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Cross-modal influence on oral size perception

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ABSTRACT

Objective: Evidence suggests people experience an oral size illusion and commonly perceive oral size inaccurately; however, the nature of the illusion remains unclear. The objectives of the present study were to confirm the presence of an oral size illusion, determine the magnitude (amount) and direction (underestimation or overestimation) of the illusion, and determine whether immediately prior cross-modal perceptual experiences affected the magnitude and direction.
Design: Participants ($N = 27$) orally assessed 9 sizes of stainless steel spheres (1/16 in to 1/2 in) categorized as small, medium, or big, and matched them with digital and visual reference sets. Each participant completed 20 matching tasks in 3 assessments. For control assessments, 6 oral spheres were matched with reference sets of same-sized spheres. For primer-control assessments, similar to control, 6 matching tasks were preceded by cross-modal experiences of the same-sized sphere. For experimental assessments, 8 matching tasks were preceded by a cross-modal experience of a differently sized sphere.
Results: For control assessments, small and medium spheres were consistently underestimated, and big spheres were consistently overestimated. For experimental assessments, magnitude and direction of the oral size illusion varied according to the size of the sphere used in the cross-modal experience.
Conclusion: Results seemed to confirm an oral size illusion, but direction of the illusion depended on the size of the object. Immediately prior cross-modal experiences influenced magnitude and direction of the illusion, suggesting that aspects of oral perceptual experience are dependent upon factors outside of oral perceptual anatomy and the properties of the oral stimulus.

1. Introduction

The ability to perceive the size of objects in the oral cavity is necessary for successful performance of a range of activities, such as chewing and swallowing, and determining the clinical outcomes of some dental treatments, such as prosthodontic treatments. However, with the exception of taste perception, oral perception has been infrequently researched, and comparatively little is known about the perceptual capacity.

Although the presence of an oral size illusion is acknowledged and oral perception of size is commonly inaccurate, research that actually establishes the presence of the oral size illusion is equivocal. Evidence indicates that the size of holes in the oral cavity, as explored with the tongue, are consistently overestimated (Anstis, 1964; Anstis & Loizos, 1967; La Pointe, Williams, & Hepler, 1973). In these studies (Anstis, 1964; Anstis & Loizos, 1967; La Pointe et al., 1973), participants matched the size of the holes with digital or visual reference sets. In some cases, the overestimation of size was greater for the smaller holes (Anstis, 1964; Anstis & Loizos, 1967), and in others it was greater for the larger holes. In contrast, one study (La Pointe et al., 1973) found a slight underestimation for the smaller holes.

This consistent overestimation in oral size perception is further supported by Dellow, Lund, Babcock, and van Rosendaal (1970). In that study (Dellow et al., 1970), participants assessed the size of intra-oral cylinders. When cylinders were presented intra-orally, most of the errors were an overestimation (Dellow et al., 1970). In more recent studies (Bittern & Orchardson, 2000; Melvin & Orchardson, 2001), participants assessed the size of small holes and pegs embedded in an inter-oral device with their tongues and fingers. For oral perception of both holes and pegs, participants overestimated the size. However, for a minority of the small and large sizes, participants tended to underestimate the sizes of the pegs (Bittern & Orchardson, 2000; Melvin & Orchardson, 2001). In contrast, La Pointe et al. (1973) showed that when visually and digitally matching the size of holes assessed with the tongue, visual assessment was more accurate than digital assessment. In a study by Engelen, Prinz, and Bosman (2002), participants assessed

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the size of steel spheres inside the mouth with and without a customized plastic covering of the palate. Regardless of palate covering, participants visually underestimated the size of the smaller spheres and overestimated the sizes of the larger spheres. In some cases, the oral size illusion was diminished when participants wore the palate covering (Engelen et al., 2002). Engelen et al. (2002) used visual matching of spheres and found underestimation of oral size. Topolinski and Türk Pereira (2012), in a recent study, used digital matching of round straws and also found underestimation.

Results of these previous studies (Anstis, 1964; Anstis & Loizos, 1967; Bittern & Orchardson, 2000; Dellow et al., 1970; Engelen et al., 2002; La Pointe et al., 1973; Melvin & Orchardson, 2001; Topolinski & Türk Pereira, 2012) are inconclusive because no clear understanding of this phenomenon can be determined: oral size perception appears to be underestimated or overestimated depending on the size and shape of the object and regardless of whether the reference matching task is visual or digital. Further, perceptual experience varies depending on an individual's environment, such as properties of the surrounding environment (Adams, Graf, & Ernst, 2004); memories, expectations, or biases (Churchland, 1988; Fisher, Hull, & Holtz, 1956; Hansen, Olkkonen, Walter, & Gegenfurtner, 2006; Pylyshyn, 1999); sociolinguistic environment (Winawer et al., 2007); or other immediately prior perceptual experiences (Pylyshyn, 1999). It seems likely that oral perception is not exempt from these influences. Therefore, the objectives of the present study were to confirm the presence of an oral size illusion, determine the magnitude (amount) and direction (underestimation or overestimation) of the illusion, and determine whether immediately prior cross-modal perceptual experiences affected the magnitude and direction.

2. Materials and methods

Participants were recruited by e-mail and excluded if they were unhealthy, had a history of choking, or had current orthodontic or prosthodontic dental treatment that would have interfered with oral size perception. The present study was approved by the local institutional review board (redacted for blind review), and all participants signed approved informed consent forms prior to participating.

In the present study, participants were tasked with assessing the size of stainless steel spheres in the oral cavity. Nine sizes of spheres were used in the assessments; they ranged in size from 1/16 inch to 1/2 inch and each sphere size was assigned a specific number (Table 1). To minimize the influence that perceptual memory may have had on size assessments from previously assessed spheres, the sphere sizes used across all assessments were not uniform. Additionally, the largest and smallest sphere sizes were not used as oral spheres during assessments, so that participants always had the opportunity to overestimate or underestimate the size of the sphere being assessed. Spheres were grouped into 3 general size categories (small, medium, or big) (Table 1). Oral size assessments were matched with a digital or visual reference set. Both visual as well as digital reference sets, rather than one or the other, were used, because previous research suggests that the oral size illusion manifests by way of both perceptual modalities. Both reference sets consisted of one of each size of sphere attached to a transparent acrylic display stand. Participants completed 20 oral size assessments (matching tasks) that were divided into 3 categories of assessments: control, primer-control, and experimental (Table 2). One sphere (#6) was never assessed, but was included in the reference sets so that there was visual and digital continuity among the spheres in the reference set, allowing the participants to make more fine-grained size assessments. All assessments occurred in the same temperature-controlled room under normal lighting conditions.

There were 6 control assessments: 3 oral–visual assessments (O–V) and 3 oral–digital assessments (O–D). For the O–V assessments, participants were blindfolded and given a cup containing a small, medium, or big sphere. Participants were instructed to place the sphere in their mouth. There were no restrictions on how participants could orally assess the size of the sphere. Participants then removed the blindfold and, with the sphere still in the mouth, matched the sphere with a visual reference set. The selection was recorded by a study investigator. Procedures for the 3 O–D assessments were the same, except participants kept the blindfold on and matched the oral sphere with a digital reference set.

Primer-control assessments were similar to control assessments, where the participant matched an oral sphere with a digital or visual reference set. However, for these assessments, participants made a digital or visual assessment of a sphere (priming sphere) that was the exact same size as the oral sphere immediately prior to the oral assessment. Participants completed 6 primer-control assessments: 3 digital–oral–visual (D–O–V) assessments and 3 visual–oral–digital assessments (V–O–D). For D–O–V assessments, participants were blindfolded and given a priming sphere in a cup. They poured the sphere from the cup into their hands and then while blindfolded digitally assessed its size. After returning the priming sphere to the cup and the cup to study investigators, participants were given a cup containing an oral sphere of the same size; they assessed oral size using the same procedure for control assessments. After completing the oral size assessment, they matched the size of the oral sphere with a visual reference set, using the same procedure as that of the control assessments. For V–O–D assessments, the procedures were the same, except participants visually assessed the size of the priming sphere and matched the size of the oral sphere with a digital reference set.

Experimental assessments were similar to primer-control assessments, where participants made a digital or visual assessment of a sphere (priming sphere) immediately prior to the oral assessment. However, for these assessments, the size of the priming sphere and oral sphere were different sphere sizes (small, medium, big). Participants completed 8 experimental assessments: 4 D–O–V and 4 V–O–D. Procedures for these assessments

Table 1
Sizes and size categories of stainless steel spheres used in the present study.

Sphere size (in)	Converted sphere size (mm)	Sphere identifier number	Sphere size category
1/16	1.6	1	Small
1/8	3.2	2	Small
3/16	4.8	3	Small
7/32	5.5	4	Medium
1/4	6.35	5	Medium
5/16	7.9	6	Medium
3/8	9.5	7	Big
7/16	11.1	8	Big
1/2	12.7	9	Big

Table 2
Oral size assessment matching tasks ($N = 20$) used in the present study.

Assessment category	Reference set assessment type		Sphere size identifier[a]		
	Visual	Digital	Priming sphere[b]	Oral sphere	Relative size
Control	O–V	O–D	NA	8	NA
Control	O–V	O–D	NA	5	NA
Control	O–V	O–D	NA	2	NA
Primer-control	D–O–V	V–O–D	7	7	$P = O$
Primer-control	D–O–V	V–O–D	5	5	$P = O$
Primer-control	D–O–V	V–O–D	2	2	$P = O$
Experimental	D–O–V	V–O–D	3	7	$P < O$
Experimental	D–O–V	V–O–D	7	5	$P > O$
Experimental	D–O–V	V–O–D	2	4	$P < O$
Experimental	D–O–V	V–O–D	7	3	$P > O$

[a] Each sphere size assessed in the present study was assigned a specific number for analyses (Table 1).
[b] Control assessments did not use a priming sphere.Abbreviations: D–O–V, digital assessment of the priming sphere and visual assessment of the reference set sphere; O–D, digital assessment of the reference set sphere followed the oral assessment; O–V, visual assessment of the reference set sphere followed the oral assessment; $P = O$, priming sphere size was equal to the oral assessment sphere size; $P < O$, priming sphere size was smaller than the oral assessment sphere size; $P > O$, priming sphere size was larger than the oral assessment sphere size; V–O–D, visual assessment of the priming sphere and digital assessment of the reference set sphere.

were the same as the procedures for primer-control assessments. In 4 of the experimental assessments, the difference between the priming sphere and the oral sphere was large (#3 as the priming sphere and #7 as the oral sphere or #7 as the priming sphere and #3 as the oral sphere). This large difference in sphere sizes was specifically used to elicit any potential effect the perception of the priming sphere may have had on the assessment of the oral sphere.

Each participant was assessed on each of the 4 assessment types (O–V, O–D, D–O–V, and V–O–D) in a random order, and within each assessment type, the order of the assessments was randomized. Table 2 summarizes the 20 oral size assessment matching tasks. Study data were collected and managed using Qualtrics software (Qualtrics Research Suite, Provo, UT).

A 1-sample Wilcoxon signed rank test was used to test whether the sample median of the participant's size estimation differed significantly from the actual size of the sphere in any of the 20 oral assessment matching tasks. A random-intercepts logistic regression analysis modeled the dependence of the size of the oral sphere and reference set assessment type on the probability of an accurate estimate. A random-intercepts linear regression analysis was used with the outcome variable as the difference between the participant's size estimation and the actual size of each sphere. The difference between the estimated size and actual size was measured as a difference of rank, and therefore difference results have no units attached. For example, if a participant's oral assessment sphere size was a #4 but the estimated size recorded during the reference set assessment was a #5, then the overall assessment was recorded as plus 1. If the estimated size recorded during the reference set assessment was a #3, then the overall assessments was recorded as a minus 1 (Table 1). Participants were treated as random effects in both analyses to allow for correlation of performance between assessments for individual participants.

Table 3
Distribution of sphere size estimates for study assessments ($N = 27$).

Sphere and reference set assessment	Assessment categories	Underestimation, no. (%)	Overestimation, no. (%)	Accurate estimation, no. (%)	*P*value
Small					
Digital	Control	10 (37)	2 (7)	15 (56)	.04
Digital	Primer-control	11 (41)	1 (4)	15 (56)	.006
Digital	Experimental	4 (15)	12 (44)	11 (41)	.08
Visual	Control	8 (30)	0 (0)	19 (70)	.008
Visual	Primer-control	11 (41)	1 (4)	15 (56)	.006
Visual	Experimental	5 (19)	3 (11)	19 (70)	.73
Medium					
Digital	Control	10 (37)	10 (37)	7 (26)	>.99
Digital	Primer-control	11 (41)	6 (22)	10 (37)	.33
Digital	Experimental $P < O$	15 (56)	4 (15)	8 (30)	.02
Digital	Experimental $P > O$	10 (37)	10 (37)	7 (26)	>.99
Visual	Control	9 (33)	5 (19)	13 (48)	.42
Visual	Primer-control	10 (37)	4 (15)	13 (48)	.18
Visual	Experimental $P < O$[a]	12 (44)	3 (11)	10 (37)	.04
Visual	Experimental $P > O$[b]	11 (41)	3 (11)	12 (44)	.06
Big					
Digital	Control	5 (19)	18 (67)	4 (15)	.004
Digital	Experimental	3 (11)	18 (67)	6 (22)	<.001
Digital	Primer-control	4 (15)	14 (52)	9 (33)	.03
Visual	Control	1 (4)	15 (56)	11 (41)	<.001
Visual	Primer-control	4 (15)	10 (37)	13 (48)	.18
Visual[b]	Experimental	5 (19)	8 (30)	13 (48)	.58

[a] $N = 25$.
[b] $N = 26$.Results obtained from 1-sample Wilcoxon signed rank test. Control assessments had no priming sphere, primer-control assessments used a priming sphere of the same size as the oral assessment sphere size, and experimental assessments used a priming sphere of a different size than the oral assessment sphere size.Percentages might not equal 100% because of rounding.Abbreviations: $P < O$, priming sphere size was smaller than the oral assessment sphere size; $P > O$, priming sphere size was larger than the oral assessment sphere size.

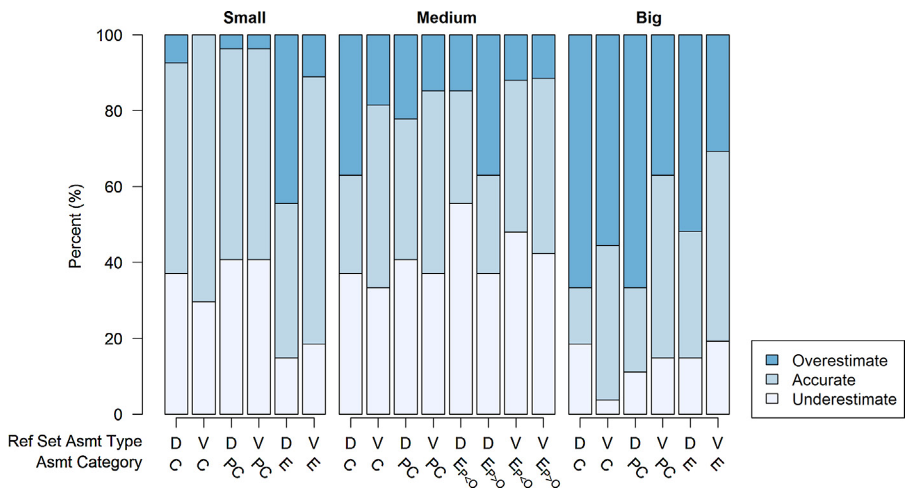

Fig. 1. Mean differences between estimated and actual oral size of spheres for digital and visual reference sets.
Abbreviations: C, control assessment; D, digital reference set assessment; E, experimental assessment; $E_{P<O}$, experimental assessment where the priming sphere size was smaller than the oral assessment sphere size; $E_{P>O}$, experimental assessment where the priming sphere size was larger than the oral assessment sphere size; PC, primer-control assessment; V, visual reference set assessment.

The predictor variables were the assessment category (control, primer-control, and experimental), the oral assessment sphere size, whether the priming sphere size was greater than the oral assessment sphere size, and the reference set assessment modality (digital or visual). As a measure of the impact of changing from a control assessment to either a primer-control or experimental assessment using the same oral assessment sphere size and reference set assessment modality, estimates of the oral assessment sphere size were summarized into concordant and discordant pairs. Bowker's test of symmetry was performed to test that the distribution of the discordant pairs was symmetrical. All analyses were conducted using SAS 9.4 (SAS Institute Inc, Cary, NC). $P<.05$ was considered statistically significant.

3. Results

Twenty-seven participants completed the present study: median age, 25 years; range, 21–34 years; 19 (70%) males. However, due to computer failure, 1 participant failed to make 3 assessments, and 1 participant failed to make 1 assessment.

3.1. Presence, magnitude, and direction of oral size illusion

Overall accuracy varied according to the size of the sphere (Table 3,Fig. 1). Even though small spheres were generally underestimated, assessments with small spheres were the most accurate (accuracy range, 41–70%), and differences between estimates for assessment categories were significant for control and primer-control assessments (all $P<.04$). Assessments with big spheres were the least accurately assessed (accuracy range, 15–48%), but differences between estimates were found for control assessments (both $P<.004$) and for digital reference set assessments for primer-control and experimental assessments (both $P<.03$). Assessments with medium spheres were slightly more accurate (accuracy range, 26–48%) than assessments with big spheres, and differences between estimates were only found for experimental assessments preceded by a smaller priming sphere (both $P<.04$).

Overall, across oral sphere size and assessment categories, the odds of an accurate estimate were 2.3 (95% confidence interval [CI] [1.6, 3.2]) times greater in visual reference set assessments than digital reference set assessments ($P<.001$). Across reference set assessment types and assessment categories, the odds of an accurate estimate were 2.5 (95% CI [1.6, 3.8]) times greater for small oral sphere size than medium oral sphere size and 2.8 (95% CI [1.7, 4.5]) times greater for small oral sphere size than big oral sphere size (both $P<.001$). There was no significant change in probability of accuracy between medium and big oral sphere sizes ($P=.56$).

The mean differences between the estimated sphere size from the digital and visual reference sets and the actual oral assessment sphere size as well as the within assessment category comparisons are shown in Table 4 and Fig. 2. All the small spheres were underestimated (range, −0.37 to −0.07), with the exception of the V–O–D experimental assessment (0.41), and all comparisons were significant (all $P<.048$), with the exception of the D–O–V experimental assessment ($P=.57$). All the medium spheres were also underestimated (range, −0.56 to −0.11), but significant differences were only found for the V–O–D experimental assessment where the priming sphere size was smaller than the oral assessment sphere size ($P=.002$) and for the D–O–V primer-control and experimental assessments (all $P=.02$). All the big spheres were overestimated (range, 0.03–0.67), even experimental assessments that included a smaller priming sphere (range, 0.03–0.37), but significant differences were only found for the control assessments (both $P\leq.001$) and the primer-control and experimental V–O–D assessments (both $P<.01$). The overall results across reference set assessment modalities were similar: small (range, −0.37 to 0.17) and medium (range, −0.50 to −0.15) spheres were underestimated, and big spheres (range, 0.20–0.50) were overestimated (Table 4 and Fig. 3). Significant differences were found for small and big spheres for the control and primer-control assessments (all $P<.008$) and for medium spheres for the primer-control and experimental assessments (all $P<.04$).

3.2. Effects of immediately prior cross-modal perceptual experiences

When comparing the experimental assessments with the control assessments, differences were found (Table 4 and Figs. 2 and 3). When a small oral assessment sphere was preceded by a larger priming sphere, sphere size was significantly overestimated in V–O–D experimental assessments (0.41 vs −0.26, $P<.001$) and overall across V–O–D and D–O–V experimental assessments (0.17 vs −0.28, $P<.001$) compared with control assessments. When a medium oral assessment sphere was preceded by a smaller priming sphere, sphere size was significantly

Table 4
Differences and comparisons between the estimated sphere size and actual sphere size for study assessments ($N = 27$).

Sphere and assessment categories	V–O–D assessments (95% CI)	*P*value	D–O–V assessments (95% CI)	*P*value	Overall results (95% CI)	*P*value
Small						
Control	−0.26 (−0.52 to 0.00)	.048	−0.30 (−0.55 to −0.04)	.02	−0.28 (−0.48 to −0.08)	.008
Primer-control	−0.37 (−0.63 to −0.11)	.005	−0.37 (−0.63 to −0.11)	.005	−0.37 (−0.57 to −0.17)	<.001
Experimental	0.41 (0.15 to 0.66)	.002	−0.07 (−0.33 to 0.18)	.57	0.17 (−0.04 to 0.37)	.11
Medium						
Control	−0.11 (−0.46 to 0.24)	.53	−0.19 (−0.53 to 0.16)	.29	−0.15 (−0.41 to 0.11)	.26
Primer-control	−0.26 (−0.61 to 0.09)	.14	−0.41 (−0.75 to −0.06)	.02	−0.33 (−0.59 to −0.07)	.01
Experimental P<O	−0.56 (−0.90 to −0.21)	.002	−0.44 (−0.80 to −0.08)[a]	.02	−0.50 (−0.77 to −0.23)	<.001
Experimental P>O	−0.11 (−0.46 to 0.24)	.53	−0.43 (−0.78 to −0.07)[b]	.02	−0.27 (−0.53 to −0.01)	.04
Big						
Control	0.48 (0.19 to 0.77)	.001	0.52 (0.23 to 0.81)	<.001	0.50 (0.28 to 0.72)	<.001
Primer-control	0.67 (0.38 to 0.95)	<.001	0.22 (−0.07 to 0.51)	.13	0.44 (0.22 to 0.67)	<.001
Experimental	0.37 (0.08 to 0.66)	.01	0.03 (−0.26 to 0.33)[b]	.82	0.20 (−0.02 to 0.43)	.08

[a] $N = 25$.
[b] $N = 26$.Differences were calculated by subtracting the actual sphere size from the estimated sphere size. Results obtained from linear regression analysis. Control assessments had no priming sphere, primer-control assessments used a priming sphere of the same size as the oral assessment sphere size, and experimental assessments used a priming sphere of a different size than the oral assessment sphere size.Abbreviations: CI, confidence interval; D–O–V, digital assessment of the priming sphere and visual assessment of the reference set sphere; $P < O$, priming sphere size was smaller than the oral assessment sphere size; $P > O$, priming sphere size was larger than the oral assessment sphere size; V–O–D, visual assessment of the priming sphere and digital assessment of the reference set sphere.

underestimated overall across V–O–D and D–O–V experimental assessments (−0.50 vs −0.15, $P = .04$) compared with control assessments, whereas when the same sphere was preceded by a larger priming sphere, no significant difference was found ($P = .46$). When a big oral assessment sphere was preceded by a smaller priming sphere, sphere size was significantly estimated as smaller in D–O–V experimental assessments (0.03 vs 0.52, $P = .01$) and overall across V–O–D and D–O–V experimental assessments (0.20 vs 0.50, $P = .03$) compared with control assessments.

3.3. Consistency of the oral size illusion

For 2 of the experimental assessments, the discordant pairs indicated values consistently shifted either to a smaller-sized or larger-sized estimated oral sphere compared with the control assessment. For the D–O–V experimental assessment that used a big oral assessment sphere size, digitally assessing a smaller priming sphere resulted in consistent, smaller-sized assessments ($P = .03$) (Table 5). For the V–O–D experimental assessment that used a small oral assessment sphere size, visually assessing a larger priming sphere resulted in consistent, larger-sized assessments ($P = .03$).

4. Discussion

Results of the present study seemed to confirm the presence of oral size illusion. Small and medium sphere sizes were consistently underestimated, and big sphere sizes were consistently overestimated, and visual assessments were more accurate than digital assessments Further, immediately prior cross-modal perceptual experiences seemed to influence the magnitude and direction of the oral size illusion. In some cases, the effects of the influence of the immediately prior cross-modal perceptual experiences were consistent.

One limitation of the present study is that there was little diversity in the age of our participants. Further, a person's ability to accurately perceive size may change with age so our results may not be generalizable to a broader population. Another limitation that affects our study's generalizability is that stainless steel spheres are nearly perfectly round and uniform in texture, which

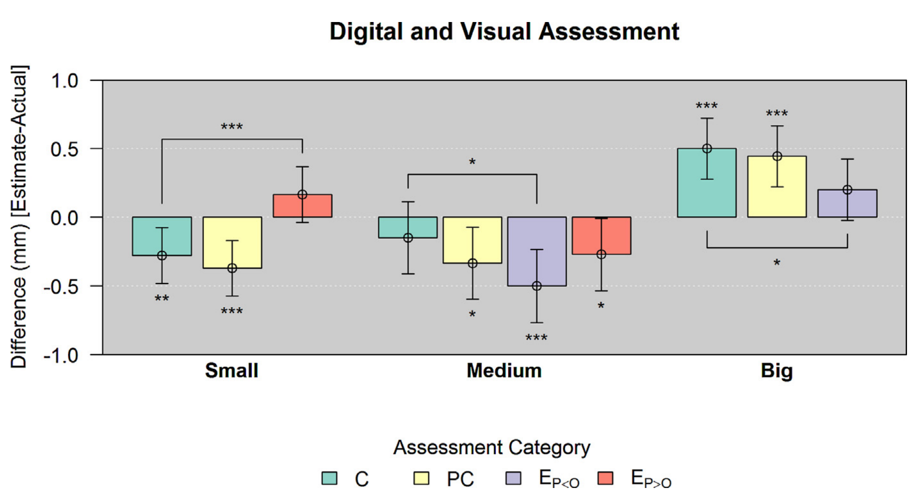

Fig. 2. Mean differences between estimated and actual oral assessment size of spheres across digital and visual reference sets.
*indicates $P < .05$; ** indicates $P < .01$; ***indicates $P < .001$ from testing either the hypothesis that the mean difference within sphere size and assessment category is equal to zero or that the mean differences within sphere size between assessment categories is equal.
Abbreviations: C, control assessment; $E_{P<O}$, experimental assessment where the priming sphere size was smaller than the oral assessment sphere size; $E_{P>O}$, experimental assessment where the priming sphere size was larger than the oral assessment sphere size; PC, primer-control assessment.

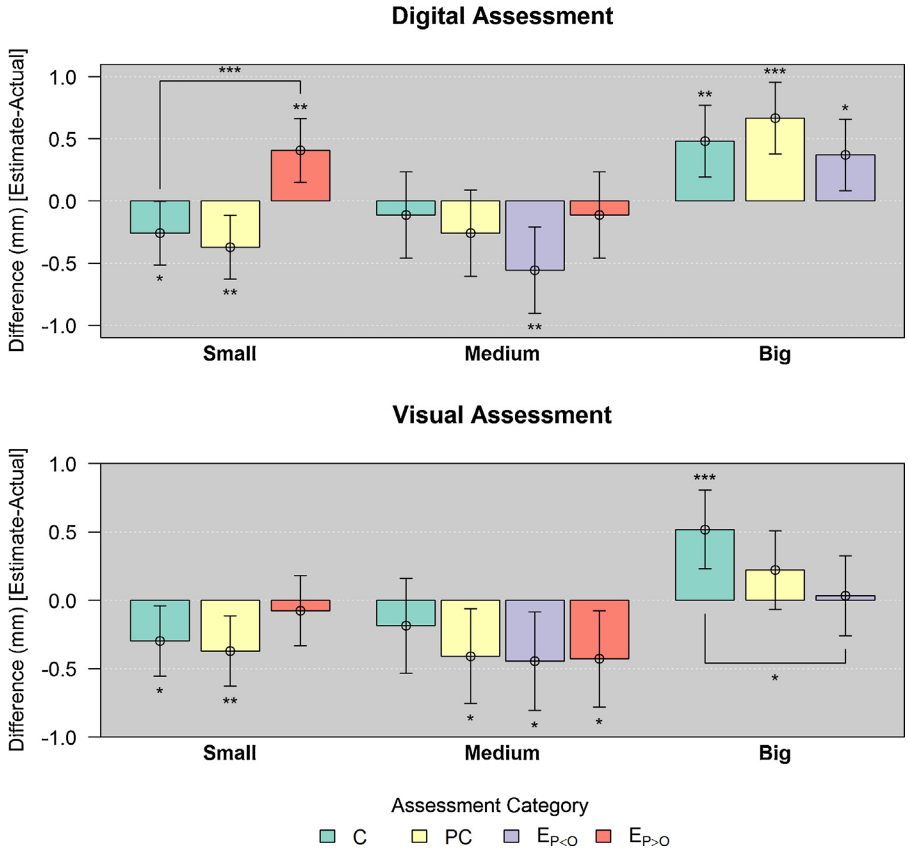

Fig. 3. Distribution of overestimation, underestimation, and accurate estimation.
*indicates $P<.05$; ** indicates $P<.01$; ***indicates $P<.001$ from testing either the hypothesis that the mean difference within sphere size and assessment category is equal to zero or that the mean differences within sphere size between assessment categories is equal.
Abbreviations: C, control assessment; $E_{P<O}$, experimental assessment where the priming sphere size was smaller than the oral assessment sphere size; $E_{P>O}$, experimental assessment where the priming sphere size was larger than the oral assessment sphere size; PC, primer-control assessment.

Table 5
Change in oral assessment sphere size estimates from control assessment to primer-control or experimental assessment with the same oral assessment sphere size and reference set assessment modality ($N=27$).

Sphere and assessment categories	Reference set assessment type	Concordant pairs, no. (%)	Discordant pairs, no. (%)		*P* value
			Smaller	Larger	
Small					
Primer-control	Digital	19 (70)	5 (19)	3 (11)	.77
Primer-control	Visual	21 (78)	4 (15)	2 (7)	.42
Experimental	Digital	8 (30)	3 (11)	16 (59)	.03
Experimental	Visual	19 (70)	1 (4)	7 (26)	.19
Medium					
Primer-control	Digital	12 (44)	10 (37)	5 (19)	.42
Primer-control	Visual	13 (48)	7 (26)	7 (26)	.50
Experimental $P<O$	Digital	10 (37)	13 (48)	4 (15)	.13
Experimental $P>O$	Digital	16 (59)	6 (22)	5 (19)	.69
Experimental $P<O$[a]	Visual	8 (32)	11 (44)	6 (24)	.57
Experimental $P>O$[b]	Visual	12 (46)	9 (35)	5 (19)	.63
Big					
Primer-control	Digital	16 (59)	5 (19)	6 (22)	.69
Primer-control	Visual	14 (52)	10 (37)	3 (11)	.20
Experimental	Digital	16 (59)	6 (22)	5 (19)	.19
Experimental[b]	Visual	17 (65)	9 (35)	0 (0)	.03

[a] $N=25$.
[b] $N=26$.Results obtained from Bowker's test of symmetry. Primer-control assessments used a priming sphere of the same size as the oral assessment sphere size, and experimental assessments used a priming sphere of a different size than the oral assessment sphere size.Percentages might not equal 100% because of rounding. Abbreviations: $P<O$, priming sphere size was smaller than the oral assessment sphere size; $P>O$, priming sphere size was larger than the oral assessment sphere size.

are properties uncommonly encountered in the course of typical oral perceptual experiences. Further studies should investigate the oral size illusion with a more diverse population of participants and with stimuli more typical of oral perceptual experiences to overcome these limitations. A third limitation is the possibility that the observed cross-modal influence on oral size perception is caused in part by perception of the comparator in the reference set. However, this possibility would not indicate the absence of cross-modal influence and it does not explain our finding that the cross-modal priming spheres influenced the oral size assessment. But the influence of the cross-modal priming spheres may not account for the entirety of the differences observed.

The potential clinical implications of the present study depend on the extent of the influence of cross-modal perceptual experience on oral size perception. When fitting dentures or other dental prostheses, clinicians should consider the cross-modal influence on oral size perception when initially fitting the device, especially since patient feedback can have a significant long-term impact on device retention. If additional research suggests that the perceived size of dental instruments is subject to cross-modal influence, then clinicians may also be able to use oral size perception to influence the perceived size of dental instruments, potentially making patients more comfortable with some dental procedures.

4.1. Presence, magnitude, and direction of oral size illusion

If a perceptual illusion is the disposition to consistently perceive something inaccurately, then our results indicate the presence of the oral size illusion. Participants consistently perceived oral assessment sphere sizes inaccurately, and identifiable patterns of this inaccuracy emerged with small and medium sphere sizes consistently underestimated and big sphere sizes overestimated. However, these results conflict with results from previous research investigating oral size illusion. Other studies (Anstis & Loizos, 1967; Engelen et al., 2002; Melvin & Orchardson, 2001) found that accuracy improved as the size of the stimulus increased. Melvin and Orchardson (2001) found that the ratio of the size of the matched stimulus to the size of the oral stimulus got closer to 1 as the size of the stimulus increased, which suggested that the degree of error decreased with increases in size. Anstis and Loizos (1967) also found their participants became more accurate as the size of the stimulus increased. However, in that study (Anstis & Loizos, 1967) the stimuli were holes, and in the Melvin and Orchardson (2001) study, the stimuli were pegs attached to a larger apparatus. The methods in a study by Engelen et al. (2002) were similar to the present study, and those authors found the accuracy of the size assessments of oral spheres improved with increases in sphere size. Overall, the accuracy of our participants decreased with increases in sphere size.

In addition to showing that accuracy decreased as size increased, the present study also corroborated the results from a study by La Pointe et al. (1973). In that study, participants were much more accurate when visually matching an oral size assessment than they were when performing the same assessment digitally. Our results also indicated that visual matching assessments of the size of an oral sphere were significantly more accurate than the same task performed digitally, regardless of assessment category.

Results of previous research (Anstis & Loizos, 1967; Bittern & Orchardson, 2000; La Pointe et al., 1973; Melvin & Orchardson, 2001) suggest that the direction of the oral size illusion tends toward overestimation. In these studies (Anstis & Loizos, 1967; Bittern & Orchardson, 2000; La Pointe et al., 1973; Melvin & Orchardson, 2001), participants orally assessed the size of objects with the lips and tongue only: they were not intra-oral objects. Further, underestimation was infrequent and the oral size illusion typically manifested as overestimation of the stimulus. Contrary to these results, we found that the oral size illusion manifested in both directions and that underestimation was more frequent than overestimation. Our result supports the study by Engelen et al. (2002), who found that small- and medium-sized spheres tended to be underestimated while large-sized spheres were overestimated. These contradictory findings may be the result of differences in study design. In the present study and in the study by Engelen et al. (2002), participants assessed the size of spheres that were completely inside the mouth. In other studies (Anstis & Loizos, 1967; Bittern & Orchardson, 2000; La Pointe et al., 1973; Melvin & Orchardson, 2001), the size of the spheres was perceived with the lips and tongue.

To clarify the specifics of the oral size illusion, future studies should investigate why small-sized spheres tend to be underestimated and large-sized spheres overestimated. Further, differences in the methods used to assess the sphere size could be investigated to determine if spheres assessed completely inside the mouth produce different oral size illusion effects compared with spheres assessed with the lips and tongue.

4.2. Effects of immediately prior cross-modal perceptual experiences

Results of the present study also indicated that immediately prior cross-modal perceptual experiences influenced the magnitude and direction of the oral size illusion. Across assessment types, smaller priming spheres with big oral assessment sphere sizes reduced overestimation of sphere size, while larger priming spheres with small oral assessment sphere sizes reduced underestimation but also caused participants to overestimate sphere sizes.

This same pattern emerged within the reference set assessments. For digital reference sets of experimental assessments, larger priming spheres reduced underestimation of both the small and medium oral assessment sphere sizes compared with the control assessments. Smaller priming spheres appeared to reduce the overestimation of big oral assessment sphere sizes and to increase the underestimation of medium oral assessments sphere sizes compared with control assessments, but these effects were not statistically significant. The visual reference set assessments exhibited the same patterns, except for the medium oral assessment sphere sizes for which there was no evidence of an effect. These results suggested that aspects of oral size perception, and oral perception more generally, can be penetrated by other perceptual experiences. Oral perception is not simply a matter of the oral perceptual anatomy and properties of the stimulus.

Additional studies should investigate at which point the effect of prior perceptual experiences diminishes or whether other mental states, such as beliefs or desires, can exhibit a similar influence upon oral perceptual experiences.

4.3. Consistency of the oral size illusion

For 2 of the experimental assessments, if the size of the priming spheres influenced the participant, the direction of the oral size perception was consistent. When the oral assessment sphere size was small and a larger visual priming sphere was used, if participants changed their estimate during the reference set assessment portion of the matching task, they were likely to digitally estimate the size of the sphere as larger than their estimate from the control assessment. Conversely, when a digital priming sphere smaller than the oral assessment sphere was used and if participants changed their estimate during the reference set assessment, they were likely to visually estimate the size of the sphere as smaller than their estimate from the control assessment.

Given the consistency of this influence, clinicians should consider it when providing care to patients, such as during the provision of oral prostheses.

When considered as a whole, results from the present study may seem puzzling. For instance, small-sized spheres were consistently underestimated and large-sized spheres were consistently overestimated. Visual matching tasks were much more accurate, overall, than digital matching tasks. Further, accuracy decreased as sphere size increased, and prior cross-modal perceptual experiences influenced oral size perception.

A potential explanation for these results is that the oral size illusion was caused by differences in the weights of the oral spheres rather than differences in the diameter of the oral spheres. Thus, differences in weight may account for the observed differences in perceived size. However, Engelen et al. (2002), who had a similar study design as the present study, discounted this possible explanation for their oral size illusion results, specifically stating that weight had no influence on the perceived oral size.

Another potential explanation of our results is that the shape of the stimulus, in this case a sphere, accounted for the differences in oral size perception. Perhaps shape perception between the modalities (oral, digital, or visual perception) is processed differently, and oral perception, like other types of perception, is penetrable by other perceptual modalities and by the perceiver's other mental states. Such an explanation would be consistent with the results of Melvin and Orchardson (2001). In that study, the properties of the stimulus influenced the presence of the oral size illusion. This explanation would also cohere with the broader literature on the penetrability of perceptual experience, which suggests that perceptual experience of properties such as size, shape, and color are often influenced by a person's other perceptual experiences and mental states (Pylyshyn, 1999).

However, the specific mechanism that would explain the results of the present study is unclear. One potential mechanism may be that the oral perceptual system, in detecting points on a surface, “assumes” that the solids are more linear than spherical. There are Bayesian models of visual perception that integrate the brain's assumptions about an object and its context into the visual processing and eventual experience of the object (Kersten, Mamassian, & Yuille, 2004). Something similar may be happening in the case of oral perception. When oral perception of a sphere occurs, the oral perceptual system may assume a ratio of volume to distance between 2 points to be closer to that of non-circular objects. Conditional on this assumption, a sphere may be perceived as smaller than it actually is because it is a shape for which increases in distance between 2 points on a surface imply an exponential increase in volume. This potential mechanism could account for our observed underestimation of small-sized spheres and for our finding that visual matching tasks were more accurate than digital matching tasks. Further, this explanation may be supported by the findings of Topolinski and Türk Pereira (2012). In that study, the size of cylinders was consistently underestimated; cylinders are another shape for which increases in distance between 2 surface points imply an exponential increase in volume. This explanation cannot, however, account for our finding that the large-sized spheres were consistently overestimated. This is not to say that a Bayesian model of oral perception cannot account for the oral size illusion or the influence that cross-modal experiences can have on it. Indeed, a Bayesian model may be the most promising route to such an account.

Because the sizes of oral spheres were both underestimated and overestimated in the present study, explanations of these results are complicated because no single explanation fits both results. For the same reason, other potential explanations fail to elucidate why we observed underestimation and overestimation. For instance, Engelen et al. (2002) suggested that the hardness of the palate meant less of the surface of a sphere would be in contact with the palate than it would be in contact with the surface of the tongue, resulting in conflicting and inaccurate size assessments. To explain their findings, Melvin and Orchardson (2001) considered oral size illusion may be a result of varying discrimination thresholds between the tongue and the fingers, but they concluded that this explanation was not compatible with their findings. This explanation also fails to account for underestimation and overestimation of oral sphere size.

Another, highly speculative, explanation for our results is grounded in evolutionary psychology. Our oral perceptual systems may have evolved to discourage the swallowing of objects larger than some specific threshold. If the oral perceptual system makes an object seem larger than it actually is, a person would be less likely to choke on the object. Similarly, objects smaller than the threshold may appear smaller than they actually are to encourage a person to swallow the object and increase the chances of getting the required nutrition. It is already known that evolution has influenced the conscious experience of taste (Breslin, 2013). So, it is plausible that evolution has also influenced the experience of oral size.

Viewing our results through evolutionary psychology may explain the consistent underestimation and overestimation and our observation that visual matching tasks of oral spheres were more accurate than digital matching tasks. A recent study by Topolinski and Türk Pereira (2012) seems to support this explanation. In that study, the authors showed that food-deprived participants, as compared to satiated participants, estimated the size of cylinders as larger in digital matching tasks even though they still underestimated the size of the cylinders. Thus, food deprivation, and plausibly the psychological states associated with hunger, may influence oral size perception.

Considering the results of the present study and the possible explanations for these result, we conclude that the factors that influence oral size perception, and oral perception in general, are numerous and interactive. Clearly, more studies are required to investigate the influence that size, shape, cross-modal experiences, and other psychological factors have on oral perceptual experience.

5. Conclusion

Results of the present study seem to confirm the presence of an oral size illusion. However, the magnitude of the oral size illusion was small, but the magnitude and direction varied by size of the sphere. Further, the magnitude and direction of the oral size illusion were influenced by immediately prior cross-modal perceptual experiences, and this influence occurred in consistent patterns in some cases. However, the explanation for these results and their potential clinical applications remains unclear. Future studies should be conducted to clarify the nature of the oral size illusion and the effect of immediately prior cross-modal perceptual experiences.

Conflict of interest

There is no conflict of interest.

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Ethical approval

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