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The Average Facial Expressions: A Range of Motion Analysis for Different Sex and Age Groups

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Background: Facial expressions are ubiquitous in communication. Therefore, assessment of mimic function is essential in facial surgery, but no reference standards are currently available. This prospective study aims to create reference values of three-dimensional landmark displacement for different sex and age groups.
Methods: Three-dimensional photographs were taken from healthy subjects in rest, maximum closed smile, and pouting. Displacement for both exercises of perioral landmarks was analyzed with MATLAB as absolute displacement and as the ratio of mouth width. Additionally, displacement in three planes was analyzed for each landmark. Averages were calculated for both genders in four age groups: 4–8, 8–12, 12–16, and >16 years.
Results: In total, 328 subjects were included. Oral landmarks predominantly moved forward and backward for both exercises. Nasal landmarks predominantly moved vertically. Growing up, oral landmark displacement decreased for smiling, whereas nasal landmark displacement increased. For pouting, oral landmark displacement increased while growing up, whereas nasal landmark displacement decreased.
Conclusions: The present study creates reference values for movement of perioral structures for different sex and age groups, for two facial expressions. These data are of great value for the assessment of mimic function and give insight into the development of facial animation over time. *(Plast Reconstr Surg Glob Open 2023; 11:e4762; doi: 10.1097/GOX.0000000000004762; Published online 18 January 2023.)*

INTRODUCTION

"Peace begins with a smile." A famous quote by Mother Theresa, by which she more or less recapitulated one of Darwin's studies from 1872. In "The expression of emotions in man and animals," Darwin depicted the importance of facial animation for social interactions.[1] Animation itself is not about "the smile," which is the end state. But it is, as often in life, about the way to "the smile," or the smiling action. An individual might have a beautiful smile on a picture, but during live interaction facial animation might have a different impact on social intercourse. Facial expressions form a universal way of communication, which is not constrained by language.[2] However, the ability to express oneself is not just about communication. It has a large social impact too. Reduced facial animation has shown to impair recognition of emotional expression by peers,[3] affect social interaction,[4,5] and influence psychological well-being.[6,7]

Obvious examples of affected function of mimic muscles are patients with facial paralysis[4,6–8] or orofacial cleft anomalies.[9,10] However, altered facial expressions are also observed in patients with dentofacial deformities,[11–13] or after orthognathic surgery.[11–14] Patterns in facial expression are influenced by underlying hard tissues,[15] which might explain altered facial expressions in dentofacial deformities.[11–13] Orthognathic surgery, the standard procedure to correct these deformities, has fairly predictable results on skeletal structures.[14,16,17] Nevertheless, soft-tissue response to orthognathic surgery, especially of the upper lip, is less predictable, as it is less relatable to the skeletal changes.[18,19] Dental occlusion often seems the primary focus in orthognathic surgery, because it is needed to get a stable result. However, the aesthetic outcome contributes considerably to patient satisfaction, and should, therefore, be leading in the treatment objectives.[20]

It is hypothesized that alterations in facial animation after surgical procedures arise from tightening or slackening of the muscles. Tightening occurs by enlarging the

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distance between origin and insertion, ie, lengthening of the muscle. Slackening occurs by reducing the distance between origin and insertion, that is, shortening of the muscle. Lengthening a muscle results in an increase in sarcomeres and protein synthesis, and therefore an increased peak tension.[21,22] One study investigated the effects of surgical repositioning of the maxilla. Anteriorly and/or inferiorly repositioning, and thereby lengthening of the muscles, increased facial movement while smiling. Likewise, superiorly and/or posteriorly repositioning, which reduces muscle length, resulted in a decrease in facial movement while smiling.[14]

There seems a need for assessment of the function of facial mimic muscles in patients if it is susceptible that surgical procedures might affect these muscles. In unilateral surgery, the contralateral side of the face should serve as a reference, to obtain symmetry. Yet, in bilateral facial surgery, for instance a Le Fort I osteotomy, this guidance is not provided, and surgeons must rely on their own experience to achieve pleasing results. This calls for reference models representing large parts of the population of the hospitals' adherent areas. These models can improve the assessment of clinical and aesthetic outcomes and proper planning of surgical procedures.

For these reference models, detailed knowledge of facial movement is required. Several studies have investigated which factors influence facial animation. Previous studies have shown that with age, the smile becomes wider horizontally, but narrows vertically.[23–25] These studies were two-dimensional (2D) and did not examine the forward and backward movements. Yet, a three-dimensional (3D) study could not find statistically significant differences in total facial movement. In that study, all individual landmark displacements were combined for comparison.[26]

The results of previous studies concerning sexual dimorphism in facial animation are also contradictory. Some studies confirmed that facial movement is larger in men than in women.[23,24,27–29] Others found no, or limited, sex-related differences.[26,30] It could be suggested that sex-related differences arise from differences in facial size and shape. Facial shape has proven to have a small, but significant effect on the extent of facial movement.[29] Also, a study found sex-related differences in verbal and nonverbal expressions; however, when corrected for intercheilion distance, these were not significant.[31]

Potential age- and sex-related differences should be taken into account when investigating facial animation. The current study aims to create reference standards of the maximum range of motion for different age and sex groups. The magnitude of specific facial movements says something about the ability to animate. For that reason, two reproducible extreme positions of the oral soft tissues were chosen as subject of the study: maximum closed smile and pouting. Since the facial actions themselves determine social intercourse to a great extent, we have investigated the range of motions from neutral to maximum positions.

These data will provide the average displacement of perioral surgical landmarks in three dimensions. Except the fact that the results could serve as reference standards, this study proposes a new method to analyze facial animation.

Takeaways

Question: What are the three-dimensional dynamics of the perioral structures in facial exercises, and how does it change with aging?

Findings: This prospective study found that oral landmarks predominantly moved forward and backward for both exercises. Nasal landmarks predominantly moved vertically. With aging, oral landmark displacement decreased for smiling, whereas nasal landmark displacement increased. For pouting, oral landmark displacement increased with aging, whereas nasal landmark displacement decreased.

Meaning: This study created reference values for movement of perioral structures for different sex and age groups, for two facial expressions.

MATERIALS AND METHODS

Population

Approval for this prospective study was provided by the local ethics committee (study number 14-652). Between December 2016 and January 2017, 3D images were captured of healthy subjects visiting the University Museum in Utrecht, The Netherlands, with the two-pod 3dMD system (3dMDface, 3dMD, Atlanta, Ga.). Healthy subjects, without a history of prior facial trauma or surgery, were included in the study. Informed consent was obtained from all participants. Ethnicity of subjects was registered. Study approval was provided by the local ethics committee. Each subject was captured in three different facial poses: neutral, closed smile, and pouting. The 3dMD system was placed in a windowless room used for daily clinical 3D imaging, illuminated with 100% LED lighting. The subjects were grouped in the age categories per 4 years. Due to the small number of inclusions in the 16- to 20-year group (six women and one men), it was decided to combine the older groups into one adult group, older than 16 years of age. This resulted in the following age groups: 4–8, 8–12, 12–16, and 16 years and older.

Image Processing

To perform analyses on the 3D images, each individual 3D image had to be converted into an aligned, subject-specific template, that is, remeshed. Remeshing and analyzing pictures were performed using the mathematic environment MATLAB (MATLAB R2020b, The MathWorks, Inc., Natick, Mass.). For the remeshing process, the following method was applied, with each step depicted in a flowchart in Figure 1. First, the individual 3D images were preprocessed to create a uniformly distributed mesh. Next, the following six anatomical landmarks were manually placed on the mesh: the left and right pupil, pronasale (pn), left and right cheilion (ch), and pogonion (pg) (step 1). These six landmarks were used in the Procrustes algorithm. This algorithm aligns the 3D

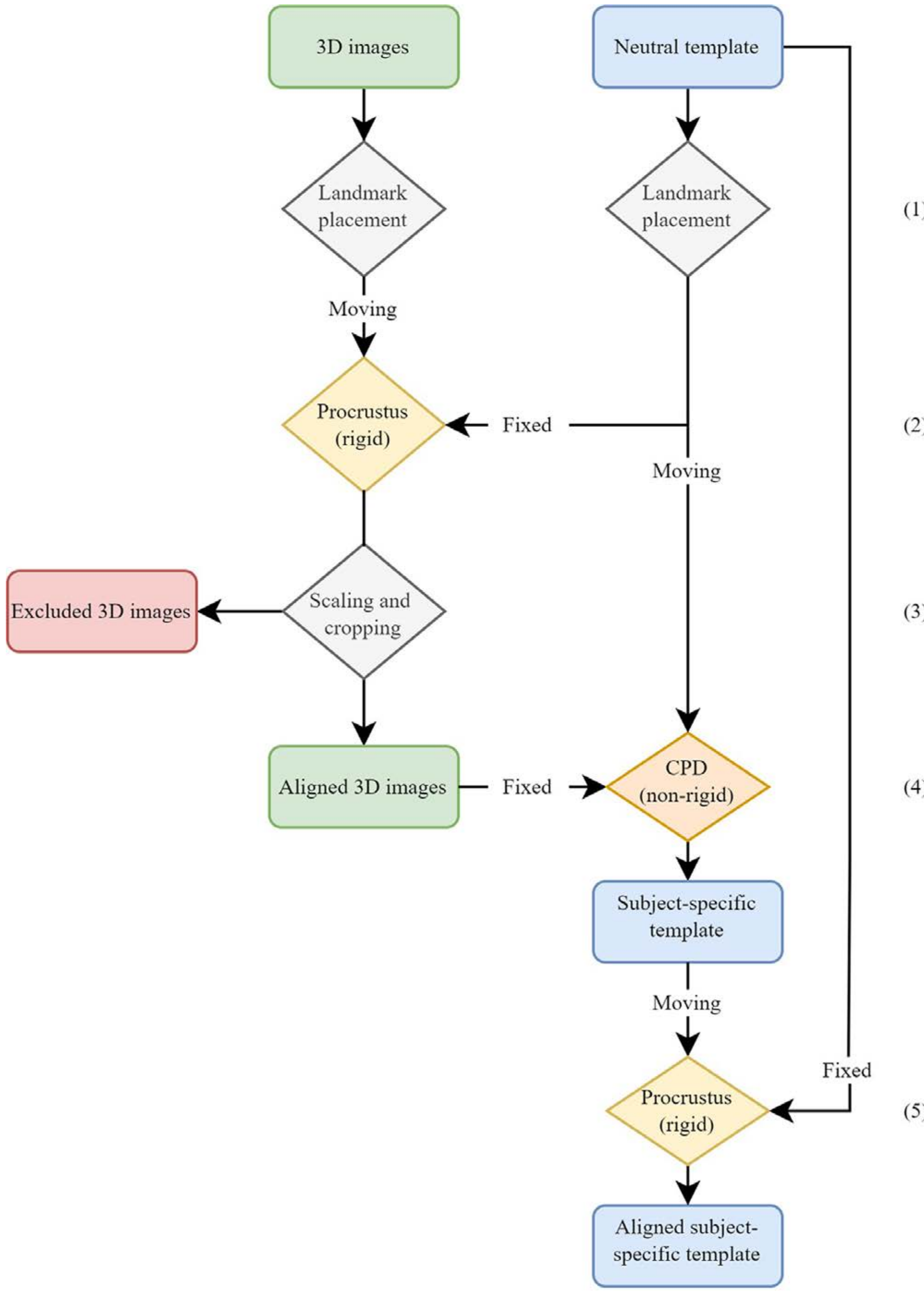

Fig. 1. Flowchart of remeshing process. Summary of all steps that were executed to process the original 3D images into a subject-specific template. CPD, coherent point drift.

image with a general template with facial contours ("neutral template"), without scaling the 3D image (ie, rigid, step 2). For each group, this face template was scaled according to the six landmarks, to account for the variation of head size between the different age groups. Also, the 3D image was cropped based on the outer boundary of the face template. Subjects whose forehead was not visible had to be excluded due to technical matching difficulties (step 3).

After the initial alignment and cropping of the 3D image, the landmark-guided coherent point drift algorithm was used. This algorithm deforms the general face template towards the 3D image and is, therefore, nonrigid. The manually placed left and right pupil, left and right cheilion, and pronasale were used as the landmarks to guide the coherent point drift (step 4). Finally, all 3D images were aligned toward the neutral template with the Procrustes algorithm using all vertices, by means of rigid registration (step 5). This resulted in every 3D image having the same position and rotation as the general face template, without scaling the face, to preserve the true facial measurements. The outcome of this remeshing process is an aligned, subject-specific template.

Landmark Displacement Analysis

During the processing of the 3D images, each image was placed in the same coordinate system of the template. The *x* axis was defined in the horizontal direction, with the *z* axis defined within the same horizontal plane in the dorsal direction. The *y* axis was defined in the vertical direction, perpendicular to the XZ-plane. For a visualization of the XYZ-coordinate system (Fig. 2). The displacement of three perioral landmarks from a neutral pose, to both a closed smile and pouting pose, was obtained by calculating the Euclidian distance between each corresponding landmark. Of three perioral landmarks, cheilion, labiale superius, and alare, the displacement was calculated, as an average of the displacement of the left and right landmark. The vector of total displacement was provided in millimeters, and as a ratio, related to the intercheilion distance of the individual. The latter makes comparison, between individuals and age groups, of the animation itself possible. Additionally, displacement in three directions was analyzed. For the horizontal movement, the displacement of landmarks on the right side of the face (being on the negative side of the *x* axis) was multiplied by −1. Therefore, lateral landmark displacement resulted in a positive outcome. By doing so, the results of left and right landmarks could be compared more easily. For the *y* axis, the upward movement resulted in a positive outcome. For the *z* axis, the forward movement resulted in a negative outcome. For further explanation and visualization of displacement analysis (Fig. 3). For each vector, the standard deviation (SD) was calculated as absolute distance in all directions. Each vector was depicted with a green-to-red color scale corresponding to SDs between 0 and 4 mm.

Statistical Analysis

Statistical analysis was performed using GraphPad Prism version 8.3.0 for Windows, GraphPad Software, San Diego, Calif., www.graphpad.com. Normality was tested using Q-Q plots. Normally distributed data were expressed by means with 95% confidence intervals. Differences between age groups within each gender were analyzed using one-way ANOVA analysis of variants. Statistically

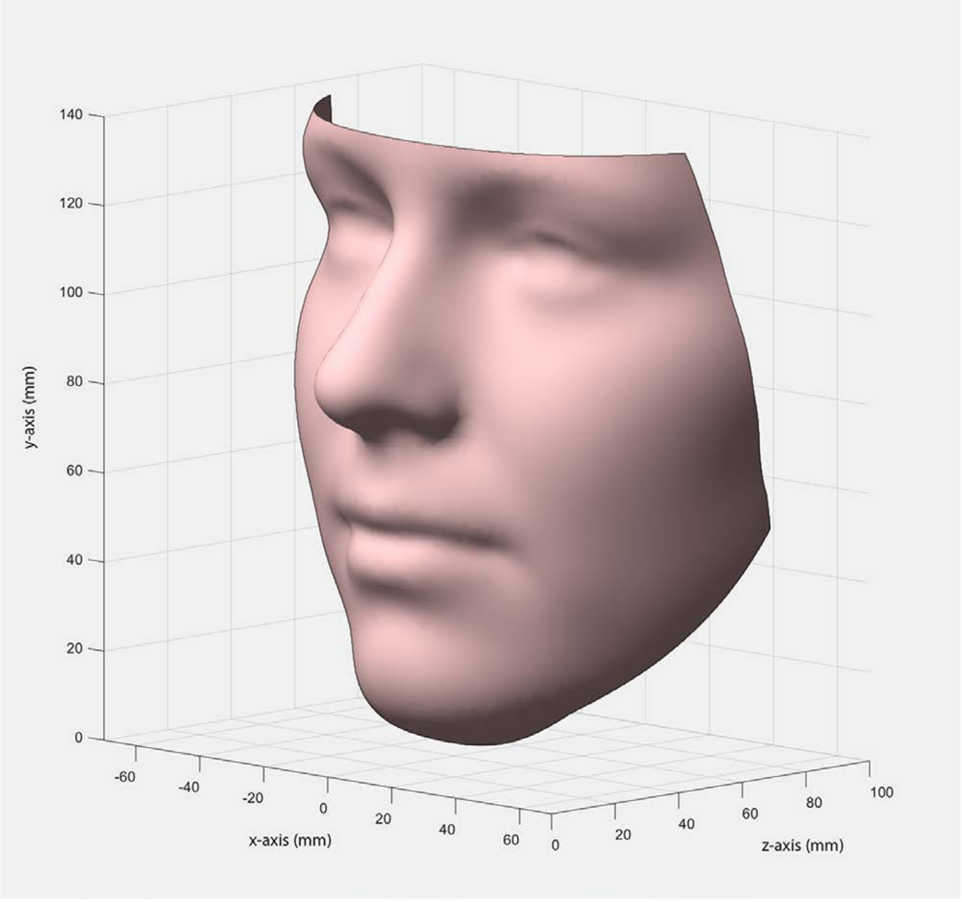

Fig. 2. XYZ-coordinate system.

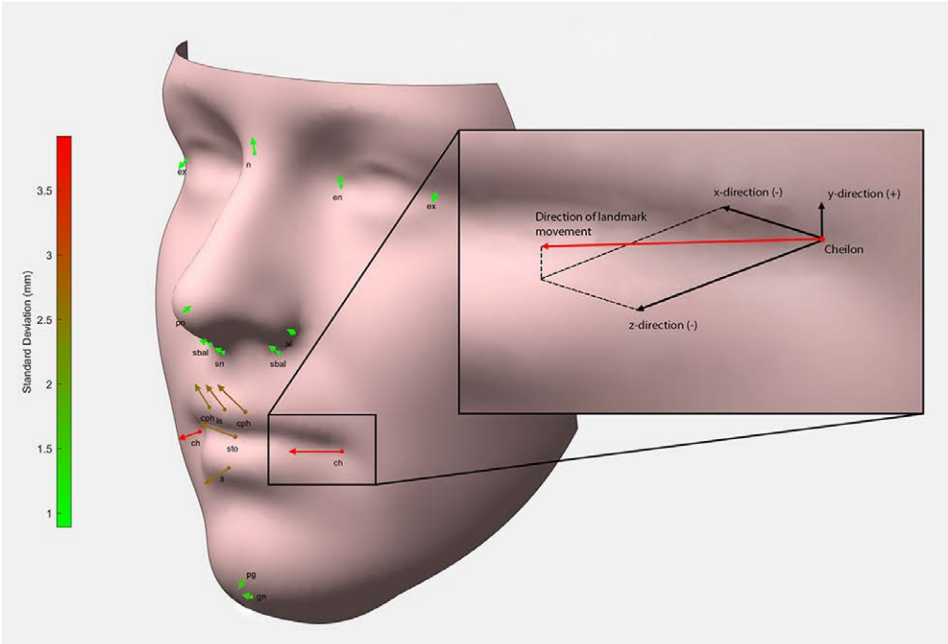

Fig. 3. Method for analyzing displacement of landmarks. For each vector, the SD was calculated as absolute distance in all directions. Each vector was depicted with a green-to-red color scale corresponding to SDs between 0 and 4 mm.

significant difference was considered at *P* values less than 0.05. For statistically significant differences, multiple comparison analyses were performed between all groups, using Tukey's post hoc tests.

RESULTS

Baseline Characteristics

In total, 406 healthy subjects were captured in three different facial positions. On 138 images, the forehead was not visible, and the corresponding patients had to be excluded due to technical matching difficulties. The remaining 328 subjects were divided by gender and age; their baseline characteristics are demonstrated in Table 1. In the total cohort, seven subjects were non-White, and all the others were White.

Landmark Displacement

Maximum Closed Smile

Landmark displacement results for the maximum closed smile for each sex and age group are presented in Table 2. The displacement of cheilion was mostly determined by the Z-component, except for the oldest male age group, where the displacement was the most substantial in the *y* axis. For alare, the X-component was the most contributing for the total vector in all age and sex groups. For crista philtri, the displacement was mostly determined by the Z-component, except for the oldest age groups of both sexes, where the Y-component was more contributing (Table 2). Graphs depicting the absolute displacement and the ratio compared to the mouth width are provided for each landmark in Figure 4.

Movement of cheilion significantly decreased at older ages for men and women, even when corrected for the mouth width (Fig. 4A and D). The absolute distance in millimeters that the alare moved increased at older ages for men and women. When corrected for mouth width, this increase was only significant in men (Fig. 4B and E). Absolute displacement of crista philtri was not significant for both sexes, but when corrected for mouth width, a significant decrease at older ages was seen (Fig. 4C and F). Results of statistical analysis between age groups for each gender can be found in Tables 3 and 4.

Table 1. Baseline Characteristics

Age Group, y	Female (n)	Mean Age, y (SD)	Age Range, y	Male (n)	Mean Age, y (SD)	Age Range, y
4–8	13	6.4 (1.0)	4–7	17	6.2 (0.7)	5–7
8–12	60	9.5 (1.1)	8–11	58	9.5 (1.1)	8–11
12–16	17	12.8 (0.9)	12–15	22	12.9 (1.0)	12–15
>16	78	40.9 (14.0)	16–74	63	45.3 (10.4)	18–75

The number of inclusions per age group and average ages. N = 328.

Pouting

Landmark displacement results for the pouting faces for each sex and age group are presented in Table 5. The most contributing component for cheilion displacement was the Z-component in all age and sex groups. For alare and crista philtri, this was the Y-component in all age and sex groups (Table 5). Graphs depicting the absolute displacement and the ratio compared to the mouth width are provided for each landmark in Figure 5.

Movement of the cheilion significantly increased at older ages for both men and women, even when corrected

Table 2. Analysis Results for Smiling Faces

Smiling		Female 4–8 n = 13	Female 8–12 n = 60	Female 12–16 n = 17	Female > 16 n = 78	Male 4–8 n = 17	Male 8–12 n = 58	Male 12-16 n = 22	Male > 16 n = 63
Cheilion									
MM	Mean (95% CI)	9.90 (7.70–12.11)	10.66 (9.78–11.53)	8.21 (6.73–9.68)	9.27 (8.54–9.99)	10.48 (8.92–12.04)	11.82 (10.77–12.88)	10.14 (8.74–11.55)	9.42 (8.70–10.14)
Ratio		24.06 (18.40–29.72)	24.47 (22.23–26.72)	17.23 (13.83–20.64)	18.21 (16.65–19.76)	26.35 (22.09–30.61)	27.33 (24.53–30.12)	21.15 (18.13–24.18)	17.54 (16.05–19.03)
X		5.42 (3.93–6.91)	5.37 (4.79–5.95)	4.35 (3.44–5.26)	4.61 (4.17–5.06)	5.74 (4.76–6.72)	6.38 (5.72–7.05)	5.21 (4.25–6.18)	4.90 (4.29–5.50)
Y		4.23 (2.76–5.70)	4.98 (4.37–5.60)	3.43 (2.39–4.48)	4.64 (4.02–5.27)	4.75 (3.77–5.73)	5.33 (4.61–6.05)	5.03 (3.73–6.33)	5.72 (5.07–6.38)
Z		6.35 (4.69–8.02)	7.15 (6.45–7.84)	5.45 (4.16–6.73)	5.23 (4.48–5.99)	6.88 (5.58–8.18)	7.80 (7.02–8.58)	6.38 (5.45–7.30)	3.88 (3.12–4.64)
Alare									
MM	Mean (95% CI)	2.38 (1.91–2.85)	2.18 (1.98–2.39)	2.31 (1.82–2.80)	2.91 (2.56–3.27)	2.25 (1.83–2.67)	2.56 (2.28–2.85)	2.41 (1.87–2.94)	3.14 (2.84–3.44)
Ratio		5.74 (4.56–6.91)	4.97 (4.47–5.47)	4.73 (3.86–5.60)	5.65 (4.94–6.36)	5.50 (4.58–6.41)	5.82 (5.19–6.46)	5.03 (3.92–6.14)	7.12 (6.44–7.80)
X		0.89 (0.48–1.30)	1.10 (0.94–1.26)	1.04 (0.74–1.34)	1.13 (0.97–1.28)	1.05 (0.68–1.42)	1.31 (1.12–1.49)	1.03 (0.75–1.31)	1.39 (1.21–1.58)
Y		0.50 (−0.42 to 1.43)	0.65 (0.36–0.94)	−0.07 (−0.92 to 0.78)	−0.03 (−0.45 to 0.38)	0.84 (0.35–1.34)	0.52 (0.09–0.95)	0.67 (−0.10 to 1.45)	0.37 (−0.05 to 0.79)
Z		0.81 (0.15–1.46)	0.37 (0.10–0.65)	−0.24 (−0.81 to 0.33)	−0.84 (−1.30 to −0.38)	0.62 (0.01–1.23)	0.18 (−0.17 to 0.54)	0.28 (−0.16 to 0.72)	−1.21 (−1.68 to −0.75)
Crista philtri									
MM	Mean (95% CI)	4.49 (3.56–5.42)	4.10 (3.72–4.48)	3.24 (2.62–3.86)	3.91 (3.54–4.29)	4.45 (3.64–5.26)	4.50 (4.01–4.98)	3.83 (3.11–4.54)	3.93 (3.55–4.30)
Ratio		10.71 (8.59–12.84)	9.38 (8.43–10.32)	6.72 (5.43–8.01)	7.63 (6.87–8.39)	11.03 (9.06–13.01)	10.36 (9.16–11.55)	7.99 (6.45–9.53)	7.23 (6.54–7.91)
X		0.63 (0.38–0.88)	0.72 (0.61–0.84)	0.52 (0.35–0.70)	0.57 (0.49–0.66)	0.79 (0.53–1.06)	0.75 (0.63–0.86)	0.59 (0.37–0.80)	0.57 (0.46–0.68)
Y		1.09 (−0.63 to 2.81)	1.50 (1.11–1.88)	0.60 (−0.40 to 1.61)	1.51 (1.00–2.02)	1.82 (1.15–2.48)	1.49 (0.94–2.03)	1.48 (0.63–2.33)	1.72 (1.09–2.34)
Z		2.90 (1.83–3.98)	3.05 (2.60–3.49)	2.21 (1.55–2.87)	1.30 (0.69–1.91)	3.48 (2.54–4.41)	3.18 (2.60–3.76)	2.76 (2.08–3.43)	0.44 (-0.22–1.10)

Displacement of landmarks from neutral to smiling position as absolute displacement in millimeters (mm), as a ratio compared to the intercheilion distance, and as absolute displacement in three directions on the XYZ-coordinate system in mm. Results are expressed as means with 95% CIs.
CI, confidence interval.

Table 3. Statistical Analysis of Results for Absolute Landmark Displacement of Smiling Faces

Women	Cheilion	Alare	Crista Philtri	Men	Cheilion	Alare	Crista Philtri
ANOVA	0.0206*	0.0061*	0.1295	ANOVA	0.0019*	0.0027*	0.1728
Tukey's				Tukey's			
Female 4–8 versus Female 8–12	0.8764	0.9536	0.8414	Male 4–8 versus Male 8–12	0.4768	0.7338	0.9996
Female 4–8 versus Female 12–16	0.4991	0.9985	0.1305	Male 4–8 versus Male 12–16	0.9895	0.9711	0.6515
Female 4–8 versus Female > 16	0.9158	0.4805	0.5982	Male 4–8 versus Male > 16	0.6593	0.0205*	0.6549
Female 8–12 versus Female 12–16	0.0363*	0.9831	0.187	Male 8–12 versus Male 12–16	0.1971	0.9433	0.3741
Female 8–12 versus Female > 16	0.0687	0.0042*	0.8968	Male 8–12 versus Male > 16	0.0008*	0.0264*	0.2344
Female 12–16 versus Female > 16	0.6243	0.2654	0.3712	Male 12–16 versus Male > 16	0.8242	0.0435*	0.9952

Statistical analysis between age groups for both genders for the smiling faces. The ANOVA and the Tukey's post hoc test were performed.
*Statistically significant ($P < 0.05$).

Table 4. Statistical Analysis of Results for Landmark Displacement Ratios of Smiling Faces

Women	Cheilion	Alare	Crista Philtri	Men	Cheilion	Alare	Crista Philtri
ANOVA	<0.0001*	0.2971	0.0004*	ANOVA	<0.0001*	0.0015*	<0.0001*
Tukey's				Tukey's			
Female 4–8 versus Female 8–12	0.9981	0.7569	0.576	Male 4–8 versus Male 8–12	0.9738	0.9647	0.9102
Female 4–8 versus Female 12–16	0.0838	0.7064	0.0097*	Male 4–8 versus Male 12–16	0.2139	0.937	0.056
Female 4–8 versus Female > 16	0.061	0.9995	0.0157*	Male 4–8 versus Male > 16	0.0008*	0.0848	0.0013*
Female 8–12 versus Female 12–16	0.0047*	0.9865	0.0269*	Male 8–12 versus Male 12–16	0.0176*	0.5806	0.055
Female 8–12 versus Female > 16	<0.0001*	0.4042	0.0177*	Male 8–12 versus Male > 16	<0.0001*	0.0247*	<0.0001*
Female 12–16 versus Female > 16	0.966	0.5327	0.7529	Male 12–16 versus Male > 16	0.295	0.0049*	0.8392

Statistical analysis between age groups for both genders for the smiling faces. The ANOVA and the Tukey's post hoc test were performed.
*Statistically significant ($P < 0.05$).

Table 5. Analysis Results for Pouting Faces

Pouting		Female 4–8	Female 8–12	Female 12–16	Female > 16	Male 4–8	Male 8–12	Male 12–16	Male > 16
		n = 13	n = 60	n = 17	n = 78	n = 17	n = 58	n = 22	n = 63
Cheilion									
MM	Mean (95% CI)	9.88 (7.96–11.81)	10.95 (10.09 - 11.82)	11.76 (10.15–13.37)	16.63 (15.77–17.48)	10.66 (8.59–12.74)	10.47 (9.49–11.45)	11.38 (10.32–12.44)	17.78 (16.65–18.92)
Ratio		23.47 (19.18–27.75)	24.53 (22.85–26.21)	24.15 (21.26–27.04)	32.10 (30.61–33.60)	26.18 (21.61–30.76)	23.62 (21.53–25.70)	23.70 (21.48–25.91)	32.52 (30.75–34.28)
X		−6.46 (−7.91 to −5.01)	−5.06 (−5.70 to −4.42)	−4.86 (−6.01 to −3.70)	−7.49 (−8.12 to −6.86)	−5.08 (−6.41 to −3.75)	−4.75 (−5.45 to −4.06)	−4.89 (−5.88 to −.90)	−7.63 (−8.31 to −6.95)
Y		−0.29 (−1.46 to 0.88)	0.18 (−0.60 to 0.95)	0.17 (−1.41 to 1.74)	−0.46 (−1.06 to 0.15)	0.63 (−1.14 to 2.41)	0.53 (−0.19 to 1.24)	0.31 (−1.12 to 1.73)	0.11 (−0.58 to 0.81)
Z		−6.91 (−8.64 to −5.19)	−8.88 (−9.68 to −8.09)	−10.04 (−11.46 to −8.62)	−14.36 (−15.10 to −13.62)	−8.24 (−10.27 to −6.20)	−8.41 (−9.35 to −7.47)	−9.47 (−10.43 to −8.52)	−15.61 (−16.62 to −14.61)
Alare									
MM	Mean (95% CI)	2.57 (1.86–3.28)	2.05 (1.85–2.25)	1.75 (1.37–2.12)	2.20 (2.00–2.41)	2.07 (1.60–2.54)	2.08 (1.85–2.30)	1.79 (1.43–2.15)	3.01 (2.69–3.33)
Ratio		6.12 (4.47–7.76)	4.66 (4.17–5.15)	3.62 (2.86–4.37)	4.26 (3.88–4.64)	5.16 (4.00–6.32)	4.75 (4.21–5.30)	3.74 (3.00–4.48)	5.53 (4.98–6.09)
X		−0.28 (−0.68 to 0.12)	−0.25 (−0.43 to −0.08)	−0.04 (−0.35 to 0.28)	−0.63 (−0.77 to −0.48)	−0.27 (−0.53 to −0.02)	−0.32 (−0.48 to −0.16)	−0.35 (−0.62 to −0.08)	−0.70 (−0.90 to −0.50)
Y		1.10 (0.00–2.20)	0.59 (0.29–0.88)	0.77 (0.25–1.28)	0.84 (0.56–1.12)	0.83 (0.28–1.38)	0.56 (0.23–0.88)	0.70 (0.27–1.14)	1.04 (0.49–1.59)
Z		−0.39 (−1.33 to 0.55)	−0.37 (−0.69 to −0.04)	−0.36 (−0.85 to 0.12)	−0.93 (−1.15 to −0.71)	−0.69 (−1.32 to −0.05)	−0.40 (−0.73 to −0.07)	−0.27 (−0.70 to 0.16)	−1.08 (−1.35 to −0.81)
Crista philtri									
MM	Mean (95% CI)	6.58 (5.14–8.02)	7.77 (7.20–8.34)	7.54 (6.56–8.52)	9.64 (9.15–10.12)	8.09 (6.55–9.64)	8.11 (7.35–8.87)	8.02 (6.87–9.18)	11.40 (10.57–12.24)
Ratio		15.75 (12.39–19.11)	17.56 (16.29–18.82)	15.64 (13.59–17.69)	18.74 (17.75–19.73)	20.14 (16.24–24.03)	18.49 (16.70–20.29)	16.79 (14.24–19.35)	20.94 (19.51–22.28)
X		−1.78 (−2.10 to −1.46)	−1.62 (−1.79 to −1.46)	−1.56 (−1.71 to −1.40)	−2.40 (−2.55 to −2.26)	−1.67 (−2.03 to −1.31)	−1.69 (−1.83 to −1.55)	−1.86 (−2.18 to −1.54)	−2.61 (−2.79 to −2.43)
Y		4.85 (3.48–6.21)	5.37 (4.83–5.90)	4.76 (3.70–5.82)	5.21 (4.78–5.65)	5.94 (4.72–7.15)	5.84 (5.21–6.46)	5.57 (4.33–6.81)	5.74 (5.14–6.34)
Z		−3.54 (−4.72 to −2.37)	−4.75 (−5.34 to −4.17)	−5.24 (−6.07 to −4.42)	−7.33 (−7.86 to −6.80)	−4.75 (−6.08 to −3.42)	−4.71 (−5.42 to −3.99)	−4.79 (−5.74 to −3.84)	−9.10 (−9.90 to −8.29)

Displacement of landmarks from neutral to pouting position as absolute displacement in millimeters (mm), as a ratio compared to the intercheilion distance, and as absolute displacement in three directions on the XYZ-coordinate system in mm. Results are expressed as means with 95% CIs.
CI, confidence interval.

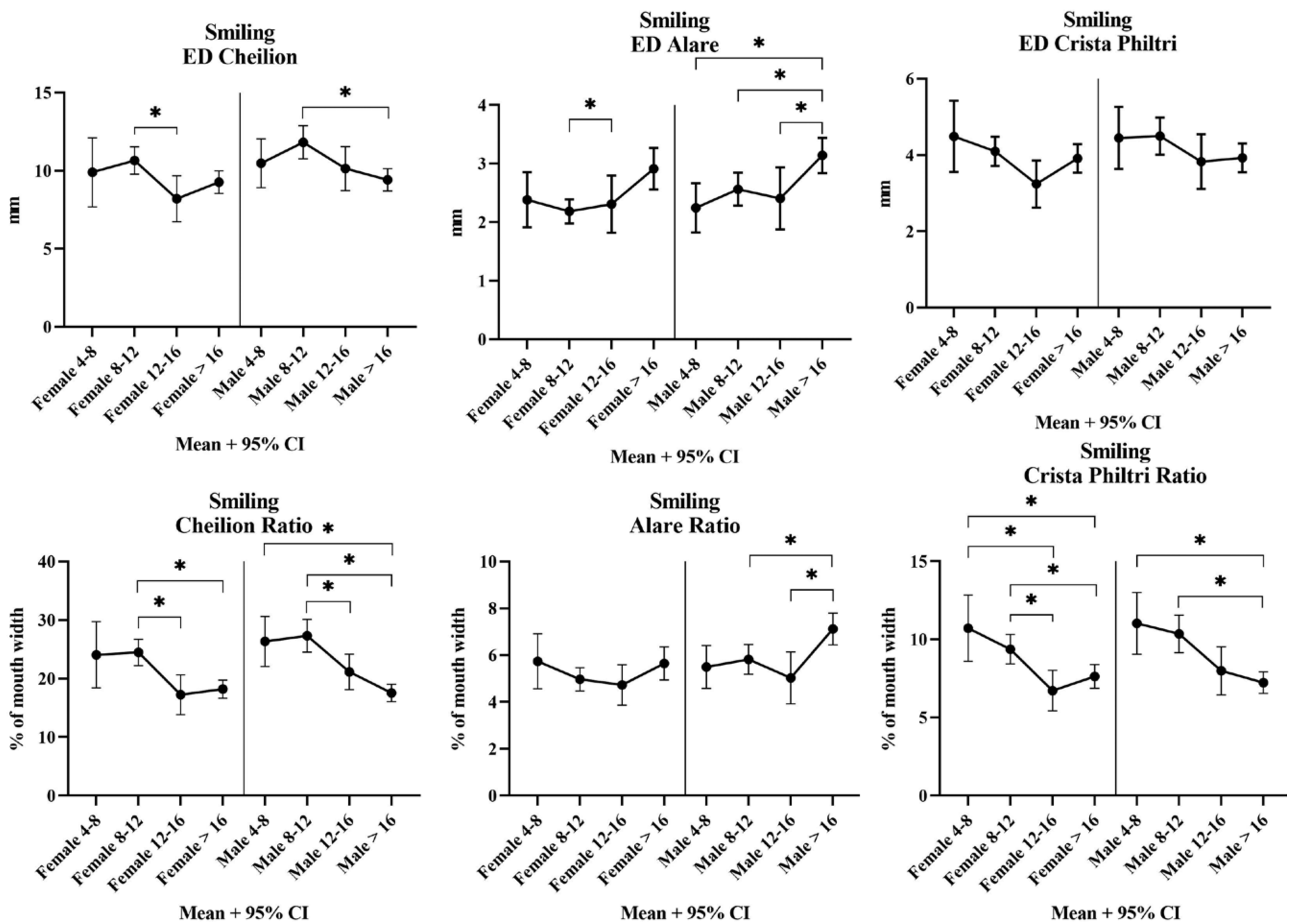

Fig. 4. Landmark displacement. A–C, EDs of displacement for cheilion, alare, and crista philtri for smiling faces. Absolute displacement in millimeters (mm), with 95% CIs for each sex and age group. D–F, Ratios of displacement for cheilion, alare, and crista philtri for smiling faces. Displacement as a percentage of the mouth width, with 95% CI for each sex and age group. CI, confidence interval; ED, Euclidean distance. *Statistically significant difference ($P < 0.05$).

Table 6. Statistical Analysis of Results for Absolute Landmark Displacement of Pouting Faces

Women	Cheilion	Alare	Crista Philtri	Men	Cheilion	Alare	Crista Philtri
ANOVA	<0.0001*	0.0547	<0.0001*	ANOVA	<0.0001*	<0.0001*	<0.0001*
Tukey's				Tukey's			
Female 4–8 versus Female 8–12	0.7546	0.2083	0.275	Male 4–8 versus Male 8–12	0.998	>0.9999	>0.9999
Female 4–8 versus Female 12–16	0.4762	0.053	0.6217	Male 4–8 versus Male 12–16	0.9424	0.8365	0.9999
Female 4–8 versus Female > 16	<0.0001*	0.5037	<0.0001*	Male 4–8 versus Male > 16	<0.0001*	0.0065*	0.0006*
Female 8–12 versus Female 12–16	0.8413	0.5834	0.9802	Male 8–12 versus Male 12–16	0.7914	0.6922	0.9995
Female 8–12 versus Female > 16	<0.0001*	0.7184	<0.0001*	Male 8–12 versus Male > 16	<0.0001*	<0.0001*	<0.0001*
Female 12–16 versus Female > 16	<0.0001*	0.2001	0.0021*	Male 12–16 versus Male > 16	<0.0001*	<0.0001*	<0.0001*

Statistical analysis between age groups for both genders for the pouting faces. The ANOVA and the Tukey's post hoc test were performed.
*Statistically significant ($P < 0.05$).

for mouth width (Fig. 5A and D). In women, absolute movement of the alare did not change significantly, but when corrected for mouth width, a significant decrease at older ages was seen. In men, significant age-related differences were seen in both the absolute movement and the ratio, with an increase in movement in the oldest age group (Fig. 5B and E). The movement of crista philtri showed a significant age-related increase in both genders (Fig. 5C and F). Results of statistical analysis between age groups for each gender can be found in Tables 6 and 7.

DISCUSSION

In the present study, the average vectors of movement of different facial landmarks were analyzed for different sex and age groups. For smiling faces, a decrease in movement was seen at older ages for the oral landmarks, whereas nasal landmarks showed an increase in movement. For pouting faces, the opposite was seen. Growing up resulted in an increase in oral landmark movement, whereas nasal landmark movement decreased. Oral landmarks predominantly moved forward and backward for

Table 7. Statistical Analysis of Results for Landmark Displacement Ratios of Pouting Faces

Women	Cheilion	Alare	Crista Philtri	Men	Cheilion	Alare	Crista Philtri
ANOVA	<0.0001*	0.0017*	0.0244*	ANOVA	<0.0001*	0.0059*	0.0346*
Tukey's				Tukey's			
Female 4–8 versus Female 8–12	0.9509	0.0497*	0.5792	Male 4–8 versus Male 8–12	0.5871	0.8929	0.7832
Female 4–8 versus Female 12–16	0.9918	0.0017*	>0.9999	Male 4–8 versus Male 12–16	0.7222	0.1558	0.3641
Female 4–8 versus Female > 16	0.0001*	0.0049*	0.1393	Male 4–8 versus Male > 16	0.0104*	0.9157	0.9668
Female 8–12 versus Female 12–16	0.9967	0.1677	0.4354	Male 8–12 versus Male 12–16	>0.9999	0.2184	0.7093
Female 8–12 versus Female > 16	<0.0001*	0.581	0.4446	Male 8–12 versus Male > 16	<0.0001*	0.1739	0.1507
Female 12–16 versus Female > 16	<0.0001*	0.56	0.0629	Male 12–16 versus Male > 16	<0.0001*	0.0038*	0.0448*

Statistical analysis between age groups for both genders for the pouting faces. The ANOVA and the Tukey's post hoc test were performed.
* Statistically significant ($P < 0.05$).

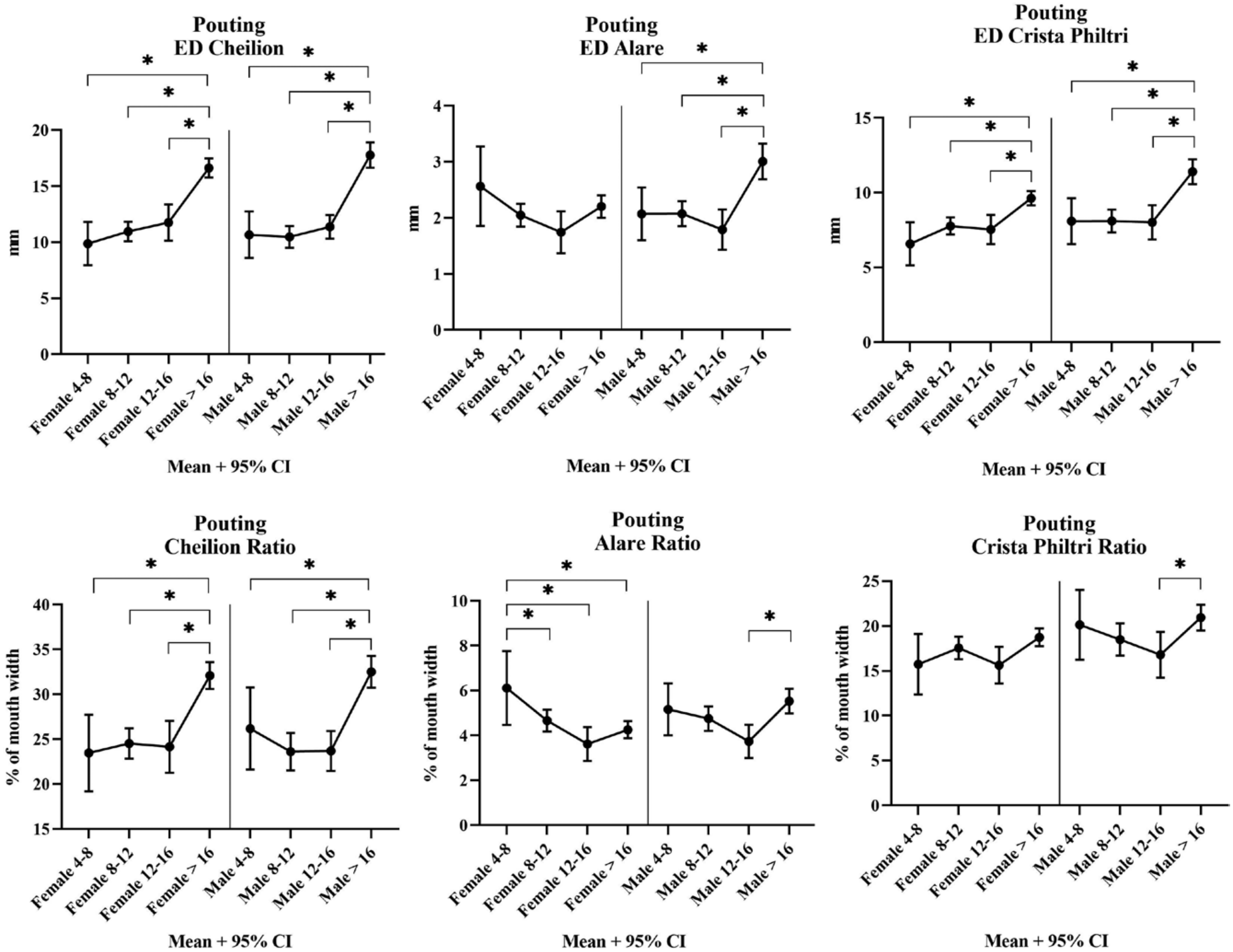

Fig. 5. Landmark displacement. A–C, EDs of displacement for cheilion, alare, and crista philtri for pouting faces. Absolute displacement in millimeters (mm), with 95% confidence intervals (95% CIs) for each sex and age group. D–F, Ratios of displacement for cheilion, alare, and crista philtri for pouting faces. Displacement as a percentage of the mouth width, with 95% CI for each sex and age group. CI, confidence interval; ED, Euclidean distance. *Statistically significant difference ($P < 0.05$).

both exercises, except the crista philtri when pouting, which moved mostly vertically. Nasal landmarks predominantly moved vertically. This implies that what we see in frontal view as horizontal widening of the oral commissure, predominantly is dorsal retraction.

A possible explanation for the increase of movement in oral landmarks with growing up for pouting might be the facial shape of young children. In young children, with voluminous cheeks, the neutral face already shows a bit of pouting. Therefore, the displacement from neutral to pouting might be less substantial. This could also explain the decrease in movement with growing up for smiling, which was more significant when corrected for mouth width. Another explanation for the difference with the older ages is the wide age range within this group since all subjects above the age of 16 years were combined. Therefore, the age group older than 16 years also included older subjects. Our assumption is that movement changes with aging, due to sagging of the skin.[32] From this point of view, it would be interesting to see if individuals that had face lifting procedures would express more animation than peers.

Several studies examined facial dynamics and the influence of sex and age. However, a comparison between these studies and the current study is difficult to draw. Dissimilarities with those studies include that some were 2D,[23,24] some only examined subjects older than 20 years,[26–31] and none of them provided vectors of movement.[23–31] Only in two studies, the same expressions as in the current study were researched: the closed smile and pouting.[23,31] All other studies examined different facial exercises.[24–30] To the best of our knowledge, the present study is the first to provide reference standards of landmark displacement in three directions for facial exercises for different young age groups.

For facial paralysis, a variety of scoring systems have been proposed to evaluate facial regions and facial expressions. However, all of them have some limitations.[33] For example, the widely used House-Brackman scale (HBS) lacks validity because of its subjective nature.[34] Or the Burres-Fisch Scale, which was developed as an objective competitor to the HBS but analyzes only the static face on 2D photographs.[35] Certain automated computer systems have been developed.[36–38] Computer-based facial motion analysis is potentially the optimal modality to quantitatively assess facial function. It could allow for a fully objective, reproducible, and standardized scale, without bias and human error. However, these systems make 2D measurements, and amplitude of movement measured in 2D is underestimated by up to 43%.[39] The Facial Reanimation Measurement System proposed by Tomat and Manktelow[40] attempts to provide a 3D scoring system, by photographing patients from different angles. Yet, they still used 2D photographs for analysis. Most importantly, the disadvantage in all of these scoring systems is that they are lacking data on younger participants. Also, because no ratios of measurements are provided, it is difficult to have an individualized reference, which is regardless of the size and shape of the head.

There is a divergence between the type of facial expressions of the current study and previous studies.[34–38,40] The current study uses the closed smile and pouting position as referential facial expressions. The maximum closed smile and pouting position were chosen, because these are two extreme positions of the mouth. Since the main objective of this study was to provide reference material, two extreme positions of the mouth would serve well. This selection was also based on the reproducibility of these expressions. Several studies concluded that the maximum closed smile (posed smile), and pouting are the most reproducible facial exercises.[41–43] Consequently, the open maximum smile, although it often has a wider range of motion, was not used in the present study.

Strengths of the present study include the correction for size of the mouth. Since the extent of movement can be influenced by the size of the mouth,[31] the current study investigated the movement as an absolute displacement, as well as a ratio of the intercheilion distance. Another strength is the use of 3D photography. The fact that oral landmarks predominantly move forward and backward has not been pointed out before. This might be due to the fact that previous studies were often in 2D, therefore only examining horizontal and vertical movement.[23–25] Additionally, 3D imaging has proven to be more reliable than 2D imaging.[39] This underlines the importance of using 3D imaging in examining facial animation.

A limitation of this study is the unbalanced age distribution of inclusions. No subject selection took place in this study, to avoid bias. Therefore, the study population should accurately depict the heterogeneous make-up of Dutch inhabitants. The downside of this was that the male group 16–20 years of age, for instance, consisted of only one subject. It was, therefore, decided to combine all subjects older than 16 years of age into one group. Future research could aim to include more subjects in groups with a smaller age range, especially for the group older than 16 years. This might provide more insight into the age-dependent changes, which were found in the present study.

To improve the outcome of facial animation after facial surgery, surgeons should not only be aware of reference standards for normal facial dynamics. Also, detailed anatomical knowledge is ubiquitous, and might be obtained from anatomical atlases.[44] A focus for future research could be the correlation between the anatomy of facial musculature and facial dynamics. A study by Zabojova et al[45] researched the lengths and vectors of mimic muscles of the upper lip in cadavers and compared them to the dynamics of the smile. Since their study results were in 2D, it is difficult to compare these results with the vectors of the current study. Also, since variability exists, it would be of great interest to research the correlation between facial muscle anatomy and facial movement in the same individual. With those data, surgery can be personalized, precisely changing the location of facial muscles to improve the outcome of facial dynamics.

The present study introduces a new method of analyzing facial animation. It creates reference values for movement of the perioral structures for different sex and age groups, for two facial expressions. Values of absolute displacement, relative displacement, and direction in three planes were researched. These data are of great value in the assessment of mimic impairment, planning and evaluation of facial surgery, and giving an insight into the development of facial animation in children.

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