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Comparison of TCATA and TDS for dynamic sensory characterization of food products

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ABSTRACT

Temporal Check-All-That-Apply (TCATA) has been recently introduced as a method for temporal sensory product characterization. Building on the standard Check-All-That-Apply (CATA) question format, assessors select all the terms they consider applicable for describing the sensations they perceive, and they do so at each moment of the evaluation process. This research further investigates the TCATA method, through its application to products of varying complexity (yogurt, salami, cheese, orange juice, French bread, and marinated mussels) using consumers and trained panellists as assessors. More importantly, to deliver new methodological insights we compare TCATA to Temporal Dominance of Sensations (TDS). This comparison will aid researchers to select the temporal method best suited to their needs. Across three countries, six studies were conducted. Within-subjects experimental designs were used in Studies 1–3 and involved trained panellists using both TCATA and TDS on the same set of products. In Studies 4–6, between-subjects experimental designs were used, and the assessors, who were consumers, evaluated samples using either TCATA or TDS. The results confirmed that TCATA is suitable for measuring the temporal sensory characteristics of products. By enabling identification of several sensory characteristics that are concurrently perceived in products, the results from this research also suggest that TCATA may provide a more detailed description of the dynamics of the sensory characteristics of products. The TDS concept of dominance appears to decrease detailed description and discrimination of attributes that are simultaneously perceived, particularly when dealing with multiple sensory modalities. The practical implications of these differences are discussed.

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1. Introduction

Sensory perception is a dynamic phenomenon (Lawless & Heymann, 2010). The perceived intensity of the sensory attributes changes along with the in-mouth transformation of food and the release of olfactory compounds during food breakdown (Sudre, Pineau, Loret, & Martin, 2012). However, the most common methods for sensory profiling do not consider this temporal aspect of sensory perception and may miss crucial information for understanding consumer preferences (Lawless & Heymann, 2010). This necessitates the study of the dynamics of sensory perception.

Several temporal sensory methods are available for dynamic sensory characterization (Cadena, Vidal, Ares, & Varela, 2014). The focus of this research is Temporal Check-All-That-Apply (TCATA), which was recently introduced by Castura, Antúnez, Giménez, and Ares (2016). TCATA is an extension of Check-All-That-Apply (CATA) questions, which are increasingly used for sensory product characterization, especially with consumers (e.g., Ares et al., 2013; Ares et al., 2014; Jaeger & Ares, 2014; Meyners & Castura, 2014; Meyners, Castura, & Carr, 2013). In TCATA, assessors are presented with a list of terms and are asked to select all the terms they consider applicable to describe the sensations they perceive at each moment of the product evaluation. For example, when evaluating salami sample, TCATA allows assessors to indicate that they simultaneously perceive it as *hard* and *salty*, or as *salty*, *pungent*, and *spicy*. Assessors check attributes when the focal sensory attributes are applicable, and uncheck them again when the sensory attributes are no longer applicable. In the salami example assessors can indicate that salami is no longer *hard* as chewing progresses, while *soft* may become applicable. The TCATA method has been used to investigate various products, such as strawberry-flavoured yogurt (Castura et al., 2016), chocolate-flavoured milk (Oliveira et al., 2015), and cosmetic creams (Boinbaser, Parente, Castura, & Ares, 2015).

To further investigate the TCATA method we present its application to six different product categories of varying complexity. To permit evaluation of the methods with different types of assessors some studies

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involved trained panellists and others involved consumers. To deliver new methodological insight we compare TCATA to Temporal Dominance of Sensations (TDS: Pineau, Cordelle, & Schlich, 2003). TDS is one of the most popular multi-attribute temporal methodologies and has been applied to a wide range of products of different complexity, including orange juice, wine, blackcurrant squashes, coffee, fish sticks, extra-virgin oil added to vegetables, and salmon–sauce combinations (Albert, Salvador, Schlich, & Fiszman, 2012; Dinnella, Masi, Zoboli, & Monteleone, 2012; Meillon, Urbano, & Schlich, 2009; Ng et al., 2012; Paulsen, Naes, Ueland, Rukke, & Hersleth, 2013; Zorn, Alcaire, Vidal, Giménez, & Ares, 2014). Similarly to TCATA, TDS can be used with trained assessors and consumers (Cadena et al., 2014).

Besides being dedicated methods for dynamic sensory characterization of foods, beverages, and personal care products, TCATA and TDS both rely on pre-determined lists of attributes, which are used to indicate how the sensory properties of a focal sample change over time. Data from both methods can be conveniently presented as smoothed curves for each sample which provide a sense of how the perceived sensory sensations evolve. A critical difference between the two methods is the concept of dominance, which is fundamental to TDS. When assessors complete a TDS task they are asked to select from the list of attributes the one attribute that at each moment of the evaluation is perceived as dominant (i.e., the attribute that catches the assessor's attention at a given time, not necessarily the most intense attribute; Pineau et al., 2009). During the course of product evaluation, the assessors have to select the new dominant sensation each time the dominant attribute changes.

By focusing exclusively on the dominant attribute, other sensory characteristics that are perceived simultaneously while consuming a product are not captured with the TDS method. This requirement for sequential selection can potentially result in loss of relevant sensory information, particularly when dealing with complex products that elicit several sensations simultaneously during consumption. For example, when assessors evaluate salami using TDS and simultaneously perceive it as *hard*, *salty*, and *spicy*, they can select only one of these attributes as dominant. Considering that TCATA enables the evaluation of more than one attribute at each moment of the evaluation, this method may provide a more complete description of how the sensory characteristics of products change over time. It is plausible that a more detailed complete product characterization could be accompanied by an increased sensory discrimination of samples.

2. Materials and methods

The empirical work comprised six studies which are summarized in Table 1. To increase the generalizability of the research, different product categories with different complexities were included: yogurt, salami, cheese, orange juice, French bread and marinated mussels. In Studies 1–3 a trained panel evaluated samples using both TDS and TCATA (i.e., a within-subjects experimental design). In Studies 4–6 samples were evaluated by consumers in accordance with a between-subjects experimental design (i.e., participants performed either the TDS or the TCATA task, not both tasks). Studies 1, 4 and 5 were carried out in Montevideo (Uruguay), Studies 2 and 3 were performed in Buenos Aires (Argentina), and Study 6 took place in Auckland (New Zealand).

Details pertaining to the materials and methods of the six studies are presented below. Length restrictions required leaving out some minor aspects of the empirical implementation of the studies, and interested readers may contact the authors for further information.

2.1. Samples

Samples in Studies 1–3 and 5 were commercial products, available in supermarkets in Montevideo (Uruguay) or Buenos Aires (Argentina). Products were purchased and maintained in storage under refrigeration temperatures (2–5 °C ± 1 °C), and removed from the refrigerator as needed immediately prior to sensory evaluation. Yogurt samples were served at (8 °C ± 1 °C), while cheese and salami samples were served at (20 °C ± 1 °C).

Samples in Study 4 corresponded to orange juices formulated with different sweeteners at equi-sweet concentrations (Alcaire et al., 2014). Samples 1 and 2 were sweetened with commercial sucrose and sucralose, respectively. Samples 3 and 4 were each sweetened with a different type of Stevia, whereas Samples 5 and 6 were identical to Samples 3 and 4 but had 10 mg L^{-1} of thaumatin added to each. Samples were prepared following the procedure described by Zorn et al. (2014). Samples were served at (8 °C ± 1 °C).

In Study 6 two marinated mussel products available in New Zealand supermarkets were evaluated. Following purchase, the mussels were stored at 3–5 °C. The adductor muscle was removed prior to serving, and samples were prepared 20 min prior to tasting. All samples were drained for 2 min.

In all studies samples were presented labelled with random 3-digit codes for identification.

2.2. Participants

2.2.1. Trained assessors

In Studies 1–3 evaluations were performed with three different panels of 12 trained assessors (ages ranging from 24 to 60 years; percentage of female assessors ranging from 50% to 80%). All assessors had been selected according to the guidelines of the ISO 8586:2012 standard (ISO, 2012) and had been involved with prior descriptive sensory evaluation of the target products. The panels had been previously trained in attribute recognition and scaling on all sensory modalities relevant to the focal samples. In Study 1 assessors had a minimum of 1 year experience in the evaluation of stirred yogurt, whereas assessors in Studies 2 and 3 had a minimum of 5 years of experience in the evaluation of the target products (salami and cheese) using descriptive sensory analysis. Four additional training sessions, each lasting 15 min, were conducted out to familiarize assessors with the TDS and TCATA tasks.

2.2.2. Consumers

Studies 3–6 were each carried out with 100–121 consumers (Table 1). In Studies 3 and 4 participants were recruited from the

Table 1
Overview of the studies included in this research.

Study	Product category	Number of samples	Type of assessors	Experimental design to compare TCATA and TDS	Total number of assessors	Replicated assessments in data collection
1	Strawberry yogurt	6	Trained assessors	Within-subjects	12	3
2	Salami	4	Trained assessors	Within-subjects	12	3
3	Pategras cheese	4	Trained assessors	Within-subjects	12	3
4	Orange juice	6	Consumers	Between-subjects	100[a]	1
5	French bread	5	Consumers	Between-subjects	100[a]	1
6	Marinated mussels	2	Consumers	Between-subjects	121[b]	1

[a] Half of the consumers completed TCATA and the other half TDS.
[b] 59 consumers completed TCATA and 62 TDS.

consumer database of the Food Science and Technology Department of Universidad de la República (Uruguay), based on their consumption of the focal products and willingness to take part in the study.

In Study 6 participants were recruited in Auckland, New Zealand by a marketing research provider based on their shellfish consumption, as well as their interest and availability to participate in the study. In this study, data were collected as part of a consumer research project that included tasting of other foods/beverages.

The participants in Studies 3–6 were aged between 18 and 70 years old and the percentage of female participants ranged from 60% to 65%. The consumer samples comprised varying household compositions, income levels, education levels, etc. but were not representative of the general populations in Montevideo and Auckland. It was a requirement that participants were familiar with computers and using a computer mouse. Participants gave written informed consent and were compensated for their participation.

2.3. Experimental procedure

The procedure for data collection was independent of assessor type (trained assessor or consumer) and is described in Sections 2.3.1 and 2.3.2 for TCATA and TDS, respectively. Section 2.3.3 provides additional experimental details (e.g., task perception measures, testing environment, palate cleansing).

2.3.1. Temporal Check-All-That-Apply (TCATA)

Assessors were instructed to review the attributes prior to the evaluation to facilitate the task of locating attributes during the TCATA evaluation. They were instructed that they had to select all the terms from a list that applied to describe the sensory characteristics of the focal sample at each moment of the evaluation and that terms that were no longer applicable should be unchecked. Assessors had to click a Start button concurrently with taking a sip/bite of the sample, and to immediately commence sample evaluation. At any time between clicking Start and the end of the evaluation time, assessors were free to check any unselected attribute, or to uncheck any selected attribute. All assessors swallowed the samples, but precise instructions were not given about the specific moment at which they should do so.

2.3.2. Temporal Dominance of Sensations (TDS)

Assessors were instructed to review the attributes prior to the evaluation to facilitate the task of locating attributes during the TDS evaluation. They were instructed that they had to select, from a list of terms, the term that caught their attention, not necessarily being the most intense, at each moment of the evaluation. No training on how to select the attribute that caught their attention, i.e. the dominant attribute, was given.

Assessors had to click a Start button concurrently with taking a sip/bite of the sample, and to immediately commence sample evaluation. To suit the focal product category, task duration varied among studies (e.g., shorter for yogurt and longer for mussels) (Table 2). However, task duration was identical for TDS and TCATA within each study. Task duration was determined following pilot testing with staff members in the different organizations.

2.3.3. Additional experimental details

In Studies 1–3, in accordance with a within-subjects experimental design, trained assessors evaluated samples using both TDS and TCATA. In each study data collection took place over six days. Assessors completed the three replicate assessments of samples with one method before starting the replicate assessments of samples using the other method. The order in which assessors completed the tasks was balanced. In Studies 4–6, in accordance with a between-subjects experimental design, consumers were randomly divided into two groups, each of which evaluated samples using a different methodology (TDS or TCATA).

In all six studies, testing took place in sensory laboratories, in standard sensory booths that were designed in accordance with ISO 8589 (ISO, 2007), under artificial daylight and temperature control (22 °C). Samples were presented in sequential monadic presentation order according to a Williams' Latin Square design (Williams, 1949) which balanced for sample order and carry-over effects. Still mineral water was used for rinsing between samples in Studies 1, 4–6. In Studies 2 and 3 unsalted bread, slices of peeled Granny Smith apple, and water were used as palate cleansers. In Study 6 consumers evaluated a warm-up sample (a commercial marinated mussel product that was different from the other two samples) to provide task familiarization before starting the study.

The duration of the task and the lists of terms were identical for TCATA and TDS (Table 2). Both TCATA and TDS used the same attribute lists, which contained between 6 and 12 terms to account for differences in product categories and degree of stimuli complexity. In studies involving trained assessors, terms were selected through evaluation of commercial samples within the product category and discussion with the panel leader, and had precise definitions and references were used. In studies involving consumers, terms were selected considering results of previous consumer studies and pilot work, but no explanations of terms were provided. Presentation order of the terms was balanced between assessors following a Williams' Latin square design, which also addressed first-order carry over effects (Williams, 1949). The terms included in each of the six studies are shown in Table 2.

In line with questions previously used to explore consumers' task perception of CATA questions and variants hereof (e.g., Jaeger & Ares, 2014), self-reported task perception measures were obtained in Studies 4–6. In these consumer studies participants answered two Likert questions immediately after completion of the task (TDS or TCATA): i) It was easy to answer the questions about these samples; and ii) It was tedious to answer the questions about these samples. The labelled 7-point scale had 1 = 'disagree extremely' and 7 = 'agree extremely' as end-point anchors.

For the studies involving consumer participants (Studies 4–6), differences in the distribution of age, gender, and frequency of consumption of the focal products were non-significant between the two experimental treatments ($p > 0.20$). Hence, it was possible to infer that differences between groups may be mainly linked to differences in study protocol, as opposed to differences in group characteristics.

Language was suited to each country: Spanish for studies in Argentina and Uruguay and English for the study conducted in New Zealand. Data

Table 2
Duration of the task and list of terms considered in TCATA and TDS for the six studies.

Study	Product category	Task duration (s)	Number of terms	List of terms
1	Strawberry yogurt	30	8	Sour, creamy, sweet, greasy mouth-coating, cream flavour, strawberry flavour, artificial flavour, off-flavour
2	Salami	40	11	Soft, hard, gummy, fibrous, greasy, pungent, characteristic salami flavour, spicy, off-flavour, salty, brittle
3	Pategras cheese	45	12	Soft, sticky, bitter, sour, creamy, firm, gummy, pungent, characteristic pategrás cheese flavour, off-flavour, salty, melting
4	Orange juice	20	6	Acid, bitter, astringent, sweet, orange flavour, off-flavour
5	French bread	25	8	Crunchy, tasty, smooth, soft, toasted, salty, hard, light
6	Marinated mussels	90	9	Chewy, firm, garlic, moist, savoury, smoky, soft, sour/acidic, sweet

collection was carried out using *Compusense-at-hand* (Compusense Inc., Guelph, Canada).

2.4. Data analysis

All data analyses were carried out using R version 3.0.2 (R Core Team, 2014).

2.4.1. Analysis of TCATA data

TCATA data were analysed in accordance with the recommendations provided by Castura et al. (2016). For each sample, aggregated data across all participants were represented using line plots, which are similar in appearance and interpretation to TDS curves (cf. Pineau et al., 2009). The citation proportion of each attribute was calculated as the proportion of judgments (assessors × replicates) for which it was selected for describing a sample at a given time (every 1 s) of the evaluation. TCATA curves were smoothed using a spline type polynomial. The maximum citations proportions for each sample were noted.

TCATA difference plots for selected pairs of samples were obtained in a manner analogous to TDS difference plots, i.e. by subtracting their citation proportions. A sign test was applied at each time point and for each attribute to evaluate whether citation proportions for the pairs of products were statistically significant from zero at the 5% significance level (Castura et al., 2016). Because proportions were based on the same attributes and products, and used in statistical tests as a basis for comparison, this percentage enabled direct comparison of TDS and TCATA results with regard to product discrimination by method.

2.4.2. Analysis of TDS data

The TDS data were analysed following standard procedures (Cadena et al., 2014). For each assessor, the attribute regarded as dominant at each time of the evaluation was recorded. The dominance rate for each attribute at a given time (every 1 s) was determined as the proportion of judgments (assessors × replicates) for which the given attribute was selected as dominant. Dominance rates were smoothed using a spline type polynomial with the R package `pspline` (Ramsey & Ripley, 2013) and plotted against time for each sample to obtain TDS curves.

Chance levels were calculated equal to the inverse of the total number of attributes plus one, as suggested by Labbe, Schlich, Pineau, Gilbert, and Martin (2009). Significance levels (P_s) were calculated using a binomial test as the minimum value dominance rates have to achieve to be significantly higher than chance level, as recommended by Pineau et al. (2009) when dealing with few evaluations, and represented on the TDS curves. The average dominance rates for the evaluation period were obtained, both globally and per-sample, as well as the number of significantly dominant attributes at each moment. The duration in which at least one attribute exceeded the significance line was determined (henceforth: "significantly dominant attributes"), and expressed as a percentage of the evaluation period. The number of attributes that were significantly dominant concurrently was also obtained, as well as the duration in which multiple attributes were significant concurrently.

TDS difference curves between the selected pairs of samples were constructed by subtracting their TDS curves at each time. Difference rate differences were considered significant when they were significantly different from zero according to the sign test at the 5% significance level. The total duration of pairwise differences that were statistically significant using this approach was expressed as a percentage of all possible comparisons in the evaluation period.

2.4.3. Task perception data

Perceived ease and tediousness of test data were analysed using Student's t-tests.

3. Results

The comparison of TCATA to TDS, a well-established and popular temporal method, is the primary contribution of this research and will better enable researchers to select the temporal method best suited for their purposes. The presentation of results is structured to facilitate this outcome through a focus on sample characterization and discrimination. It is beyond the scope of the paper to present full results for all samples in all studies. Interested readers may contact the authors for further details (pertaining to either TCATA or TDS).

3.1. Sample characterization: citation proportions in TCATA and dominance rates in TDS

When using TCATA, assessors have to select all the attributes that apply to describe the sample, at each moment of the evaluation. With the exception of the first few seconds at the start of the evaluation, all assessors (trained panellists and consumers) always checked more than one attribute. On average, 1.3 to 3.0 attributes were selected by each consumer to describe each of the samples. In relative terms, average citation proportions in TCATA ranged from 0.22 to 0.27 (Tables 3i and 4i) and maximum citation proportions ranged between 0.45 and 0.90 (Tables 3ii and 4ii). The maximum citation proportions illustrate that some of the CATA terms were used by almost all assessors, at one or more times during the evaluation, e.g. *artificial flavour* for Sample 5 in Study 1 (maximum proportion 0.78) and *smoky* for Sample 2 in Study 6 (maximum proportion 0.90). For TDS, the "comparative values" — dominance rates — were lower, as expected given that assessors could check only one attribute at a time. As shown in Tables 3iv and 4iv average dominance rate across samples ranged from 0.06 to 0.11, whereas maximum dominance rates for the individual samples were lower than 0.50 in all studies (Tables 3v and 4v).

These differences between citation proportions in TCATA and dominance rates in TDS were observed in all attributes, regardless of the type of assessors involved in the study. Results aligned with expectations based on the characteristics of the two methods with respect to the number of characteristics that can be selected by each assessor at each moment of the evaluation (one attribute only in TDS vs. the possibility of multiple attributes at the same time in TCATA).

3.2. Sample characterization: dynamic sensory product profiles elicited by TCATA and TDS

In accordance with expectations, the results presented in this section illustrate how similar changes in the sensory profile of samples during consumption were uncovered by both temporal methods. For ease of presentation, the studies conducted with different groups of assessors are summarized in different sub-sections. Yet, as will be shown, the nature of the similarities and differences in the information provided by TCATA and TDS were stable across all studies. They supported the proposition that TCATA leads to a more detailed sample characterization than TDS.

3.2.1. Results from studies conducted with trained assessors

Fig. 1 shows exemplar TCATA and TDS curves for the three studies conducted with trained assessors. In Study 1 (Strawberry yogurt), Sample 3 was characterized by five dominant attributes in TDS, which appeared in sequential order during the evaluation: *creamy*, *sour*, *strawberry flavour*, *cream flavour*, and *greasy mouth-coating* (Fig. 1a). These five attributes were among those with the highest citation proportions in TCATA and reached their maximum citation at different moments of the evaluation. However, the period of time during which the attributes were relevant for describing samples in TCATA was longer than the time they were dominant in TDS. For example, *cream flavour* was dominant only for 1 s during the TDS evaluation, whereas it was among the terms with the highest citation proportion during the last half of the evaluation (Fig. 1a). Another relevant difference between

Table 3
Summary of results for the three studies comparing TCATA and TDS with trained assessors.

Methodology	Parameters	Study 1 (strawberry yogurt)	Study 2 (salami)	Study 3 (Pategras cheese)
TCATA	(i) Average citation proportion across samples	0.26	0.27	0.22
	(ii) Maximum citation proportion for individual samples	0.60–0.78	0.70–0.86	0.66–0.77
	(iii) Percentage of all possible comparisons between pairs of samples that were significant throughout the evaluation	23%	19%	17%
TDS	(iv) Average dominance rate across samples	0.11	0.07	0.07
	(v) Maximum dominance rate for individual samples	0.33–0.50	0.30–0.40	0.39–0.43
	(vi) Number of significantly dominant attributes for individual samples	3–5	2–4	3–5
	(vii) Percentage of the evaluation time during which at least one attribute was significantly dominant	76%	69%	79%
	(viii) Maximum number of attributes simultaneously dominant for individual samples	2–3	2	2–3
	(ix) Time (s) with simultaneous dominant attributes for individual samples	2–13	6–21	1–12
	(x) Non-significantly dominant attributes across samples	–	*Soft*, *fibrous*, *gummy*, *greasy*, *brittle*	*Sour*, *sticky*, *gummy*, *off-flavour*
	(xi) Percentage of all possible comparisons between pairs of samples that were significant throughout the evaluation	14%	8%	9%

the information provided by TCATA and TDS was related to the term *sweet*. Although this term was among the most cited in TCATA, showing citation proportions similar to those of the attributes *creamy* and *greasy mouth-coating*, this attribute did not reach significant dominance at any point during the TDS evaluation.

Fig. 1b shows TCATA and TDS curves for one of the salami samples in Study 2 (Sample 1). The dynamic profile of the sample obtained using TDS was characterized by four dominant attributes: *hard* and *off-flavour* at the beginning of the evaluation, and *salty* and *pungent* at the end of the evaluation. These attributes tended to be dominant for small periods of time at different moments of the evaluation. *Hard*, *off-flavour*, *salty*, and *pungent* showed citation proportions higher than 0.4 TCATA, and reached maximum citation proportions at similar times as the maximum dominance rates were reached in TDS. However, the period of time during which these attributes were relevant for characterizing samples was longer in TCATA than in TDS. For this sample it was interesting to note that at the end of the TDS evaluation the terms *spicy*, *characteristic salami flavour*, and *fibrous* showed citation proportions similar to those of the terms *pungent* and *off-flavour* in TCATA, but they were not significantly dominant.

Similar differences between TCATA and TDS were found in Study 3 (Pategras cheese), as exemplified in Fig. 1c for Sample 2. The term *melting* had a citation rate close to 0.5 near the end of the TCATA evaluation but was not significantly dominant at any time in TDS. The dynamic sensory profile of this sample was characterized by the fact that none of the attributes reached significant dominance in TDS for several periods of time during the evaluation.

3.2.2. Results from studies conducted with consumers

Differences between TCATA and TDS in the studies involving consumers were similar to those observed with trained assessors. Curves for exemplar samples in Studies 4–6 are shown in Fig. 2. When the TDS curve of Sample 5 in Study 4 (orange juice) was considered, only the term *sweet* was identified as significantly dominant for describing its dynamic sensory profile (Fig. 2a). However, TCATA provided a different description of this sample, as it was characterized by four attributes: *acid*, *orange flavour*, *off-flavour*, and *orange flavour* (Fig. 2a), which showed similar citation proportions.

Similar results were obtained in Study 5 (French bread). Although *crunchy* was the only significant attribute during the TDS evaluation of Sample 5, several other attributes received similar citation proportions in the TCATA task (Fig. 2b). According to this methodology Sample 5 was characterized by crunchiness at the beginning of the evaluation and by *tastiness*, *saltiness*, *softness*, and *lightness* at the end.

In Study 6 (marinated mussels), Sample 1 was mainly characterized by the dominance of the term *sour*/*acidic* throughout the TDS evaluation and the dominance of *chewiness* in the middle of the evaluation (Fig. 2c). Although these two attributes showed high citation proportions in TCATA, the temporal profile of Sample 1 was also characterized by the term *moist*, which had a similar citation proportion to the previous two attributes. Although the term *sweet* was only significantly dominant for 2 s in TDS, the TCATA data showed *sweet* cited at proportions higher than 0.4 for a period of 20 s.

Table 4
Summary of results for the three studies comparing TCATA and TDS with consumers.

Methodology	Parameter	Study 4 (orange juice)	Study 5 (French bread)	Study 6 (mussels)
TCATA	(i) Average citation proportion across samples	0.22	0.23	0.24
	(ii) Maximum citation proportion for individual samples	0.45–0.78	0.60–0.72	0.88–0.90
	(iii) Percentage of all possible comparisons between pairs of samples that were significant throughout the evaluation	28%	16%	18%
TDS	(iv) Average dominance rate across samples	0.10	0.08	0.06
	(v) Maximum dominance rate for individual samples	0.26–0.41	0.30–0.32	0.41–0.43
	(vi) Number of significantly dominant attributes for individual samples	1–2	1–3	2–3
	(vii) Percentage of the evaluation time during which at least one attribute was significantly dominant	59%	54%	57%
	(viii) Maximum number of attributes simultaneously dominant for individual samples	1–2	1–2	2
	(ix) Time (s) with simultaneous dominant attributes for individual samples	2	2	26–27
	(x) Non-significantly dominant attributes across samples	*Acid*, *astringent*	*Hard*, *toasted*, *salty*	*Firm*, *garlic*, *moist*, *savoury*, *soft*
	(xi) Percentage of all possible comparisons between pairs of samples that were significant throughout the evaluation	14%	9%	14%

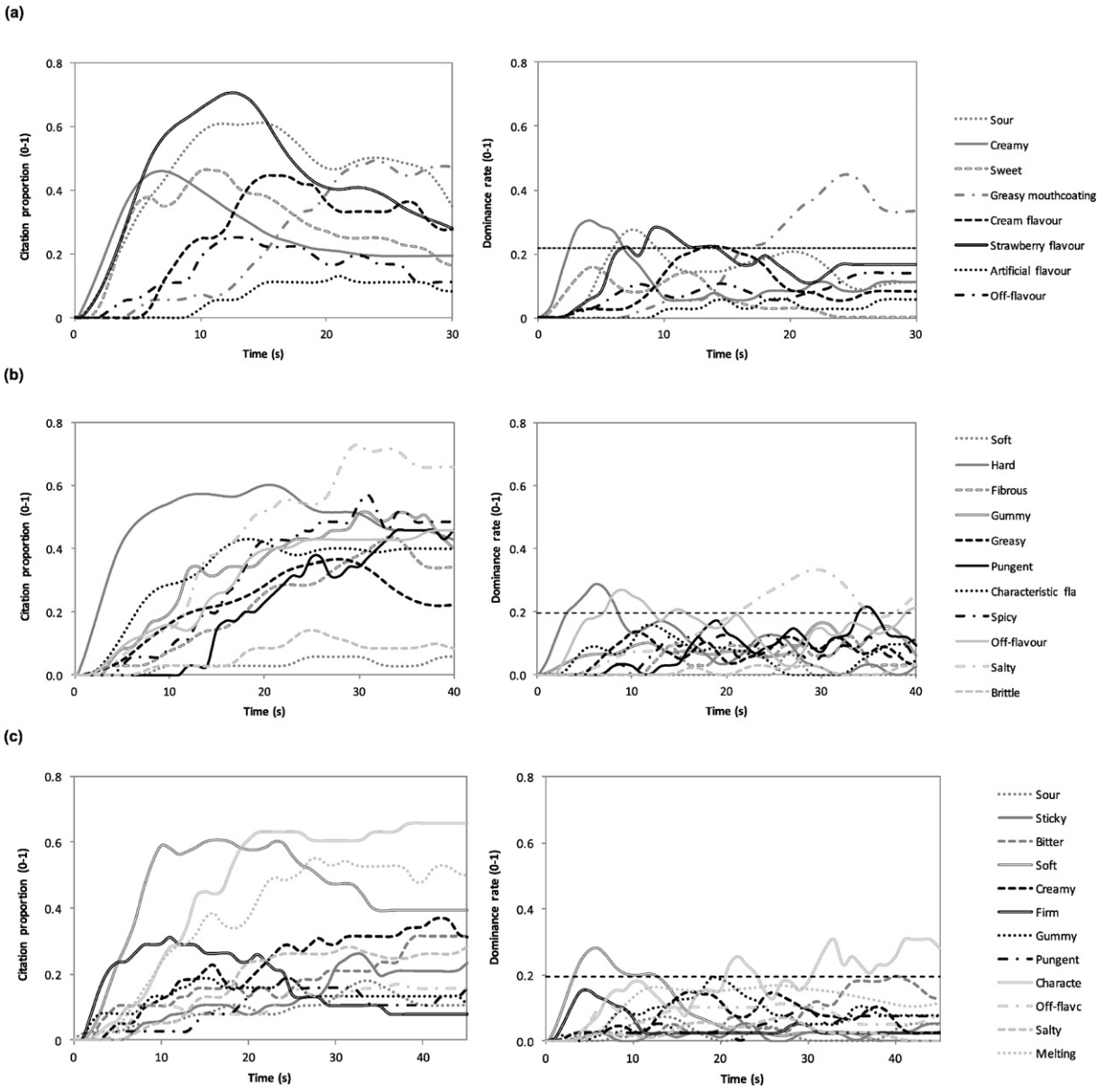

Fig. 1. Exemplar TCATA (left) and TDS (right) curves obtained with trained assessors: (a) Sample 3 in Study 1 (strawberry yogurt), (b) Sample 1 in Study 2 (salami), and (c) Sample 2 in Study 3 (Pategras cheese). Horizontal dotted lines in TDS curves correspond to the 5% significance level.

3.2.3. Similarities and differences in the dynamic sensory product profiles elicited by TCATA and TDS

The results described above suggest that several terms which were highly relevant for describing samples in TCATA were not significantly dominant in TDS. As shown in Tables 3vi and 4vi, samples tended to be described with a small number of dominant attributes throughout the TDS evaluation (between 1 and 5). This suggests that several attributes did not reach significance throughout the evaluation, probably due to lack of consensus among assessors on which attributes were dominant (Tables 3x and 4x). However, the number of attributes with relatively high citation proportion in TCATA was larger. For example, in Studies 2 and 3 for some of the attributes with the highest citation proportions in TCATA (suggesting that they could be considered relevant for describing the samples), dominance rates in TDS did not reach significance level for all samples (Fig. 1b and c).

TDS identified at least one attribute as significantly dominant during the majority of the product evaluations in the six studies. As shown in Table 3vii, in the studies performed with trained assessors at least one significantly dominant attribute was detected between 69% and 79% of the evaluation time. This percentage was lower in studies involving consumers. As shown in Table 4vii, in Studies 4–6 at least one of the terms was identified as significantly dominant attributes for approximately 55% of the TDS evaluation period.

A hallmark of the TDS method is its focus on the dominant attribute (at any point in time) and it was not unexpected to find that, across the six studies, there were few instances where more than one attribute were significantly dominant (Figs. 1 and 2). As shown in Table 3viii, in the studies involving trained assessors between 2 and 3 attributes were significantly dominant at the same time during the TDS evaluations, but this occurred for less than half of the evaluation duration (Table 3ix). In the studies involving consumers the number of simultaneously dominant attributes tended to be lower (Table 4viii) and the period of time during which simultaneously dominant attributes occurred was observed to be shorter in duration (Table 4ix). When dealing with complex products in which several sensory characteristics are perceived simultaneously, dominance rates in TDS may be low, both in absolute terms and relative to TCATA citation proportions, as TDS assessors may differ in the attributes they select as dominant at any

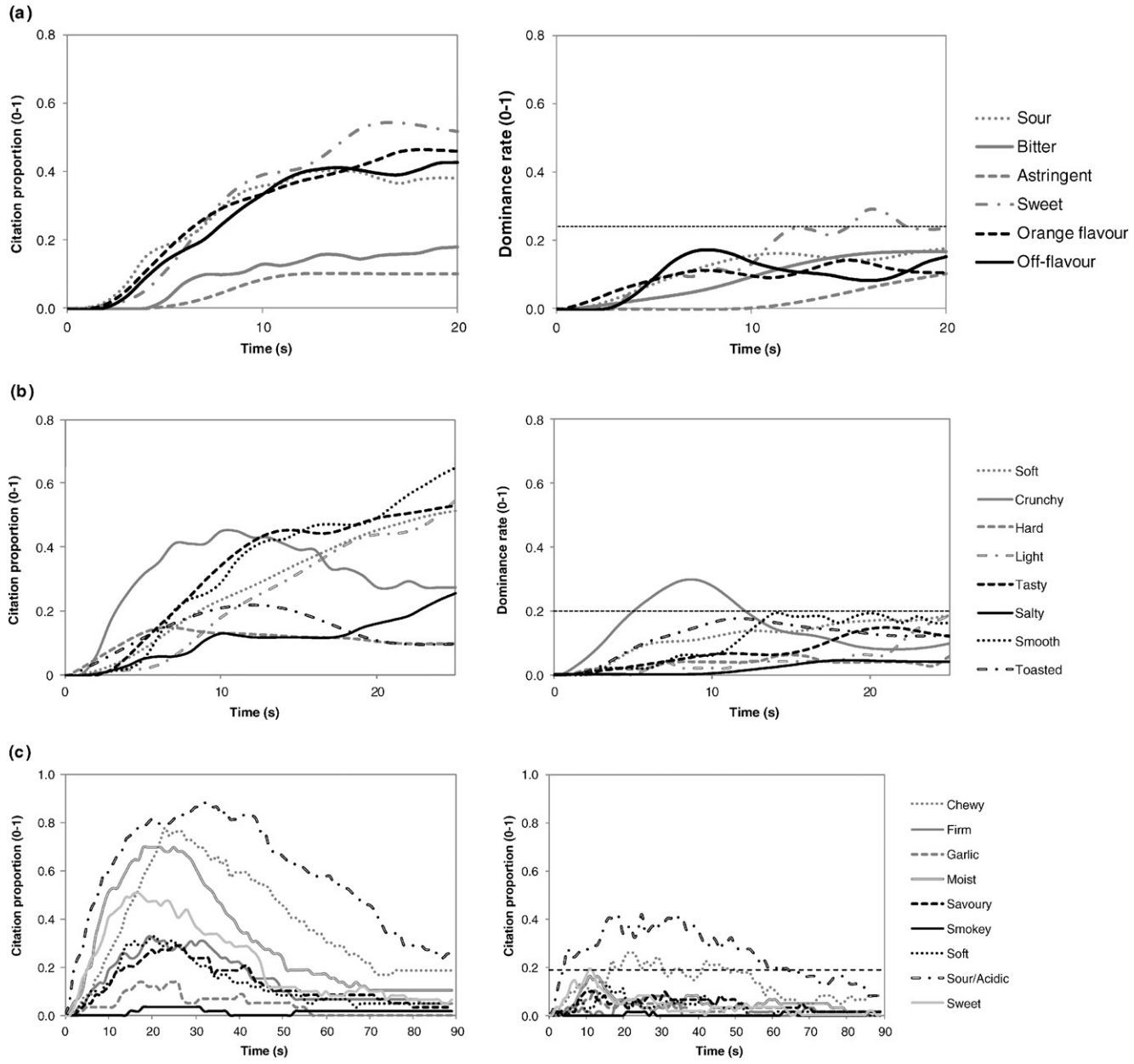

Fig. 2. Exemplar TCATA (left) and TDS (right) curves obtained with consumers: (a) Sample 5 in Study 4 (orange juice), (b) Sample 5 in Study 2 (French bread), and (c) Sample 1 in Study 6 (mussels). Horizontal dotted lines in TDS curves correspond to the 5% significance level.

given moment. By contrast, TCATA studies enabled identification of attributes that were simultaneously perceived for relatively long periods of time during the evaluations. As exemplified in Figs. 1 and 2, the number of attributes which received high citation proportions for describing samples was higher than in TDS. Commensurate with the characteristics of the CATA approach, TCATA allows assessors to simultaneously select multiple attributes as applicable for describing the sensory properties of products. Across product categories and assessor types, these results show that for relatively long periods of time during the evaluation period more than one attribute were strongly perceived. Overall, TCATA facilitates a more detailed temporal characterization of the sensory properties of samples.

3.3. Sample discrimination by TCATA and TDS

3.3.1. Results from studies conducted with trained assessors

Differences in the discriminative ability of TCATA and TDS were uncovered in all the three studies. Although many differences between samples were similarly identified in both methodologies, TCATA tended to be more discriminative than TDS throughout the evaluation period. As shown in Table 3iii and xi, the percentage of pairwise comparisons between samples that were significant during the evaluations was higher in TCATA than in TDS for the six studies. TDS had lower discrimination rates than TCATA, implying that the latter provided more complete sensory information regarding differences among samples. Fig. 3 shows difference curves for exemplar comparisons between pairs of samples from studies involving trained assessors.

Pairwise differences between Samples 1 and 6 in Study 1 (strawberry yogurt) were highly similar for both methodologies. As shown in Fig. 3a, differences in *off-flavour* and *artificial flavour* were identified in both TCATA and TDS during most of the evaluation period. More subtle differences between these two samples during different periods of the evaluation were identified differently by the two methodologies. Some differences were detected only by TDS (e.g. *strawberry flavour*), while the others were detected only by TCATA (e.g. *creaminess*), but these discrepancies had relatively short durations (cf. Fig. 3a).

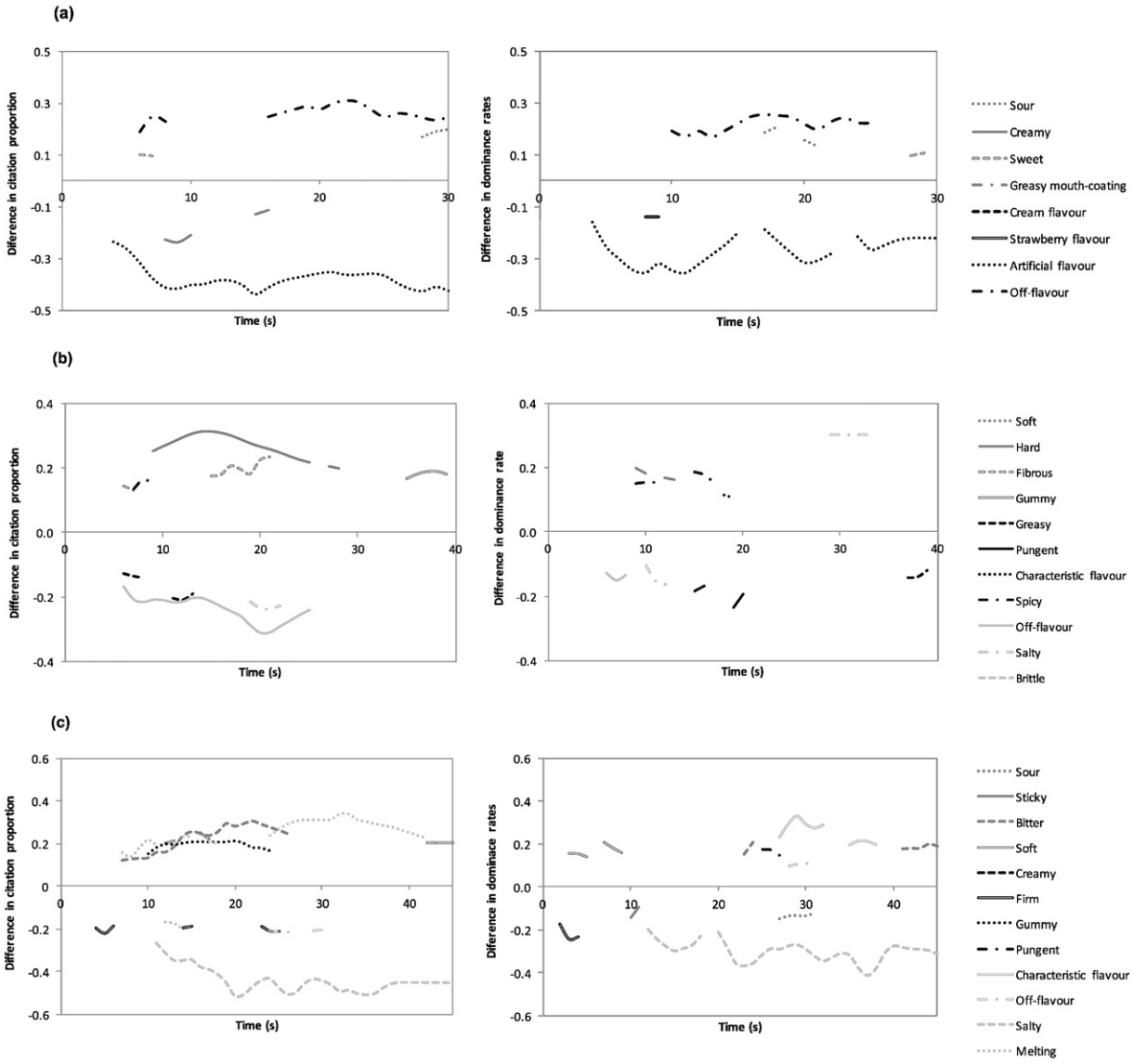

Fig. 3. TCATA (left) and TDS (right) difference curves showing significant differences between exemplar pairs of samples obtained with trained assessors: (a) Sample 1 — Sample 6 in Study 1, (b) Sample 4 — Sample 3 in Study 2, and (c) Sample 1 — Sample 3 in Study 3. Positive values for the difference indicate that the first sample received higher citation proportions/dominance rates than the second sample, whereas negative values indicate the opposite.

In Study 2 (salami), pairwise differences between Samples 4 and 3 were similar in the two methodologies, but the magnitude of differences in proportions tended to be larger in the TCATA than the TDS data, as illustrated in Fig. 3b. In the TCATA task the two samples differed in at least one attribute during the majority of the evaluation, whereas in TDS differences between samples were detected only in short periods of time. Differences between samples in the term *fibrous* were detected only by TCATA. On the contrary, differences between samples in *characteristic salami flavour* were identified only in the TDS task during a brief time period in mid-evaluation.

Similarly, in Study 3 (Pategras cheese) TCATA detected more differences between Samples 1 and 3, and for longer time durations (Fig. 3c). For example, differences between Samples 1 and 3 in *characteristic flavour* were significant for 37 s in TCATA but for only 8 s in TDS. Also, TCATA detected significant differences in *gumminess* between several pairs of samples that TDS did not. On the contrary, differences in *pungency* were only detected by TDS. However, differences between Samples 1 and 3 in *saltiness*, which were clearly relevant for discriminating these two samples, were detected similarly by both methodologies (Fig. 3c).

3.3.2. Results from studies conducted with consumers

Differences in the discriminative potential of the methodologies were also found in the studies involving consumers. As shown in Table 4iii and xi, a higher percentage of all possible pair-wise comparisons between samples was significant throughout the evaluation for TCATA than for TDS. Differences in the conclusions regarding differences among samples were identified, as exemplified in Fig. 4 for selected pairs of samples in Studies 4–6.

In Study 4, pairwise differences between samples 4 and 5 were mainly related to the terms *orange flavour*, *bitterness*, and *off-flavour*. These differences were identified by both TDS and TCATA (Fig. 4a). However, TCATA identified significant differences in *astringency* and *sweetness*, which were not detected by TDS. Similar outcomes were observed in Study 5. Differences between samples 3 and 2 were markedly larger in TCATA than in TDS, particularly related to the terms *crunchy* and *light*, which were only significant in the TCATA methodology (Fig. 4b).

In Study 6, both TCATA and TDS methodologies found that samples differed in the term *smoky*, as shown in Fig. 4c. However, TCATA detected significant differences between samples for the term *savoury* as well,

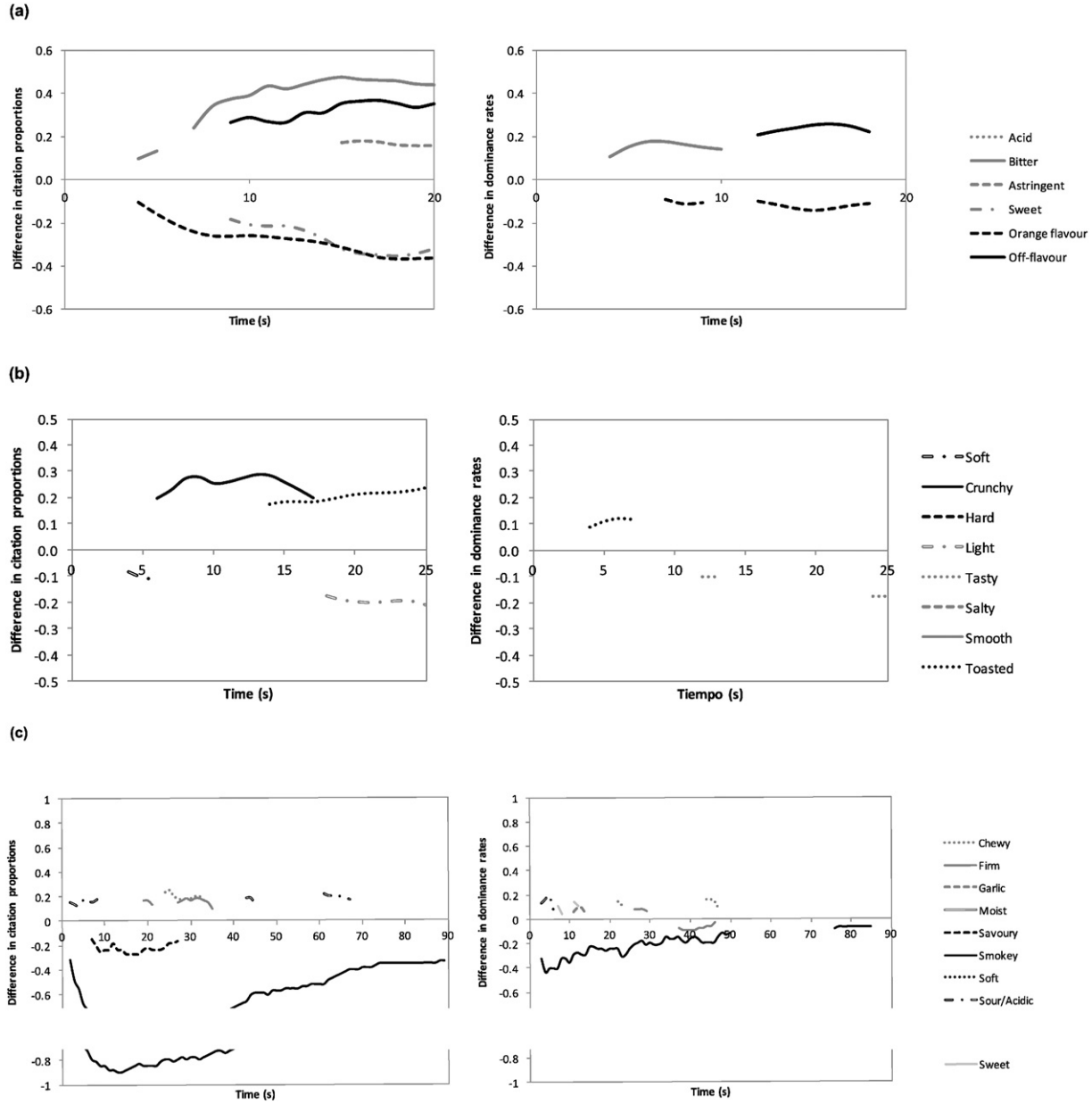

Fig. 4. TCATA (left) and TDS (right) difference curves showing significant differences between exemplar pairs of samples obtained with consumers: (a) Sample 4 — Sample 5 in Study 1, (b) Sample 3 — Sample 2 in Study 2, and (b) Sample 1 — Sample 2 in Study 6. Positive values for the difference indicate that the first sample received higher citation proportions/dominance rates than the second sample, whereas negative values indicate the opposite.

which were not detected in TDS. There were other pairwise differences that were significant over small periods of time for only one of the two methodologies (Fig. 4c).

3.3.3. Similarities and differences in sample discrimination by TCATA and TDS

The results revealed instances where some of the terms were not significantly dominant for all samples in TDS permitted discrimination among samples in TCATA. For example, in Study 2 the term *gummy* did not reach dominance in TDS for all samples (Table 3x), but significantly discriminated Samples 3 and 4 (Fig. 3b) using TCATA. This attribute also differentiated Sample 1 from the rest of the samples in TCAT A: citation proportions of this attribute for Sample 1 were significantly higher than for Samples 2, 3, and 4 for different periods of time during the evaluation (data not shown). Similar results were observed with the term *sticky* in Study 3, which significantly discriminated between Sample 4 and the other three samples in TCATA, although not reaching dominance in TDS for all samples (data not shown).

3.4. Self-reported task perceptions

Immediately following completion of the TCATA or TDS task, consumers were asked to answer two task perception questions. The means, standard deviations, and *p*-values from the ANOVA comparing TCATA and TDS presented in Table 5. Across the studies, the mean responses to the statement "It was easy to answer the questions" aligned with the verbal anchors "agree moderately" or "agree strongly," regardless of method. For the statement "It was tedious to answer the questions," again regardless of method, the mean responses aligned to the verbal anchors "disagree extremely" or "disagree strongly." Although TCATA was found to be significantly less tedious than TDS in Studies 5 and 6, the average tediousness scores in each case differed by less

Table 5
Summary of results for the comparison of task perceptions for TCATA and TDS with consumers in Studies 4–6. Values shown are means with standard deviations between brackets. Rating scale anchored at 1 = "disagree extremely" and 7 = "agree extremely".

Statement about task perception		Study 4 (orange juice)	Study 5 (French bread)	Study 6 (mussels)
It was easy to answer the questions	TCATA	5.3 (1.4)	5.9 (1.6)	5.9 (1.1)
	TDS	5.3 (1.6)	5.6 (1.9)	5.9 (0.9)
	p-Value	0.84	0.06	0.96
It was tedious to answer the questions	TCATA	2.1 (1.5)	1.4 (1.0)	2.4 (1.1)
	TDS	2.3 (1.8)	1.6 (1.0)	2.9 (1.2)
	p-Value	0.63	0.04	0.02

than 0.5 points in the 7-point Likert scale, a magnitude that we considered small.

4. Discussion

Results from the present study suggest that TCATA has the potential to deliver a more detailed description of the dynamic perception of multiple sensory modalities of foods/beverages during consumption. Evidence hereof was obtained across six studies, involving different product categories and evaluations with trained assessors, as well as consumers.

TCATA permits concurrent attribute selection, which seemed to provide a more comprehensive overview of the temporal evolution of the sensory characteristics of products than provided by TDS. This could be explained by the fact that in TCATA assessors focus their attention on all the attributes that apply for describing the products at each moment of time. In each of the studies, some of the attributes with the highest citation proportions in TCATA, which were thus considered as relevant for describing the sensory characteristics of the products, were not dominant in TDS (cf. Figs. 1 and 4). This suggests that attributes that are highly relevant for describing a product at a specific moment of the evaluation may not be the ones that catch consumers' attention. For this reason, TDS may not fully describe how all the sensory characteristics of the products evolve with time during consumption.

Evidence of greater sample discrimination with TCATA than TDS (Tables 3 and 4) was a second noteworthy finding from this research. TCATA tended to detect significant differences among samples for a larger number of attributes and for longer periods of time than TDS (Figs. 2 and 4). While several conclusions regarding similarities and differences among samples were similar between TCATA and TDS in the majority of the studies, differences between the methodologies were quite marked in some cases.

Further research comparing TCATA and TDS is needed to confirm the findings obtained in this research and it is recommended that such work also be conducted using samples with known sensory differences. Assuming that findings are replicated, it is relevant to begin to consider the practical implications for the differences in the performance of the two methods.

The method of TCATA is an extension of CATA questions and is anchored in perception of the presence/absence of focal sensory attributes. The TDS method, on the other hand, is anchored in the concept of dominance, which conceptually differentiates it from all other sensory methods (Meyners, 2010). Yet, consensus regarding the definition of this concept is lacking (Cadena et al., 2014). A dominant attribute was defined as "the most intense sensation" by Labbe et al. (2009) and as "most striking sensation, the new sensation popping up, not necessarily the most intense" by Pineau et al. (2009). Although the majority of the studies conducted in the last few years use the latter definition, it is not clear how assessors understand this definition. Training for the purpose of homogenizing the conceptualization of dominance has been performed in few occasions (e.g. Lecourt, Duineveld, & Simons, 2009) as the recommendation for TDS training is to focus on attribute identification (Pineau et al., 2012). Consequently, different criteria for identifying the dominant sensation could be applied by different participants. This may lead to dispersion of the TDS responses, and in turn hinder identification of significantly dominant attributes and discrimination among samples. In the present work some attributes that were highly relevant for describing samples in TCATA had low dominance rates in TDS which did not reach significance. This was more common when several sensory attributes were perceived at the same time. This suggests that heterogeneity in the evaluation of dominance can decrease the ability of TDS to provide a detailed description of the dynamics of the sensory characteristics of samples, particularly when dealing with product characterizations that require simultaneous consideration of multiple sensory attributes and/or perceptual modalities. In support of this interpretation, other authors have already reported similar results. For example, Labbe et al. (2009), Lenfant, Loret, Pineau, Hartmann, and Martin (2009), Meillon et al. (2009), Teillet, Schlich, Urbano, Cordelle, and Guichard (2010) and Saint-Eve et al. (2011) have reported maximum dominance rates that are below 0.4, as well as instances in which several attributes show similar dominance rates that do not reach significance. For practitioners, this effectively translates to an information loss regarding how the sensory properties of the focal products evolve over time during consumption. In this sense, TCATA may be a better methodological choice when a detailed description is required of how the sensory characteristics of the product evolve over time. On the other hand, TDS seems the more appropriate choice when the research question requires the identification of the attributes that catch assessors' attention at each moment of the evaluation.

Self-reported task-perception data were obtained in three studies with consumers and revealed that both methods were perceived as "easy" and "not tedious." These results support our experiences during data collection where none of the participants commented about the complexity or difficulty of the tasks. The mean values for task perception of the TCATA and TDS methods (Table 5) were similar to results previously reported for CATA questions (Ares et al., 2013; Jaeger & Ares, 2014; Jaeger et al., 2014, 2015), further suggesting that the dynamic nature of TCATA and TDS affected neither consumers' perception of task complexity nor task difficulty. In terms of the comparison between the two methods, we found that asking consumers to check and uncheck the terms that describe samples during the test (i.e. TCATA) did not affect the perceived ease/difficulty of the task relative to selecting the dominant term (i.e. TDS). Yet, in Studies 5 and 6 mean perceived tediousness scores were significantly higher for TDS than for TCATA in Studies 5 and 6 (Table 5). Although the differences in mean values were relatively small, it could perhaps provide a clue to why the two methods perform differently. The suggestion is that the question regarding tediousness of the task tap into a broader perceptual response with a negative valence. TCATA results suggest that assessors experience multiple sensory attributes during product consumption, in alignment with our own experiences when evaluating the focal products.

New avenues for research have emerged on the basis of this research. We consider those pertaining to conceptualisation of the dominance construct to be particularly interesting. Correlation between attribute intensity and dominance has been reported by Bruzzone, Ares, and Giménez (2013). This could suggest that participants complete the TDS task in a manner different from what is intended, possibly because they do not understand what dominance means. Research aimed at better understanding how assessors complete the TDS task could be illuminating. Qualitative methods would likely be most suited for this purpose, including protocol analysis which has been previously used for similar purposes in sensory and consumer research (Jaeger, Cardello, & Schutz, 2013). Such an approach would also be beneficial for TCATA, for example to explore whether de-selecting attributes that no longer apply is burdensome for participants and whether training prior to the data collection process could ease the task for respondents.

5. Conclusions

Results from the present research showed that TCATA and TDS provided comparable sample information, although some differences were uncovered. For every product category and regardless of whether assessors were trained panellists or consumers, TCATA provided better sensory discrimination between samples over the evaluation period than TDS.

We conclude that the two methods complement each other. TCATA provides a more detailed characterization of the dynamics of the sensory characteristic of products throughout consumption than TDS. However, TCATA does not enable to evaluate the ability of sensory attributes to capture consumers' attention. In accordance with the comments from previous contributors (Labbe et al., 2009; Meillon et al., 2009) results from the present work revealed that TDS does not capture information regarding sensations other than the dominant attribute. It remains an open question which of the two approaches better explains consumers' hedonic perception of products.

The current research was performed across multiple sensory modalities. This appears to be contrary to the typical use of TDS (Di Monaco, Su, Masi, & Cavella, 2014). We acknowledge that comparisons performed within a single modality (e.g., texture or flavour) may yield different results to the results reported here. However, restricting the evaluation to a single modality hinders a more complete capture of the sensory experiences during consumption and may therefore be associated with less ecological validity.

Author contributions

All authors contributed to the development of the research. G.A., L.A. J.C.C. and S.R.J. wrote the paper. G.A., L.A. and J.C.C. analysed the data.

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