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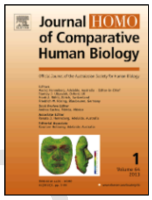

Sexual dimorphism in human facial expressions by 3D surface processing

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ABSTRACT

Human face is a dynamic system where facial expressions can rapidly modify geometry of facial features. Facial expressions are believed to be universal across world populations, but only a few studies have explored whether grimacing is sexually dimorphic and if so to what extent. The present paper explores inter- and intra-individual variation of human facial expressions with respect to individual's sex based on a set of neutral and expression-varying 3D facial scans. The study sample composed of 20 individuals (10 males and 10 females) for whom 120 scans featuring grimaces associated with disgust, surprise, "u" sound, smile and wide smile were collected by an optical scanner Vectra XT. In order to quantify the dissimilarity among 3D images, surface comparison approach based on aligned 3D meshes and closest point-to-point distances was carried out in Fidentis Analyst application.

The study revealed that sexual dimorphism was indeed one of the factors which determined the extent and characteristics of facial deformations recorded for the studied expressions. In order to produce a grimace, males showed a tendency towards extending their facial movements while females were generally more restrained. Furthermore, the facial movements linked to the wide smile and "u" sound were revealed as the most extensive relative to the other expressions, while the smile and surprise were shown indistinguishable from the neutral face.

Introduction

Human face represents a highly complex conveyor of information about individual's sex, age, state of health or emotions (Alley, 2013). These characteristics encoded in external facial features, such as size, shape or colour permit conducting various practical tasks including personal identification and group classification (De Angelis et al., 2009; Urbanová, 2016; Wilkinson and Rynn, 2012; Woodward et al., 2003), face perception (Bruce and Young, 2012), sexual mate choice (Fink et al., 2007; Windhager et al., 2011), clinical diagnostics (Kau et al., 2007) or growth and development assessment (Bulygina et al., 2006; Kau and Richmond, 2008; Scherbaum et al., 2007).

For the majority of these practical applications face processing requires that the face be in the standard anatomical position bearing neutral or quasi-neutral facial expressions. However, face is prone to voluntary as well as involuntary grimacing, i.e. facial movements produced by the contraction of facial muscles. This results in temporary deformations of facial features and leads to the formation of a facial expression (Ekman and Friesen, 1978). In humans, facial expressions are believed to be universally displayed across world populations (Cole et al., 1989; Darwin, 1872; Eckman, 1972,) and as postulated by Ekman and Friesen (1971) linked to six primary emotions – happiness, surprise, fear, sadness, anger and disgust.

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The ability to form a facial expression is an important aspect of human non-verbal communication. However, facial movements alter geometry of key facial features to a degree which, sometimes, interferes with simple descriptive tasks and facial processing (Bruce, 1982; Bruce and Young, 2012; Wilkinson and Rynn, 2012). In practical applications, such as recognition or identification tasks, the presence of facial expressions introduces inconvenient noise into biological data, which has a negative impact on accuracy rates (Drira et al., 2013; Faltemier et al., 2007; Mian et al., 2005; Russ et al., 2006; Samir et al., 2006; Smeets et al., 2012; Wang et al., 2007).

Traditionally, changes in facial appearance are described by the aforementioned approach grounded in primary emotions. Alternatively, facial action coding system (FACS) by Ekman and Friesen (1978) has been widely employed. FACS represents a classification system where facial expressions are decomposed into anatomically relevant components of facial movements. Like facial appearance in the neutral relaxed state, facial expressions are also known to be highly variable. Focusing on expressions associated with the smile, Holberg et al. (2006) revealed that the inter-landmark distances between neutral and smiling faces in the same individual reached up to 10%, as opposed to the among-person variability, which accounted for up to 60%.

Yet, limited knowledge has been gathered on sexual dimorphism in facial expressions. Although sex-related differences in facial morphology and their developmental and age dependency is a vastly researched topic (Bishara et al., 1998; Enlow and Hans, 1996) relations between quality and quantity of facial movements and individual's sex have been scarcely explored. For instance, sex-related differences in facial movements were shown by Weeden et al. (2001) who reported that grimacing in males was more extensive than that in females, whereas Sforza et al. (2010a, 2010b) revealed no or limited sex-related differences. Also, as a prerequisite to sex-related specificity in facial motions, soft tissue, muscle tissue included, is reportedly thicker in males almost across the entire face, particularly in the superciliary region, as opposed to females, who exhibit thicker cheek-composing layers (Volk et al., 2014; Wilkinson, 2004). Similarly, McAlister et al. (1998) made a notable observation that the zygomaticus major muscle was thicker in females despite contradictory reports by Şatıroğlu et al. (2005) who noted no such differences. Furthermore, Sforza et al. (2010a) hinted at sexual dimorphism in the displacement of the landmarks located at the superciliary region. Ultimately, Sidequersky et al. (2016) observed that males exhibited tendencies to extend their facial movements, although the presence of sex-related differences in basic facial expressions was not supported by the processed data.

In the last decade, the state-of-the-art of facial processing started relying on enhanced acquisition technologies, such as 3D optical scanning and automated 3D image processing. These technologies maximise the amount and complexity of processed data, particularly by the inclusion of depth information (Gupta et al., 2007; Li, 2013; Sandbach et al., 2012; Tsalakanidou and Malassiotis, 2010). As a result, they rapidly became a welcome extension to the traditional methods having relied to that point primarily on conventional 2D photography and/or real-time visual assessment (Fetter, 1967; Halberstein, 2001; Hulanicka, 1973; Kleinberg et al., 2007; Porter and Doran, 2000; Urbanová et al., 2010). Moreover, a number of novelties have allowed taking into account time as the fourth dimension. These dynamic 3D motion devices allow tracking 3D motions or capturing 4D recordings (Al-Anezi et al., 2013; Sandbach et al., 2012; Vandeventer et al., 2015). In addition to expensive devices such as 3DMD systems, low-cost options based on 3D sensors, such as Kinect sensors, have been shown applicable to record facial dynamics (Li et al., 2013).

The present paper aims to explore morphological variations within a sample of static 3D facial models bearing a variety of facial expressions and to exploit the degree of facial grimacing relative to individual's sex by employing a complex mesh-based digital data processing.

Materials and methods

Data acquisition

The studied set of 120 3D facial models was retrieved from The FIDENTIS 3D Face Database (www.fidentis.cz). Twenty volunteers (10 males and 10 females) of Czech and Slovak nationality aged between 20 and 32 years (average age of 22.6) were recorded six times each in order to collect a set of facial expressions: a neutral face and five pre-determined facial expressions – disgust, surprise, "u" sound, smile and wide smile (Table 1; Fig. 1). Face geometry in terms of textured surface shell meshes was recorded by Vectra XT, a half-body imaging stereophotogrammetry-based optical system. Prior to recording, the hair covering the forehead and earlobes was adjusted and all accessories, e.g. earrings and glasses were removed. To record a facial expression each participant was presented with a pictogram, and asked to produce the depicted expression. As a foundation for describing facial expressions, facial action coding system (FACS) as developed by Ekman and Friesen (1978) was considered. In all cases, digital images were captured by a lab assistant upon an agreed signal. Prior to recording all participants were given a brief explanation regarding the scanning principles, the purpose of the study and instructions on which expressions would be recorded. No additional coaching or prior training of facial expressions was conducted. The expressions were recorded only once, as the subject of interest was the variation in the extent of facial deformation and sexual dimorphism. Thus, within subject repeatability was not assessed. Data acquisition and pre-processing were conducted by one operator.

Pre-processing

3D images were processed in Mirror® Medical Imaging Software (http://www.canfieldsci.com), where they were manually trimmed of unwanted background and technically unsuitable parts. The edited models were then adjusted to the origin of the Carte-

Table 1
Definition of studied expressions, adapted from Ekman and Friesen (1978).

Expression	Definition	Main muscles used
Neutral face	Neutral face with opened eyes	–
Disgust	Nose wrinkling, upper lip raised	*m. levator labii superioris alaequae nasi, m. depressor anguli oris, m. depressor labii inferioris*
Surprise	Eyebrows raised, eyes widened, mouth opened	*m. frontalis – pars medialis* and *lateralis, m. levator palpebrae superioris, m. masseter*, relaxed *m. temporalis* and *m. pterygoideus medialis*
Vowel "u"	Volunteer was scanned while saying vowel "u"	*m. orbicularis oris*
Smile	Lip corners tightened and raised, pushed up cheeks	*m. zygomaticus major, m. orbicularis oculi – pars orbitalis*
Wide smile	Lip corners raised, pushed up cheeks, mouth opened with visible teeth	*m. zygomaticus major, m. orbicularis oculi – pars orbitalis*

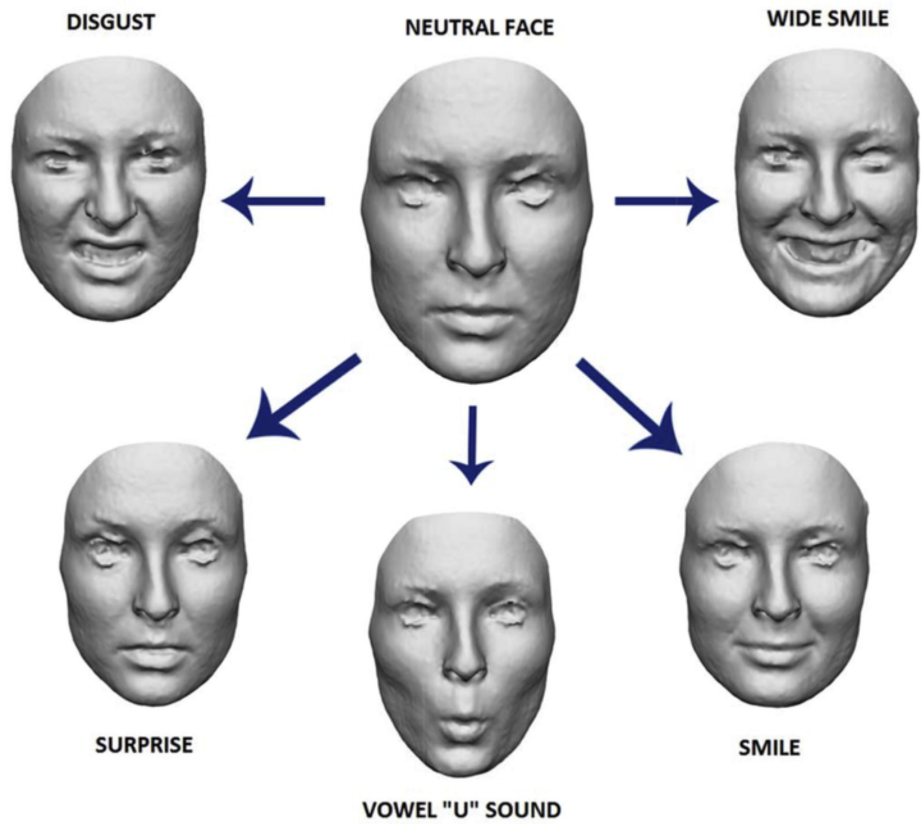

Fig. 1. Visualisation of studied expressions according to the definition (Table 1).

sian coordinates system defined by the landmark pronasale. The horizontal and vertical planes corresponding to the Frankfurt horizontal and mid-sagittal body planes respectively were further determined by five landmarks defined according to Fetter (1967) and Farkas (1994): left/right tragion; left/right endocanthion and left palpebra inferior. The adjustment was conducted in MeshLab 1.3.2 (Cignoni et al., 2008).

The meshes were further edited in GOM Inspect program, where unequal and non-corresponding parts (ears, neck) were removed and holes were filled. In concordance with our previous studies (Chalás et al., 2017; Jandová et al., 2015; Urbanová, 2016), the number of vertex points per mesh was reduced to 10,000. This allowed us to ease computational requirements at a minimum loss of the facial geometry. Although the texture was originally recorded, the colour information was further disregarded.

Surface mesh comparison

The edited meshes were processed using FIDENTIS Analyst 1.32 (Chalás et al., 2014). In order to compare 3D meshes the program uses the iterative closest point (ICP) (Besl and McKay, 1992) as an alignment technique and absolute closest point-to-point distances as a measure of dissimilarity. The ICP algorithm was set as follows: error rate of 0.05, maximum iterations of 10 and the number of average meshes of 3. For the purpose of the study two dissimilarity metrics – root mean square (RMS) and 75th percentile (PERC75) were computed from closest point-to-point distances and subsequently used as a univariate metric for quantifying mesh-to-mesh variation.

Two types of mesh processing were conducted. Focusing on intra-individual variation, the “one to all” processing mode incorporated in FIDENTIS Analyst software was used to compare the neutral expression against the array of expression-varying faces. This was conducted for each individual separately and the values of dissimilarity metrics (RMS, PERC75) quantified the amount of deformation in facial geometry between the neutral and the expression-varying face, i.e. intra-individual variation. In order to standardise 3D scans, the neutral face was taken as a reference on which the expression-varying meshes were fitted. For intra-individual variation, no scale adjustment was set, thus male and female faces were not standardised by size.

In order to determine the within-sample variation, i.e. to quantify both among-person variation in facial geometry and the expression-induced deformation, the dataset of 120 scans composed of neutral and expression-varying faces was processed by a multiple mesh comparison. For that purpose, a modified ICP algorithm was employed. The total set of meshes was firstly aligned to an average face derived from the input set and then continuously re-computed as the alignment progressed. In the process of aligning the faces, scale function was enabled in order to produce size-invariant results. As a result, male and female faces were standardised by size.

Results were visualised and interpreted by means of group-specific average faces derived from the tested datasets. Local variations were further highlighted by surface superimposition, intersection contours, fog simulations and cross cuts as described by Furmanová (2015). All functionalities are incorporated in FIDENTIS Analyst software.

Statistical analysis

Focusing on intra-individual variation, the values of RMS and PERC75 obtained by using “one to all” processing mode were firstly subjected to descriptive statistics. Further, Kruskal-Wallis’s test was employed in order to test differences in the extent of facial deformation among studied expressions. The null hypothesis was that the extent of facial deformation did not differ significantly among grimaces. Additionally, Mann-Whitney’s *U* test was carried out to test the presence of sexual dimorphism in the extent of facial deformation with the null hypothesis that the observed differences in the extent of facial deformation were accidental. The alternative hypotheses were expected for both tests.

For the within-sample variation, the outputs in form of distance matrices (RMS- and PERC75-based) were tested for inter-individual variations, sex-related and expression-specific facial deformations by means of one-way and two-way non-parametric multivariate analyses of variance (PERMANOVA). Firstly, two-way PERMANOVA was carried out to test whether the observed differences in distance matrices were expression-related and sex-related and if there was any interaction between these factors. Secondly, sex and an individual were used as tested factors. The null hypothesis considered no relationship of used factors to the values of observed differences in distance matrices and no interaction between these factors. However, alternative hypotheses were expected to be confirmed. To clarify the differences among expressions, one-way PERMANOVA was applied, post hoc tests included. The null hypothesis assumed that observed differences among the different expressions were accidental. A rejection of the null hypothesis was expected. In addition, one-way analysis of similarity (ANOSIM) was used to test size-invariant differences between sexes. The null hypothesis assumed no sex-related differences. Again, a rejection of the null hypothesis was expected.

All tests were computed in program Past 3 (Hammer et al., 2001) with the number of permutations set to 9999 rounds. If not stated otherwise, an alpha level of 0.05 was used as the cut-off for significance.

Results

Intra-individual variations

Descriptive statistics for both used dissimilarity metrics showed that the lowest values of distances between a grimace and a neutral face were acquired for smiling faces, followed by the surprise and “u” sound while the disgust and wide smile produced the greatest deviations from the neutral face (Table 2). According to the values of standard deviations, the surprise and disgust were the most variable of the studied expressions, whereas the smile was the least varying one (Table 2).

The Kruskal-Wallis’s test showed, that the extent of facial deformation differed significantly among grimaces (PERC75: $F = 37.69$, p-value = 0.00 and RMS: $U = 32.91$, p-value = 0.00). Post-hoc tests confirmed that the expressions of surprise were the least different from the neutral faces, whereas for the disgust (PERC75: p-value = 0.01 and RMS: p-value = 0.00) and “u” sound (PERC75: p-value = 0.01 and RMS: p-value = 0.05) the degree of facial change was significantly greater than that in smiling faces. In addition, the expressions associated with wide smiles were shown to differ significantly from all remaining expressions (p-

Table 2
Descriptive statistics illustrating the magnitude of intra-individual variance for the studied facial expressions.

Expression	RMS			PERC75		
	Mean	Median	SD	Mean	Median	SD
Disgust	2.07	2.06	0.57	2.18	2.20	0.49
Surprise	1.91	1.68	0.69	1.93	1.81	0.55
Vowel “u”	2.05	1.97	0.42	1.94	1.90	0.31
Smile	1.69	1.60	0.32	1.75	1.70	0.25
Wide smile	2.61	2.64	0.41	2.63	2.64	0.43

RMS – root mean square; PERC75 – 75th percentile; SD – standard deviation.

value = 0.00). These results were valid for both dissimilarity metrics (Table 3) and visually were noticeable in the cheek and mouth regions (Fig. 2).

When grouped according to sex, distances from the neutral face tend to be larger for males across studied expressions as was shown by descriptive statistics (Table 4). When tested by Mann-Whitney’s *U* test the dataset revealed statistically significant differences between males and females for expressions associated with the surprise (PERC75: p-value = 0.08 and RMS: p-value = 0.05), “u” sound (PERC75: p-value = 0.10 and RMS: p-value = 0.10) and smile (PERC75: p-value = 0.03 and RMS: p-value = 0.16; not significant) if alpha level of 0.10 or less was considered. Local variations demonstrated by surface superimposition and cross cuts of average models (Fig. 3) show that for both sexes a large portion of the facial deformations was located at the cheeks. In addition, facial movements localised in the nasal regions were uncovered; particularly in the widely smiling (Figs. 2, 3) and disgust depicting faces (Fig. 3). In males the major deformations linked to the surprise were located in the mouth, chin, eyebrow regions, forehead and nose as opposed to females where the variation was associated mostly with the mouth and only moderately with the eyebrows. For the “u” sound expression, males exhibited the major variations in the cheeks, mouth region, medial part of eyebrows and nose, while in females only the mouth region and cheeks were affected. Similarly, for the smile males exhibited noticeable deformations located at

Table 3
Results of Mann-Whitney’s *U* test testing differences in the degree of expression-related facial deformation. P-values based on testing PERC75 values are stated below diagonal, while RMS-based p-values are above the diagonal. The asterisk indicates significant difference at 5% level.

Expressions	Disgust	Surprise	Vowel “u”	Smile	Wide smile
Disgust	–	*0.05	0.11	*0.00	*0.00
Surprise	0.13	–	0.51	0.64	*0.00
Vowel “u”	0.74	0.10	–	*0.05	*0.00
Smile	*0.01	0.45	*0.01	–	*0.00
Wide smile	*0.00	*0.00	*0.00	*0.00	–

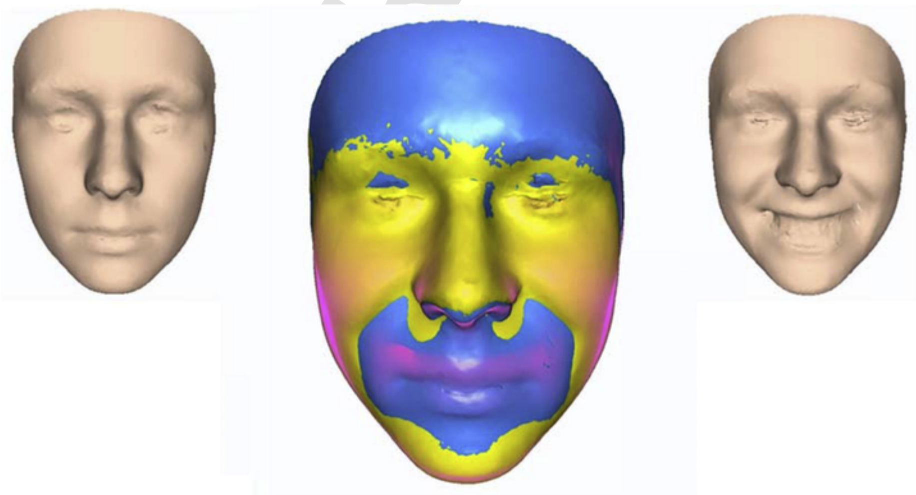

Fig. 2. Differences between the average neutral (right, blue colour or dark) and widely smiling face (left, yellow colour or light). Superimposed facial geometry is accompanied by fog-simulations (pink colour, or additional shade on cheeks and upper lip) that emphasise the regions of dissimilarity (see on-line colour version). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 4
Descriptive statistics illustrating the sex-specific magnitude of intra-individual variance. The asterisk (*) indicates significant differences between males and females at 5% level, ** marks differences at 10% level as revealed by Mann-Whitney's *U* test.

Expression	Descriptor	Male (N = 10)		Female (N = 10)	
		RMS	PERC75	RMS	PERC75
Disgust	Mean	2.24	2.31	1.90	2.04
	Median	2.06	2.24	1.90	1.97
	SD	0.64	0.51	0.46	0.45
Surprise	Mean	2.23	2.19	1.59	1.67
	Median	2.02**	2.06**	1.49	1.57
	SD	0.83	0.64	0.31	0.27
Vowel "u"	Mean	2.23	2.06	1.87	1.82
	Median	2.26**	2.09**	1.83	1.74
	SD	0.46	0.36	0.31	0.20
Smile	Mean	1.84	1.83	1.54	1.67
	Median	1.78*	1.74	1.54	1.64
	SD	0.34	0.23	0.22	0.25
Wide smile	Mean	2.74	2.74	2.48	2.52
	Median	2.76	2.70	2.48	2.53
	SD	0.37	0.46	0.43	0.38

RMS – root mean square; PERC75 – 75th percentile; SD – standard deviation.

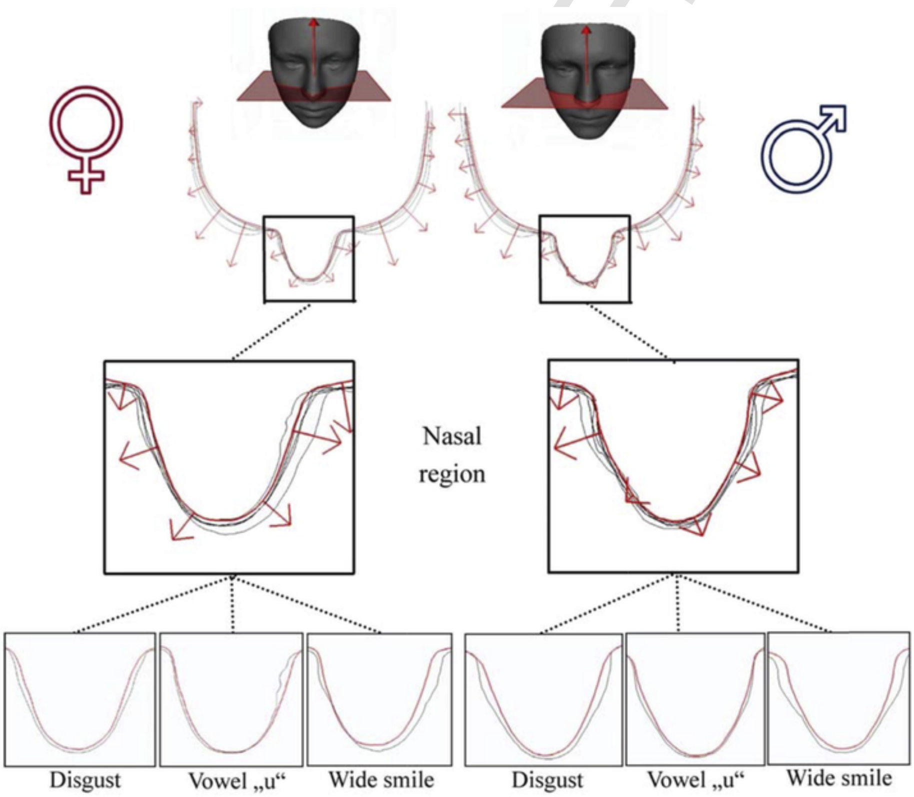

Fig. 3. Cross cuts demonstrating facial deformations from the average neutral face (red line with arrows pointing out) and an array of average expression-related faces (black lines), displayed separately for females and males (see the coloured version on-line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the mouth corners, lower parts of the cheeks, chin, medial part of the eyebrows and nose, while in females only movements of the corners of the mouth and cheeks were noticeable (Fig. 4).

Within-sample variation

The two-way PERMANOVA with sex and expression set as factors confirmed the sex-related and expression-related variations in both tested metrics. Yet, no interactions between factors were revealed (Table 5). Once sex and an individual were set as factors, variations were shown for both separately, but again, no statistically significant interactions between factors were revealed (Table 6).

Similarly, one-way PERMANOVA revealed statistically significant differences among expressions (PERC75: F = 4.7, p-value = 0.0001 and RMS: F = 3.9, p-value = 0.0001), where post hoc tests specified that the faces recorded for the wide smile and "u" sound varied distinctively from the remaining expressions, neutral faces included, and these results were valid for both measures of dissimilarity (Table 5). Similarly, the disgust depicting faces differed from the neutral faces while no significant differences were revealed between the neutral and surprise or smile varying faces. Also, expressions associated with the disgust were not distinguishable from the faces associated with the surprise (RMS) and smile (PERC75, RMS) (Table 7). Separately for each sex the statistically significant results were reported only for the wide smile.

The one-way ANOSIM employed in order to test differences between sexes revealed significant results, where males exhibited larger variations in grimacing than females (PERC75: R = 0.16, p-value = 0.0001; RMS: R = 0.11, p-value = 0.0001). The same results were obtained when the tested matrix was restricted to the neutral faces only. In addition to quantitative differences, sexes also differed in quality of responses. Fig. 5 shows that in neutral faces the largest amount of observed inter-individual variations in males was located in the shape of the nose. This observation persisted in all expression-varying faces. Additional variation was showed in the infraorbital orbital region in the disgust, surprise and both smile expressions; in the mouth in all expressions (except wide smile); and in the inner eyebrow and inner eye corner region in the disgust and surprise expressions.

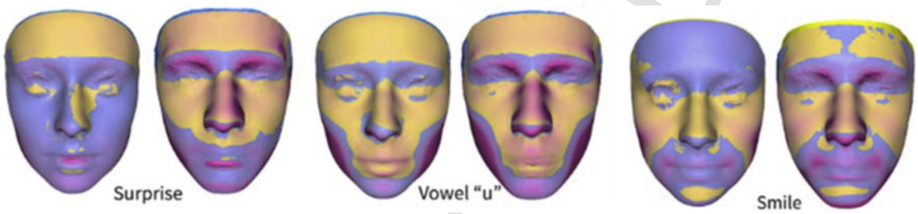

Fig. 4. Superimposition displaying differences (see on-line colour version) between the average neutral (blue colour) and expression-varying faces (yellow colour) for females (left) and males (right). The pink coloured fog simulations represent the regions with major dissimilarities. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 5
Results of a two-way PERMANOVA with sex and expressions set as factors.

	PERC75					RMS				
Source	SS	df	MS	F	p	SS	df	MS	F	p
Sex	91.66	1	91.66	12.57	0.00	76.25	1	76.25	10.09	0.00
Expressions	181.21	5	36.24	4.97	0.00	154.22	5	30.85	4.08	0.00
Interaction	5.79	5	1.16	0.16	1.00	8.51	5	1.70	0.23	1.00
Residual	787.57	108	7.30			816.34	108	7.56		
Total	1066.20	119				1055.30	119			

PERC75 – 75th percentile; RMS – root mean square; SS – sum of squares; MS – mean sum of squares.

Table 6
Results of a two-way PERMANOVA with sex and individuals set as factors.

	PERC75					RMS				
Source	SS	df	MS	F	p	SS	df	MS	F	p
Sex	91.66	1	91.66	12.00	0.00	76.25	1	76.25	9.49	0.00
ID	760.64	19	40.03	5.24	0.00	733.83	19	38.62	4.81	0.00
Interaction	−397.25	19	−20.91	−2.74	1.00	−397.75	19	−20.93	−2.60	1.00
Residual	611.18	80	7.64			643.01	80	8.04		
Total	1066.20	119				1055.30	119			

PERC75 – 75th percentile; RMS – root mean square; SS – sum of squares; MS – mean sum of squares.

Table 7
P-values of a one-way PERMANOVA testing expression-related differences. P-values based on testing PERC75 values are stated below the diagonal, while RMS-based p-values are above the diagonal. The asterisk(*) indicates significant difference at 5% level.

Expressions	Disgust	Surprise	Vowel "u"	Smile	Wide smile	Neutral
Disgust	–	0.14	*0.00	0.23	*0.00	*0.03
Surprise	*0.04	–	*0.01	*0.06	*0.00	0.12
Vowel "u"	*0.00	*0.01	–	*0.00	*0.00	*0.04
Smile	0.14	*0.02	*0.00	–	*0.00	0.27
Wide smile	*0.00	*0.00	*0.00	*0.00	–	*0.00
Neutral	*0.02	0.12	*0.02	0.11	*0.00	–

Conversely, in females, among-person differences were associated primarily with the shape of the chin and again, this observation was consistent with all expressions (Fig. 5). Additional variation was observed in the mouth region for the "u" sound and disgust and in the infraorbital region for the disgust.

Discussion

Human face is a dynamic system where a number of facial features can change significantly over a short time. Hence, the presence of facial expressions in records of facial morphology is, sometimes, viewed as a "noise", which can negatively affect subsequent biological data processing. Recently, significant effort has been given to the research dealing with expression-related changes in facial morphology, either in seeking a proper manner to eliminate the effect of facial movements (Al-Osaimi et al., 2008; Bronstein et al., 2007; Russ et al., 2006; Smeets et al., 2012) or as a way to conduct facial expression recognition (Mishra et al., 2015; Sandbach et al., 2012; Tian et al., 2005; Tsalakanidou and Malassiotis, 2010) or to assess the reproducibility or variability of selected verbal and non-verbal facial movements (Popat et al., 2008, 2010, 2012; Sidequersky et al., 2016). However, to date, the primary focus of methods based on 3D surface processing has been on facial expressions at an individual level, with limited regards to group-specific characteristics, particularly to sexual dimorphism (Gibelli et al., 2017). The present study explored individual and among-person differences in six different facial expressions with the main interest to specify sex-related differences. It should be emphasised that in all cases the recorded individuals were asked to replicate the expressions according to a simplified chart. Therefore, all facial movements were voluntary and not conveying individuals' emotional state. This was meant to bring a certain degree of consistency into the collected data. In real world situations, however, it is to be expected that larger variance, particularly for facial movements associated with emotions, would be recorded.

When intra-individual variation was considered, our results showed that in two out of five studied expressions; specifically the smile and surprise, the geometry of the expression-varying face could not be distinguished from the geometry of the neutral face. This is in contradiction with the study by Gibelli et al. (2017) who found happy and surprise expressions as the most different from the neutral face in males. For the smiling faces, the extent of recorded facial deformation was shown to be relatively consistent across the studied sample of this study. Therefore, it appears that the used 3D approach simply was not sensitive enough to describe the subtle morphological changes. Conversely, the surprise-related grimacing varied largely among studied individuals and although the distances between neutral and grimacing faces were, on average, lower relative to the remaining expressions. Thus, the variable responses of the studied individuals to the requested expression are a likely explanation for the obtained results. The acquired results were also confirmed by the among-person analysis, which combined the induced facial deformation with the underlying inter-individual differences recorded for the facial features.

As expected, the wide smile and "u" sound were both among the expressions which required the most extensive facial movements. These results are in concordance with Wang et al. (2006) who similarly identified the wide smile as the expression producing distinctive facial deformations. In addition, the disgust-varying faces revealed statistically significant results if tested against expression-free faces. Combining the expression-present faces with the among-person morphological differences, the analysis showed that the disgust-depicting faces could not be distinguished from smiling and surprised faces. The expression is universally associated with a nose wrinkling and this was adequately represented in the pictogram displayed to the recorded individuals. The nasal morphology was additionally pointed as one of the sources for the inter-individual variation observed within the studied sample. Therefore, it is safe to assume that for the smile, disgust and surprise the expression-induced geometry overlapped with the morphological variation in the facial features.

Interestingly, some of the observed facial deformations were located at the nasal region, where the width of the nasal wings was mostly affected. The nose is considered one of the most stable components of a human face, resilient and invariant to facial movements (Faltemier et al., 2007; Mian et al., 2015). Therefore, the acquired results may be of practical use in region-based methods of facial recognition (Faltemier et al., 2007; Mian et al., 2015).

Regarding sexual dimorphism in facial expressions the acquired results revealed that for all studied grimaces males exhibited more extensive, although not significantly in all cases, facial shape and size-related deformations from the neutral faces than females. This means that contractions of facial muscles beneath the skin were larger in male faces regardless of the purpose and/or contracted muscle groups. In literature, sex differences in facial movements have been reported in previous studies, some of them

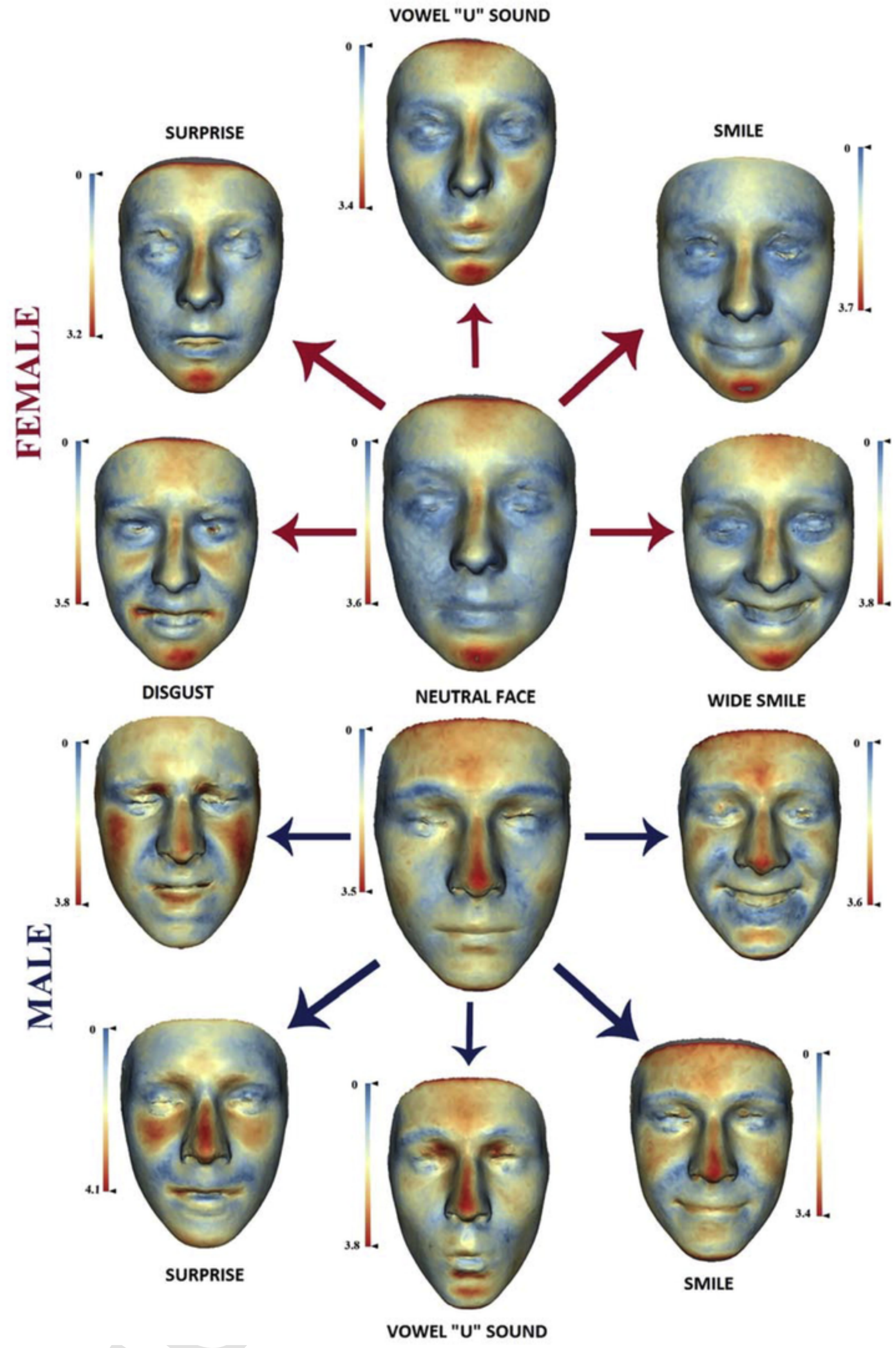

Fig. 5. Female (top) and male (bottom) average faces demonstrating among-person variations in the studied expressions. The local variations are displayed using colour map visualization tools (see on-line colour version) – blue colour corresponds to smallest values of point-to-point distances whereas red colour indicates areas with the largest values of distances. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

could be explained by differences in facial dimensions (Giovanoli et al., 2003; Tzou et al., 2005), whereas others are standardised by size (Weeden et al., 2001). Additionally, some studies revealed no sex-related effects (Sforza et al., 2010a, 2010b), despite size standardised.

Sexual dimorphism in the overall muscle mass relative to the body size is a well-documented phenomenon (Wells, 2007), and has been equally reported for various facial muscles (McAlister et al., 1998; Volk et al., 2014). What should not be overlooked, however, is that male-female differences are in many forms also present on submacroscopic level of structures and molecular mechanisms of muscle tissue. Males have proportionally more muscle fibres which also vary in structure, composition, and velocity of contraction. Regulatory mechanisms of muscle formation are in a direct relation with levels of sex hormones, androgens in particular. Testosterone, for instance, was shown to be responsible for differential growth of certain muscle groups and is therefore hypothesised to regulate muscle-specific genes (Mateescu and Thonney, 2002). All of these factors are likely to interact in the formation of sexual dimorphism observed in the facial movements.

Furthermore, morphological characteristics of male and female faces should be taken into account. The facial appearance is co-formed by soft tissue and underlying hard tissue characteristics (Enlow, 1968). Sexual dimorphism in the craniofacial skeleton is manifested in size and shape of the facial skeleton (Baughan and Demirjian, 1978; Enlow, 1968) as well as in the number of craniofacial traits (Jurda and Urbanová. 2016; Walrath et al., 2004) and with large practical implications in the field of skeletal anthropology (Buikstra and Ubelaker, 1994; Jantz and Ousley, 2005; Slice and Ross, 2009; Urbanová and Králík, 2008). Therefore, varying degree of development of cranial features in conjunction with positions of the muscles can be another, albeit less apparent, source of the observed sex-related differences.

Ultimately, an alternative explanation for slightly exaggerated expressions in males can be found in different cognitive abilities and adaptations to social interactions. According to Lawrence et al. (2015), females are more accurate than males at emotion recognition. In addition, clinical observation supports that the neural circuits underlying the perception and mimicry of facial expressions are more sensitive and tractable in females (Hontanilla and Marre, 2014; Korb et al., 2015). Consequently, the male tendencies to over-act the requested expressions might be viewed as a compensatory mechanism reflective of their certain cognitive shortcomings.

Focusing on within-group variability, males showed a higher level of variability in the extent of facial movements when standardised by size in our study. The difference in variance, i.e. variable ranges of male and female values, is a slightly overlooked aspect of sexual dimorphism in somatic parameters. In the majority of somatic traits, the variance of male phenotype exceeds the variance of female phenotype (Lehre et al., 2009). Focusing on the face, it is due to the nature of ontogenetic development, which includes stages of extended maturation in males (Bulygina et al., 2006). It is safe to say that our results are consistent with the general pattern.

Logically, the extent and pattern of sexual dimorphism varied noticeably among the expressions. Altogether sex-related differences were present for three out of five studied facial grimaces – surprise, "u" sound and smile. This is in disagreement with studies by Sforza et al. (2010a) and by Sidequersky et al. (2016), which reported no sex-related differences in facial motions. In contrast to our case, however, both reported studies were carried out by employing a landmark-based approach. Although landmark-based and mesh-based approaches have been shown to be complementary in studies focusing on face processing (Urbanová, 2016), the employment of craniofacial landmarks is known to reduce the amount of processed information (Jurda and Urbanová, 2016).

A proper explanation for the obtained results ought to be sought in the contracting muscle groups. The surprise is produced by contracting the frontalis and masseter muscles and relaxing the temporalis muscle. The masseter and temporalis muscles have been both reported as larger in males in comparison to females (Volk et al., 2014) which may partially explain the different quantitative responses between males and females. In contrast, the attachment of the frontalis muscle is influenced by the protrusion of the supraorbital ridges – a highly sexual dimorphic cranial feature (Bishara et al., 1998; Enlow and Hans, 1996). Therefore, the different muscle strength can be explained in terms of the displacement of the sites of frontalis muscle attachment. This interpretation is consistent with observations made by Sforza et al. (2010a) who also pinpointed the sex-related differences in the superciliary region.

The same commentary is applicable to the observed differences in the other two grimaces – the "u" sound and the smile. Both are primarily induced by contractions of the orbicularis oris muscle, in the smile then jointly with the zygomaticus major muscle. Both facial muscles are, once again, known to be sexually dimorphic in size; the orbicularis oris muscle is larger in males, while the zygomaticus major has been shown to be thicker in females (McAlister et al., 1998; Volk et al., 2014). Therefore at least the orbicularis oris muscle exhibits the characteristics enabling to produce more extensive facial movements. This also concurs with Popat et al. (2012) who showed that females had a more protrusive articulation of words relative to males. For the smile, the inconsistencies between the size of the zygomatic muscles and the restricted facial movements in females suggest that additional factors take place.

The results suggesting sexually dimorphic patterns in facial movements may have important practical implications. Facial gender classification is one of the areas of automated facial recognition which has grown significantly in recent years. The motivation for such systems are gender-based human-computer interactions in surveillance, marketing or passive demographic data collection (Ngan and Grother, 2015). In general, gender classification, as well as personal identification, are generally more accurate in males than females (Urbanová and Chalás, 2016). This applies to constrained, i.e. expression-free as well as in the wild, i.e. expression-present faces (Urbanová and Chalás, 2016). As many studies orientated at automated facial recognition state empirical observations without specifying cause, we can only speculate how our results relate to the current knowledge or whether they shed light on the imbalance in gender classification rates.

Uncited references

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