Theoretical Issues in Ergonomics Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ttie20

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To cite this article: Hyung Nam Kim (2022): The frequency of facial muscles engaged in expressing emotions in people with visual disabilities via cloud-based video communication, Theoretical Issues in Ergonomics Science, DOI: 10.1080/1463922X.2022.2081374

To link to this article: https://doi.org/10.1080/1463922X.2022.2081374

Published online: 26 May 2022.

THEORETICAL ISSUES IN ERGONOMICS SCIENCE
https://doi.org/10.1080/1463922X.2022.2081374

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The frequency of facial muscles engaged in expressing emotions in people with visual disabilities via cloud-based video communication

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ABSTRACT
As technology is advancing quickly, and various assistive technology applications are introduced to users with visual disabilities, many people with visual disabilities use smartphones and cloud-based video communication platforms such as Zoom. This study aims at advancing knowledge of how people with visual disabilities visualize voluntary emotions via facial expressions, especially in online contexts. A convenience sample of 28 participants with visual disabilities were observed as to how they show voluntary facial expressions via Zoom. The facial expressions were coded using the Facial Action Coding System (FACS) Action Units (AU). Individual differences were found in the frequency of facial action units, which were influenced by the participants' visual acuity levels (i.e., visual impairment and blindness) and emotion characteristics (i.e., positive/negative valence and high/low arousal levels). The research findings are anticipated to be widely beneficial to many researchers and professionals in the field of facial expressions of emotions, such as facial recognition systems and emotion sensing technologies.

ARTICLE HISTORY
Received 23 December 2021
Accepted 19 May 2022

KEYWORDS
Visual impairment; blindness; voluntary facial expressions; facial action units; emotions; zoom

Relevance to human factors/ergonomics theory

This study advanced knowledge of facial muscle engagements while people with visual disabilities visualize their emotions via facial expressions, especially in online contexts. The advanced understanding would contribute to building a fundamental knowledge foundation, ultimately applicable to universal designs of emotion technology that can read users' facial expressions to customize services with the focus on adequately accommodating the users' emotional needs (e.g., ambient intelligence) regardless of users' visual ability/disability.

1. Introduction

People perceive a range of emotions in oneself and others but also visualize emotions through different modalities including nonverbal vocalizations (Sauter et al. 2010), language (Landis 2006), body cues (Aviezer, Trope, and Todorov 2012), prosody (Adolphs, Damasio,

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and Tranel 2002), and facial expressions (Ekman 1993). Facial expressions are considered as one of the most important aspects of human communication and social interaction (Schmidt and Cohn 2001; Xu et al. 2017). In case that vision is limited, humans can still use other sensory modalities such as auditory or touch senses to obtain information from environments and perceive various emotions (Buimer et al. 2018).

It is well documented that individual differences exist in facial expressions of emotions (Cohn et al. 2002; Hildebrandt, Olderbak, and Wilhelm 2015; Peleg et al. 2006). The differences are induced by the variation of facial muscles and facial nerves (Goodmurphy and Ovalle 1999). The facial muscles are considered as striated muscles that are attached to the bones of the skull, contributing to two major tasks: mastication and facial expressions (Westbrook, Nessel, and Varacallo 2021). Such individual differences are also observed in people with visual disabilities. Galati, Miceli, and Sini (2001) found that sighted decoders tended to attribute distinctive labels to facial expressions posed by children with congenital blindness (n = 10, age ranged from 6 months to 4 years old), except sadness and fear expressions. The two facial expressions were confused with one another and difficult to be distinguished by sighted decoders. Roch-Levecq (2006) also found that both groups of children with blindness and normal vision were able to understand the basic emotions (e.g., fear, happiness, sadness, and anger), but there was a significant difference in the facial expressions between the two groups of children, especially with regard to the emotions of fear and happy. Kunz, Faltermeier, and Lautenbacher (2012) found that people with congenital blindness were less capable of facially encoding different intensities of physical distress (e.g., pain) as compared to their peers with normal vision.

Facial expressions can be recognized and understood by two dimensions: valence (positive and negative emotions) and arousal (high and low emotions) (Russell and Bullock 1985), which are constructs of a Circumplex Model of Emotion (Russell 1980). For example, happy and angry emotions are presented as high-arousal positive and negative emotions, respectively. People use different facial muscles to display various facial expressions in response to positive and negative emotions (i.e., valence factors). Young college students who are given photos of happy faces tend to show facial reactions using the zygomatic major muscle (i.e., facial muscle related to lips) while those given photos of angry faces tend to actively use the corrugator supercilia muscle (i.e., facial muscle related to eyebrows) (Dimberg and Karlsson 1997). Zhang et al. (2011) used facial electromyographic (EMG) reactions to investigate the facial muscle activities of young college students in response to graphic stimuli of emotional pictures that have various features such as a combination of valence (positive/negative) and arousal (high/low). They observed that zygomaticus muscle activities were more responsive to positive pictures while corrugator muscle activities were more responsive to negative pictures. Yet, Roch-Levecq (2006) found no significant difference in facial expressions posed by children with blindness in response to positive and negative emotions. Fujimura, Sato, and Suzuki (2010) investigated the effect of arousal and valence levels of emotions on facial mimicry among young college students. The term *mimicry* refers to unconscious imitation of behavior shown by others (Seibt et al. 2015). Facial mimicry describes the context that an individual imitates unconsciously others' emotional facial expressions (Rymarczyk et al. 2019). Fujimura, Sato, and Suzuki (2010) observed that the zygomatic major muscle was more actively engaged in expressing high-arousal positive emotions while the corrugator supercilia muscle was more actively engaged in expressing both high- and low-arousal negative emotions.

Individual differences influence the degree to which people use facial muscles in expressing emotions. For example, people with different visual acuity levels show different facial expressions (Chiesa, Galati, and Schmidt 2015; Cole, Jenkins, and Shott 1989; Galati et al. 2003; Kunz, Faltermeier, and Lautenbacher 2012). Thompson (1941) found that there was initially no significant difference in facial expressions between babies with blindness and their peer babies with normal vision; however, as time went on, those with blindness smiled less frequently. Thompson (1941) claimed that those babies with blindness tended to have a very limited opportunity to observe others' facial expressions, imitate them, and accordingly develop models, ultimately leading to lack of facial expressions. On the other hand, Matsumoto and Willingham (2009) argued that facial expressions of emotions are not affected by observational learning. They examined the degree to which facial muscles were engaged in expressing emotions between congenitally blind (early onset), non-congenitally blind (late onset), and sighted athletes in terms of individual facial actions and overall facial actions. They found no differences in the level of individual facial actions although the groups with blindness showed more actions associated with head and eye movements.

There have been research efforts to investigate facial expressions posed by people while using online communication tools (Alyüz et al. 2016; Aslan et al. 2014; D'mello and Graesser 2010; Whitehill et al. 2014). The findings of research on facial expressions online can widely be beneficial to many stakeholders in various domains such as interactions between teachers and students via online education. Bian et al. (2019) developed a publicly available facial expression database (a set of videos and images) in online learning settings, which focused on five academic emotions: enjoyment, confusion, fatigue, distraction, and neutral. Zhang et al. (2020) also used facial expressions of e-learners to measure the degree to which students are engaged in learning activities online. There have been researchers who tried to develop facial expression recognition systems to help people with visual disabilities to read other people's facial expressions in person (Ashok and John 2018; Zhao et al. 2018); however, there is still lack of research on how people with visual disabilities share their facial expressions of emotions in online communication environments. There are other researchers (Den Uyl and Van Kuilenburg 2005) trying to develop an online facial expression recognition system, yet the system is set for sighted people. In order to develop a highly sophisticated system to recognize facial expressions posed by people with visual disabilities, it is essential, as a first step, to obtain a deep understanding of how the target users take emotional stimuli, perceive emotions, and express them via facial muscle movements. Thus, given such a deep understanding, a highly advanced technology could be developed, applicable to users with visual disabilities. This study focuses on advancing knowledge of facial expressions posed by people with visual disabilities in online settings, such as Zoom (i.e., cloud-based video communication).

Many previous studies were merely limited to inter-comparisons of facial expressions between people with visual disabilities and sighted people or merely focused on children (or young college students) with visual disabilities over adults with visual disabilities. This study focuses on advancing knowledge of individual differences within the group of adults with visual disabilities (i.e., intra-comparisons) including those with moderate/severe visual impairment and those with blindness (including those with no light perception at all). A recent systematic literature review by Valente, Theurel, and Gentaz (2018) examined the facial expressions of emotions posed by people with blindness. They found that little attention has been paid to 'voluntary' facial expressions in those with blindness as only 8 articles

(38%) investigated voluntary expressions. The results of this study are, thus, expected to address the knowledge gap; that is, little is known about the frequency of facial muscle movements engaged in expressing voluntary emotions in people with various vision status while being online.

2. Methods

2.1. Participants

A convenience sample of 28 participants with visual impairment and blindness were invited. Inclusion criteria were English speaking, 18 years old or older, and low visual acuity. Visual acuity between 20/200 and 20/400 is considered as severe visual impairment while visual acuity less than 20/400 refers to blindness (World Health Organization 2008). We recruited research participants in collaboration with community organizations such as community low vision centers and a public library for the blind. Approval for this study was obtained from the Institutional Review Board (IRB). Informed consent was obtained from all participants in the study. Characteristics of the participants were presented in Table 1.

Table 1. Descriptions of the participants.

Participants	n = 28
Visual acuity	
Between 20/200 and 20/400	9
Between 20/400 and 20/1200	4
Less than 20/1200, but has light perception	13
No light perception at all	2
Duration of visual impairment (years)	27.71 ± 23.92
Onset of visual impairment (years)[a]	
Early onset	0.4 ± 1.26
Late onset	47.89 ± 14.93
Age (years)	58.64 ± 17.93
Gender	
Male	11
Female	17
Race/Ethnicity	
African American	10
European American	16
Hispanic American	1
Others	1
Occupation	
Employed	9
Unemployed	19
Head of household	
Living alone	7
With family, relatives, friends, or combination of them	21
Education	
High school or equivalent	6
Certificate or training program	1
Associate	6
Bachelors (BA or BS)	4
Masters	10
Doctorate	1
Marital status	
Married	14
Not Married	6
Widow(er)	3
Divorced	5

[a] *Participants with early-onset of vision loss had lost their sight before 11 years of age (Voss et al. 2004).*

2.2. Procedures

Interviews were conducted via Zoom videoconferencing. Participants' family members were allowed to assist with downloading the Zoom application in the participant's computing devices (e.g., smartphones and computers) if necessary. Four out of 28 participants (14%) obtained help from their family members in installing the Zoom app, while the majority of the participants (86%) were already the Zoom users. Once the interview began, the participant's helper should be absent from the interview. The participants were instructed to pose facial expressions of the eight emotions including anger, fearful, disgust, happy, surprised, neutral, calm, and sad in a random order. While the participants expressed the emotions, we used the Zoom app to capture their expressions. When they mistakenly looked at other places instead of the camera due to their visual challenge, we instructed them to adjust the position of their head. A demographic survey was used to understand the characteristics of the participants. We read the survey questions out loud, clearly and slowly to help the participants understand fully. We repeated questions when they requested.

2.3. Data analysis

The facial expressions were coded by using the Facial Action Coding System (FACS), that is, a comprehensive system to distinguish all possible visible anatomically based facial actions (Ekman and Friesen 1978; Ekman and Friesen 1976). The FACS helped to break down all visually discernible facial expressions into individual components of muscle movements, called Action Units. The Action Units cover various facial components (e.g., brows, eyelids, lips, head, nose, and cheeks). Statistical analyses were performed using the IBM SPSS Statistics for Macintosh, version 24 (IBM Corp 2016). The coding was accomplished by FACS coders who were trained based on the instructions of Cohn, Ambadar, and Ekman (2007) and competent with coding facial expressions using the FACS as shown in previous research (Kim and Sutharson 2022). The interrater reliability was also assessed using a subset (10%) of the total data (Geisler and Swarts 2019; Leclerc and Dassa 2009), e.g., a coder watched the sample of the facial expression videos and coded them for the presence of the FACS' Action Units. The interrater reliability for the coders was found to be $k = 0.66$ (95% CI: 0.32 to 1.00), $p < .05$, which is a substantial agreement according to Landis and Koch (1977).

3. Results

3.1. The frequency of action units engaged in expressing emotions

As shown in Figure 1, various combinations of action units were employed in expressing emotions. Emotions were expressed via, for example, a single action unit or a combination of several action units (ranging from 2 to 6 action units). In the following sections, a set of statistical analyses were reported in detail.

As Mauchly's test confirmed that there was no indication of any violation of sphericity, $\chi^2(27) = 24.88$, $p = .59$, the frequency of Action Units engaged in expressing the eight emotions was compared via the within-subjects tests. The difference between the means was found to be statistically significant, $F(7, 189) = 15.86$, $p < .001$, $\eta^2 = .37$. As shown in Table 2, the

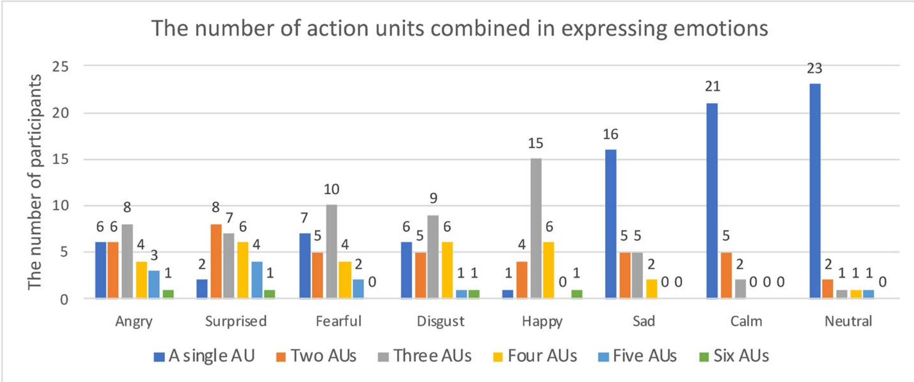

Figure 1. Different combinations of action units were employed to express an emotion.

Table 2. Pairwise comparisons for the frequency of action units engaged in expressing an emotion.

Frequency of Action Units (Mean ± SD)		Mean Difference	Std.		95% Confidence Interval for Difference	
(i) Emotion	(j) Emotion	(i – j)	Error	Sig.	Lower Bound	Upper Bound
Anger (2.86 ± 1.43)	Neutral (1.43 ± 1.00)	1.43	0.23	< 0.001	0.62	2.23
	Calm (1.39 ± 0.79)	1.46	0.27	< 0.001	0.53	2.40
Fearful (2.64 ± 1.25)	Neutral (1.43 ± 1.00)	1.21	0.27	0.004	0.27	2.16
	Calm (1.39 ± 0.79)	1.25	0.25	0.001	0.38	2.12
Disgust (2.82 ± 1.33)	Neutral (1.43 ± 1.00)	1.39	0.27	0.001	0.46	2.33
	Calm (1.39 ± 0.79)	1.43	0.27	< 0.001	0.48	2.38
Happy (3.14 ± 0.93)	Neutral (1.43 ± 1.00)	1.71	0.24	< 0.001	0.90	2.53
	Calm (1.39 ± 0.79)	1.75	0.23	< 0.001	0.96	2.54
	Sad (1.79 ± 1.07)	1.36	0.24	< 0.001	0.54	2.18
Surprised (3.32 ± 1.36)	Neutral (1.43 ± 1.00)	1.89	0.29	< 0.001	0.88	2.91
	Calm (1.39 ± 0.79)	1.93	0.29	< 0.001	0.92	2.94
	Sad (1.79 ± 1.07)	1.54	0.28	< 0.001	0.57	2.50
Neutral (1.43 ± 1.00)	Sad (1.79 ± 1.07)	0.36	0.28	1.00	–0.62	1.34
	Calm (1.39 ± 0.79)	0.04	0.21	1.00	–0.69	0.76
Sad (1.79 ± 1.07)	Calm (1.39 ± 0.79)	0.39	0.18	1.00	–0.23	1.02

pairwise comparisons were followed. The frequency of Action Units engaged in expressing the emotions varied depending on the type of emotions. Neutral and calm emotions were expressed with a fewer number of Action Units as compared to other emotions: anger, fearful, disgust, happy, and surprised. Sad emotion was expressed with a fewer number of Action Units as compared to happy and surprised. Yet, there was no significant difference in the number of Action Units engaged in expressing between neutral, calm, and sad emotions.

3.2. The frequency of action units engaged in expressing emotions with different valence and arousal levels

3.2.1. Emotions with different valence levels

We compared the number of Action Units by referring to the Circumplex Model of Affect (i.e., valence and arousal) (Russell 1980). According to the Circumplex Model of Affect, the emotions of *anger, fearful, surprised, and disgust* were categorized as high-arousal negative emotion, *happy* as high-arousal positive emotion; *sad* as low-arousal negative

Table 3. Tukey's HSD tests to compare the frequency of action units engaged in expressing emotions with different valence levels (positive, negative, and neutral).

Frequency of Action Units (Mean ± SD)		Mean Difference	Std.		95% Confidence Interval for Difference	
(i) Emotion	(j) Emotion	(i – j)	Error	Sig.	Lower Bound	Upper Bound
Positive (2.27 ± 1.23)	Negative (2.69 ± 1.37)	−0.42	0.21	0.11	−0.90	0.07
	Neutral (1.43 ± 1.00)	0.84	0.30	0.02	0.13	1.55
Negative (2.69 ± 1.37)	Positive (2.27 ± 1.23)	0.42	0.21	0.10	−0.07	0.90
	Neutral (1.43 ± 1.00)	1.26	0.27	< 0.001	0.62	1.89
Neutral (1.43 ± 1.00)	Positive (2.27 ± 1.23)	−0.84	0.30	0.02	−1.55	−0.13
	Negative (2.69 ± 1.37)	−1.26	0.27	< 0.001	−1.89	−0.62

Table 4. Tukey's HSD tests to compare the frequency of action units engaged in expressing emotions with different arousal levels (high, low, and neutral).

Frequency of Action Units (Mean ± SD)		Mean Difference	Std.		95% Confidence Interval for Difference	
(i) Emotion	(j) Emotion	(i – j)	Error	Sig.	Lower Bound	Upper Bound
High Arousal (2.96 ± 1.28)	Low Arousal (1.59 ± 0.95)	1.37	0.19	< 0.001	0.93	1.81
	Neutral Arousal (1.43 ± 1.00)	1.53	0.24	< 0.001	0.96	2.10
Low Arousal (1.59 ± 0.95)	Neutral Arousal (1.43 ± 1.00)	0.16	0.27	0.825	−0.48	0.80

emotion; *calm* as low-arousal positive emotion; and *neutral* as neutral-arousal neutral emotion. Welch's ANOVA indicated that there was a significant difference in the number of Action Units engaged in expressing between emotions with different valence levels: positive, negative, and neutral, $F(2, 76.27) = 16.06$, $p < .001$, *est.* $\omega^2 = .52$. As shown in Table 3, Tukey's HSD tests showed that more Action Units were engaged in expressing positive emotions than neutral emotion, as well as negative emotions than neutral emotion.

3.2.2. Emotions with different arousal levels

Welch's ANOVA indicated that there was a significant difference in the number of Action Units engaged in expressing between emotions with different arousal levels: high, low, and neutral, $F(2, 74.87) = 43.99$, $p < .001$, *est.* $\omega^2 = .75$. As shown in Table 4, Tukey's HSD tests found that more Action Units were engaged in expressing high-arousal emotions than low-arousal emotions as well as high-arousal emotions than neutral emotion.

3.2.3. Emotions with a combination of different arousal and valence levels

Welch's ANOVA indicated that there was a significant difference in the number of Action Units engaged in expressing between emotions with a combination of different valence and arousal levels: high-arousal positive, high-arousal negative, low-arousal positive, and low-arousal negative, $F(3, 68.08) = 29.05$, $p < .001$, *est.* $\omega^2 = .75$. As shown in Table 5, Tukey's HSD tests revealed that more Action Units were engaged in expressing high-arousal positive emotions than low-arousal positive emotions; high-arousal positive emotions than low-arousal negative emotions; high-arousal negative emotions than low-arousal positive emotions; and high-arousal negative emotions than low-arousal negative emotions. It suggests that the arousal factor, *high*, plays a significant role in the number of Action Units engaged in expressing emotions.

Table 5. Tukey's HSD tests to compare the frequency of action units engaged in expressing emotions with different arousal and valence levels.

Frequency of Action Units (Mean ± SD)		Mean Difference	Std.		95% Confidence Interval for Difference	
(i) Emotion	(j) Emotion	(i − j)	Error	Sig.	Lower Bound	Upper Bound
High + Positive (1.39 ± 0.79)	High + Negative (2.91 ± 1.35)	0.23	0.25	0.79	−0.42	0.89
	Low + Positive (1.39 ± 0.79)	1.75	0.32	< 0.001	0.92	2.58
	Low + Negative (1.79 ± 1.07)	1.36	0.32	< 0.001	0.53	2.18
High + Negative (2.91 ± 1.35)	Low + Positive (1.39 ± 0.79)	1.52	0.25	< 0.001	0.86	2.17
	Low + Negative (1.79 ± 1.07)	1.13	0.25	< 0.001	0.47	1.78
Low + Negative (1.79 ± 1.07)	Low + Positive (1.39 ± 0.79)	0.39	0.32	0.61	−0.43	1.22

3.3. The frequency of action units engaged in expressing emotions, depending on the participants' sociodemographic backgrounds

A one-way ANOVA was conducted to compare the degree to which Action Units were engaged in expressing the eight emotions, especially depending on the participants' different sociodemographic backgrounds. We did not find any significant difference associated with the sociodemographic backgrounds, except the condition of vision status. There was a significant difference in the number of Action Units between participants with visual impairment and their peers with blindness when expressing anger and happy. The frequency of Action Units engaged in expressing *anger* was greater in those with visual impairment (3.11 ± 1.76) than their peers with blindness (2.74 ± 1.28), $F\ (1,\ 26) = 11.51,\ P < .05,\ \eta^2 = .31$. The frequency of Action Units engaged in expressing *happy* was greater in those with visual impairment (3.33 ± 1.12) than their peers with blindness (3.05 ± 0.85), $F\ (1,\ 26) = 6.40,\ P < .05,\ \eta^2 = .20$.

4. Discussions

4.1. Facial muscles engaged in expressing emotions

Individual differences were detected in terms of the frequency of Action Units engaged in expressing voluntary facial expressions. The participants used a fewer number of Action Units in expressing calm compared to other emotions including angry, fearful, disgust, happy, and surprised. Calmness is typically considered as a state of peace of mind that differs from other strong emotions such as excitement (Lee et al. 2013). Ji et al. (2021) also found that sighted people used a fewer number of Action Units in expressing calm as compared to other emotions including sad, angry, fearful, disgust, happy, and surprised. The results suggest that both people with and without visual disabilities are likely to use a fewer number of Action Units in expressing the calm emotion.

4.2. Emotions by valence and arousal levels

4.2.1. Valence

It was found that the degree to which Action Units were engaged was different depending on the valence level of emotions such as positive, negative, and neutral emotions. The results of the present study are in accordance with the following findings by previous research. For example, the participants in this study used the *zygomaticus major muscle for lip corner puller* multiple times in expressing happy (i.e., positive emotion) while they never used the lip muscles in expressing angry (i.e., negative emotion). Dimberg, Thunberg, and Elmehed (2000) conducted a study with sighted people to measure the magnitude of facial electromyographic (EMG) reactions in emotion-relevant facial muscles. They reported that the zygomaticus major muscle activity (lip muscles) was significantly engaged in expressing happy than angry. In contrast to the zygomaticus major muscle, the orbicularis oculi muscle (eye muscles) showed a different pattern of engagement in that the participants in this study used the orbicularis oculi muscle more in expressing angry than happy. A similar result was reported in the study by Zhang et al. (2011) where sighted participants showed a greater activity of corrugator muscles (i.e., muscles related to orbicularis oculi) in expressing negative emotions than positive emotions. The results, thus, suggest that those with visual disabilities tend to use the muscles around lips in expressing positive emotions (happy) while use the muscles around eyelids in expressing negative emotions (angry). We found similar results in the literature that e-learners expressed positive emotions (e.g., delight) facially by using the zygomaticus major muscle (McDaniel et al. 2007; Vail et al. 2016), while expressed negative emotions (e.g., frustration) by using facial muscles related to eyes/eye brows (D'Mello, Craig, and Graesser 2009; J. Grafsgaard et al., 2013; J. F. Grafsgaard et al., 2013).

4.2.2. Arousal

We also observed that individual differences are likely to be related with different arousal levels (e.g., high, low, and neutral emotions). The participants in this study tended to use a greater number of Action Units in expressing high-arousal emotions than low-aroual emotions. For example, they showed a greater engagement of the corrugator muscle in expressing high-arousal emotions than low-arousal emotions. Zhang et al. (2011) also observed that the corrugator muscle activity was more actively engaged in expressing high-arousal emotions as compared to low-arousal emotions among sighted people. The muscle of lip corner puller was also actively engaged in expressing high-arousal emotions than low-arousal emotions, which was consistent with the result of the study by Zhang et al. (2011). The results, thus, suggest that those with visual disabilities tend to use the muscles related to eyelids and lips in expressing high-arousal emotions than low-arousal emotions.

4.2.3. A combination of valence and arousal

We further investigated the degree to which Action Units were engaged differently depending on the combination of valence and arousal levels. We argue that the high-arousal factor is likely to lead to a greater engagement of Action Units. For example, among positive emotions, high-arousal emotions led to a greater engagement of Action Units as compared to low-arousal emotions. Among negative emotions, high-arousal emotions led also to a greater engagement of Action Units as compared to low-arousal emotions. Even when a mutually exclusive combination was considered, the combination including high-arousal factor led to a greater engagement of Action Units in expressing emotions. For example, 'high-arousal' *positive* emotions were engaged with more Action Units as compared to low-arousal negative emotions, and 'high-arousal' *negative* emotions were engaged with more Action Units as compared to low-arousal positive emotions. A similar result was also found in the literature in that sighted people tended to use a greater range of motion in four joints (neck extension, truck tilt and rotation) when expressing both 'high-arousal' positive and negative emotions as compared to low-arousal positive and negative emotions (Crane 2009).

4.3. Emotions by vision status

We uncovered that the participants with visual impairment showed a greater engagement of Action Units in expressing anger and happy as compared to their peers with blindness. In contrast to the participants with blindness, their peers with visual impairment could somewhat rely on their residual vision; thus, a better visual acuity level would probably lead to a greater engagement of facial Action Units. Yet, there is a different point of view. Matsumoto et al. (2009) reported that athletes with blindness used more Action Units in expressing emotions than did their sighted peers. Based on the research findings by Matsumoto et al. and this present study, we hypothetically argue that the facial expressions of people with 'visual impairment' may be more active than that of those with 'blindness', but the facial expressions of those with 'blindness' may be more active than people with 'normal vision'. As we did not directly compare between people with visual impairment, blindness, and normal vision, there is a need to conduct research on exploring the individual differences in facial expressions between the three groups. Yet, it should be noted that Matsumoto et al. (2009) measured 'spontaneous' facial expressions but this study measured 'voluntary' facial expressions. Schmidt et al. (2006) examined the facial muscle movements such as zygomaticus major activity for smile. They observed that the zygomaticus activity (e.g., lip movement) was significantly different between *spontaneous* and *voluntary* facial expressions in terms of onset/offset speed, amplitude of movement, and offset duration. Our future research will, thus, examine the individual differences in facial expressions between the three groups under the same experimental conditions (e.g., either spontaneous or voluntary facial expressions).

5. Limitations

Although the participants were specifically instructed to display their facial expressions, they may have already been affected by other emotions that they had perceived before participating in this study. For example, they are probably happy (or sad) in the morning, maintain the mood, and participate in the study in the afternoon. On the other hand, they were probably shy to show their facial expressions to others although it was for research purposes. Our future study will be designed to address those limitations.

6. Conclusion

As there has been little attention paid to voluntary facial expressions of emotions perceived by people with visual impairment and blindness, this study contributed to advancing knowledge about how they use facial muscles and the degree to which they are affected by different emotional characteristics such as high/low arousal and positive/negative valence as well as different vision status. As there have been only a handful of published reports, the findings of this study are expected to contribute to building a fundamental knowledge foundation and be widely beneficial to many researchers and professionals who are in the domain of emotion sensing technologies and facial recognition systems. Future research will also include sighted people and observe how they show facial expressions of emotions in the context of online communication.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Hyung Nam Kim is an Assistant Professor in the Department of Industrial and Systems Engineering at the North Carolina A&T State University. He earned his PhD in Industrial and Systems Engineering from Virginia Tech. His research interests include human factors, human-computer interaction, health informatics and safety.

Funding

This material is based upon work supported by the National Science Foundation under Grant No. 1831969.

References

Adolphs, R., H. Damasio, and D. Tranel. 2002. "Neural Systems for Recognition of Emotional Prosody: A 3-D Lesion Study." *Emotion (Washington, D.C.)* 2 (1): 23–51. doi:10.1037/1528-3542.2.1.23.

Alyüz, N., E. Okur, E. Oktay, U. Genc, S. Aslan, S. E. Mete, D. Stanhill, B. Arnrich, and A. A. Esme. 2016. "Towards an Emotional Engagement Model: Can Affective States of a Learner Be Automatically Detected in a 1: 1 Learning Scenario?" In *24th ACM Conference on User Modeling Adaptation and Personalization (UMAP)*, Halifax Nova Scotia Canada.

Ashok, A., and J. John. 2018. "Facial Expression Recognition System for Visually Impaired." In *International Conference on Intelligent Data Communication Technologies and Internet of Things (ICICI) 2018. ICICI 2018. Lecture Notes on Data Engineering and Communications Technologies*. Vol. 26, edited by J. Hemanth, X. Fernando, P. Lafata, and Z. Baig, 244–250. Cham: Springer. doi:10.1007/978-3-030-03146-6_26.

Aslan, S., Z. Cataltepe, I. Diner, O. Dundar, A. A. Esme, R. Ferens, G. Kamhi, E. Oktay, C. Soysal, and M. Yener. 2014. "Learner Engagement Measurement and Classification in 1: 1 Learning." In *13th International Conference on Machine Learning and Applications*, Detroit, MI.

Aviezer, H., Y. Trope, and A. Todorov. 2012. "Body Cues, Not Facial Expressions, Discriminate between Intense Positive and Negative Emotions." *Science* 338 (6111): 1225–1229. doi:10.1126/science.1224313.

Bian, C., Y. Zhang, F. Yang, W. Bi, and W. Lu. 2019. "Spontaneous Facial Expression Database for Academic Emotion Inference in Online Learning." *IET Computer Vision* 13 (3): 329–337. doi:10.1049/iet-cvi.2018.5281.

Buimer, H. P., M. Bittner, T. Kostelijk, T. M. Van Der Geest, A. Nemri, R. J. Van Wezel, and Y. Zhao. 2018. "Conveying Facial Expressions to Blind and Visually Impaired Persons through a Wearable Vibrotactile Device." *PloS One* 13 (3): e0194737. doi:10.1371/journal.pone.0194737.

Chiesa, S., D. Galati, and S. Schmidt. 2015. "Communicative Interactions between Visually Impaired Mothers and Their Sighted Children: Analysis of Gaze, Facial Expressions, Voice and Physical Contacts." *Child: Care, Health and Development* 41 (6): 1040–1046.

Cohn, J. F., Z. Ambadar, and P. Ekman. 2007. "Observer-Based Measurement of Facial Expression with the Facial Action Coding System." *The Handbook of Emotion Elicitation and Assessment* 1 (3): 203–221.

Cohn, J. F., K. Schmidt, R. Gross, and P. Ekman. 2002. "Individual Differences in Facial Expression: Stability over Time, Relation to Self-Reported Emotion, and Ability to Inform Person Identification." In *Proceedings of the 4th IEEE International Conference on Multimodal Interfaces*, Pittsburgh, PA.

Cole, P. M., P. A. Jenkins, and C. T. Shott. 1989. "Spontaneous Expressive Control in Blind and Sighted Children." *Child Development* 60 (3): 683–688. doi:10.2307/1130733.

Crane, E. A. 2009. *Measures of Emotion: How Feelings are Expressed in the Body and Face During Walking*. Doctoral diss., University of Michigan. http://hdl.handle.net/2027.42/63627.

D'mello, S. K., and A. Graesser. 2010. "Multimodal Semi-Automated Affect Detection from Conversational Cues, Gross Body Language, and Facial Features." *User Modeling and User-Adapted Interaction* 20 (2): 147–187. doi:10.1007/s11257-010-9074-4.

Den Uyl, M., and H. Van Kuilenburg. 2005. "The FaceReader: Online Facial Expression Recognition." In *Proceedings of Measuring Behavior 2005 - 5th International Conference on Methods and Techniques in Behavioral Research*, Wageningen, The Netherlands.

Dimberg, U., and B. Karlsson. 1997. "Facial Reactions to Different Emotionally Relevant Stimuli." *Scandinavian Journal of Psychology* 38 (4): 297–303. doi:10.1111/1467-9450.00039.

Dimberg, U., M. Thunberg, and K. Elmehed. 2000. "Unconscious Facial Reactions to Emotional Facial Expressions." *Psychological Science* 11 (1): 86–89.

D'Mello, S. K., S. D. Craig, and A. C. Graesser. 2009. "Multimethod Assessment of Affective Experience and Expression during Deep Learning." *International Journal of Learning Technology* 4 (3/4): 165–187. doi:10.1504/IJLT.2009.028805.

Ekman, P. 1993. "Facial Expression and Emotion." *The American Psychologist* 48 (4): 384–392. doi:10.1037//0003-066x.48.4.384.

Ekman, P., and E. Friesen. 1978. *Facial Action Coding System: A Technique for the Measurement of Facial Movement*. Palo Alto, CA: Consulting Psychologists Press.

Ekman, P., and W. V. Friesen. 1976. "Measuring Facial Movement." *Environmental Psychology and Nonverbal Behavior* 1 (1): 56–75. doi:10.1007/BF01115465.

Fujimura, T., W. Sato, and N. Suzuki. 2010. "Facial Expression Arousal Level Modulates Facial Mimicry." *International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology* 76 (2): 88–92.

Galati, D., R. Miceli, and B. Sini. 2001. "Judging and Coding Facial Expression of Emotions in Congenitally Blind Children." *International Journal of Behavioral Development* 25 (3): 268–278. doi:10.1080/01650250042000393.

Galati, D., B. Sini, S. Schmidt, and C. Tinti. 2003. "Spontaneous Facial Expressions in Congenitally Blind and Sighted Children Aged 8–11." *Journal of Visual Impairment & Blindness* 97 (7): 418–428. doi:10.1177/0145482X0309700704.

Geisler, C., and J. Swarts. 2019. *Coding Streams of Language: Techniques for the Systematic Coding of Text, Talk, and Other Verbal Data*. Collins, CO: WAC Clearinghouse Ft.

Goodmurphy, C. W., and W. K. Ovalle. 1999. "Morphological Study of Two Human Facial Muscles: Orbicularis Oculi and Corrugator Supercilii." *Clinical Anatomy* 12 (1): 1–11. doi:10.1002/(SICI)1098-2353(1999)12:1<1::AID-CA1>3.0.CO;2-J.

Grafsgaard, J., J. B. Wiggins, K. E. Boyer, E. N. Wiebe, and J. Lester. 2013. "Automatically Recognizing Facial Expression: Predicting Engagement and Frustration." In *Proceedings of the Sixth International Conference on Educational Data Mining*, Memphis, TN.

Grafsgaard, J. F., J. B. Wiggins, K. E. Boyer, E. N. Wiebe, and J. C. Lester. 2013. "Automatically Recognizing Facial Indicators of Frustration: A Learning-Centric Analysis." In *Humaine Association Conference on Affective Computing and Intelligent Interaction*, Geneva, Switzerland.

Hildebrandt, A., S. Olderbak, and O. Wilhelm. 2015. "Facial Emotion Expression, Individual Differences." In *International encyclopedia of the social & behavioral sciences*, 667–675. James D. Wright Publisher Name: Elsevier Location: Oxford.

IBM Corp. 2016. *IBM SPSS Statistics for Macintosh, Version 24.0*. IBM Corp.

Ji, R., A. Micheletti, N. K. Jerinkic, and Z. Desnica. 2021. "Emotion Pattern Detection on Facial Videos Using Functional Statistics." *arXiv preprint arXiv:2103.00844*

Kim, H. N., and S. Sutharson. 2022. "Individual Differences in Spontaneous Facial Expressions in People with Visual Impairment and Blindness." *British Journal of Visual Impairment*: 026461962110709. doi:10.1177/02646196211070927.

Kunz, M., N. Faltermeier, and S. Lautenbacher. 2012. "Impact of Visual Learning on Facial Expressions of Physical Distress: A Study on Voluntary and Evoked Expressions of Pain in Congenitally Blind and Sighted Individuals." *Biological Psychology* 89 (2): 467–476. doi:10.1016/j.biopsycho.2011.12.016.

Landis, T. 2006. "Emotional Words: What's So Different from Just Words?" *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior* 42 (6): 823–830. doi:10.1016/S0010-9452(08)70424-6.

Landis, J. R., and G. G. Koch. 1977. "The Measurement of Observer Agreement for Categorical Data." *Biometrics* 33 (1): 159–174. doi:10.2307/2529310.

Leclerc, B.-S., and C. Dassa. 2009. "Interrater Reliability in Content Analysis of Healthcare Service Quality Using Montreal's Conceptual Framework." *The Canadian Journal of Program Evaluation* 24 (2): 81–102.

Lee, Y.-C., Y.-C. Lin, C.-L. Huang, and B. L. Fredrickson. 2013. "The Construct and Measurement of Peace of Mind." *Journal of Happiness Studies* 14 (2): 571–590. doi:10.1007/s10902-012-9343-5.

Matsumoto, D., and B. Willingham. 2009. "Spontaneous Facial Expressions of Emotion of Congenitally and Noncongenitally Blind Individuals." *Journal of Personality and Social Psychology* 96 (1): 1–10.

McDaniel, B., S. D'Mello, B. King, P. Chipman, K. Tapp, and A. Graesser. 2007. "Facial Features for Affective State Detection in Learning Environments." In *Proceedings of the Annual Meeting of the Cognitive Science Society*, Nashville, TN.

Peleg, G., G. Katzir, O. Peleg, M. Kamara, L. Brodsky, H. Hel-Or, D. Keren, and E. Nevo. 2006. "Hereditary Family Signature of Facial Expression." *Proceedings of the National Academy of Sciences* 103 (43): 15921–15926. doi:10.1073/pnas.0607551103.

Roch-Levecq, A. C. 2006. "Production of Basic Emotions by Children with Congenital Blindness: Evidence for the Embodiment of Theory of Mind." *British Journal of Developmental Psychology* 24 (3): 507–528.

Russell, J. A. 1980. "A Circumplex Model of Affect." *Journal of Personality and Social Psychology* 39 (6): 1161–1178. doi:10.1037/h0077714.

Russell, J. A., and M. Bullock. 1985. "Multidimensional Scaling of Emotional Facial Expressions: Similarity from Preschoolers to Adults." *Journal of Personality and Social Psychology* 48 (5): 1290–1298. doi:10.1037/0022-3514.48.5.1290.

Rymarczyk, K., Ł. Żurawski, K. Jankowiak-Siuda, and I. Szatkowska. 2019. "Empathy in Facial Mimicry of Fear and Disgust: Simultaneous EMG-fMRI Recordings during Observation of Static and Dynamic Facial Expressions." *Frontiers in Psychology* 10: 701. doi:10.3389/fpsyg.2019.00701.

Sauter, D. A., F. Eisner, P. Ekman, and S. K. Scott. 2010. "Cross-Cultural Recognition of Basic Emotions through Nonverbal Emotional Vocalizations." *Proceedings of the National Academy of Sciences* 107 (6): 2408–2412. doi:10.1073/pnas.0908239106.

Schmidt, K. L., Z. Ambadar, J. F. Cohn, and L. I. Reed. 2006. "Movement Differences between Deliberate and Spontaneous Facial Expressions: Zygomaticus Major Action in Smiling." *Journal of Nonverbal Behavior* 30 (1): 37–52.

Schmidt, K. L., and J. F. Cohn. 2001. "Human Facial Expressions as Adaptations: Evolutionary Questions in Facial Expression Research." *American Journal of Physical Anthropology* 116 (S33): 3–24. doi:10.1002/ajpa.20001.

Seibt, B., A. Mühlberger, K. Likowski, and P. Weyers. 2015. "Facial Mimicry in Its Social Setting." *Frontiers in Psychology* 6: 1122. doi:10.3389/fpsyg.2015.01122.

Thompson, J. 1941. "Development of Facial Expression of Emotion in Blind and Seeing Children." *Archives of Psychology* 264 (37): 1–47.

Vail, A. K., J. B. Wiggins, J. F. Grafsgaard, K. E. Boyer, E. N. Wiebe, and J. C. Lester. 2016. "The Affective Impact of Tutor Questions: Predicting Frustration and Engagement." In *9th International Conference on Educational Data Mining*, Raleigh, NC.

Valente, D., A. Theurel, and E. Gentaz. 2018. "The Role of Visual Experience in the Production of Emotional Facial Expressions by Blind People: A Review." *Psychonomic Bulletin & Review* 25 (2): 483–497. doi:10.3758/s13423-017-1338-0.

Voss, Patrice, Maryse Lassonde, Frederic Gougoux, Madeleine Fortin, Jean-Paul Guillemot, and Franco Lepore. 2004. "Early-and Late-Onset Blind Individuals Show Supra-Normal Auditory Abilities in Far-Space." *Current Biology : CB* 14 (19): 1734–1738.

Westbrook, K., T. Nessel, and M. Varacallo. 2021. *Anatomy, Head and Neck, Face*. Treasure Island, FL: StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK493209/.

Whitehill, J., Z. Serpell, Y.-C. Lin, A. Foster, and J. R. Movellan. 2014. "The Faces of Engagement: Automatic Recognition of Student Engagementfrom Facial Expressions." *IEEE Transactions on Affective Computing* 5 (1): 86–98. doi:10.1109/TAFFC.2014.2316163.

World Health Organization. 2008. *Change the Definition of Blindness*. Geneva. https://www.who.int/health-topics/blindness-and-vision-loss

Xu, Q., Y. Yang, Q. Tan, and L. Zhang. 2017. "Facial Expressions in Context: Electrophysiological Correlates of the Emotional Congruency of Facial Expressions and Background Scenes." *Frontiers in Psychology* 8: 2175. doi:10.3389/fpsyg.2017.02175.

Zhang, Z., Z. Li, H. Liu, T. Cao, and S. Liu. 2020. "Data-Driven Online Learning Engagement Detection via Facial Expression and Mouse Behavior Recognition Technology." *Journal of Educational Computing Research* 58 (1): 63–86. doi:10.1177/0735633119825575.

Zhang, J., O. V. Lipp, T. P. Oei, and R. Zhou. 2011. "The Effects of Arousal and Valence on Facial Electromyographic Asymmetry during Blocked Picture Viewing." *International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology* 79 (3): 378–384.

Zhao, Y., S. Wu, L. Reynolds, and S. Azenkot. 2018. "A Face Recognition Application for People with Visual Impairments. Understanding Use beyond the Lab." In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, Montréal, Canada.