cognitive science in moscow

Eye Movement Strategies in Facial Expression Recognition are Not Related to the Strength of Inversion and Thatcherization Effects

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Abstract. The present research focuses on the mechanisms of facial expression recognition. We explored the relationship between eye movement strategies in face perception processes and the intensity of holistic perception effects — namely, the inversion effect. It was assumed that if holistic and feature-based mechanisms rely on certain specific image viewing strategies, the intensity of the inversion effect would be associated with certain eye movement characteristics (the number of examined facial features and the number of gaze transitions between them). The strength of the inversion effect indicated the dominance of the mechanisms of holistic perception. This was measured as a decrease in the accuracy of expression recognition of inverted images. In a facial expression recognition experiment, we analyzed responses and eye tracking data of 92 participants. Photographs of four characters from the WSEFEP database (Olszanowski et al., 2015) were used as stimuli. Each model displayed seven basic expressions. Stimuli were presented in three conditions: upright, inverted and thatcherized. A within-subjects design was used. The results showed a significant correlation between the effects of inversion and thatcherization, which argues in favor of the universality of the mechanism used by a particular person in face expression recognition. We found a high correlation between the eye movement characteristics under the three conditions of presentation, which indicates an individual-specific type of oculomotor activity. However, no correlation was found between the strength of holistic processing and certain eye movement characteristics. Most likely, oculomotor strategies for collecting information do not reflect the analytic or holistic mechanisms of its processing in facial expression recognition.

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Keywords: facial expression recognition, eye movement strategies, analytic mechanisms, holistic mechanisms, inversion effect, thatcherization effect

Note. The article is partially based on an earlier paper reporting preliminary results in the conference proceedings volume: Luniakova, E. & Gani-zada, J. (2019). [Eye movement strategies in facial expression recognition are not related to the strength of the inversion effect]. In E. V. Pechenkova & M. V. Falikman (Eds.), *[Cognitive Science in Moscow: New Research. 2019 Conference proceedings]* (pp. 328–334). Moscow: Buki Vedi, IPPiP.

Acknowledgements. This research was supported by RFBR Grant 18-013-01087A.

Received August 5, 2019, accepted September 21, 2019.

Introduction

For human beings, faces are among the most significant objects that are encountered in the environment. A human face is a special visual stimulus, mainly processed holistically unlike most other visual perceptual stimuli.

There are several interpretations of the term "holistic" in the psychology of face perception. Tanaka and Farah (1993) state that the face is perceived like a gestalt; that is, its features are not explicitly mentally represented as parts from which the perceptual image of a face is formed but rather the holistic image affects how each feature is perceived. Diamond and Carey (1986) discuss configural processing, which involves analyses of the spatial relationships between facial features. In any case, some stimulus transformations disrupt holistic processing, thereby reducing the success of recognition of a face, its parts and facial expression. The same transformations usually do not affect the perception of non-facial objects.

Some well-known phenomena that are specific for face perception illustrate those statements. People are more accurate in the recognition of facial features belonging to a certain familiar person (e. g., deciding which of two noses is Larry's nose), if they are presented with features in the context of the whole face, but not in isolation. This phenomenon is known as the "part-whole" effect (Tanaka & Farah, 1993). The inversion effect demonstrates the destruction of holistic processing when the image of a face is rotated 180 angular degrees. In this position, recognition of a face appears to be much slower and less accurate than in upright orientation (Yin, 1969). The effect of the composite face illustrates the mutual influence of the parts of the face on each other. Using a composite image made up of two (upper and lower) halves of faces of different famous people as stimuli, it has been shown that if the upper and lower halves are clearly aligned participants tend to experience great difficulties in recognition of the original people. A slight horizontal shift of the parts (so that they become misaligned) increases the success rate (Young, Hellawell & Hay, 1987).

According to numerous studies, the characteristics of eye movements during face examinations may reflect the type of perceptual information processing, namely the primary role of feature-based or holistic mechanisms in this process. Thus, some authors (Hsiao & Cottrell, 2008; Caldara, Zhou & Miellet, 2010; Chuk, Chan & Hsiao, 2017; Menshikova & Krivykh, 2017; Hills, 2018) suggest that eye movement strategies that reflect feature-based processing are characterized by numerous fixations on the internal facial features (eyes, nose and mouth), with a large number of transitions between them. The substantial number of fixations in the center of a face (usually in the area of the nose or nose bridge) and rare shifts to other features signifies holistic eye movement strategies. In contrast, other authors associate feature-based processing with long fixations on certain significant features, and holistic processing with the examining of several facial areas (Schwarzer, Huber & Dümmler, 2005; Bombari, Mast & Lobmaier, 2009). Meanwhile, the fact that there are similar fixation patterns during face examining in natural conditions and in distorted stimuli (while holistic mechanisms are blocked) provide grounds for an alternative hypothesis that there is no obvious correlation between eye movement strategies and face processing mechanisms. Such evidence is provided by eye tracking data obtained on upright and inverted faces (Williams & Henderson, 2007) as well as aligned and misaligned faces (Heering & Rossion, 2008). A detailed study of the facial expression recognition of inverted and thatcherized stimuli and eye movement characteristics during this process was performed by Barabanshchikov and Zhegallo (2011; 2012). The research showed that despite significant differences in the efficiency of expression recognition of the ordinary and thatcherized faces in upright and inverted presentations, changes in the eye movement strategies were not pronounced. The proportion of a limited number of isostatic eye movement patterns of face viewing in the sample was preserved. This work also suggests that eye movement strategies are not associated with analytic or holistic facial processing.

In fact, we have not seen any publications of a direct comparison of the strength of the effects of holistic perception and eye movement strategies that observers mainly use. The proportion of the contribution of feature-based or holistic mechanisms to the perception of a person depends on the particular observer's properties (age, affiliation with a particular culture, individual characteristics), and thus seems not to be universal. Eye movement strategies used by different people during face examinations also differ.

In this work, we compared the strength of the inversion effect and strength of the thatcherization effect in facial expression recognition with such characteristics of the subject's eye movements as the number of viewed areas of interests (AOI) and the number of gaze transitions between them. The number and shapes of AOIs that the face is usually divided into vary from study to study. The major inner facial features like the eyes, mouth and nose, and periphery features like the shape of the face, chin and hairstyle are basic, the most often analyzed in the discussion about holistic or feature-based processing. It is known that most fixations during face perception fall on the inner facial areas. Thus we found it possible to mark up a face into six areas of interest: right eye, left eye, nose, mouth, and two combined areas — "inner zones of the face" (consisting of forehead, cheeks and chin) and "periphery" (consisting of hairstyle and clothing items). The number of viewed AOIs and the number of gaze transitions between AOIs are comparable with the stated ideas about holistic and feature-based strategies for eye movements. Therefore, the presence of correlations between these parameters and the strength of the inversion effect could be an argument in favor of the relationship between the manner of visual information collecting and facial perception processing.

Method

Participants

One hundred and four participants volunteered for the experiment. Participants were aware of the purpose of the study and gave their consent to participate, which was consistent with the principles of the WMA Declaration of Helsinki. However, because of dropout of several poor-quality records of eye movements, the final sample consisted of 92 participants (46 men, 46 women; average age 21 years, $SD = 2.7$).

Stimuli

Stimuli were photographs of two males and two females from the WSEFEP database (Olszanowski et al., 2015). Each model displayed seven basic facial expressions: neutral expression, anger, fear, disgust, joy, surprise and sadness. We morphed photos of two of the characters (one male and one female) to make their facial expressions less pronounced. Morphed images were created with Abrosoft FantaMorph 5, wherein we combined photographs of the same character's highly pronounced expression with his/her neutral expression. Images with a 60% morph rate of the intensity of emotional expression were selected as stimulus material.

Each photo was prepared for three presentation conditions: upright, inverted (180 degrees inverted) and thatcherized + inverted (see Figure 1). (For brevity further in the text we will use only the term "thatcherized" instead of "thatcherized + inverted".) To achieve the thatcherization effect, we first rotated eyes and mouth zones 180 degrees and then inverted the resulting image. Eighty-four stimuli (4 characters × 7 expressions × 3 presentation conditions) were used in total. Each stimulus (the head of a character) subtended a visual angle of 11.5–13 angular degrees horizontally, and 16 angular degrees vertically at a viewing distance of 70 cm.

Procedure

The experiment began with a written instruction. Nine-point calibration preceded the presentation of the stimuli. In total, we performed 84 sequentially randomized trials each featuring a unique stimulus. Each trial began with the presentation of a fixation cross on the left or right (50:50) side of the stimulus. Presentation of a stimulus within a trial (one per trial) lasted 1300 ms. This time was enough for the participants to make several fixations, and we could assess their strategy of eye movements. The duration of the trial was not excessive, so the task was quite difficult, which allowed us to assess individual differences in the effectiveness of facial expression recognition. At the end of a trial, each participant had to answer which expression the character displayed by choosing one of the seven proposed options, using a mouse click. The whole experiment lasted about 20–25 minutes.

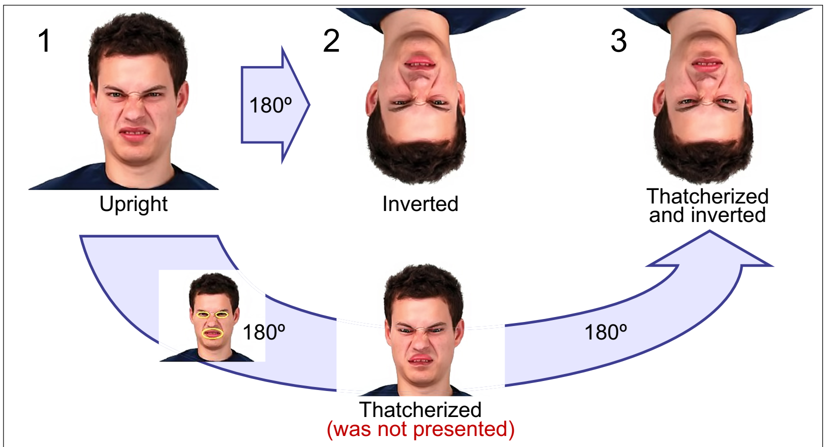

Figure 1. Three types of stimulus conditions and the way the original stimuli were distorted. 1 — Upright condition. 2 — Inverted condition. 3 — Thatcherized (thatcherized + inverted) condition.

Equipment

Eye movements were recorded binocularly at a 500-Hz sampling rate using a SMI RED 500 eye-tracker device with standard software. Participants sat in front of a 22-inch LED monitor with a resolution of 1680 × 1050 pixels at a distance of about 70 cm. A chin rest was not used.

Results

Eye tracking data analysis was performed with standard SMI Be-Gaze software. SPSS Statistic was used for statistical data processing.

For each participant, we calculated the strength of the inversion and thatcherization effects as a difference between the frequencies of the correct expression recognition of control (upright) and test (inverted or thatcherized) stimulus conditions. To analyze eye movement strategies, each stimulus face was marked up into six AOIs: right eye, left eye, nose, mouth, "inner zones of the face" (forehead, cheeks and chin) and "periphery" (hairstyle, clothing items). We calculated the average number of AOIs in which the participant made fixations (AOI count) and number of gaze transitions between AOIs (transition count) for each presentation condition (upright, inverted, thatcherized).

The Kolmogorov–Smirnov test revealed a difference between the distribution of intensities of the inversion and thatcherization effects and the normal distribution. Therefore, in further analysis, we used ANOVA and the Wilcoxon signed-rank test and two correlation coefficients — Pearson's r for parametric data and Spearman's ρ for nonparametric data.

Both the inversion effect and the thatcherization effect were revealed in most participants, but the intensity of these effects varied by sample: 14% to 42% ($M = 18\%$) for the inversion effect; 3% to 54% ($M = 23\%$) for the thatcherization effect. The Wilcoxon signed-rank test revealed significant differences in the severity of the effects: the facial expression was more difficult to recognize on a thatcherized face than on an inverted one ($Z = -4.752$, $p < .001$). However, data analysis revealed a statistically significant correlation between individual values of the inversion effect and the thatcherization effect ($\rho = .595$, $p < .001$).

Figure 2 contains the sample mean of eye movement parameters in the three stimulus conditions. We were interested in the effect of presentation conditions on individual parameters of eye movements. Due to the significance of between-subject variance in each condition, we standardized individual values by subtracting each participant's "mean AOI count" (average values for the three conditions) from his or her "AOI count" separately for each condition. The same was done for the "transition count" parameter. Repeated measures GLM with Sidak adjustment for multiple comparisons revealed significant differences between different conditions within the transition count indicator ($F(1) = 14.167$, $p < .001$,

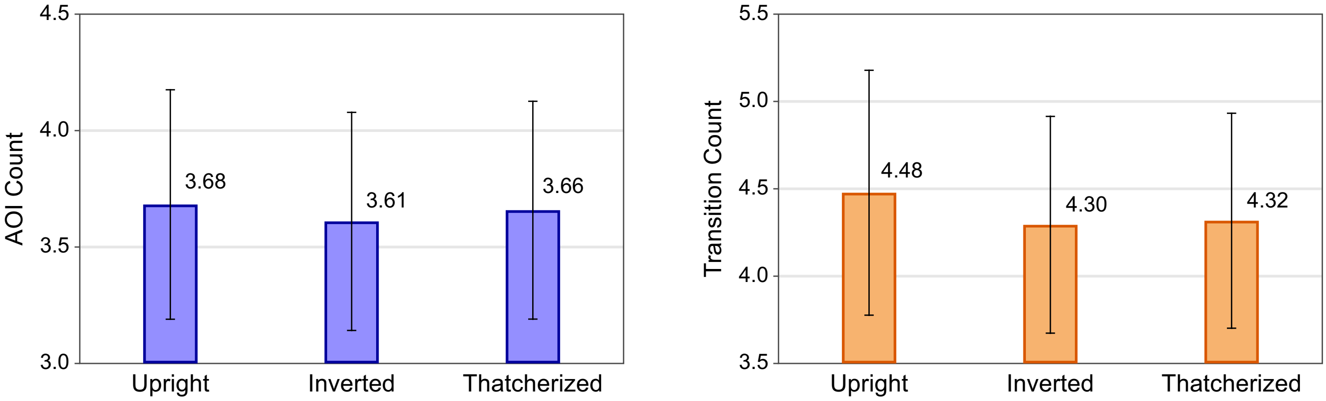

Figure 2. Sample mean of eye movement parameters in the three stimulus conditions: A — AOI count; B — transition count. Error bars refer to the standard error.

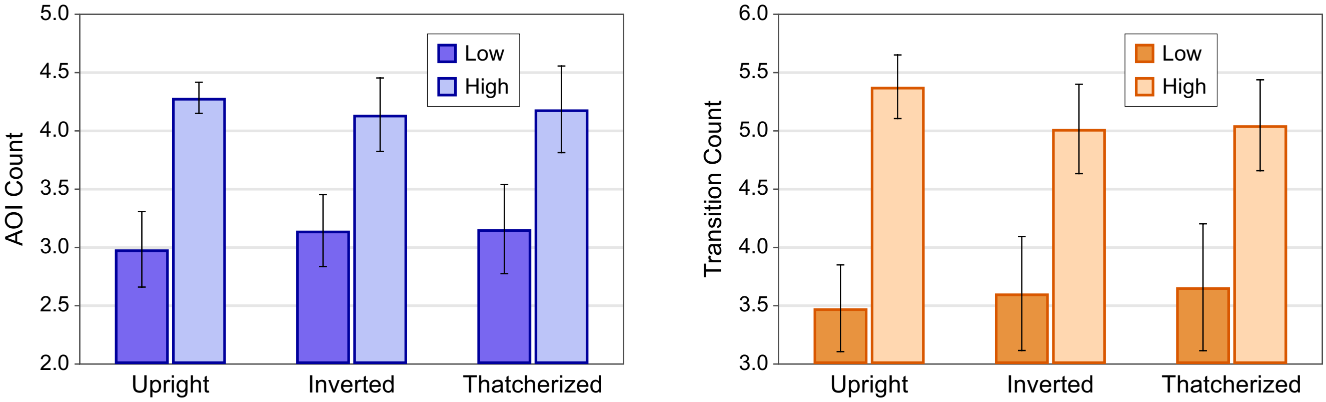

Figure 3. A — average number of AOIs visited in "Low" and "High" groups in the three stimulus conditions; B — average number of transitions between AOIs in "Low" and "High" groups in the three stimulus conditions. Error bars refer to the standard error.

$\eta_p^2 = .135$) and no differences between different conditions within the AOI count indicator ($F(1) = 0.470$, $p = .495$, $\eta_p^2 = .005$). The pairwise multiple comparisons test showed that the number of transitions between AOIs significantly declined from the upright to the inverted and thatcherized stimulus conditions ($p < .001$, $p = .001$ respectively).

High correlation between the individual parameters of eye movements under the different conditions of stimulus presentation was revealed both for AOI count ($r = .920$ (thatcherized and inverted); $r = .740$ (inverted and upright); $r = .759$ (upright and thatcherized)) and for transition count (respectively, $r = .901$; $r = .816$; $r = .811$), $p < .001$ in every case. This allowed us to point out individual dynamic strategies of eye movements during facial expression recognition. To illustrate this we used data from the upright stimuli to distinguish upper ("High") and lower ("Low") groups of participants from the whole sample, differing in both analyzed eye movement parameters. Participants who entered the lower quartiles (both in the AOI count and transition count) formed the lower group ($n = 20$; 22% of the sample), which was characterized by a limited number of viewed facial areas ($M = 2.98$, $SD = 0.32$) and rare gaze transitions between them ($M = 3.47$, $SD = 0.37$). Participants who entered the upper quartiles of both parameters formed the upper group ($n = 17$; 18% of the sample), which was characterized by a high number of viewed facial areas ($M = 4.28$, $SD = 0.13$) and frequent gaze transitions ($M = 5.38$, $SD = 0.27$). The described eye movement strategies tended to persist with changes in the stimulus presentation conditions, namely with inversion and thatcherization of the stimuli (see Figure 3).

The main purpose of the study was to compare eye movement strategies and the strength of holistic effects in each participant. Spearman's ρ was used because of an abnormal distribution of intensities of the inversion and thatcherization effects. No significant correlations were found between the strength of perceptual effects and eye movement characteristics (see Table 1).

Discussion

Despite differences in the intensities of inversion and thatcherization effects, the results showed a significant correlation between the strength of these effects in individual participants. Participants demonstrating a substantial impairment in facial expression recognition with image inversion were also less successful under the thatcherized stimulus condition. Participants who were less susceptible to the inversion effect also showed a less pronounced effect of stimulus thatcherization. This argues in favor of the universality of the perceptual mechanism underlying these effects.

We also observed a high correlation between the parameters of eye movements under various presentation conditions. Participants prone to visiting a limited number of internal facial features retained this tendency even when the image was inverted or thatcherized. The same refers to participants who showed a tendency to switch often between the eyes, nose and mouth of the

Table 1. **The Value of the Correlation Coefficient ρ Representing the Relationship Between the Strength of the Inversion and Thatcherization Effects and Eye Movement Parameters (the Average Visited AOI Count and the Number of Transitions Between AOIs)**

		Inversion Effect		Thatcherization Effect	
	Presentation Condition	Correlation Coefficient	Significance (2-way)	Correlation Coefficient	Significance (2-way)
AOI Count	Thatcherized	.088	.404	.114	.281
	Inverted	.078	.459	.130	.217
	Upright	.140	.183	.133	.205
Transition Count	Thatcherized	.104	.324	.199	.057
	Inverted	.097	.358	.178	.090
	Upright	.103	.330	.086	.413

Note. Values were counted under three conditions: upright, inverted and thatcherized (in each condition, $N = 92$).

person in the photo. However, it should be noted that our analysis showed a small but significant decrease in the number transitions in inverted stimuli in comparison to upright ones. The reduced number of saccades between AOIs may be interpreted as a contradiction to some other researchers' data. Xu and Tanaka (2013) described a total increase in the number of saccades in a discrimination task with two successively presented inverted faces compared to the upright condition. Uts and Karbon (2016) showed that the number and duration of fixations on an upright face were less than on an inverted one. However, it should be noted that there is some difficulty of direct comparison of the data because of the different parameters used. We did not analyze the total number of saccades and fixations, their duration and distribution by specific facial areas. In this study, we were interested in the number of facial features viewed by the participant (whether making one or more fixations on each feature) and the number of gaze transitions between them, rather than within a certain area. In addition, the data were obtained in different visual tasks with different experimental procedures and different durations of stimulus presentation. So, we can point out that, individually, specific eye movement strategies in the process of facial expression recognition are generally stable. This is consistent with the finding that eye movement patterns are weakly dependent on the upright or inverted presentation conditions (Williams & Henderson, 2007; Barabanshchikov & Zhegallo, 2012).

Nonetheless, we found no correlations between the strength of inversion and thatcherization effects and eye movement characteristics. This differs from the expected result and is more consistent with the findings of Williams and Henderson (2007) and Heering and Rossion (2008). It seems that the oculomotor strategies for collecting information do not display the analytic or holistic mechanisms of its processing in facial expression recognition. More likely, they are independent parts of the perceptual process, possibly representing the individual manner of visual information collection.

Conclusion

The results of the study allow us to draw certain conclusions about the presence of correlation in the strength of the effects of inversion and thatcherization, as well as the presence of correlations in such eye movement parameters as the number of viewed AOIs and the number of glance transitions between them. This suggests the universality of some perceptual mechanisms underlying the effects of inversion and thatcherization, as well as the presence of individual dynamic strategies of eye movements during facial expression recognition. At the same time, the results do not support the hypothesis that eye movement strategies (in particular, the number of facial areas viewed and the rate of gaze shifts between facial features) are a reflection of holistic or feature-based face processing.

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Стратегии движений глаз при распознавании лицевой экспрессии не связаны с выраженностью эффектов инверсии и тэтчеризации

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Аннотация. Данная работа посвящена исследованию механизмов распознавания лицевой экспрессии. В частности, изучался вопрос о наличии взаимосвязи между стратегиями движения глаз при рассматривании лица и выраженностью холистических эффектов восприятия, а именно эффекта инверсии. Предполагалось, что если в основе холистических и аналитических перцептивных механизмов лежат определенные специфические стратегии рассматривания изображений, то будет обнаружена связь между высокой выраженностью эффекта инверсии и определенными характеристиками движений глаз (количеством черт лица, на которые приходились фиксации, и числом переходов взгляда между ними). Высокая выраженность эффекта инверсии, измеряемого как снижение точности распознавания экспрессий на перевернутых на 180° лицах в сравнении с предъявляемыми в обычном виде, свидетельствует о доминировании холистических процессов в восприятии лица. В эксперименте по распознаванию лицевой экспрессии мы проанализировали ответы и данные регистрации движений глаз 92 участников. В качестве стимулов использовались фотографии четырех персонажей из базы данных WSEFEP (Olszanowski et al., 2015), каждый из которых изображал по семь базовых эмоций. Стимулы предъявлялись испытуемым в трех условиях: обычном, перевернутом на 180° и тэтчеризованном. Был использован внутрисубъектный дизайн. Полученные результаты выявили значимую корреляцию между проявлениями эффектов инверсии и тэтчеризации, что свидетельствует в пользу универсальности механизма, используемого конкретным человеком при распознавании лицевой экспрессии. Выявлена высокая корреляция между характеристиками движений глаз в трех условиях предъявления, что свидетельствует об индивидуально-специфическом типе глазодвигательной активности. Однако корреляции между выраженностью холистических механизмов и исследованными параметрами движений глаз обнаружено не было. Вероятно, окуломоторные стратегии сбора информации не отражают аналитические или целостные механизмы ее обработки при распознавании лицевой экспрессии.

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Ключевые слова: распознавание лицевой экспрессии, стратегии движения глаз, аналитические механизмы, холистические механизмы, эффект инверсии, эффект тэтчеризации

Статья частично основана на материалах более ранней публикации предварительных результатов в сборнике конференции: *Лунякова Е. Г.*, *Гани-задэ Д. С.* Стратегии движений глаз при распознавании лицевой экспрессии не связаны с выраженностью эффекта инверсии // Когнитивная наука в Москве: новые исследования. Материалы конференции 19 июня 2019 г. / Под ред. Е. В. Печенковой, М. В. Фаликман. М.: Буки Веди, ИППиП. С. 328–334.

Благодарности. Исследование выполнено при поддержке гранта РФФИ (Проект № 18-013-01087А).

Статья поступила в редакцию 5 августа 2019 г. Принята в печать 21 сентября 2019 г.

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