a column represent a significant difference at p<0.05 (Tukey's HSD)*

Table 3. Overall mean liking scores for beer samples by cluster.

Beer Sample	**Cluster 1 (n=23)**	**Cluster 2 (n=50)**	**Cluster 3 (n=28)**
0% Ethanol	4.04 ^{bB}	6.78 ^{aA}	4.04 ^{aB}
0.5% Ethanol	4.57 ^{bB}	6.44 ^{aA}	4.29 ^{aB}
2.8% Ethanol	4.00 ^{bB}	6.72 ^{aA}	4.96 ^{aB}
5% Ethanol	6.65 ^{aA}	6.32 ^{aA}	2.32 ^{bB}

Different letters within a cluster ^{ab} *or beer sample* ^{AB} *represent a significant difference in liking (Tukey's HSD (p<0.05))*

Table 4. Average proportion of consumer panel citations of TCATA sensory attributes.

	Flavour Attributes			Taste Attributes			Mouthfeel Attributes			
Beer Sample	Malty	Hoppy	Fruity	Bitter	Sweet	Sour	Fullness/ Body	Alcohol Warming	Tingly	Astringent
0% Ethanol	0.39	0.18	0.18	0.32	0.23 ^{c}	0.17	0.08 ^{b}	0.06 ^{b}	0.22	0.20
0.5% Ethanol	0.35	0.22	0.17	0.31	0.29 ^{bc}	0.18	0.13 ^{b}	0.04 ^{b}	0.21	0.16
2.8% Ethanol	0.37	0.16	0.19	0.31	0.36 ^{b}	0.13	0.13 ^{b}	0.09 ^{b}	0.22	0.17
5% Ethanol	0.31	0.17	0.25	0.27	0.48 ^{a}	0.14	0.19 ^{a}	0.17 ^{a}	0.25	0.15

^{abc}Different letters within a column represent significant differences among samples (Fisher's Exact Test ($p<0.05$)).

Table 5. Ordered probit coefficients and associated p values illustrating the relationship between overall liking (9-pt hedonic scale) and temporal liking (15-cm line scale) for all consumer clusters and beer samples at 10, 20, 40 and 60 seconds of evaluation. Bold font indicates significant relationships ($p<0.05$).

0% Ethanol Beer						
	Cluster 1		Cluster 2		Cluster 3	
Evaluation time (s)	coefficient	p-value	coefficient	p-value	coefficient	p-value
10	0.161	0.191	-0.105	0.114	0.011	0.949
20	0.214	0.130	0.165	0.081	0.155	0.716
40	-0.183	0.426	0.156	0.076	0.648	0.468
60	0.528	**0.015**	0.260	**0.006**	0.553	0.331
0.5% Ethanol Beer						
	Cluster 1		Cluster 2		Cluster 3	
Evaluation time (s)	coefficient	p-value	coefficient	p-value	coefficient	p-value
10	-0.056	0.663	-0.054	0.519	0.05	0.842
20	0.243	0.1	0.029	0.801	-0.189	0.708
40	0.100	0.681	0.446	**0.001**	0.979	0.319
60	0.392	**0.049**	0.321	**0.001**	0.801	0.328
2.8% Ethanol Beer						
	Cluster 1		Cluster 2		Cluster 3	
Evaluation time (s)	coefficient	p-value	coefficient	p-value	coefficient	p-value
10	$-3.3x10^{-6}$	1	0.857	0.289	0.281	0.809
20	-0.13	0.4	0.109	0.272	0.471	0.151
40	0.80	**0.014**	0.336	**0.009**	-0.363	0.569
60	-0.589	0.841	0.119	0.282	0.636	0.192
5% Ethanol Beer						
	Cluster 1		Cluster 2		Cluster 3	
Evaluation time (s)	coefficient	p-value	coefficient	p-value	coefficient	p-value
10	0.528	**0.005**	-0.28	0.676	0.051	0.622
20	0.526	0.066	0.253	**0.005**	0.672	**0.002**
40	-0.763	0.114	0.117	0.379	-0.261	0.638
60	0.780	**0.041**	0.258	0.032	0.821	0.163

Table 6. z and associated p values from regression analysis denoting influence of TCATA attributes on temporal liking by cluster over consumption time. Black shading shows a significant negative driver of liking; grey shading shows a significant positive driver of liking.

Cluster 1								
	0% Ethanol		0.5% Ethanol		2.8% Ethanol		5% Ethanol	
Attribute	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Malty	-5.30	**<0.0001**	1.77	0.077	4.51	**<0.0001**	-4.40	**<0.0001**
Astringent	-6.20	**<0.0001**	0.47	0.636	-6.13	**<0.0001**	0.55	0.580
Alcohol	-2.13	**0.033**	-4.14	**<0.0001**	0.48	0.634	0.35	0.728
Bitter	-1.98	**0.048**	-8.34	**<0.0001**	-6.33	**<0.0001**	2.55	**0.011**
Fruity	-4.77	**<0.0001**	5.10	**<0.0001**	-1.99	**0.047**	6.54	**<0.0001**
Body	3.15	**0.002**	-5.63	**<0.0001**	5.06	**<0.0001**	8.24	**<0.0001**
Sour	-11.00	**<0.0001**	-4.17	**<0.0001**	0.48	0.633	-6.57	**<0.0001**
Sweet	-4.89	**<0.0001**	3.15	**0.002**	1.51	0.131	5.20	**<0.0001**
Tingly	2.08	**0.037**	6.31	**<0.0001**	4.31	**<0.0001**	4.06	**<0.0001**
Cluster 2								
	0% Ethanol		0.5% Ethanol		2.8% Ethanol		5% Ethanol	
Attribute	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Malty	6.37	**<0.0001**	5.17	**0.000**	8.91	**<0.0001**	0.90	0.369
Astringent	9.45	**<0.0001**	-2.47	**0.013**	-6.06	**0.000**	-7.17	**<0.0001**
Alcohol	6.38	**<0.0001**	2.06	**0.039**	-0.50	0.616	3.97	**<0.0001**
Bitter	0.14	0.892	1.50	0.134	3.76	**<0.0001**	0.16	0.871
Fruity	2.86	**0.004**	0.61	0.543	4.64	**0.000**	14.32	**<0.0001**
Body	0.09	0.926	-1.78	0.076	0.02	0.984	-4.93	**<0.0001**
Sour	-2.88	**0.004**	1.22	0.223	1.00	0.318	1.03	0.304
Sweet	2.94	**0.003**	7.92	**<0.0001**	4.59	**<0.0001**	-0.17	0.861
Tingly	2.12	**0.034**	-2.44	**0.015**	-5.57	**<0.0001**	-3.81	**<0.0001**
Cluster 3								
	0% Ethanol		0.5% Ethanol		2.8% Ethanol		5% Ethanol	
Attribute	z-value	p-value	z-value	p-value	z-value	p-value	z-value	p-value
Malty	-5.18	**<0.0001**	-4.30	**<0.0001**	0.95	0.342	-0.79	0.428
Astringent	-1.88	0.061	-2.61	**0.009**	3.88	**<0.0001**	-4.67	**<0.0001**
Alcohol	-0.32	0.749	-1.30	0.194	-0.88	0.380	-3.73	**<0.0001**
Bitter	3.13	**0.002**	1.44	0.150	-6.24	**<0.0001**	-5.17	**0.000**
Fruity	1.82	0.069	-1.69	0.091	3.97	**<0.0001**	0.31	0.760
Body	0.33	0.742	-0.02	0.986	9.24	**<0.0001**	1.18	0.239
Sour	2.69	**0.007**	3.52	**<0.0001**	2.46	**0.014**	4.31	**<0.0001**
Sweet	1.38	0.168	4.57	**<0.0001**	-5.15	**0.000**	-3.68	**<0.0001**
Tingly	15.88	**<0.0001**	5.28	**<0.0001**	1.12	0.261	7.36	**<0.0001**

Figure Legends:

Figure 1. Temporal liking curves for Cluster 1 (A), Cluster 2 (B) and Cluster 3 (C) showing the mean liking of each beer sample by cluster.

Figure 2. Smoothed TCATA attribute curves (continuous lines) for A: 0% ethanol; B: 0.5% Ethanol; C: 2.8% ethanol and D: 5% ethanol. Thicker segments represent time period where proportion of citation is significantly different to the other 3 samples. In contrast, dotted lines represent pooled average proportion of citations for the other 3 samples, where significantly different ($p<0.05$). Each attribute is represented by a different colour.

Figure 3. Principal components analysis (PCA) biplot of the TCATA citation of attribute data over the 60s period for all beer samples. The arrow head > indicates swallow time (at 10s) and shows the development of these attributes over the 60 sec evaluation period. Beer sample trajectories are labelled with the ethanol concentration at the first 40 sec of evaluation time. Time markers (dots) ● are positioned along the remainder of each of the trajectories at 5 sec intervals to show progression of evaluation time

Figure 1

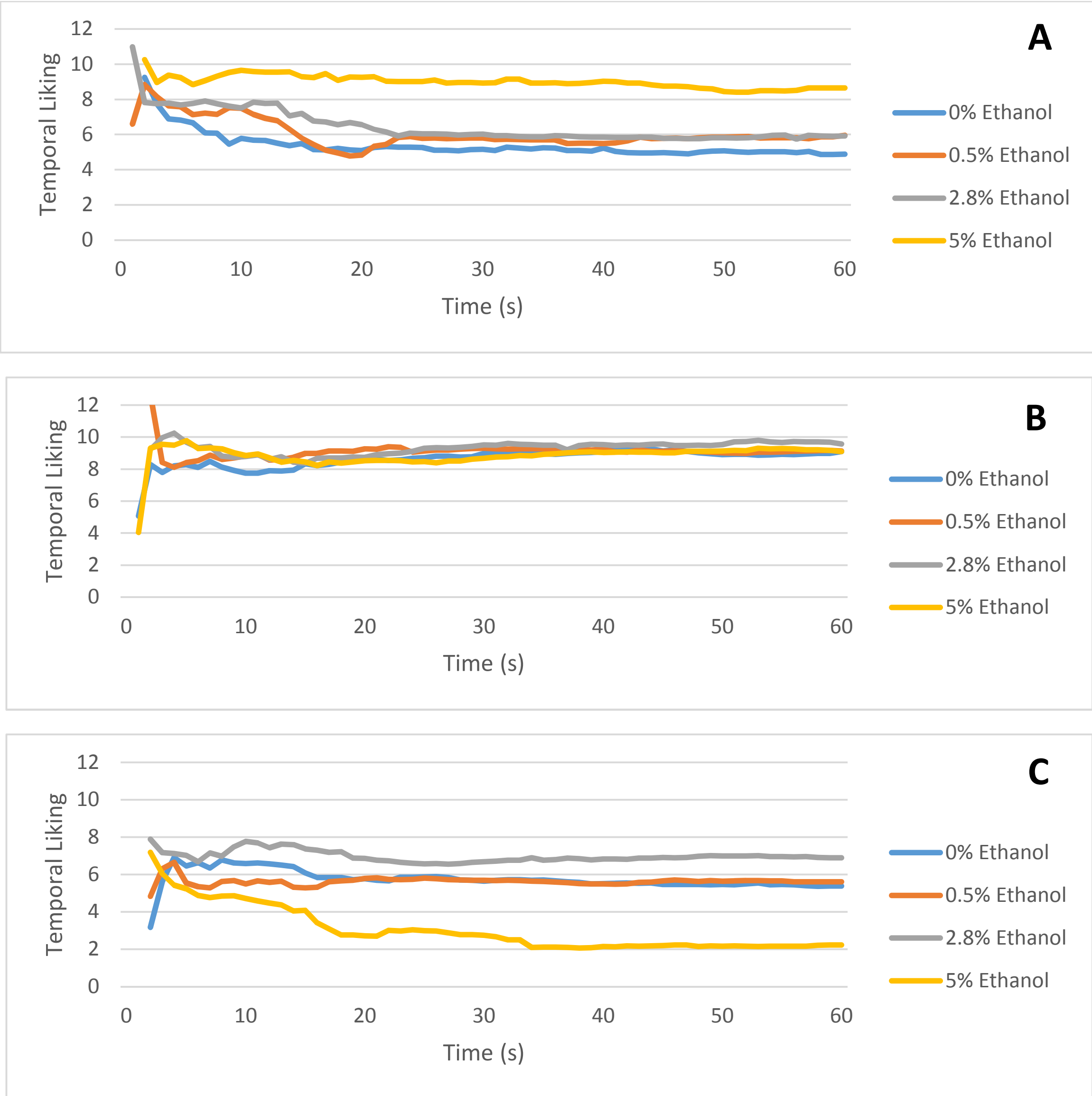
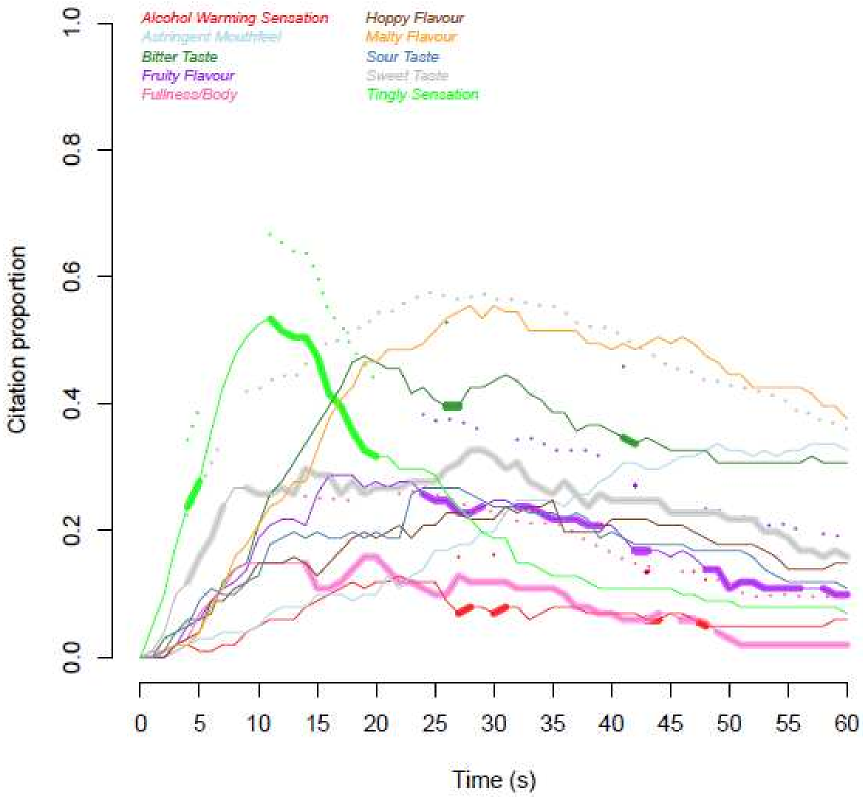
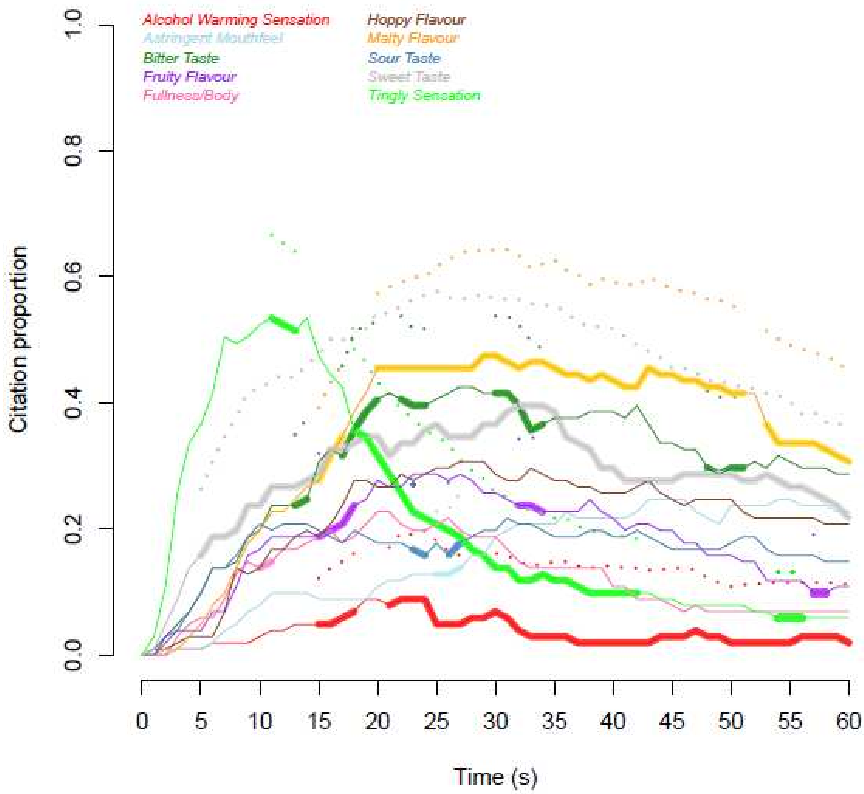

A
B
C
Temporal Liking
Time (s)
0% Ethanol
0.5% Ethanol
2.8% Ethanol
5% Ethanol

Figure 2

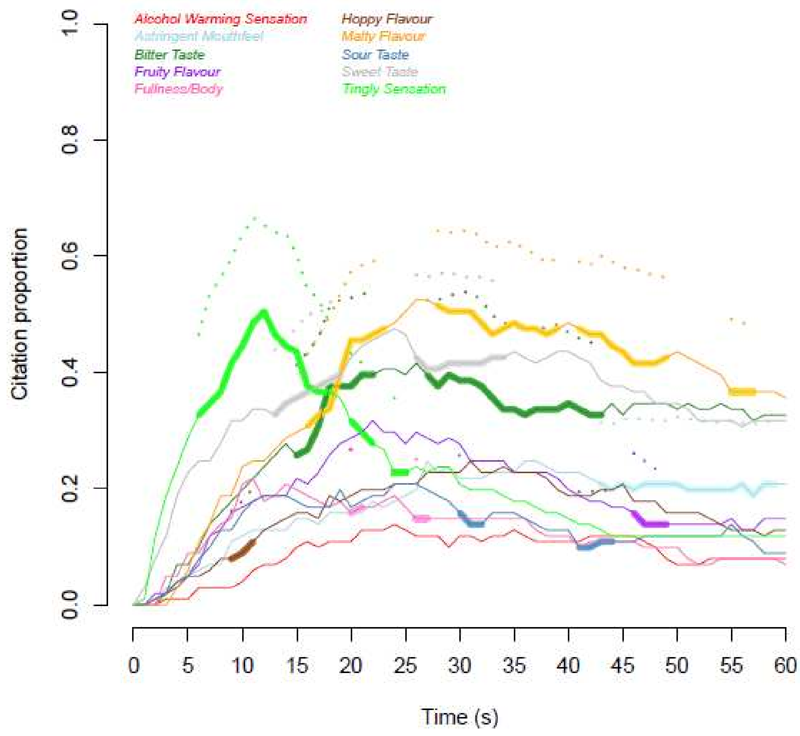
A. **0% Ethanol**



B. **0.5% Ethanol**



C. **2.8% Ethanol**



D. **5% Ethanol**

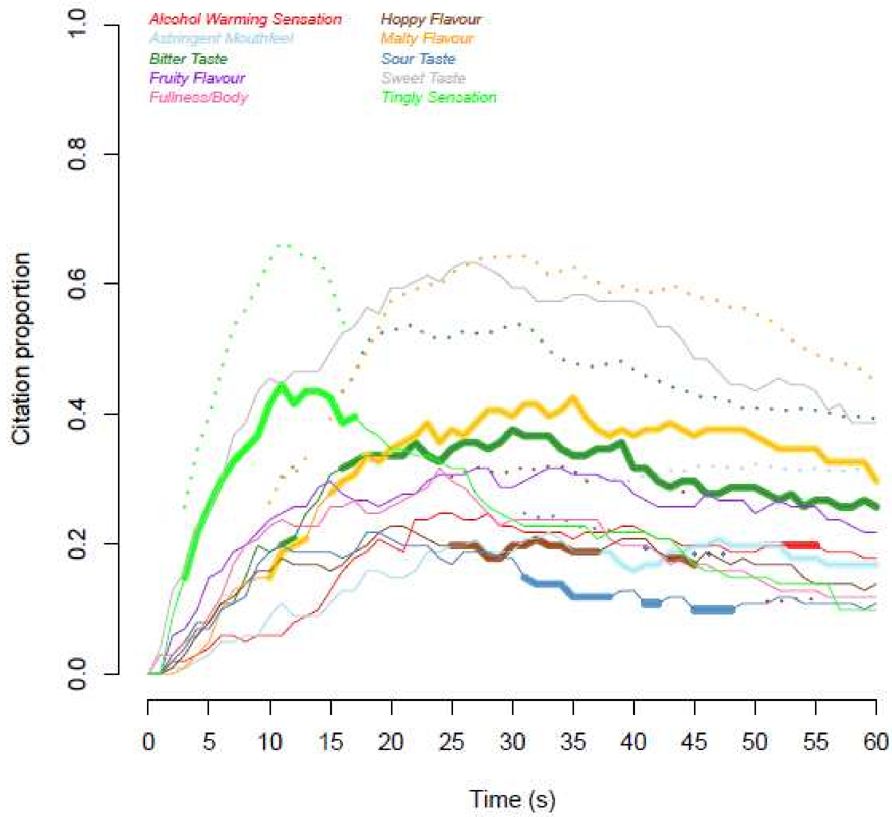
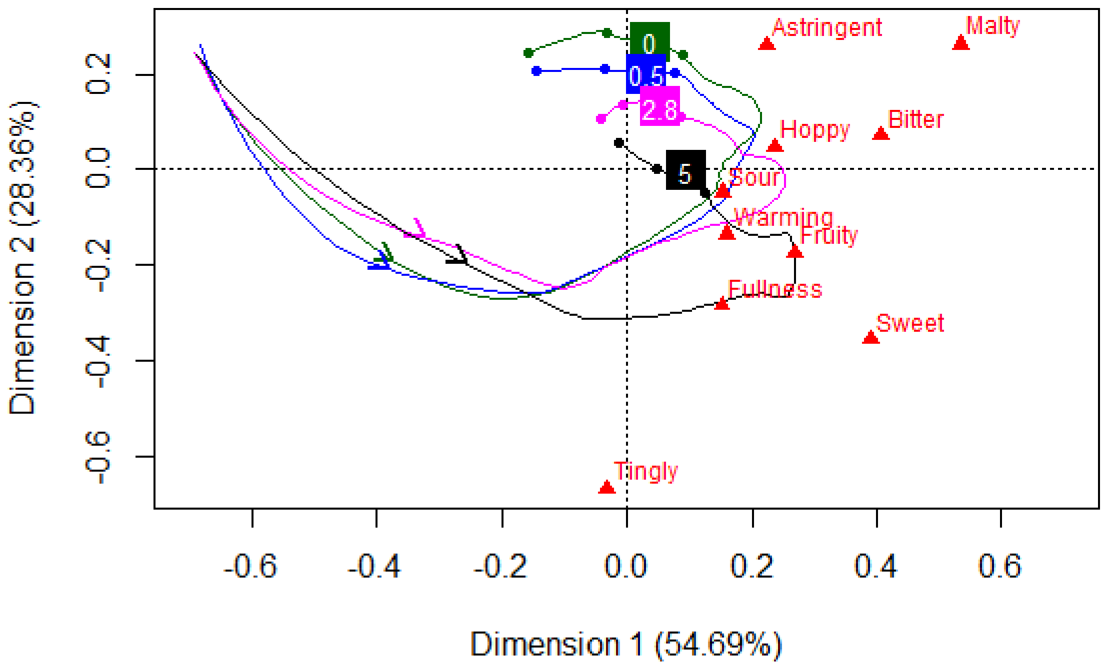


Figure 3


Astringent
Malty
Hoppy
Bitter
Sour
Warming
Fruity
Fullness
Sweet
Tingly
0
0.5
2.8
5
Dimension 2 (28.36%)
Dimension 1 (54.69%)
0.2
0.0
-0.2
-0.4
-0.6
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6