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Research article

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Post-COVID Color Perception: The Impact of COVID-19 on Color Naming

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Abstract: **Introduction**. There is an accumulating evidence of various ophthalmological symptoms, accompanied by visual impairment, post-COVID-19. We hypothesized that color vision may have been affected post-COVID-19 too manifesting as changes in color-naming patterns. To test this hypothesis, we compared color naming in individuals who have recovered from COVID-19 (N = 201, 54 men and 147 women, aged 19–65 years, M = 33.4, SD = 13.2) and those participants whose responses were obtained before the pandemic (hereafter, non-COVID-19 controls) (N = 2,457, 1,052 men and 1,402 women, aged 16–98 years, M = 41.36, SD = 17.7). **Methods**. We collected data in an online experiment (http://colournaming.com) with Russian respondents in their native language. Participants were presented, with virtual color cards selected from 606 stimuli randomly by a computer program. We asked respondents to name each color using the most appropriate color descriptor (an unconstrained color-naming method). **Results**. The study showed that, compared to non-COVID-19 controls, post-COVID-19 respondents revealed an altered pattern of color naming. In particular, we found a significant increase in 'brown', 'green', and 'gray' names, along with an increased use frequency of achromatic modifiers "dirty", "pale", "dull", and "pastel". **Discussion**. These differences suggest general "darkening" and decreased saturation of perceived colors. The change in the color-naming pattern provides an indirect evidence of the impact of coronavirus on color vision. We speculate that a relatively high frequency of use of color terms *koričnevyj* 'brown' and *seryj* 'gray' may reflect an accelerated aging of the crystalline lens, while general "darkening" and desaturation of perceived colors may point to an affected processing of luminance contrast. These assumptions are currently being tested (by the authors) in COVID-19 survivors by using a color vision diagnostic test.

Keywords: color perception, psycholinguistic experiment, color naming, COVID-19, post-COVID syndrome, color categories, color vision, CIELAB, color space, chromatic discrimination

Highlights:

- In post-COVID-19 (Russian) individuals, the pattern of color naming is altered with regard to both relative frequency of basic color terms and their denotative meanings.

➢ The revealed differences indicate general "darkening" and desaturation of perceived colors, in post-COVID-19 individuals.
➢ Provided these phenomena will be confirmed by testing color vision in post-COVID-19 individuals, they may be indicative of an affected processing of luminance contrast.

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Introduction

There is an accumulating evidence that COVID-19 survivors reveal various ophthalmological symptoms accompanied by visual impairment. The most common symptoms include eye pain (19.4 %), photophobia (13.9 %), light flashes or floaters (11.8 %), blurred vision (11.1 %), and red eyes (10.4 %) (Gangaputra & Patel, 2020). Clinically, such symptoms may be associated with higher intraocular pressure, spasm of ocular muscles, clouding of the vitreous body (reducing the intensity of light falling onto the retina), and various symptoms of retinopathy – dilation of retinal veins and arteries, discrete changes in the structure of photoreceptor outer segments and inner retinal layers (Costa et al., 2021; Invernizzi et al., 2020; Yusef et al., 2021).

Currently it is unclear whether coronavirus affects color vision. However, according to previous studies unrelated to COVID-19, the changes in the visual system functioning, such as higher intraocular pressure and retinopathy, are accompanied by color-vision impairment. In particular, a significant number of patients with long-term ocular hypertension revealed selective changes in functioning of both blue-yellow and red-green channels (see, e.g., Castelo-Branco et al., 2004). Also, in patients with type II diabetes mellitus, diabetic retinopathy caused by microvascular changes in the retina is accompanied by color-vision impairment along the blue-yellow axis of the color space (for a review, see Simunovic, 2016). Moreover, in comparison with healthy normal trichromats, such patients have difficulties in discriminating low-saturated colors and predominantly rely on their differences in luminance (Bimler et al., 2014).

Psycholinguistic studies demonstrated that changes in physiological processes in the eye and the visual system affect color naming. For example, age-related changes in the visual system – such as yellowing and clouding of the crystalline lens, decreased pupil size and photoreceptor sensitivity – are manifested in a greater variability of naming colors in green, blue, purple, and brown parts of color space, as well as in an increase of frequency of compounds with *seryj*- 'gray'- and achromatic modifiers (*svetlyj* 'light', *tëmnyj* 'dark') (Hardy et al., 2005; Lindsey & Brown, 2002; Wijk et al., 1999, 2002).

In the present context, it is worth ing that psycholinguistic experiments may provide an insight on the nature of the change or impairment of color vision. In particular, analysis of color-naming patterns in observers with different types of color-vision abnormalities enabled to make inferences about characteristics of their color vision and reconstruct their perceptual color spaces (Montag, 1994; Paramei, 1996; Shepard & Cooper, 1992). Furthermore, the kind of distortions of color space structure has been shown to reflect the type and the degree of color -vision abnormality (anomalous trichromacy or dichromacy) (Paramei, 1996).

In the present study of color names, we leaned upon Berlin and Kay's (1969/1991) theory of universal basic color categories (BCCs) and the corresponding basic color terms (BCTs). The BCTs are to apply to diverse classes of objects and be psychologically salient to all informants implying that they occur in ideolects of all respondents and used by them with high consensus. In Russian, there are 12 BCTs; six of them are primary – *čërnyj* 'black', *belyj* 'white', *krasnyj* 'red', *zelënyj* 'green', *žëltyj* 'yellow', and *sinij* 'blue'; the remaining six categories are secondary – *koričnevyj* 'brown', *goluboj* 'light blue', *rozovyj* 'pink', *oranževyj* 'orange', *fioletovyj* 'purple', and *seryj* 'gray' (see, e.g., Griber et al., 2021).

In addition to BCTs, native Russian speakers have a rich vocabulary of color names which includes combinations of BCTs with achromatic modifiers (*svetlyj* 'light', *tëmnyj* 'dark', etc.), suffixed forms (e.g., *sinevatyj* 'bluish'), as well as non-BCTs, such as *vasil'kovyj* 'cornflower', *lososevyj* 'salmon', *salatovyj* 'lettuce-colored', *bordovyj* 'claret', etc. (see, Griber et al., 2018).

Based on the available data, we hypothesized that, compared to controls, post-COVID-19 respondents may have impaired color vision; if this is the case, it would manifest itself as an altered color-naming pattern – for example, as a predominance of certain BCTs and/or as changed frequencies of certain compound names. We also hypothesized that there would be a change in the denotative meanings of the BCTs, i.e., color stimuli they denote. To test this hypothesis, we compared color naming of individuals who have recovered from COVID-19 with healthy controls' responses that had been obtained before the pandemic (Griber et al., 2021).

Methods

Participants

In the study 2022, the post-COVID-19 sample comprised 201 participants (54 men, 147 women) aged 19–65 years (M = 33.4, SD = 13.2). All respondents had suffered from coronavirus infection in various forms of the disease and the doctor's confirmed diagnosis. Responses (N = 5,215) from the 2022 sample were compared with those (N = 55,515) from the pre-pandemic control group obtained in 2018–2019 that comprised 2,457 participants (1,052 men, 1,402 women) aged 16–98 years (M = 41.36, SD = 17.7), with normal color vision confirmed by the Barbour test (Barbur et al., 1994).

Self-report of wellbeing in post-COVID-19 participants

To assess coronavirus-related changes in wellbeing and lifestyle, we used *the COVID-19 Yorkshire Rehabilitation Scale* (C19-YRS), with 15 items (O'Connor et al., 2022), modified for Russian-speaking respondents by one of the authors (Yu. A. Griber).

Almost all the participants in our study (96.5 %) commented that in some degree the disease had changed their usual way of life. In particular, more than a half (54 %) developed dyspnea, 6 % severely dyspnea; they became fatigued more quickly than before the disease (55.8 %). More than a third (37 %) post the disease registered problems with mobility (walking, movement). After the recovery many (54.2 %) still experience pain or discomfort in their joints, cough during strenuous exercise or without such, heart problems, problems with hearing and blood pressure, headaches, and abnormal blood test results. Individual participants remarked on hair loss, weight gain, muscle weakness, or drowsiness. The disease also affected effectiveness of their routine activities, life satisfaction, and subjective wellbeing (Klimochkina et al., 2022). By the time of the study, more than half (54.2 %) experienced problems with performing their usual activities (household chores, leisure) or professional activities (work or studies).

The participants commented that they tried not to think about the disease, however, almost half of them (45.5 %) failed. Many respondents reported experiencing anxiety and depression (Dovbysh & Kiseleva, 2020). A few (4.5 %) even had thoughts of harming themselves in some way. These symptoms are in accord with those described in a systematic review of a large number of COVID-19 studies in various countries (Ceban et al., 2022).

There also appeared cognitive problems – with concentration (39.1 %) and short-term memory (38.5 %). Further, some respondents (23.7%) reflected on a change in the way they interacted with others: it became more difficult for them to comprehend the content of the oral or written narrative, to express their own thoughts or conduct a conversation. The overwhelming majority (82.1 %) reported changed sense of smell and more than half (55.8 %) changed sense of taste during or after the disease.

In general, using a scale from 0 to 10, with "0" indicating "it can't be worse" and 10 standing for "excellent", the post-COVID-19 participants gave, on average, wellbeing rating of 6.

The online experiment

We collected data from native Russian speakers in an online experiment (http://colournaming.com). The participants were instructed to choose most appropriate names for virtual color stimuli randomly selected by the computer program from a predefined set of samples (see, e.g., Griber et al., 2021). Participants could offer any linguistic form of a color name – a simple or a complex word, binary compounds or multi-component words.

The devices used for the experiment (computer, laptop, or tablet PC) were chosen by the participants individually. The color samples were presented one-by-one, on a gray background; the presentation time was not limited. Each subsequent stimulus appeared only after the color name of the previous one has been entered using a keyboard.

Stimuli

A total of 606 color samples were used in the study, whose photometric coordinates were defined using the CIELAB system. The CIELAB system is an international standard that enables characterization of a color using three coordinates: two coordinates represent chromaticity (a^* – red-green and b^* – blue-yellow components) and the third one represents lightness (L^*). The chromaticity coordinates (a^* and b^*) may be both positive and negative: a positive value of a^* corresponds to the reddish gamut, while a negative value of a^* corresponds to the greenish gamut. A positive value of b^* corresponds to the yellow(ish), while a negative value of b^* corresponds to blue part of color space. The lightness value (L^*) can vary from $L^* = 0$ (black) to $L^* = 100$ (white). Medium L^* values correspond to shades of gray.

The theoretical framework for this model, developed by the International Commission on Illumination (*Communication Internationale de l'Eclairage*, *CIE*), is based on Hering's (1964) opponent-colors theory. According to this theory, normal color vision implies three postreceptor channels; two of these are chromatic and opponent – red-green and blue-yellow; the achromatic channel transmits information about lightness, not about hue.

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Intergroup comparisons

The following linguistic indices were used for the intergroup comparison of color-naming patterns in post-COVID-19 participants and non-COVID-19 controls:

(1) frequency of the BCTs (N = 12) and most frequently offered non-BCTs;

(2) frequency of achromatic modifiers;

(3) number of words in color descriptors;

(4) color-naming patterns.

Psycholinguistic analysis of intergroup comparison included:

(5) estimating centroids of the BCCs and most frequent non-BCCs, coordinates of the points in the CIELAB color space, calculated as weighted averages for the corresponding BCC along each of the dimensions (a^*, b^*, L^*);

(6) estimating distances between BCC centroids in the CIELAB color space;

(7) cluster analysis of the shifts in denotative meanings of the BCTs and most frequent non-BCTs.

Data analysis

We compared diversity of color names derived from the BCTs using the Simpson index (Simpson, 1949) according to the formula:

$D = 1 - \Sigma(n_i (n_i - 1)) / N(N-1)$,

where n_i corresponds to the number of color names (word types) and N is the number of responses.

The Simpson index takes into account not only the number of word types in the dataset but also the number of occurrences of each word type. Its value ranges from 0 to 1 and represents the probability that two responses chosen at random from the dataset may contain different types of color names.

Since each color sample was described by certain CIELAB coordinates, systematization of the responses enabled us to produce denotative maps of colors for each of the BCC.

Since in 3D color space color categories are not points but areas with fuzzy borders and a cloud-like shape, for each of the BCC we calculated a "center of gravity" (centroid) – average values of the three CIELAB coordinates (a^*, b^*, L^*) of all the color samples with the same name.

The centroids were represented graphically in 2D and 3D CIELAB space. To compare centroids of the BCCs and most frequent non-BCCs in the CIELAB color space, we applied *Delta E2000* color difference formula (ΔE^*00; CIELAB) (Sharma et al., 2005).

Psycholinguistic analysis of the data (7) was performed using an agglomerative hierarchical clustering R program of *the Microsoft R Open 3.5*. Distances between clusters were calculated using Ward's minimum variance algorithm (Ward.D2; Ward, 1963). For visualization, *ggplot2* package was used.

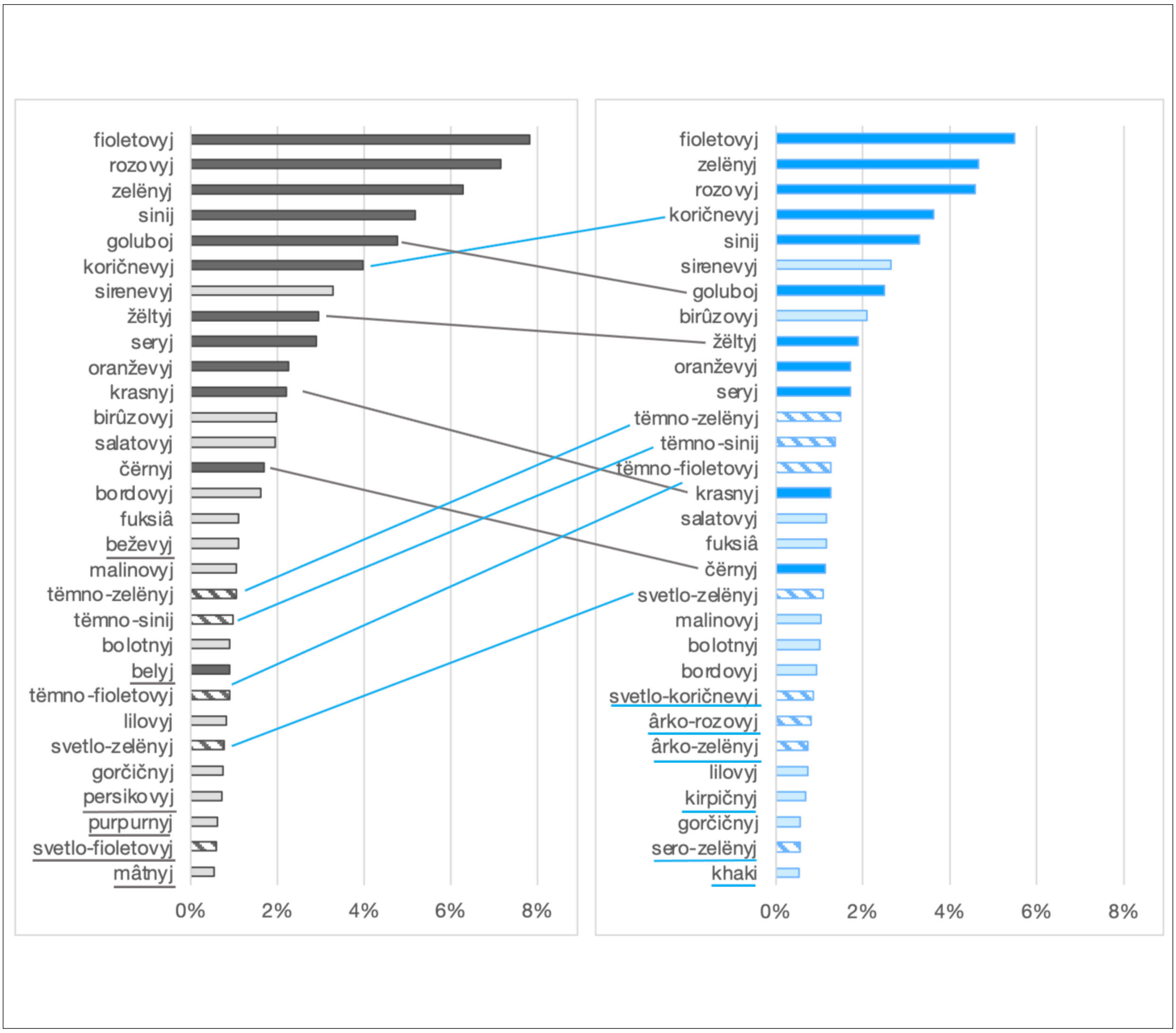
Results

(2.1) Linguistic analysis: frequency of occurrence of color terms and color-naming patterns

Comparative analysis of ranks of the 30 most frequently used color names (Fig. 1) showed that the participants of both groups used BCTs more frequently than non-BCTs. Notably, post-COVID-19 participants were much less likely to use color name *belyj* 'white', which ranked 49, compared to rank 22 in non-COVID-19 controls. Also, post-COVID-19 respondents offered color names *čërnyj* 'black' and *krasnyj* 'red' less frequently (ranks 15 and 18, respectively) compared to controls (ranks 11 and 14, respectively).

Figure 1

30 most frequent Russian color names in non-COVID (left) and post-COVID (right) respondents

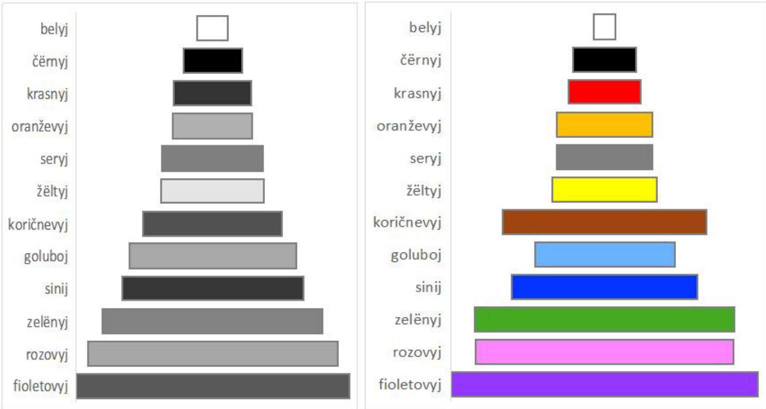


BCTs are indicated by bars, frequent non-BCTs by unfilled bars, and modified or compound terms are thatched. Underlined are color names offered frequently by one group but not by the other.

Ranking based on frequency of the 12 BCTs in both groups is comparable with one exception: post-COVID-19 participants used color name *koričnevyj* 'brown' considerably more frequently. Figure 2 shows a hierarchical diagram of relative frequency of each of the 12 BCTs. The hierarchy is organized in the order for non-COVID-19 controls (left), from highest (bottom) to lowest frequency (top). For the group of post-COVID-19 participants (right), the order of the BCT frequency is identical to that of the controls, despite the change in relative frequency of the BCTs.

Figure 2

Frequency of the 12 Russian basic color terms in non-COVID-19 controls (left) and post-COVID-19 participants (right)

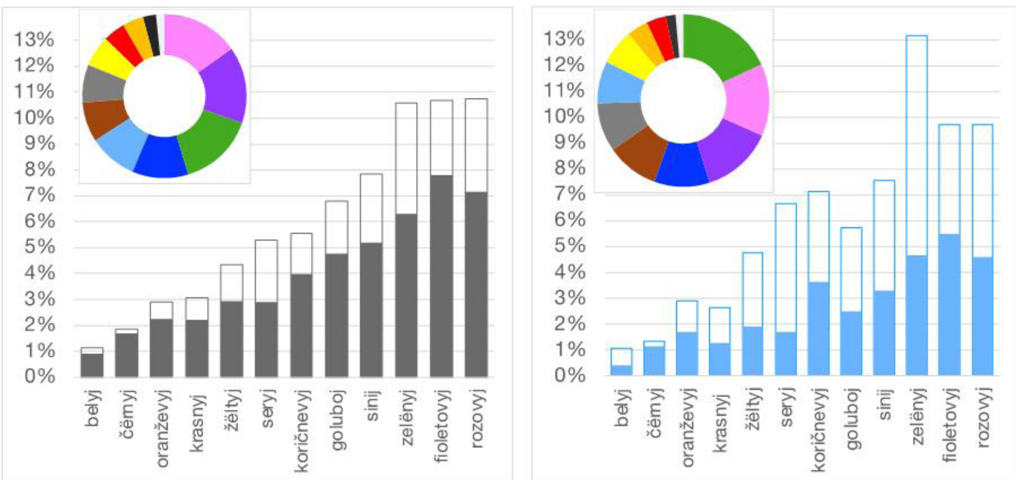


Furthermore, post-COVID-19 participants used elaborated color names derived from the BCTs *zelënyj* 'green', *koričnevyj* 'brown', *seryj* 'gray', *žëltyj* 'yellow', and *oranževyj* 'orange' more frequently than controls; in contrast, they offered derivatives of BCTs *goluboj* 'light blue', *sinij* 'dark blue' and *krasnyj* 'red' much less frequently than controls (Fig. 3).

In addition, compared to controls, in post-COVID-19 participants, the Simpson diversity index was markedly higher for two BCTs – *zelënyj* 'green' (0.63 and 0.85, respectively) and *koričnevyj* 'brown' (0.43 and 0.71, respectively).

Figure 3

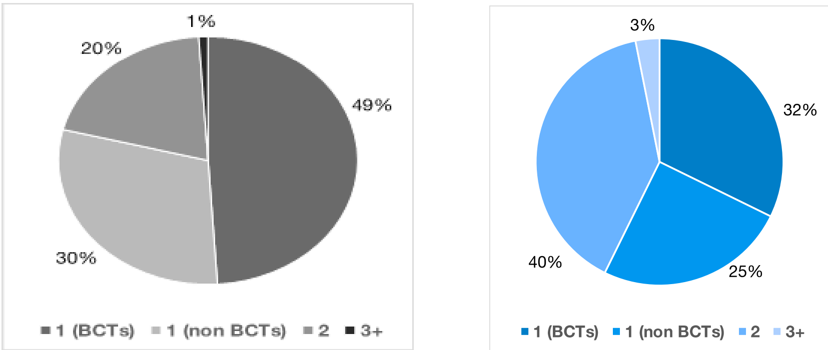
Relative size of the "families" derived from the 12 Russian BCTs in non-COVID-19 controls (left) and post-COVID-19 participants (right). In each "family", the proportion of a BCT is shown by a solid bar supplemented by the proportion of its derivative forms.



Noteworthy, the respondents who had recovered from COVID-19 were inclined to use lexically elaborated color descriptors (Fig. 4). In particular, compared to non-COVID-19 controls, they used less frequently monolexemic *krasnyj* 'red' (49 % and 32 %, respectively) or non-BCT *birûzovyj* 'turquoise' (30 % and 25 %, respectively), and preferred multi-component names to itemize and specify the color (e.g., *nežno-zelënyj travânoj* 'soft/tender green grass' or *koričnevyj s rozovatym ottenkom* 'brown with a pinkish tint').

Figure 4

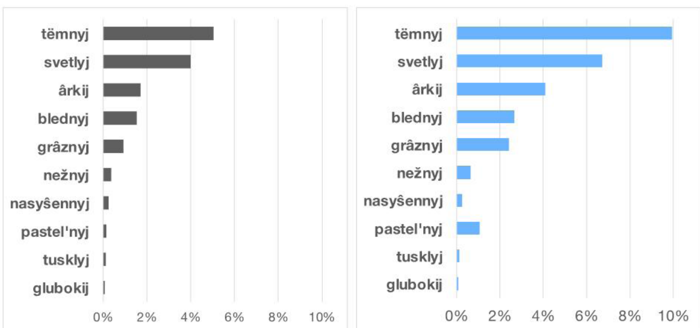
The number of words in Russian color descriptors in the groups of non-COVID-19 controls (left) and post-COVID-19 respondents (right)



Another important difference between the two groups was prevalence of a certain color-naming patterns. Compared to the control group, those who had recovered from COVID-19 were (almost) twice as likely to use achromatic modifiers – *tëmnyj* 'dark' (5.0 % and 10.0 %, respectively), *svetlyj* 'light' (4.0 % and 6.7 %), *ârkij* 'bright' (1.7 % and 4.1 %), *blednyj* 'pale' (1.5 % and 2.7 %), or *nežnyj* 'soft, tender' (0.4 % and 0.7 %). Furthermore, they were almost three times as likely to use *grâznyj* 'dirty' (0.9 % and 2.4 %, respectively) and almost seven times as likely to use *pastel'nyj* 'pastel' (0.2 % and 1.1 %), implying unsaturated and dull shades (Fig. 5). Also, in their responses, frequent were lightness-modified BCTs (e.g., *tëmno-zelënyj* 'dark green', *tëmno-sinij* 'dark *sinij*' or *tëmno-fioletovyj* 'dark purple') (cf. Fig. 1).

Figure 5

Frequency of achromatic modifiers in Russian compound color names in non-COVID (left) and post-COVID (right) respondents

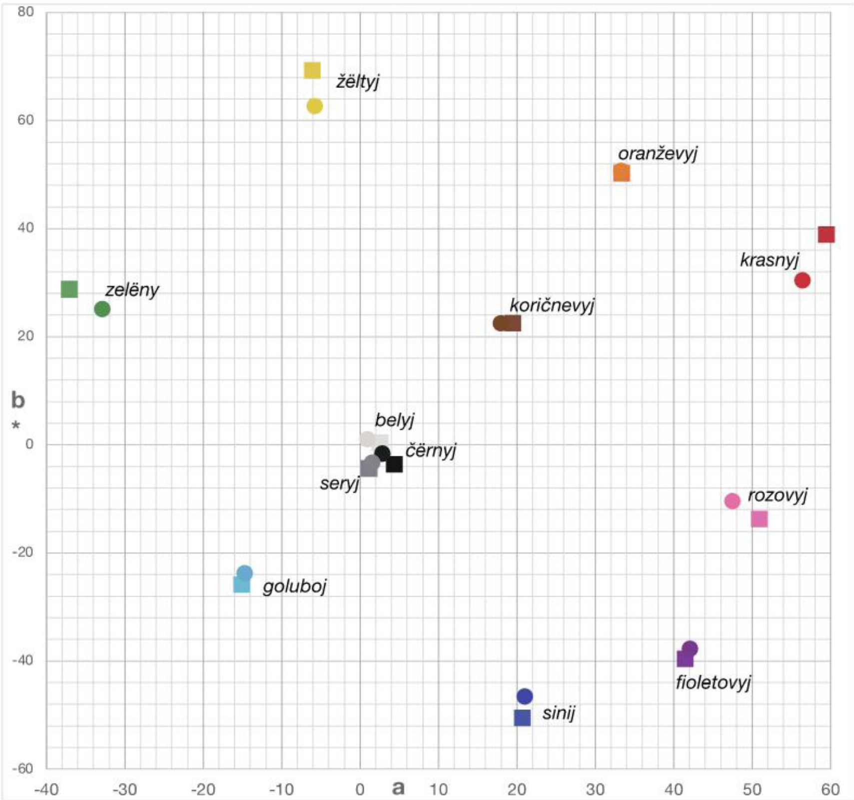


(2.2) Psycholinguistic analysis: coordinates of centroids of basic color categories in the CIELAB color space

Between the groups of post-COVID-19 participants and non-COVID-19 controls, the greatest CIELAB differences in centroids were found for the "opponent" primary BCCs *krasnyj* 'red' (ΔE*ab = 4.22) and *zelënyj* 'green' (ΔE*ab = 3.42); *žëltyj* 'yellow' (ΔE*ab = 2.68) and *sinij* 'dark blue' (ΔE*ab = 2.60); and f *belyj* 'white' (ΔE*ab = 3.14) and *čërnyj* 'black' (ΔE*ab = 2.81). In addition, in post-COVID-19 participants centroids of *krasnyj* 'red' and *zelënyj* 'green', *žëltyj* 'yellow' and *sinij* 'dark blue' BCCs were shifted to the periphery of the CIELAB chromatic plane *a*b**, compared to non-COVID controls (Fig. 6).

Figure 6

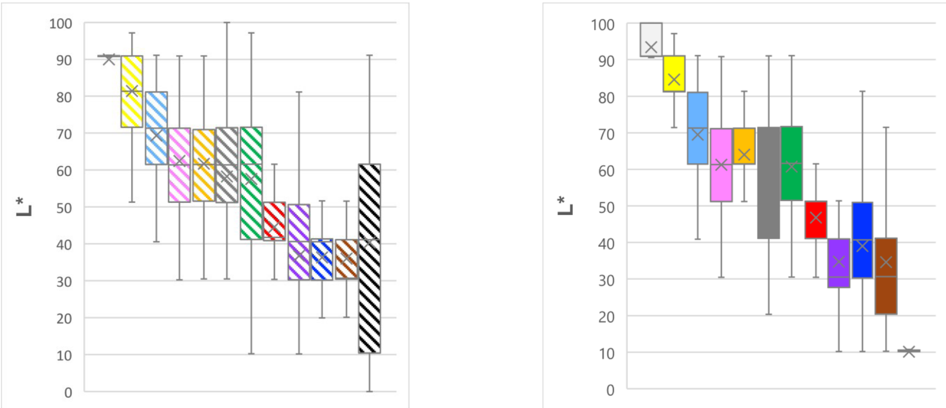
*Centroids of the 12 Russian basic color categories in projection onto the chromatic plane a*b* of the CIELAB color space. Circles – non-COVID-19 controls, squares – post-COVID-19 participants*



For post-COVID-19 participants, denotative meanings of "darker" chromatic categories of *koričnevyj* 'brown' and *sinij* 'dark blue', as well as those of light(er) achromatic categories of *seryj* 'gray' and *belyj* 'white', had a much larger variation in the lightness component (*L**). In comparison, denotative meanings of *žëltyj* 'yellow', *oranževyj* 'orange', *fioletovyj* 'purple', and *čërnyj* 'black' varied much less along the lightness dimension (Fig. 7).

Figure 7

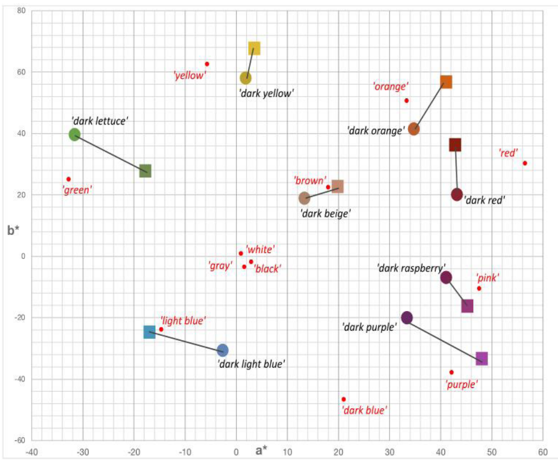
Lightness (L) of colors denoted by the BCTs in non-COVID-19 controls (left) and post-COVID-19 participants (right). The 12 Russian BCCs are arranged according to the mean lightness (L*) of their denotata (in descending order) for the group of non-COVID-19 controls*



Also, we found considerable differences in denotative meanings of non-BCTs *beževyj* 'beige', *salatovyj* 'lettuce-colored', *lilovyj* 'mauve', *malinovyj* 'raspberry', predominantly when these denoted darker shades of blue, green, purple, brown, and red areas of color space, as illustrated by Figure 8. The shifts of centroids of these non-BCCs to the periphery of the chromatic plane *a*b** in post-COVID-19 participants indicates that, compared to the controls, they used the names in question to denote more saturated colors.

Figure 8

*Centroids of the categories of color names denoting dark shades in projection onto the chromatic plane a*b* in the CIELAB color space. Circles – non-COVID-19 controls, squares – post-COVID-19 participants. Red points and accompanying names (in red) depict centroids and names of the "parent" BCTs or frequent non-BCTs*



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For post-COVID-19 participants, Tables 1–5 present detailed information on the centroid shifts (in DE_{00} units) of BCCs and some non-BCCs with frequent achromatic modifiers (*tëmnyj* 'dark', *svetlyj* 'light', *ârkij* 'bright', *blednyj* 'pale', and *grâznyj* 'dirty'). Table 1 indicates that the greatest "darkening" is observed for the color names in the blue-purple area of color space, *goluboj* 'light blue' and *lilovyj* 'mauve', while the greatest "dullness" of perceived colors is observed in the yellow-green areas (Table 5).

Table 1

Centroids (sr) of color names with the modifier tëmnyj 'dark' on each of the three coordinates of the CIELAB color space and their shifts (DE_{00}) in post-COVID-19 participants compared to the controls

Color names	Non-COVID-19 controls			Post-COVID-19 participants			DE_{00}
	sr_L*	sr_a*	sr_b*	sr_L*	sr_a*	sr_b*	
tëmno-bordovyj 'dark claret'	19.05	28.03	–0.85	18.97	28.38	–2.73	1.16
tëmno-fioletovyj 'dark purple'	19.92	28.96	–23.82	21.72	27.27	–23.79	1.51
tëmno-birûzovyj 'dark turquoise'	49.41	–21.34	–7.69	50.90	–23.15	–7.38	1.85
tëmno-sirenevyj 'dark lilac'	38.60	35.57	–30.70	40.05	31.51	–28.17	2.05
tëmno-sinij 'dark b *sinij*'	20.22	15.19	–31.75	22.77	16.38	–34.47	2.09
tëmno-rozovyj 'dark pink'	50.62	44.13	–4.38	50.28	48.68	–7.70	2.12
tëmno-seryj 'dark gray'	30.94	1.23	–6.23	34.83	1.02	–6.47	3.14
tëmno-zelënyj 'dark green'	29.52	–17.23	11.38	34.06	–18.53	12.47	3.70
tëmno-koričnevyj 'dark brown'	19.40	14.30	11.48	23.71	15.42	8.21	4.12
tëmno-beževyj 'dark beige'	58.51	13.35	18.86	62.73	19.90	22.72	5.51
tëmno-oranževyj 'dark orange'	50.24	34.75	41.41	54.22	41.11	56.72	6.37
tëmno-salatovyj 'dark lettuce'	61.06	–31.57	39.60	55.43	–17.74	27.78	8.34
tëmno-žëltyj 'dark yellow'	67.19	1.89	58.02	77.97	3.60	67.71	8.52

Color names	Non-COVID-19 controls			Post-COVID-19 participants			DE_{00}
	sr_L*	sr_a*	sr_b*	sr_L*	sr_a*	sr_b*	
tëmno-krasnyj 'dark red'	31.80	43.18	20.09	30.50	42.88	36.22	8.97
tëmno-malinovyj 'dark raspberry'	29.64	41.07	–6.92	39.35	45.23	–16.26	9.15
tëmno-goluboj 'dark light blue'	53.79	–2.65	–30.72	58.16	–16.93	–24.71	10.67
tëmno-lilovyj 'dark mauve'	28.10	33.43	–20.10	44.83	48.04	–33.39	15.38

Table 2

Centroids (sr) of color names with the modifier svetlyj 'light' in each of the three coordinates of the CIELAB color space and their shifts (DE_{00}) in post-COVID-19 participant compared to the controls s

Color names	Non-COVID-19 controls			Post-COVID-19 participants			DE_{00}
	sr_L*	sr_a*	sr_b*	sr_L*	sr_a*	sr_b*	
svetlo-koričnevyj 'light brown'	53.60	15.60	24.71	54.10	15.14	24.72	0.59
svetlo-fioletovyj 'light purple'	56.25	34.68	–35.84	56.04	36.17	–36.33	0.62
svetlo-rozovyj 'light pink'	74.73	27.54	–6.27	73.14	29.57	–5.83	1.54
svetlo-krasnyj 'light red'	52.93	47.61	21.83	51.18	48.74	23.37	1.88
svetlo-žëltyj 'light yellow'	85.20	–6.74	44.86	85.32	–3.02	42.87	2.55
svetlo-seryj 'light gray'	77.48	1.09	–2.98	78.37	2.86	–4.19	2.57
svetlo-lilovyj 'light purple'	67.56	24.25	–21.52	68.06	21.17	–25.12	3.39
svetlo-sirenevyj 'light lilac'	67.78	25.29	–26.22	67.09	33.76	–27.51	3.93
svetlo-zelënyj 'light green'	75.39	–36.50	24.79	80.10	–32.32	29.48	4.68

Color names	Non-COVID-19 controls			Post-COVID-19 participants			DE_{00}
	sr_L*	sr_a*	sr_b*	sr_L*	sr_a*	sr_b*	
svetlo-bordovyj 'light claret'	42.99	35.51	0.68	46.13	31.69	5.84	4.72
svetlo-birûzovyj 'light turquoise'	81.76	–30.44	2.33	88.96	–31.95	0.76	4.88
svetlo-oranževyj 'light orange'	72.94	21.48	43.84	73.90	27.07	37.50	5.70
svetlo-salatovyj 'light lettuce'	85.50	–35.36	33.14	80.27	–34.32	46.77	6.59
svetlo-beževyj 'light beige'	81.98	7.17	17.94	81.12	1.73	11.08	6.71
svetlo-sinij 'light blue'	52.11	10.82	–41.98	60.01	–2.14	–31.38	9.40
svetlo-goluboj 'light light blue'	79.03	–15.55	–12.36	71.81	–1.01	–18.90	14.12

Table 3

Centroids (sr) of color names with the modifier blednyj 'pale' in each of the three coordinates of the CIELAB color space and their offsets (DE_{00}) in post-COVID-19 participants compared to the controls

Color names	Non-COVID-19 controls			Post-COVID-19 participants			DE_{00}
	sr_L*	sr_a*	sr_b*	sr_L*	sr_a*	sr_b*	
bledno-rozovyj 'pale pink'	72.94	25.08	–3.20	71.69	29.06	–1.02	2.54
bledno-krasnyj 'pale red'	57.78	44.29	18.96	56.78	54.05	22.44	3.20
bledno-zelënyj 'pale green'	73.03	–27.03	17.58	76.36	–21.32	16.70	3.73
bledno-žëltyj 'pale yellow'	85.13	–7.87	40.18	85.99	–0.96	34.35	5.20
bledno-oranževyj 'pale orange'	68.63	26.94	37.31	71.32	18.11	27.83	5.25
bledno-sirenevyj 'pale lilac'	69.05	17.52	–20.02	78.14	17.08	–23.21	7.03
bledno-sinij 'pale blue'	53.00	3.50	–28.31	61.26	0.64	–31.71	7.78
bledno-goluboj 'pale light blue'	76.65	–9.59	–11.11	79.12	–4.26	–21.53	8.41
bledno-salatovyj 'pale lettuce'	81.80	–29.89	25.83	91.11	–51.21	46.27	10.50
bledno-fioletovyj 'pale purple'	60.83	25.05	–25.93	49.02	39.74	–24.84	13.24

Table 4

Centroids (sr) of color names with the modifier ârkij 'bright' in each of the three coordinates of the CIELAB color space and their offsets (DE_{00}) in post-COVID-19 participants compared to the controls

Color names	Non-COVID-19 controls			Post-COVID-19 participants			DE_{00}
	sr_L*	sr_a*	sr_b*	sr_L*	sr_a*	sr_b*	
ârko-krasnyj 'bright red'	49.43	69.30	42.96	48.45	73.25	44.36	1.37
ârko-rozovyj 'bright pink'	57.25	70.31	–16.99	56.89	74.58	–22.19	1.97
ârko-salatovyj 'bright lettuce'	84.81	–57.42	56.87	83.57	–53.42	48.88	2.38
ârko-sinij 'bright blue'	35.54	52.38	–78.61	38.59	45.63	–75.82	3.53
ârko-goluboj 'bright light blue'	67.53	–12.65	–34.25	63.30	–10.77	–37.33	3.76
ârko-birûzovyj 'bright turquoise'	81.93	–42.64	–4.66	87.24	–47.44	–0.47	4.68
ârko-zelënyj 'bright green'	75.95	–55.01	45.06	81.93	–60.38	52.65	4.75
ârko-sirenevyj 'bright lilac'	52.95	56.93	–50.56	56.15	49.14	–55.34	5.47
ârko-fioletovyj 'bright purple'	44.51	59.15	–54.62	37.52	61.70	–59.63	6.39
ârko-žëltyj 'bright yellow'	85.73	–7.32	76.04	91.35	–17.53	77.53	6.50

Table 5

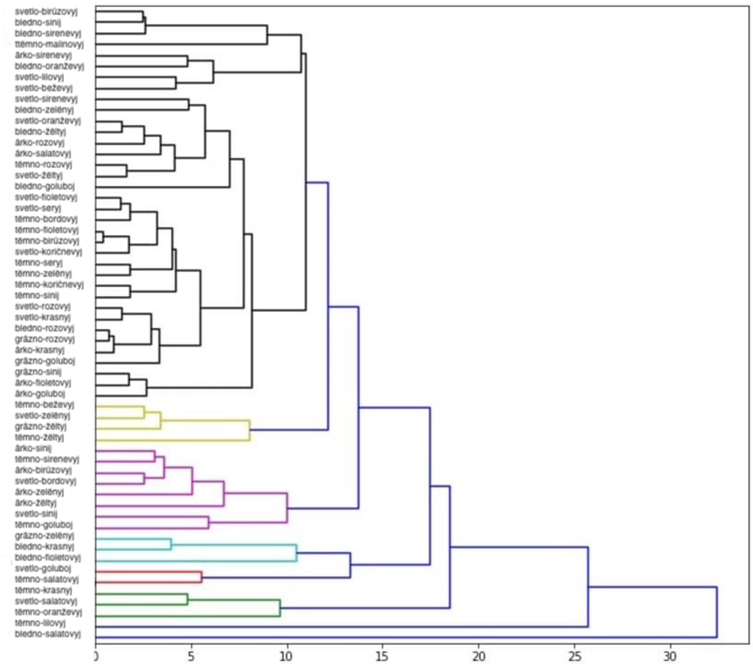
Centroids (sr) of color names with the modifier grâznyj 'dirty' in each of the three coordinates of the CIELAB color space and their offsets (DE_{00}) in post-COVID-19 participants compared to the controls

Color names	Non-COVID-19 controls			Post-COVID-19 participants			DE_{00}
	sr_L*	sr_a*	sr_b*	sr_L*	sr_a*	sr_b*	
grâzno-goluboj 'dirty light blue'	60.62	–7.87	–16.13	61.52	–6.45	–13.40	2.02
grâzno-rozovyj 'dirty pink'	59.43	26.84	0.00	58.42	31.49	2.23	2.62
grâzno-sinij 'dirty blue'	37.85	–1.92	–22.56	31.95	–0.39	–26.61	5.11
grâzno-žëltyj 'dirty yellow'	69.04	–5.04	51.76	76.29	–0.91	57.25	6.35
grâzno-zelënyj 'dirty green'	49.78	–17.60	23.00	44.80	–7.93	26.62	8.95

Cluster analysis revealed that vectors of the centroid shifts are similar for the color descriptors that specify color discernment by lightness and/or saturation. In particular, the shift vectors are similar within the following color clusters: (i) light or unsaturated blue and yellow shades (*svetlo-birûzovyj* 'light turquoise', *bledno-sinij* 'pale *sinij*', *bledno-goluboj* 'pale *goluboj*', *svetlo-žëltyj* 'light yellow', *bledno-žëltyj* 'pale yellow', and *svetlo-beževyj* 'light beige'); (ii) dark shades of yellow (*tëmno-beževyj* 'dark beige', *grâzno-žëltyj* 'dirty yellow', and *tëmno-žëltyj* 'dark yellow'); (iii) light shades of green (*svetlo-zelënyj* 'light green'); and (iv) unsaturated shades of green and red (*grâzno-zelënyj* 'dirty green', and *bledno-krasnyj* 'pale red') (Fig. 9).

Figure 9

Dendrogram representing outcomes of the cluster analysis of the vector shifts, in the CIELAB color space, of color-name centroids



Discussion

Results of the present study are in accord with the hypothesis that, compared to non-COVID-19 controls, post-COVID-19 participants reveal an altered color-naming pattern.

First, it is apparent that relative frequency of the BCTs differs noticeably between the two groups: post-COVID-19 participants use *koričnevyj* 'brown' much more frequently compared to *žëltyj* 'yellow' and *oranževyj* 'orange' in the controls. The occurrence of the color terms *zelënyj* 'green' and *seryj* 'gray' increases, while the occurrence of the color terms *sinij* 'dark blue' and *fioletovyj* 'purple' decreases. Also, the color terms *belyj* 'white' is offered much less frequently by post-COVID-19 participants.

It is worth noting that a similar increase in the number of *green* and *grey* terms and a decrease in the use of *blue* and *purple* terms was observed in young English-speaking observers in an experiment with a yellow filter that simulated the yellowing and thickening of the crystalline lens that occurs during its natural physiological aging (Hardy et al., 2005). Moreover, these observers frequently referred to short-wavelength colors as *dark*, while the colors that, unfiltered, looked pale blue, bluish, or cyan/ turquoise were referred to by them as *greenish*. These phenomena were, however, not observed in in the experiment's older observers with a naturally aged lens. The authors (Hardy et al., 2005) consider that the decrease in the *blue* and *purple* names under the simulated condition indicates a decrease in light absorption in the short-wavelength part of the spectrum due to lens yellowing (brunescence hypothesis; Lindsey & Brown, 2002). Moreover, it points out the role of central perceptual factors – namely, a general change in the spectral composition of filtered light, which in younger observers occurred abruptly, in a very short (experimental) period, impeding the process of perceptual adaptation that occurs slowly during natural aging.

The difference in the color-naming pattern of older observers and young observers provided with the yellow filter estimated by Hardy et al. (2005) is of note in view of the present study results which conceivably are due to an accelerated (abrupt) lens aging – yellowing and thickening – in post-COVID-19 participants. Since the period of illness was relatively short, the visual system probably cannot fast compensate for the overall change in the spectral light composition. The hypothesis of a "sudden" lens aging, as a result of coronavirus infection, currently is being tested experimentally by the authors using a color vision diagnostic test.

Apart from the changes in the relative frequency of color names, the respondents who had recovered from COVID-19 also showed changes in the denotative meanings of the BCCs – a shift, from the center to the periphery of the chromatic plane, of the centroids of the "opponent" BCCs *krasnyj* 'red' and *zelënyj* 'green', *žëltyj* 'yellow' and *sinij* 'dark blue'. Similar changes of denotative meanings of the BCCs are documented in individuals with various congenital and acquired abnormalities of color vision. It was found that deterioration of chromatic discrimination (along red-green and blue-yellow channels) was accompanied by an elevated "weight" of the two achromatic characteristics – brightness and saturation (Paramei, 1996; Paramei & Bimler, 2001a, 2001b). A similar tendency was also observed in diabetic patients (Bimler et al., 2014).

Furthermore, the present experiment demonstrated that the two groups differ in the pattern of color-descriptor word formation, in particular, the tendency of post-COVID-19 participants to produce complex color names, with an increased number word components, variety of BCT derivatives, modified terms, binary and multicomponent word combinations. According to previous findings (e.g., Mkrtychian et al., 2021; Wijk et al., 1999, 2002), such complex elaboration of the color-descriptor structure may be the marker of difficulties in precise nomination (of memory retrieval of adequate lexical units) experienced by COVID-19 survivors when they search for appropriate color naming.

Frequently these respondents added to BCTs and variously structured non-BCTs achromatic modifiers *tëmnyj* 'dark', *svetlyj* 'light', *ârkij* 'bright', *tusklyj* 'dull', *nasyŝennyj* 'saturated', *grâznyj* 'dirty', *bleklyj* 'faded', etc.. These adjectives allow specifying a certain characteristic of a color – its lightness/brightness, saturation, and purity. Probably, for post-COVID-19 participants these aspects become essential fro nominating the perceived color.

Furthermore, high frequency of the modifier *tëmnyj* 'dark' in combination with BCTs, which in the color space denote color categories of relatively low lightness – green, blue, and purple (namely, *tëmno-zelënyj* 'dark green', *tëmno-sinij* 'dark *sinij*', *tëmno-fioletovyj* 'dark purple') – and, in some cases, use of color descriptors with the '*dark*' modifier instead of the color name *čërnyj* 'black' indicate general subjective "darkening" of the corresponding colors.

The COVID-19 survivors' relatively high frequency of the BCTs *koričnevyj* 'brown' and *seryj* 'gray', as well as the use of the modifiers *grâznyj* 'dirty', *blednyj* 'pale', *tusklyj* 'dull', and *pastel'nyj* 'pastel' indicate a decrease in saturation, relative loss of vividness of perceived colors.

Undertaking a color vision diagnostic test in COVID-19 survivors will allow to assess whether the blue-yellow opponent system is predominantly affected, the impairment typical for the majority of acquired color vision deficiencies (Simunovic, 2016). Finally, if the phenomena of general "darkening" and loss of vividness of perceived colors will be confirmed the color vision diagnostic test, these might indicate an impairment of processing of luminance contrast in COVID-19 survivors (cf. Bimler et al., 2009).

We cannot exclude the possibility that the phenomena found in this study are reversible and may (progressively) lessen with an increasing time lapse after the COVID-19 disease. If this indeed would be the case, the results of the present study can be useful in clinical practice for monitoring recovery and wellbeing of COVID-19 survivors.

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Yu. A. Griber contributed to the study design; supervised the experiment, collected, analyzed and interpreted the; participated in writing the manuscript and formatted it in line with the journal requirements.

G. V. Paramei contributed to the study design; wrote the Introduction, analyzed and interpreted the results; participated in writing the manuscript and in editing its English translation.

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Conflict of Interest Information

The authors have no conflicts of interest to declare.