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The role of smell, taste, flavour and texture cues in the identification of vegetables

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ABSTRACT

It has been shown that the identification of many foods including vegetables based on flavour cues is often difficult. The effect of providing texture cues in addition to flavour cues on the identification of foods and the effect of providing taste cues only on the identification of foods have not been studied. The aim of this study was to assess the role of smell, taste, flavour and texture cues in the identification of ten vegetables commonly consumed in The Netherlands (broccoli, cauliflower, French bean, leek, bell pepper, carrot, cucumber, iceberg lettuce, onion and tomato). Subjects ($n = 194$) were randomly assigned to one of four test conditions which differed in the sensory cues available for vegetable identification: taste, smell (orthonasal), flavour (taste and smell) and flavour-texture (taste, smell and texture). Blindfolded subjects were asked to identify the vegetable from a list of 24 vegetables. Identification was the highest in the flavour-texture condition (87.5%). Identification was significantly lower in the flavour condition (62.8%). Identification was the lowest when only taste cues (38.3%) or only smell cues (39.4%) were provided. For four raw vegetables (carrot, cucumber, onion and tomato) providing texture cues in addition to flavour cues did not significantly change identification suggesting that flavour cues were sufficient to identify these vegetables. Identification frequency increased for all vegetables when perceived intensity of the smell, taste or flavour cue increased. We conclude that providing flavour cues (taste and smell) increases identification compared to only taste or only smell cues, combined flavour and texture cues are needed for the identification of many vegetables commonly consumed in The Netherlands.

1. Introduction

The daily recommended intake of vegetables is met by less than 15% of adults and less than 3% of children in The Netherlands. Median vegetable consumption in The Netherlands is 103–140 g/day for adults and 60–92 g/day for children (Van Rossum, Fransen, Verkaik-Kloosterman, Buurma-Rethans, & Ocke, 2011). These values are far below the recommended daily intake of at least 200 g/day for adults and 150 g/day for children (Gezondheidsraad, 2015). Similar consumption patterns have been observed in other countries (Alexy, Sichert-Hellert, & Kersting, 2002; Bowen, Klose, Syrette, & Noakes, 2009; Dennison, Rockwell, & Baker, 1998).

The dislike for the taste of vegetables, specifically for bitterness, has been suggested to cause low vegetable consumption (Brug, Tak, te Velde, Bere, & De Bourdeaudhuij, 2008; Dinehart, Hayes, Bartoshuk, Lanier, & Duffy, 2006; Drewnowski & Gomez-Carneros, 2000; Tak, te Velde, & Brug, 2008). However, it was recently demonstrated that vegetables display low taste and flavour intensities compared to other foods (Lim & Padmanabhan, 2013; Martin, Visalli, Lange, Schlich, & Issanchou, 2014; Poelman, Delahunty, & de Graaf, 2017; Van Dongen, van den Berg, Vink, Kok, & de Graaf, 2012; Van Stokkom, Teo, Mars, de Graaf, van Kooten, & Stieger, 2016). Van Stokkom et al. (2016) determined the taste intensities of ten vegetables commonly consumed in The Netherlands using a modified Spectrum Method. In the modified Spectrum method, a sensory profiling method, three reference solutions representing fixed intensities for each taste modality are used by trained panellists to evaluate the intensity of each taste (sweetness, sourness, bitterness, umami, saltiness) on an absolute intensity scale. In general, the intensities of all taste modalities for most vegetables were very low. Sweetness was the most intense

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taste, followed by sourness and bitterness. Another study using the Spectrum method found that vegetables had low taste intensities compared to other foods (Poelman et al., 2017). It is therefore likely that other sensory properties such as appearance, smell, flavour and texture, influence acceptance of vegetables.

To assess the influence of sensory cues provided for the identification of foods, Schiffman (1977) studied the effect of combined removal of visual cues by blindfolding and textural cues by pureeing, on identification of 20 commonly consumed foods, including 10 vegetables. The absence of visual and textural cues means that only flavour cues (taste and smell) were provided for the identification of the foods. Identification of foods in young adults (students, 18–22 y) and elderly (67–93 y) was considerably impaired when only flavour cues were provided. Identification by students ranged from 4% to 67% from cabbage to corn. Identification by elderly ranged from 0% to 69% from broccoli to tomato. Students identified most foods better than elderly when flavour cues were provided for identification. These results suggest that visual and texture cues might be important for identification of foods. Schiffman (1977) quantified the identification of foods under one experimental condition only i.e. when flavour cues were provided. The effect of providing texture cues in addition to flavour cues on identification was not investigated by Schiffman (1977), nor anyone else. Smell cues play a role in identification of foods, as shown by previous studies which used sniffing sticks to assess identification of smell and mainly focussed on differences in identification ability between different ages and sexes (Hummel, Kobal, Gudziol, & Mackay-Sim, 2007; Hummel, Sekinger, Wolf, Pauli, & Kobal, 1997; Sorokowska et al., 2015). However, it remains unclear how the influence of smell in identification relates to the influence of other sensory cues. To summarize, currently knowledge is lacking on the contribution of specific sensory cues on the identification of vegetables.

The aim of this study is to assess the role of smell, taste, flavour and texture cues in the identification of ten vegetables commonly consumed in The Netherlands. We hypothesize that each of the sensory cues contributes differently to the identification of vegetables and that identification depends on the preparation method and type of vegetable.

2. Materials & methods

2.1. Subjects

Adults were recruited through social media, flyers and a list of individuals available at the Division of Human Nutrition, Wageningen University. Inclusion criteria comprised a good general health, understanding of the Dutch language and aged between 18 and 65 years. Subjects with allergies or intolerances to vegetables were excluded from participation, as well as subjects experiencing problems with chewing, swallowing, tasting or smelling. Pregnant or breast-feeding women were excluded from the study. Subjects were asked not to wear perfume and not to eat or drink (except water) 1 h prior to the test session. Subjects received financial compensation for participation in the study. One subject was removed from the dataset since the nose clip fell off multiple times in the taste condition. In total 194 subjects were included in the study (147 females, 47 males, 37.8 ± 16.6 y). Ethical approval was not required for the study according to the Medical Research Ethics Committee of Wageningen University. The study was registered under number 16/02.

2.2. Study design

Subjects ($n = 194$) were randomly assigned to one of four test conditions using a between subjects design: smell ($n = 48$), taste ($n = 49$), flavour ($n = 48$) and flavour-texture ($n = 49$). Subjects were blindfolded in all four test conditions and asked to identify ten vegetables from a list of 24 vegetables in each of the conditions. In the smell condition, subjects sniffed non-pureed vegetables (identification based on orthonasal smell cues). In the taste condition, subjects tasted pureed vegetables while wearing a nose clip to eliminate smell cues (identification based on taste cues). In the flavour condition, subjects tasted pureed vegetables without a nose clip (identification based on orthonasal and retronasal smell and taste cues). In the flavour condition, subjects did not sniff the vegetables before tasting. In the flavour-texture condition, subjects tasted non-pureed vegetables (identification based on smell, taste, texture and auditory cues).

2.3. Vegetable selection and preparation

The ten vegetables most frequently consumed in the Netherlands were selected for the study (Van Rossum et al., 2011): broccoli (*Brassica oleracea* var. *Italica*, variety Ironman), cauliflower (*Brassica oleracea* var. *botrytis*, variety Easytop), French bean (*Phaseolus vulgaris*, variety unknown), leek (*Allium ampeloprasum* L., variety Harston), bell pepper (*Capsicum annuum,* variety Davos), carrot (*Daucus carota,* variety Evora), cucumber (*Cucumis sativus,* variety Proloog), iceberg lettuce (*Lactuca sativa* L., variety unknown), onion (*Allium cepa* L., variety Alfa) and tomato (*Solanum lycopersicum* L., variety Arvento). Fresh vegetables were bought at a local supermarket and stored at 4 °C for a maximum of three days. Some vegetables were boiled and offered warm, other vegetables were offered raw, depending of the more common way to consume the vegetable (Borgdorff-Rozeboom, 2013). Broccoli, cauliflower, French bean and leek were boiled before preparation of the purees or one-bite portions. Cooking times (time in boiling water) and vegetable/water ratio were for broccoli and cauliflower 8 min, 212/500 g, French bean 10 min, 224/500 g and leek 8 min, 238/500 g. Bell pepper, carrot, cucumber, onion and tomato were prepared at the start of the test day and stored at 7 °C during the test day. Vegetable purees were prepared by pureeing vegetables with a hand blender until a homogenous, smooth consistency was obtained (±30 s/200 g). Carrots were first chopped using a food processor and pureed afterwards. Broccoli, cauliflower, French bean and leek samples were stored in bowls in a water bath at 60 °C after preparation for a max of 3.5 h. Therefore, preparation of these vegetables was performed twice a day, as well as preparation of lettuce. Serving temperature of the boiled vegetables was 50 ± 5 °C. Raw vegetables were served at room temperature. Vegetables were presented to the blindfolded subjects by the researcher either as one-bite portions (smell and texture conditions) or as a puree (taste and flavour conditions). Sample size was ~10 g. All vegetable samples were offered in non-transparent plastic containers (50 ml) covered with a lid. In the smell condition, blindfolded subjects were asked to identify the vegetable by sniffing two one-bite portions from the foam container. In the taste and flavour conditions, blindfolded subjects received ~10 g of vegetable puree from the researcher on a spoon. In the flavour-texture condition, blindfolded subjects received a one-bite portion from the researcher on either a fork or a spoon, depending on the vegetable.

2.4. Test procedure

Participation in the study consisted of one test session of approximately 45 min at the University of Applied Sciences Inholland Delft or Wageningen University. Upon arrival at the test location, subjects signed an informed consent and completed a questionnaire to examine fulfilment of the inclusion criteria. When subjects were eligible, subjects received detailed instructions including how to ask to try the vegetable a second time and how to indicate when they were ready. Subjects were instructed to wear the blindfolds until the investigator gave permission to remove them. Subjects were told not to mention any answers out loud. After the instruction, subjects were placed in a quiet test room and completed a general questionnaire about population characteristics on a laptop or tablet computer (EyeQuestion® version 3.16.26, Logic8). Additionally, the questionnaire contained questions on vegetable consumption frequency of the target vegetables as well as the other vegetables on the 24-item list. Choice options for consumption frequency were 'never', 'less than once a year', 'yearly (1–11 times a year)', 'monthly (1–3 times a month)', 'weekly (1–6 times a week)' and 'daily'. After completion of the general questionnaire subjects were blindfolded and subjects in the taste condition had a nose pin placed on their nose. After receiving a sample once or twice, the sample was discarded and subjects could remove their blindfolds. Using a laptop or tablet computer, subjects were asked to identify the vegetable from a list of 24 vegetables frequently consumed in The Netherlands. Next to the ten vegetables that were actually presented, choice options included asparagus, beetroot, Brussels sprout, celery, chicory, corn, eggplant, endive, mushrooms, peas, radish, red cabbage, spinach and zucchini. The 24 options were placed in alphabetical order. Subjects subsequently rated overall perceived intensity of the smell, taste or flavour on a 100 mm line scale anchored with 'weak' and 'strong' at the ends. In the smell condition, subjects rated the perceived intensity of the smell of the vegetable. In the taste condition, subjects rated the perceived intensity of the taste of the vegetable. In the flavour and flavour-texture conditions, subjects rated the perceived intensity of the flavour of the vegetable. For the sake of clarity, in the following the respective perceived intensities assessed under the four conditions are referred to as intensity. A break of 20 s was given between samples, during which subjects could drink some water or eat an unsalted cracker to cleanse the palate. In the smell condition, subjects were provided coffee beans to neutralise their nasal palate. The ten vegetables were presented, either pureed or not, in semi-random order. Onion was always the last sample to avoid potential carry-over effects due to the strong odour and lingering taste of onions.

2.5. Data analyses

Statistical data analyses were performed using IBM SPSS Statistics software (version 21), using a significance level of $p < 0.05$. Population characteristics were presented as percentages or means with standard deviations. Kruskal-Wallis H tests and Mann-Whitney U tests were performed to verify whether age, BMI and weekly vegetable consumption were the same across conditions and test locations, respectively. Correct frequencies of identification (%) were calculated per condition for each vegetable, hereafter identification frequency. A three-way log-linear analysis was performed to determine whether frequencies of identification depended on test conditions and vegetables. Separate Chi-square tests on frequency of identification were performed for the four test conditions averaged over the ten vegetables. In addition, Chi-square tests on frequency of identification were performed to assess significant differences between frequencies of identification in different conditions per vegetable. Yates continuity corrections were applied for 2×2 contingency tables. Spearman correlation coefficient was determined for the correlation between frequency of identification (%) and consumption frequency of vegetables. Point biserial correlation coefficient (Field, 2009) was determined for age and vegetable identification.

Mean smell, taste and flavour intensities for each vegetable were calculated per condition. A mixed model analysis of variance was performed to assess the main effect of test condition on intensity rating with intensity as a repeated measures variable and condition as a variable measured between subjects. Maulchy's test indicated that sphericity was violated for the main effect of vegetable type, $\chi^2(44) = 84.410$, $p < 0.001$. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.908$). Significant differences in intensities between conditions within a vegetable were determined by a one-way independent analysis of variance. Games-Howell *post hoc* tests were performed, since the assumption of equal variances was violated. Differences in intensities between vegetables averaged over the conditions were determined by repeated measures analysis of variance. Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(44) = 135.696$, $p < 0.001$. Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.844$). Pearson's correlation coefficients were determined for identification frequency and intensity.

3. Results

3.1. Subject characteristics

Demographic characteristics of the subjects and consumption frequency of the ten vegetables are summarized in Tables 1 and 2. Age, BMI and weekly vegetable consumption did not differ significantly between test conditions or locations.

3.2. Vegetable identification

Vegetables were significantly less often identified in the smell and taste conditions compared to the flavour condition [$\chi^2(1) = 51.360$, $p < 0.001$ and $\chi^2(1) = 57.457$, $p < 0.001$] (Fig. 1). Vegetables were identified significantly more often in the flavour-texture condition compared to all other test conditions [$\chi^2(1) = 238.991$, $\chi^2(1) = 251.467$ and $\chi^2(1) = 77.517$, $p < 0.001$ for the smell, taste and flavour conditions].

Boiled vegetables were on average less frequently identified than raw vegetables (45.3% versus 64.9%). Identification frequency significantly increased between the taste and flavour-texture condition for boiled and raw vegetables. For raw vegetables, identification frequency significantly increased between the taste and flavour condition. For most boiled vegetables, there was no significant increase in identification frequency between the taste and flavour condition (Fig. 2).

Table 1
Self-reported subject characteristics ($n = 194$).

Characteristic	Mean (±SD), percentage (%)
Age (years)	37.8 ± 16.6
Gender (% male)	24.0%
Test location (% in Wageningen)	67.5%
BMI (kg/m^2)	23.7 ± 4.1
Smoker	2.6%
Education level (%)	
Low (no or only primary school)	0.5%
Intermediate (high school)	26.8%
High (university)	72.7%
Fruit consumption frequency (portions/day)	1.5 ± 0.9
Vegetable consumption (g/day)	162 ± 59

Table 2
Self-reported consumption frequencies ($n = 194$) of ten vegetables commonly consumed in The Netherlands. Not all percentages add up to 100.0% due to rounding.

Consumption frequency (% of subjects)	Never	Less than once a year	Yearly	Monthly	Weekly	Daily
Broccoli	–	1.5	13.9	55.2	29.4	–
Cauliflower	4.1	5.2	39.7	44.3	6.7	–
French bean	–	–	11.9	55.2	33.0	–
Leek	2.1	1.5	20.1	49.0	26.8	0.5
Bell pepper	1.5	1.0	2.1	21.6	68.0	5.7
Carrot	1.0	1.0	10.8	43.8	38.7	4.6
Cucumber	2.6	2.1	7.7	22.7	56.7	8.2
Lettuce	–	–	4.6	24.2	64.9	6.2
Onion	0.5	0.5	2.6	10.3	68.6	17.5
Tomato	0.5	0.5	1.5	13.4	68.6	15.5

Fig. 1. Frequency of identification (%) per condition averaged over ten vegetables commonly consumed in The Netherlands. In the smell condition, subjects ($n = 48$) sniffed non-pureed vegetables (identification based on smell cues). In the taste condition, subjects ($n = 49$) tasted pureed vegetables while wearing a nose clip (identification based on taste cues). In the flavour condition, subjects ($n = 48$) tasted pureed vegetables without a nose clip (identification based on smell and taste cues). In the flavour-texture condition, subjects ($n = 49$) tasted non-pureed vegetables (identification based smell, taste and texture cues). Significant differences between conditions are indicated by letters A-C ($p < 0.001$). Same letters indicate no significant difference between frequencies of identification.

The five most frequently selected vegetables from the 24-item option list are summarized for all ten vegetables in Table 3. For each vegetable presented, the vegetable most often selected from the 24-item option list was the correct vegetable. Identification frequency correlated weakly with the consumption frequency of the presented vegetable ($r = 0.10$, $p < 0.001$).

3.3. *Intensity of vegetable smell, taste and flavour cues*

Perceived intensities assessed under the four conditions are referred to as intensity hereafter. A significant main effect of test condition on intensity was found [F (3, 187) = 25.574, $p < 0.001$]. Intensities in the four conditions averaged over all vegetables differed significantly from each other ($p < 0.001$), except for the flavour and flavour-texture conditions. Highest mean intensities were found in the flavour and flavour-texture condition (58.1 and 59.8), followed by the smell (47.6) and taste condition (40.5) (Appendix I).

Significant differences in intensities between the taste and flavour conditions were found for all vegetables. Smell and flavour intensities differed significantly from each other for French bean, carrot, lettuce, onion and tomato. No significant differences were found between intensities in the flavour and flavour-texture conditions for any of the vegetables tested. A significant main effect of vegetable on intensity rating was found [F (8.170, 1527.760) = 77.995, $p < 0.001$]. Onion had a significantly higher intensity compared to the other vegetables, whereas the intensity of lettuce was significantly lower than all other vegetables (Appendix I).

The frequency of identification correlated positively with perceived intensity of the sensory cue ($r = 0.73$, $p < 0.001$) (Fig. 3).

4. Discussion

To assess the role of smell, taste, flavour and texture cues in the identification of vegetables blindfolded Dutch adults were asked to identify ten vegetables from a list of 24 vegetables based on different sensory cues. For all vegetables, highest frequencies of identification were found in the flavour-texture condition, *i.e.* when flavour and texture cues were present. This was expected as in this condition subjects were provided with all sensory cues except visual cues to identify the vegetables. Identification frequency in the smell, taste and flavour conditions did not significantly differ from each other for broccoli, cauliflower, leek and lettuce, but identification frequency did significantly increase in the flavour-texture condition, indicating that texture cues were needed in addition to flavour cues for the identification of these vegetables. French bean and all raw vegetables except lettuce were significantly less often identified in the smell and taste conditions compared to the flavour and flavour-texture conditions, indicating that these vegetables were more difficult to identify by only their smell or taste cues, while the combination of both sensory cues in the flavour condition significantly improved identification. For four raw vegetables (carrot, cucumber, onion and tomato) frequencies of identification did not differ significantly between the flavour and flavour-texture conditions. As the presence of texture cues in addition to flavour cues did not significantly increase the frequency of identification, flavour cues seem to be sufficient for the identification of these vegetables. For boiled vegetables (broccoli, cauliflower, French bean and leek), bell pepper and lettuce, frequencies of identification differed significantly between the flavour and flavour-texture conditions. These results indicate that texture cues play a significant role in the identification of these vegetables. Frequencies of identification did not differ significantly between the smell and taste conditions, except for carrot, smell and taste play a minor role in the identification of vegetables. Furthermore, frequency of identification increased with increasing perceived intensity of smell, taste or flavour of the vegetables. Larsson, Finkel, and Pedersen (2000) showed that perceived odour intensity was

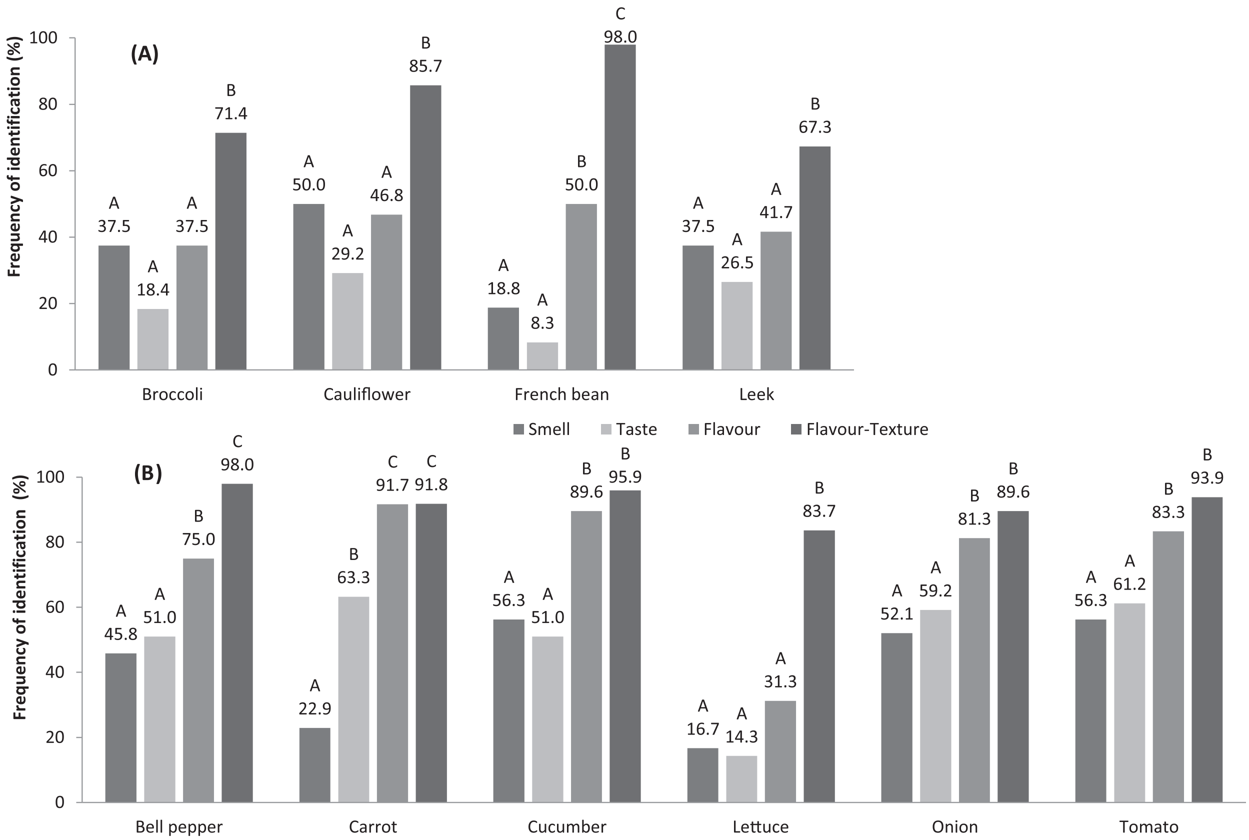

Fig. 2. Frequency of identification (%) of ten vegetables commonly consumed in The Netherlands per condition for (A) boiled and (B) raw vegetables. In the smell condition, subjects ($n = 48$) sniffed non-pureed vegetables (identification based on smell cues). In the taste condition, subjects ($n = 49$) tasted pureed vegetables while wearing a nose clip (identification based on taste cues). In the flavour condition, subjects ($n = 48$) tasted pureed vegetables without a nose clip (identification based on smell and taste cues). In the flavour-texture condition, subjects ($n = 49$) tasted non-pureed vegetables (identification based smell, taste and texture cues). Significant differences between conditions within a vegetable are indicated by letters A-C ($p < 0.05$). Same letters indicate no significant difference between frequencies of identification.

Table 3
Frequency of vegetable selection from a 24-item option list for ten vegetables commonly consumed in The Netherlands. Frequencies for the five most often selected vegetables are presented.

Vegetable presented	Frequency of five most often selected vegetables (%)				
Broccoli	Broccoli 41.2	Cauliflower 28.4	Brussels sprout 5.2	French bean 4.6	Carrot 4.1
Cauliflower	Cauliflower 53.1	Broccoli 20.3	Brussels sprout 10.9	Endive 3.1	Carrot 2.6
French bean	French bean 44.0	Broccoli 9.3	Cauliflower 8.3	Peas 7.3	Brussels sprout 4.7
Leek	Leek 43.3	Onion 14.4	Carrot 5.2	Zucchini 5.2	Chicory 4.6
Bell pepper	Bell pepper 65.5	Celery 5.2	Peas 3.1	Tomato 2.6	Zucchini/tomato 2.6
Carrot	Carrot 67.5	Radish 5.7	Celery 5.2	Peas 3.1	Lettuce 2.6
Cucumber	Cucumber 73.2	Tomato 4.1	Carrot 3.1	Eggplant 2.1	Lettuce/eggplant 2.1
Lettuce	Lettuce 36.6	Endive 12.9	Chicory 6.2	Radish 5.7	Leek/Zucchini 4.6
Onion	Onion 70.5	Leek 14.0	Radish 6.2	Celery 3.1	Bell pepper 1.6
Tomato	Tomato 73.7	Cucumber 4.1	Celery 3.1	Radish 3.1	Bell pepper 2.6

a predictor for odour identification (Larsson et al., 2000, p. P304), in this study higher intensities might also have led to higher identification frequencies. However, subjects could have also reported higher intensities because they were able to identify the vegetable. Lowest intensity ratings were reported in the taste condition, which is in accordance with previous literature stating that vegetables display low taste intensities (Lim & Padmanabhan, 2013; Martin et al., 2014; Poelman et al., 2017;

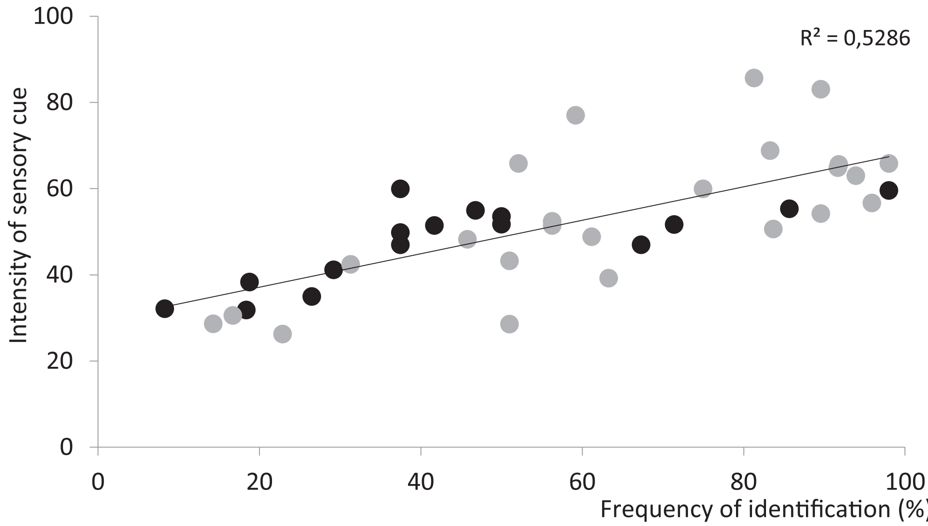

Fig. 3. Perceived intensity of sensory cue versus frequency of identification (%) for raw (●) and boiled (●) vegetables commonly consumed in The Netherlands for all four conditions (smell, taste, flavour and flavour-texture).

Van Dongen et al., 2012; Van Stokkom et al., 2016). By removal of the nose clip, intensity increased (between the taste and flavour conditions), showing the importance of also smell as shown by Mojet, Christ-Hazelhof, and Heidema (2005) with young adults (19–33 yrs) (Mojet et al., 2005).

Identification frequencies for vegetables in the flavour condition were considerably higher in our study than those reported by Schiffman (1977): broccoli (frequency of identification of 15% averaged over the students and elderly in Schiffman's study versus 37.5% in the present study in the flavour condition), carrot (35% versus 91.7%), cucumber (3.5% versus 89.6%), green/French bean (22% versus 50%) and tomato (60.5% versus 83.3%). An explanation for the differences in identification frequencies between the two studies is the method used to quantify identification. In our study, subjects identified the vegetables from a 24-item list, whereas in Schiffman's study subjects had to recall the vegetable from memory which is a more difficult task. Furthermore, Schiffman (1977) diluted the vegetable purees by adding water, which might have decreased the taste intensity of the vegetables making it more difficult to identify the vegetables. Moreover, elderly subjects in the study of Schiffman were between 67 and 93 years old (versus 18–65 years old in the present study) and might have had decreased taste and smell sensitivities (Cain, Reid, & Stevens, 1990; Doty et al., 1984; Stevens, Cain, Demarque, & Ruthruff, 1991). In the current study, increased age was also associated with decreased likelihood of vegetable identification ($r = -0.15$, $p < 0.05$), which is in accordance with literature (Boyce & Shone, 2006; Doty et al., 1984; Schiffman, 1977).

Although most raw vegetables were more frequently identified than boiled vegetables, lettuce provided an exception and was not identified often compared to the other vegetables. The low identification frequency of lettuce is probably due to the low smell, taste and flavour intensities. The presence of textural cues in addition to flavour cues improved identification significantly for lettuce compared to the other conditions. Texture also appears to play a major role in the identification of boiled vegetables, as the flavour-texture condition had significantly higher frequencies of identification compared to the other three conditions. This might be explained by the fact that during boiling, volatile flavour molecules are released from the food matrix (Hewitt, Mackay, & Konigsbacher, 1960; MacLeod & MacLeod, 1970). As a result of the loss of flavour volatiles, identification of the vegetable might have become more difficult in conditions without texture cues (smell, taste and flavour conditions). However, no clear differences in intensity were found between raw and boiled vegetables. Degradation or Maillard reactions during boiling of the vegetables might have influenced the flavour or aroma profile of the cooked vegetable which might have influenced identification frequency. Another explanation for the low frequencies of identification of boiled vegetables could be that these vegetables were often misidentified for other, similar vegetables. The misidentifications of the boiled vegetables appear to be related to similarities between vegetables of the same species or genus. Broccoli, Brussels sprout and cauliflower are members of the group of cabbages (*Brassica oleracea*) which produce volatile compounds responsible for the typical cabbage flavour, including sulphides, isothiocyanates and cyanides (Buttery, Guadagni, Ling, Seifert, & Lipton, 1976). Moreover, French beans were found to produce the same low-boiling volatiles as cauliflower (Self, Casey, & Swain, 1963), which can explain why these vegetables were mixed-up by more than 5% of the subjects. Leek and onion are both are members of the *Allium* genus and produce organic sulphur compounds upon cutting that are typical for this group of plants (Block, 2009). Misidentifications in raw vegetables were less common and more dispersed over the choice options. Lettuce was one of the most difficult vegetables to identify in most conditions and was most commonly misidentified for endive. Lettuce and endive are both members of the same botanical family, the Asteraceae/Compositae and the same part of the plants are eaten, namely the leaves (Pennington & Fisher, 2009).

The intensities of the sensory cues of onion were significantly higher than the intensities of the sensory cues of all other vegetables. The intensities of the sensory cues of tomato were significantly higher than the intensities of the sensory cues of all other vegetables except for bell pepper, which is similar to results found by Van Stokkom et al. (2016).

As subjects tasted pureed vegetables in two test conditions, this might have led to differences in flavour profiles compared to the flavour profiles of non-pureed vegetables. However, no significant differences were found between flavour intensity ratings in the flavour (evaluating pureed vegetables) and flavour-texture (evaluating non-pureed vegetables) conditions, which implies pureeing did not have an effect on flavour perception in this study. In addition, Van Stokkom et al. (2016) found that basic taste intensities did not differ significantly between boiled and mashed vegetables and between raw and cold pureed vegetables. The difference in serving temperature between boiled (50 ± 5 °C) and raw vegetables (20 °C) might have indicated to the subjects how the presented vegetable is generally consumed. This is supported by the fact that boiled vegetables were mostly mistaken for vegetables that are often heated before consumption. Boiled vegetables were not cooled down to room temperature before serving to make the serving temperature more comparable to a real-life consumption situation. The consistency of the pureed samples was not equal across the ten vegetables. Schiffman (1977) added water to some of the foods to obtain purees with similar consistencies. We did not do this in the current study, leading to minor texture differences of the pureed vegetables by which might have assisted in identification. However, the addition of water to the samples results in smell, taste and flavour dilution, causing the vegetable samples to be less representative of the real-life consumption situation. In the flavour-texture conditions, especially for the crispier (raw) vegetables, auditory cues were present (Fillion & Kilcast, 2002) which might have helped in the identification of these vegetables.

5. Conclusions

The current study assessed the role of smell, taste, flavour and texture cues in the identification of ten vegetables that are frequently consumed in The Netherlands. Smell and taste cues led to considerably lower identification frequencies compared to flavour and flavour-texture cues. For identification of carrot, cucumber, onion and tomato, flavour cues were important. For all other vegetables, flavour and texture cues were more important for identification. This suggests that texture cues in addition to flavour cues and auditory cues contribute to the identification of vegetables, especially vegetables typically consumed warm, while flavour cues are important for the identification of vegetables typically consumed raw. These results show which sensory cues are important for the identification of vegetables and are of interest to sensory scientists and product developers who investigate sensory factors which potentially contribute to food preference and selection. However, the relationships between food identification and preference go beyond the scope of this study and should be investigated further.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.appet.2017.10.039.

Appendix I. Mean intensities (±SD) of sensory cues for the smell, taste, flavour and flavor-texture condition of vegetables, intensity of vegetable averaged over four conditions (smell condition: subjects rated perceived smell intensity; taste condition: subjects rated perceived taste intensity; flavour and flavour-texture conditions: subjects rated perceived flavour intensity and intensity averaged over ten vegetables per condition. Letters A-C indicate significant differences in intensities (p < 0.05) between test conditions within a vegetable. Same letters indicate no significant difference between mean intensities. Numbers 1–6 indicate significant differences between vegetable intensities averaged over the four conditions.

Mean intensity (±SD) of sensory cue per condition and intensity averaged over four conditions					
Vegetable	Smell	Taste	Flavour	Flavour-Texture	Average over conditions
Broccoli	49.8 ± 21.0^{A}	31.8 ± 18.5^{B}	46.9 ± 18.9^{A}	51.6 ± 19.7^{A}	45.2 ± 20.8^{1}
Cauliflower	53.5 ± 20.6^{A}	41.1 ± 23.6^{B}	54.9 ± 19.8^{A}	55.3 ± 18.6^{A}	$51.3 \pm 21.4^{2,3}$
French bean	38.3 ± 22.2^{A}	32.1 ± 20.8^{A}	51.7 ± 21.5^{B}	59.5 ± 19.5^{B}	45.5 ± 23.5^{1}
Leek	59.9 ± 21.7^{A}	34.9 ± 19.9^{B}	51.4 ± 19.7^{AC}	46.9 ± 21.7^{C}	$48.1 \pm 22.4^{1,2,3}$
Bell pepper	48.2 ± 23.5^{AB}	43.2 ± 22.4^{B}	59.9 ± 23.6^{AC}	65.8 ± 16.9^{C}	$54.6 \pm 23.4^{3,4}$
Carrot	26.2 ± 23.0^{A}	39.2 ± 21.8^{B}	64.8 ± 18.2^{C}	65.6 ± 16.4^{C}	$49.1 \pm 26.0^{1,2,3}$
Cucumber	52.4 ± 20.6^{A}	28.5 ± 18.3^{B}	54.2 ± 17.8^{A}	56.6 ± 22.1^{A}	$48.2 \pm 22.7^{1,2}$
Lettuce	30.5 ± 18.8^{A}	28.6 ± 20.7^{A}	42.4 ± 19.8^{B}	50.6 ± 23.7^{B}	38.4 ± 22.7^{5}
Onion	65.8 ± 21.2^{A}	77.0 ± 19.7^{AC}	85.6 ± 11.3^{B}	83.0 ± 9.9^{BC}	77.5 ± 18.8^{6}
Tomato	51.4 ± 21.8^{A}	48.8 ± 23.5^{A}	68.8 ± 16.3^{B}	63.0 ± 20.3^{B}	57.9 ± 21.9^{4}
Average over vegetables	47.6 ± 24.4^{A}	40.5 ± 25^{B}	58.1 ± 22.2^{C}	59.8 ± 21.3^{C}	–

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