How the fear of COVID-19 changed the way we look at human faces

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Do we look at persons currently or previously affected by COVID-19 the same way as we do with healthy ones? In this eye-tracking study, we investigated how participants (N = 54) looked at faces of individuals presented as "COVID-19 Free", "Sick with COVID-19", or "Recovered from COVID-19". Results showed that participants tend to look at the eyes of COVID-19-free faces longer than at those of both COVID-19-related faces. Crucially, we also found an increase of visual attention for the mouth of the COVID-19-related faces, possibly due to the threatening characterisation of such area as a transmission vehicle for SARS-CoV-2. Thus, by detailing how people dynamically changed the way of looking at faces as a function of the perceived risk of contagion, we provide the first evidence in the literature about the impact of the pandemic on the most basic level of social interaction.

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Abstract

Do we look at persons currently or previously affected by COVID-19 the same way as we do with healthy ones? In this eye-tracking study, we investigated how participants (N = 54) looked at faces of individuals presented as "COVID-19 Free", "Sick with COVID-19", or "Recovered from COVID-19". Results showed that participants tend to look at the eyes of COVID-19-free faces longer than at those of both COVID-19-related faces. Crucially, we also found an increase of visual attention for the mouth of the COVID-19-related faces, possibly due to the threatening characterisation of such area as a transmission vehicle for SARS-CoV-2. Thus, by detailing how people dynamically changed the way of looking at faces as a function of the perceived risk of contagion, we provide the first evidence in the literature about the impact of the pandemic on the most basic level of social interaction.

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1. Introduction

The COVID-19 pandemic caused by SARS-CoV-2 is a global health concern that may cause severe threats to individuals' lives (World Health Organization, 2020a). Alongside the potentially fatal disease and the wide variability of physical health problems caused by the new beta-coronavirus, it is increasingly evident that the pandemic produced strong social, economic, and psychological effects (Bavel et al., 2020; Brooks et al., 2020; Fiorillo & Gorwood, 2020; Pfefferbaum & North, 2020). Therefore, in a fast and sadly predictable way, many clinical and psycho/sociological findings related to COVID-19's collateral effects have been accumulated. However, much less has been said about how the aftereffects of the current situation may reverberate on non-pathological, daily-life cognitive functioning. After all, if COVID-19 changed the world as we have been knowing it, one might wonder whether and, if so, how the "cognitive interface" between humans and the (post-COVID-19) world may transform.

When thinking about which "sensors" might primarily constitute such a kind of human interface with the world, the response is straightforward: Eyes. Indeed, studying how humans look at their surroundings may provide very useful insights about the cognitive processes underlying a wide variety of human behaviours as well as how people interact with the environment (Federico & Brandimonte, 2020; Hayhoe & Ballard, 2005; Henderson, 2017; Liversedge & Findlay, 2000; Milner & Goodale, 2006; Rahal & Fiedler, 2019; Rayner, 1998). From the heterogeneous sets of stimuli present in the environment, there are some that mainly attract the attention of human beings when it comes to interacting with their own kind: others' human faces and, specifically, others' eyes (Senju & Johnson, 2009a). Indeed, more than nose and mouth, eyes constitute a major visual-attentional target for adults involved in face exploration (Hernandez et al., 2009; Mertens et al., 1993; Walker-Smith et al., 1977). Also, humans tend to shift attention according to others' eye-gaze direction. Thus, as well as capturing and holding attention, eye-gaze may also elicit spatial orienting (for a comprehensive review, see Dalmaso, Gastelli & Galfano, 2020).

Whereas in many species direct-gaze perception may produce an aversive response (Emery, 2000), the so-called "eye-contact effect" – by describing a broad set

52 of neurocognitive effects associated with making eye contact with others – seems to be
53 a foundation of human social interaction, hence constituting the basis of social cognition
54 (Csibra & Gergely, 2006; Kleinke, 1986; Senju et al., 2006; Senju & Johnson, 2009a). In
55 addition, in the context of self-referential processing (i.e., the way humans process
56 stimuli concerning themselves), direct-gaze perception appears to produce a wide
57 range of social-related effects. Indeed, the so-called "watching-eyes effects" may favour
58 pro-social actions, positive appraisals of others, memory and self-awareness (Conty,
59 George & Hietanen, 2016).

60 Although at different degrees of consciousness, eye-contact effects seem to be
61 governed by the so-called "social brain", an extensive and composite brain network
62 involved in human social interaction (Adolphs, 2009). To date, an atypical eye-contact
63 pattern is one of the most significant symptoms of Autism Spectrum Disorder, which is a
64 disorder that severely affects social functioning (American Psychiatric Association,
65 2013; Senju & Johnson, 2009b). Also, the intranasal administration of oxytocin, a
66 neuropeptide mainly implicated in social-communicative function (Insel, 2010), appears
67 to enhance eye contact in both autistic and neurotypical individuals (Auyeung et al.,
68 2015). Thus, the mutual eye-contact experience we do daily when interacting with
69 people probably substantiates one of the most powerful mechanisms to engage others
70 (Senju & Johnson, 2009b). It seems, therefore, plausible that such a characteristic
71 social behaviour might be affected by how severely COVID-19 impacted our
72 psychosocial functioning, habits, and social interaction (Bagcchi, 2020; Bavel et al.,
73 2020).

74 As stated above, most people fear the COVID-19 pandemic (Pakpour & Griffiths,
75 2020). Fear is a foundation emotion whose function is to protect animals against
76 dangerous, threatening and aversive situations (Misslin, 2003). The neural counterparts
77 of such an emotion are the cortical and subcortical areas implicated in the social brain
78 network (LeDoux, 2003). Indeed, fear's brain networks are in charge of distinct
79 defensive responses (e.g., flight, fight, freezing, avoidance) and may be triggered
80 automatically either by unconditioned or conditioned stimuli (Misslin, 2003). In particular,
81 the activity of the amygdala, an important crossroad of human emotional life, plays a
82 significant role in reading social signals from the face, particularly in modulating direct

83 gaze on others (Adolphs, 2010; Hietanen, 2018; Johnson et al., 2005; Kawashima et al.,

84 1999). This is true even for cortically blind patients (Burra et al., 2013). Thus, whereas

85 others' direct gaze typically signal attention and social inclusion (Wirth et al., 2010),

86 threatening stimuli, such as threat-priming faces, should be hardly considered as

87 "social-engaging cues" so that one would likely avoid direct gaze with them (Skuse,

88 2003). In particular, if COVID-19-infected people were recognised as a possible threat

89 to individual health, one might perceive them as minacious stimuli and, therefore, avoid

90 or reduce direct eye-contact with them. In other words, others' human faces visual

91 exploration might subtly change as an effect of the perceived risk of COVID-19

92 contagion.

93   Whereas making a specific experimental hypothesis about the lower duration of

94 eye contact for COVID-19-related faces appears intriguing in itself, it may open the

95 avenue to a further research question: how are other aspects of COVID-19-related

96 faces looked at? Some useful insights might come by considering how threatening

97 stimuli can automatically capture attention, even unconsciously (Lin et al., 2009). Take,

98 for example, the well-known "weapon focus" effect. The higher concentration of a crime

99 eyewitness' attention on the weapon (i.e., the threatening stimulus) may result in a

100 lower ability to remember other crime details (Loftus et al., 1987). Thus, one may ask

101 what kind of threat-related information can be "extracted" from COVID-19-related faces?

102   According to the World Health Organization, infected people may spread the

103 SARS-CoV-2 by emitting small liquid particles (i.e., larger respiratory "droplets" or

104 smaller "aerosols") through their mouth (World Health Organization, 2020b). Such a

105 piece of critical information – which substantiates the effectiveness of face masks in

106 preventing transmission of SARS-CoV-2 (Bhardwaj & Agrawal, 2020) – has been

107 repeatedly reported by media, hence becoming part of the semantic knowledge about

108 the post-COVID world. In a sense, the mouth seems to be an important transmission

109 vehicle for the virus, so that one may reasonably predict that this area of a human face

110 might represent a "threatening stimulus" for an interlocutor who, for some reasons, finds

111 himself interacting with a person infected with COVID-19. Thus, whereas, on the one

112 hand, one might expect lower eye contact for COVID-19-related faces, on the other

113   hand, one may also predict an increase of attention for those face areas that are
114   typically associated with the risk of virus transmission (i.e., the mouth).

115   To test the above hypotheses, in the present study, we analysed by eye-tracking
116   the visual-attentional patterns of participants engaged in an online, ecological, free-
117   observation task in which they were simply required to look at human-face stimuli
118   generated by Artificial Intelligence. We manipulated the perceived risk of infection
119   prompted by the faces by randomly indicating the immunological status of each face as
120   "COVID-19 free" (i.e., individuals who never contracted the virus), "Sick with COVID-19"
121   (i.e., individuals who are currently infected with COVID-19), or "Recovered from COVID-
122   19" (i.e., individuals who got COVID-19 but who have now fully recovered). We included
123   the "Recovered from COVID-19" condition to assess whether the COVID-19-related
124   stigma (Bagcchi, 2020) may reverberate on the way people look at faces of patients
125   who survived COVID-19. We thereby conjectured that participants should tend to avoid
126   eye contact for individuals presented as suffering from COVID-19. Also, COVID-19-
127   related faces should attract participants' visuospatial attention towards the areas of the
128   stimulus implicitly recognised as threatening, that is, the mouth. Finally, we included *ad-*
129   *hoc* self-report psychometric measures (i.e., a post-experimental interview;
130   *Supplementary Material 1*) to assess participants' perceived risk of contagion in relation
131   to their attitude towards the COVID-19 pandemic.

132   2. Materials & Methods

133   Due to the pandemic situation at the study's date (November 2020), we devised a web-
134   based, online experiment by using custom software and scripts. All participants were
135   safe at home whilst participating in the study and used their own devices (i.e., personal
136   computers or notebooks) to perform the experiment. All experimental procedures
137   followed the ethical standards laid down in the Declaration of Helsinki (1964).
138   Accordingly, the study received approval (approval number: CVD-19-ET) from the
139   Ethics Committee of Suor Orsola Benincasa University (Naples, Italy).

140   *2.1. Participants*

141 Fifty-four participants (31 females; mean age = 26.46 years, SD = 5.82) with self-
142 reported normal or corrected-to-normal vision were enrolled in the experiment.
143 Participants were all Caucasians. We calculated the sample size on the basis of
144 previous similar studies (Hernandez et al., 2009; Mertens et al., 1993; Walker-Smith et
145 al., 1977) and by considering an a-priori power analysis (Cohen, 2013; Faul et al., 2007)
146 to detect a small effect size (η_p^2 = .20) within a repeated-measures ANOVA, with a
147 power of .90 and an alpha level of .05 (computed N = 53). All participants had no history
148 of neurological or psychiatric disorders and gave informed consent on their participation
149 by indicating their explicit consent via a specific online form. Four female participants
150 were excluded from data analyses due to their performance above 3.0 SD (outliers).

151 *2.2.   Materials*

152 In this study, we used images of human faces generated by Artificial Intelligence and an
153 *ad-hoc* post-experimental interview.

154 *2.2.1. Human faces*

155 For the experiment, we used 18 images of faces (9 females) generated through
156 machine learning by implementing a generative adversarial network (Karras et al.,
157 2020). By adopting GAN-generated faces, we kept constant the aspect ratio between
158 eyes and mouth, hence maintaining invariant the spatial disposition and size of all
159 anatomical features of the faces. Once images were generated, we erased each one's
160 background by using a proprietary algorithm freely available online at the URL
161 "https://www.remove.bg" (Kaleido AI GmbH, Austria). Then, we grayscaled all the
162 images using the specific function of the KRITA open-source raster graphics editor
163 (v.4.4.1 for Apple macOS). As a result, we obtained 18 images of monochrome faces
164 that appear as real to the human eye. Before enrolling participants and starting with the
165 study, we assessed the degree of authenticity of all the GAN-generated faces by asking
166 independent testers (N = 10; 5 females) to check whether each face appeared real. All
167 the independent testers considered all the stimuli as real faces. An example of faces
168 involved in the study can be seen in *Figure 1*. We randomly divided the faces into three

169 groups that correspond to the three experimental conditions of the experiment: 6 x
170 "COVID-19 Free", 6 x "Sick with COVID-19", 6 x "Recovered from COVID-19". Each
171 experimental condition was matched for face sex (3 females for each condition). We
172 changed the experimental-condition assignment for each group of faces at every 18
173 participants. Thus, at the end of the study (N = 54), each face was displayed in all the
174 experimental conditions, hence controlling for possible effects generated by the specific
175 salience of individual stimuli.

176 *Figure 1* about here

177 *2.2.2. Post-experimental interview*

178 We developed an *ad-hoc* post-experimental interview (PEI) for the study
179 (*Supplementary Material 1*). The PEI was introduced to assess participants' risk
180 perception of coming into contact with a COVID-19 patient as well as their propensity to
181 engage in protective behaviours. The risk perception items included six risk judgments
182 adapted from prior research on the psychometric paradigm (Slovic, 1987, 2016), which
183 evaluated the following facets of perceived risk: probability, fear, knowledge, control,
184 and severity. Regarding protective behaviours, participants were asked to evaluate how
185 often they engaged in COVID-19-protective behaviours (such as using the hand
186 sanitiser) in the previous two weeks (6 items) and how often they plan to engage in
187 COVID-19-protective behaviours in the next two weeks (6 items). The PEI also included
188 demographic information (7 items) and questions about prior exposure to COVID-19 (4
189 items). The PEI was edited and published online by using the Google Forms platform.

190 2.3. *Procedure*

191 Each participant received a link through which she could access the online platform for
192 the experiment. Once accessed and prior to the test, participants digitally signed
193 informed consent. Instructions about the experiment and the required experimental
194 setting appeared on the screen. Participants were asked to configure their webcam by
195 following the instruction they read on screen. Then, they completed an eye-tracking
196 calibration procedure by looking at and then clicking on red dots that sequentially

197 appeared on 40 parts of the screen. Afterwards, the eye-tracking study started. The
198 experimental instructions were: "*Now you will see some people's faces. Before each*
199 *face, you will read if the person is currently SICK WITH COVID, RECOVERED FROM*
200 *COVID, or NEVER SICK WITH COVID. Please, look at faces in the most natural way*
201 *possible*". Then, the eye-tracking experiment started. A single trial of 6 images of faces
202 related to each experimental condition was administered. Thus, 18 faces were randomly
203 presented according to the experimental visual flow (*Figure 2*): before each stimulus, a
204 fixation point (i.e., a screen-centred white cross over grey background) was shown for
205 500ms. Then, a label indicating the state of health of the coming face appeared for
206 2000ms, followed by a second fixation point (500ms). Then, a face appeared for
207 5000ms. After the face, a black screen appeared for 4000ms in order to permit the
208 retina to relax. Each single presentation lasted 12 seconds. Overall, the stimuli
209 presentation lasted 216 seconds. At the end of the stimulation, participants were
210 redirected to a Google Forms webpage to conclude the experiment by responding to the
211 Post Experimental Interview (PEI). At the end of the PEI, participants were asked to
212 evaluate the authenticity of the face stimuli they had previously seen. Globally, the study
213 lasted about 20 minutes for each participant. At the end of the experiment, participants
214 were debriefed regarding the study's purposes and the methods by redirecting them to a
215 specific webpage. All participants reported all stimuli as being real human faces.

216 *Figure 2* about here

217 *2.4. Apparatus and software paradigms*

218 Participants used their devices to access the online experiment. Technical prerequisites
219 for participating in the study were using Google Chrome browser and having a personal
220 computer or a notebook with a webcam. We developed the online experiment by using
221 different classes of technologies. For the user-interaction interface (e.g., experimental
222 instructions page, page transitions, etc.), we developed webpages using PHP
223 programming language, JavaScript script language, and MySQL database. Those
224 pages acted as a bridge between the different parts of the experiment, hence guiding
225 participants from the first (i.e., eye-tracking part), to the second (i.e., post-experimental

226 interview), and then, to the third part of the study (i.e., participants' final evaluation of
227 the stimuli). To acquire participants' gaze data, we used the RealEye.io (RealEye sp. z
228 o.o., Poland) platform, an online eye-tracking technology based on WebGazer library
229 (Papoutsaki et al., 2016). The eye-tracking technology we used (Papoutsaki et al.,
230 2016) has been compared with other commercial-grade, high-level eye-tracking
231 systems and sensors (Semmelmann & Weigelt, 2018). When analyses do not require a
232 very detailed spatial resolution, as in the detail level required by this study, results
233 between systems appear to be comparable. Thus, online webcam-based eye tracking
234 has been proved to be a reliable solution in such a kind of cognitive studies
235 (Semmelmann & Weigelt, 2018). We included in the study only participants who had
236 devices and webcams capable of obtaining at least a sampling rate of 20Hz. To
237 construct and publish the post-experimental interview, we used the Google Forms
238 platform. To extract and analyse participants' gaze data, we engineered and developed
239 different ad-hoc, custom-made scripts using PHP programming language and the
240 MySQL Database Management System. All the face stimuli involved in the experiment
241 were presented at the best-fitted resolution for participants' displays (auto-resizing
242 stimuli).

243 *2.5. Gaze-behavioural data*

244 We analysed gaze-behavioural data in terms of dwell time, that is, the amount of time
245 (expressed in milliseconds) that participants spent looking at different Areas of Interest
246 (AOIs). We thereby defined two distinct AOIs: the eye area (i.e., a rectangular area
247 comprising both the eyes) and the mouth area (i.e., a rectangular area including the
248 mouth). For all the stimuli, we maintained fixed both the size and the spatial position of
249 the AOIs. An example of the AOIs used in the study can be seen in *Figure 3*. For the
250 eye-tracking data analyses, we used a two-time-window approach (Federico &
251 Brandimonte, 2019) aimed at studying the initial (i.e., the first 500ms) and the full visual
252 exploration of the faces (i.e., all the 5000ms). We chose a two-time approach to
253 characterise the time course of participants' visual-spatial exploration. Therefore, we
254 analysed the first-500ms time window to explore the initial stage of participants' visual
255 exploration. Such a time interval acted as an at-a-first-glance indication in data analysis,

256 highlighting participants' initial fixation patterns as soon as the stimuli appeared.
257 Secondly, we extended the time window of analysis by including participants' full visual
258 exploration (i.e., 5000ms), thus taking into account the effect of time on the
259 experimental manipulations we made. A preliminary qualitative indication of differences
260 in participants' visual-attentional patterns can be appreciated in the heatmaps depicted
261 in *Figure 4*.

262   *Figure 3 and 4* about here

263 *2.6.   Data analyses*

264 We implemented multiple data analyses. First, we considered how participants looked
265 at the faces as the information we manipulated about their immunological status
266 changed. Thus, we performed two 3 x 2 repeated measure analysis of variance with
267 "Immunological Status" ("COVID-19-free" vs. "Sick with COVID-19" vs. "Recovered from
268 COVID-19") as a 3-level factor and "AOIs" (eyes vs. mouth) as a 2-level factor on face
269 fixation duration (expressed in milliseconds) for each time window of analysis (500ms
270 and 5000ms). Secondly, we analysed the post-experimental interviews (PEI) data to
271 explore whether and, if so, to what extent participants' risk perception towards COVID-
272 19 and COVID-19-related behaviours and intentions were associated with their gaze-
273 behavioural data. Risk perception is known to be a multi-dimensional construct (Slovic,
274 1987); therefore, we conducted a principal component analysis with varimax rotation to
275 investigate its dimensional structure. Data were previously checked for sphericity and
276 sampling adequacy using the Kaiser-Meyer-Olkin (KMO) and Bartlett tests. The other
277 constructs involved in the PEI were expected to be mono-dimensional, hence we
278 aggregated the responses to obtain, for each participant, a COVID-19-related behaviour
279 score and a COVID-19-related intention score. Pearson correlations were then
280 calculated between the PEI scales and the face fixation duration in each condition, both
281 at 500ms and 5000ms. We used an alpha level of 0.05 for all the analyses and Tukey
282 HSD correction for the post-hoc comparisons.

283 **3. Results**
284

3.1.   Eye-tracking results

Eye-tracking data related to participants' initial visual exploration (i.e., 500ms) are summarised in *Table 1*, whereas data related to the full exploration (i.e., 5000ms) are reported in *Table 2*.

3.1.1. Initial visual exploration (first 500ms)

Regarding the way participants initially visually explored the faces (i.e., within the first 500ms), the results of a repeated-measure analysis of variance showed an interaction between "Immunological Status" and "AOIs", $F(2, 98) = 3.01$, $p = 0.023$, $\eta^2p = 0.074$. Post-hoc pairwise comparisons revealed that eyes of COVID-19-free faces were fixated longer than eyes of COVID-19-related (i.e., "Sick with COVID" and "Recovered from COVID") faces ($p < 0.05$). The interaction effect is shown in *Figure 5(A)*. No main effects of "Immunological Status" or "AOIs" were found.

Figure 5 about here

3.1.2. Full visual exploration (5000ms)

By extending the time window of eye-tracking analysis to 5000ms to examine participants' full visual exploration, the results of a repeated-measure analysis of variance revealed a main effect of "AOIs" on face visual exploration, $F(1,49) = 4.19$, $p = 0.046$, $\eta^2p = 0.079$. The main effect was due to longer fixations to Eye AOIs than Mouth AOIs. However, and most important, an interaction between "Immunological Status" and "AOIs" was also found, $F(2,98)$, $p < .001$, $\eta^2p = 0.196$. Post-hoc pairwise comparisons revealed that eyes of COVID-19-free faces were fixated longer than eyes of sick-with-COVID-19 faces ($p = 0.013$) and recovered-from-COVID-19 faces ($p < .01$). Also, the mouth was fixated longer for both sick-with-COVID-19 ($p = 0.032$) and recovered-from-COVID-19 ($p = 0.025$) faces than for COVID-19-free faces. The interaction effect is shown in *Figure 5(B)*. No main effect of "Immunological Status" was found.

3.2.   Post-experimental interview

311 PEI responses are summarised in *Table 3*. A principal component analysis was
312 conducted to assess the dimensional structure of the six risk-perception items.
313 Preliminarily, we checked data for sampling adequacy and sphericity: the KMO value
314 was .59 and Bartlett's test of sphericity was significant ($\chi2(15)$ = 44.32, p = 0.001), thus
315 indicating that the sampling was adequate and the inter-item correlations were large
316 enough, hence suggesting that a principal component analysis was appropriate. The
317 number of factors retained was determined through parallel analysis (Dinno, 2009;
318 Horn, 1965), inspection of scree plots and interpretability of each component. The
319 parallel analysis suggested a two-factor solution accounting for 58% of the total
320 variance, but both the scree plot and the components' interpretability supported instead
321 the extraction of three factors, which accounted for 73% of the total variance (*Table 4*).
322 Items 3.1, 3.4, and 3.6 represented the *Severity* dimension (Cronbach's α = .68), items
323 3.2 and 3.3 represented the *Probability* dimension (Cronbach's α = .45), and item 3.5
324 the *Knowledge* dimension. Scores of section 4 and 5 items were aggregated separately
325 to create a COVID-19-related behaviour scale (Cronbach's α = .60) and a COVID-19-
326 related intention scale (Cronbach's α = .71), respectively. Pearson's correlation
327 coefficients among the PEI scales and the gaze-behavioural data are reported in *Table*
328 *5*. An interesting pattern emerged, with face fixation duration and scores in the
329 perceived Severity being negatively correlated with fixations to Eye AOIs and positively
330 correlated with fixations to Mouth AOIs (both at 500ms and 5000ms), although the only
331 statistically significant correlations were with the Mouth AOI in the recovered-from-
332 COVID-19 face condition (at 5000 ms, r = .41, p = 0.003) and with the Eye AOI in the
333 COVID-19-free face condition (at 500 ms, r = -.29, p = 0.043). No significant correlations
334 were found with the other dimensions of risk perception, nor with the COVID-19-related
335 behaviour and intention scales.

336 **4. Discussion**

337 In this study, we examined how participants looked at faces of individuals who could be
338 presented as "COVID-19 Free", "Sick with COVID-19", or "Recovered from COVID-19".
339 In so doing, we aimed at investigating how the multitude of psychosocial effects
340 produced by the current pandemic (Bagcchi, 2020; Bavel et al., 2020) and the related

state of generalised apprehension and fear (Pakpour & Griffiths, 2020) may reverberate on daily-life, socially-based human cognitive functioning. Specifically, we chose to analyse how the current dramatic contingencies may affect the way people interact with one another. We focused our attention on how humans look at others' faces because *eye-contact effects* constitute one of the most powerful and human-characterising social behaviours (Csibra & Gergely, 2006; Hernandez et al., 2009; Kleinke, 1986; Mertens et al., 1993; Senju & Johnson, 2009a; Walker-Smith et al., 1977; Wirth et al., 2010; Conty et al., 2016; Dalmaso et al., 2020). Therefore, we posited that faces of people who were considered possible threatening stimuli due to their COVID-19-related illness might become the target of distinctive visual-attention patterns as compared to the more reassuring faces of COVID-19-free individuals, possibly because COVID-19-related faces activate implicit cognitive mechanisms associated with risk avoidance and fear (Adolphs, 2009, 2010; Hietanen, 2018; Johnson et al., 2005; Kawashima et al., 1999; LeDoux, 2003; Lin et al., 2009; Loftus et al., 1987; Misslin, 2003; Skuse, 2003).

Consistent with our predictions, participants looked at the eyes of faces presented as "COVID-19 Free" significantly longer than faces presented as "Sick with COVID-19" or "Recovered from COVID-19". Such a peculiar visual-attentional pattern seems to emerge from the very first visual exploration time interval (i.e., 500ms), suggesting, as an at-first-glance indication, an initial detachment-from-threatening-stimuli mechanism (see *Figure 5A*). However, and most important, by extending the time window of the eye-tracking analysis to 5000ms – thus covering participants' full visual exploration – we found the same higher eye-focused pattern for COVID-19-free faces. Notably, within the extended time window, the main effect of *AOIs* with eyes receiving longer fixations than mouth was mitigated by a significant interaction. Thus, when considering both time windows of analysis, results clearly indicate that participants' implicit visual-attention patterns were modulated by explicit information on the health status of to–look-at faces, with a higher amount of eye contact for COVID-19-free faces than for both sick-with/recovered-from-COVID-19 faces.

Along with differences in eye contact as a function of health status, within the extended time window of analysis (5000ms), we found a longer time allocation of visual-spatial attention for the mouth's face area under both sick-with-COVID-19 and

recovered-from-COVID-19 conditions as compared to the COVID-19-free condition. Interestingly, participants visually explored the eyes and the mouth of COVID-19-related faces in a complementary way. Indeed, participants looked at the eyes of COVID-19-related faces about 200ms less than COVID-19-free faces. Symmetrically, participants fixated the mouth of COVID-19-related faces about 200ms longer than COVID-19-free ones (see *Figure 5B*). Thus, besides the implicit and sudden detachment-from-eyes mechanism, shorter eye fixation strongly supports the idea of a greater attraction exerted by the mouth in the quality of the threat-related area of the stimulus (Lin et al., 2009; Loftus et al., 1987). Indeed, as we stated above, SARS-CoV-2 may spread through respiratory droplets and aerosols (World Health Organization, 2020b). Such contagion-related information is nowadays part of the semantic reservoir of the general population. Therefore, one may reasonably assume how the threatening characterisation of the mouth may depend on the specific transmission modality of the virus (i.e., airborne). Whereas this study represents the first exploration of such a complex phenomenon in the context of the COVID-19 pandemic, future studies should explicitly explore the risk-perception mechanisms associated with other diseases.

Critically, we found overlapping results for sick-with-COVID-19 and recovered-from-COVID-19 conditions for all the effects we found. Whereas such overlap might affect the stigma associated with COVID-19 (Bagcchi, 2020), it may also depend on the compromised and uncertainty-governed informative context generated by the pandemic (Koffman et al., 2020). Indeed, the massive profusion of often inaccurate, or even fake, news about the disease outcomes and the transmission modalities may have led people to take an incorrect, anxiety-modulated precautionary attitude towards the individuals recovered from COVID-19 (Usher et al., 2020; van der Linden et al., 2020). In this regard, it should be noticed that individuals largely use Internet and social media to obtain information regarding COVID-19. The ability to check for the correctness of Internet-distributed information is inevitably limited so that the risk to get fake news is consistently high (Lazer et al., 2018). Also, the large availability of COVID-19-related information may generate information overload and overconcern among people, thus fuelling the fear of COVID-19 (Farooq et al., 2020).

402   Individuals are frightened by COVID-19 (Pakpour & Griffiths, 2020). To date, the

403   fear of COVID-19 has led some individuals to commit suicide (Goyal et al., 2020;

404   Mamun & Griffiths, 2020) and the size of the problem is so large that some scholars

405   have built ad-hoc scales (Ahorsu et al., 2020). Based on that knowledge, besides gaze-

406   behavioural measures, we included some *ad-hoc* psychometric measures to explore the

407   perceived risk of COVID-19 contagion. The factorial analysis of participants' post-

408   experimental-interview (PEI) revealed three risk-related main factors (i.e., perceived

409   severity of COVID-19 contagion, probability of controlling the risk of infection, and

410   knowledge about COVID-19) that explain over 73% of variance. This result is consistent

411   with the typical factorial structures reported in the risk-perception literature, which

412   include both cognitive (knowledge and probability of controlling the risk) and emotional

413   (severity) dimensions (Loewenstein et al., 2001; Oh et al., 2015; Slovic, 1987, 2016).

414   The idea that fear might be at the root of the overlapping results for sick-with-COVID-19

415   and recovered from COVID-19 seems to be further supported by the correlation (r = .41)

416   between perceived severity and time of observation of the Mouth AOIs of recovered-

417   from-COVID-19 faces. Also, within our sample, the perceived severity of COVID-19

418   contagion was negatively correlated with fixations to the eyes and positively correlated

419   with fixations to the mouth, within both time windows of analysis. However, it should be

420   noted that, although adequate for studying eye movements, this study's sample size is

421   too small to measure individual psychosocial differences. Therefore, the correlation

422   analyses we propose here should be considered only as a non-exhaustive support to

423   interpret and discuss the gaze-behavioural effects we found, which constitute the

424   study's main result. Thus, by underlining how the most critical findings of the present

425   research are those related to how participants changed their visual-attentional patterns

426   as a function of faces' COVID-19 immunological status, the PEI data should be

427   considered as potentially fruitful direction for future research aimed at exploring the

428   most profound psychosocial implications of COVID-19.

429   To sum up, the interaction we found between immunological status and how

430   participants looked at different characteristics of the faces suggests that the COVID-19-

431   related contingencies we are experiencing may resonate on basic cognitive processing

432   underlying social interaction. Indeed, in our study, participants' performance in an

433   implicit task (free face observation) was substantially influenced by explicit information
434   (immunological status) provided prior to the test. Persuaded by the evidence
435   accumulated during the last twenty years of neuroscientific research, we are keen to
436   interpret our results in terms of abrupt triggering of the neurocognitive systems involved
437   in social functioning, fear and gaze-behavioural control (Adolphs, 2009, 2010; Hietanen,
438   2018; Johnson et al., 2005; LeDoux, 2003; Lin et al., 2009; Loftus et al., 1987; Misslin,
439   2003; Senju & Johnson, 2009a; Skuse, 2003; Wirth et al., 2010). By providing the first
440   evidence about the effects of the pandemic on the most basic level of social cognition
441   (i.e., eye contact), the present research shed new light on how flexible and adaptive
442   cognitive processing may lead humans to interact with the environment in a plastic way,
443   by integrating multiple sources of information (Federico et al., 2021; Federico &
444   Brandimonte, 2020).

445   **5. Conclusions**

446   COVID-19 pandemic produced and is still producing strong psychosocial effects within
447   the general population. Whereas current research has addressed the clinical and bio-
448   psycho-sociological effects of COVID-19, much less space has been devoted to the
449   pandemic's consequences on non-pathological and daily-life cognitive functions. In the
450   context of the neuroscience/psychological perspective of social cognition, we
451   investigated whether and, if so, how humans modify their social-interaction modalities
452   due to the COVID-19-related contingencies. In particular, we analysed how people
453   looked at faces of individuals presented as COVID-19 free, sick with COVID-19, or
454   recovered from COVID-19. We found that participants tended to look at the eyes of
455   COVID-19-free faces longer than at those of both COVID-19-related faces. Crucially,
456   under both COVID-19-related conditions, the implicit detachment-from-eyes mechanism
457   we report seems to be compensated by increasing visual attention to the mouth area.
458   This increase suggests a threatening characterisation of the mouth as a transmission
459   vehicle for SARS-CoV-2. Notably, such an implicit gaze-behavioural pattern appears to
460   be consistent with the self-report psychometric measures we introduced to find out how
461   participants perceived the risk of COVID-19 contagion. As an initial exploration of a very
462   complex reality, this article reports the first evidence in the literature about the

463   pandemic's psychological and social reverberations on the most basic level of human

464   social interaction.

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662

663

Figure 1

Example of stimuli used in the study

Example of face stimuli used in the study (A – F). All the faces were generated through machine learning by implementing a generative adversarial network (Karras et al., 2020).

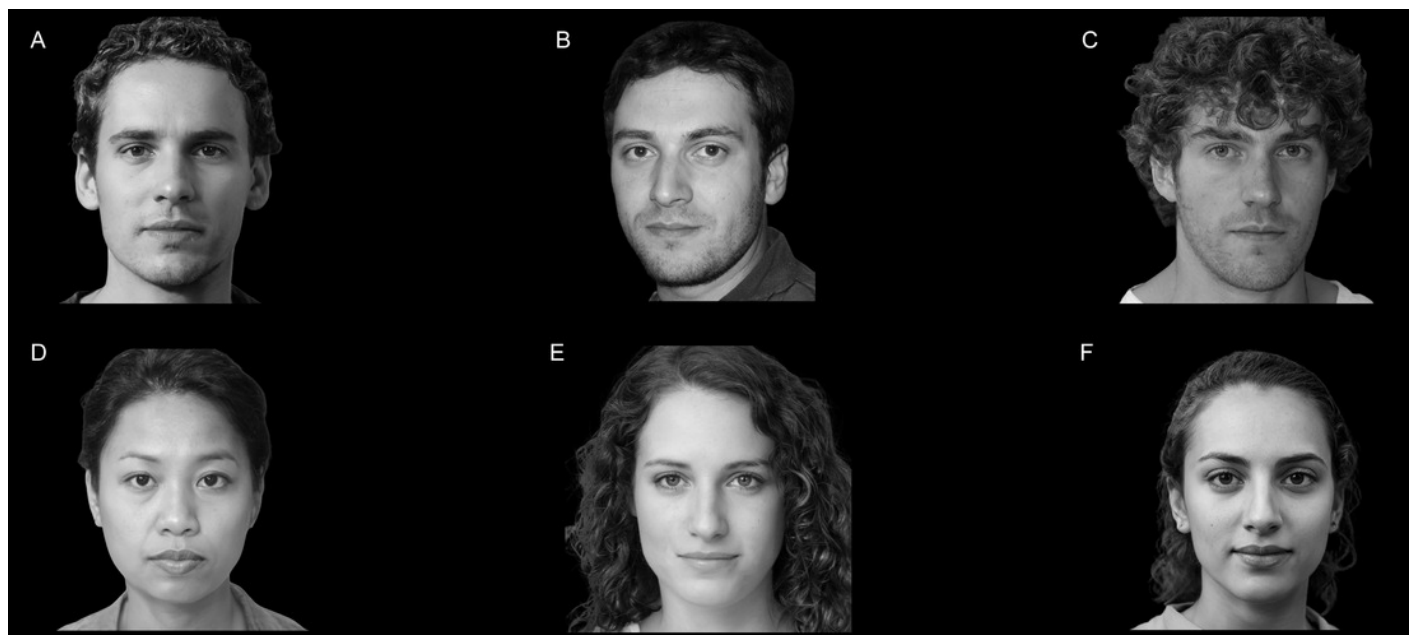



Figure 2

Experimental flow

A fixation point appeared for 500ms, followed by a label indicating the Immunological Status (i.e., "COVID-19 free", "Sick with COVID-19", or "Recovered from COVID-19"), which was shown for 2000ms. Then, a second fixation point (500ms) appeared followed by a face stimulus that remained on the screen for 5000ms. Finally, a black screen appeared for 4000ms.

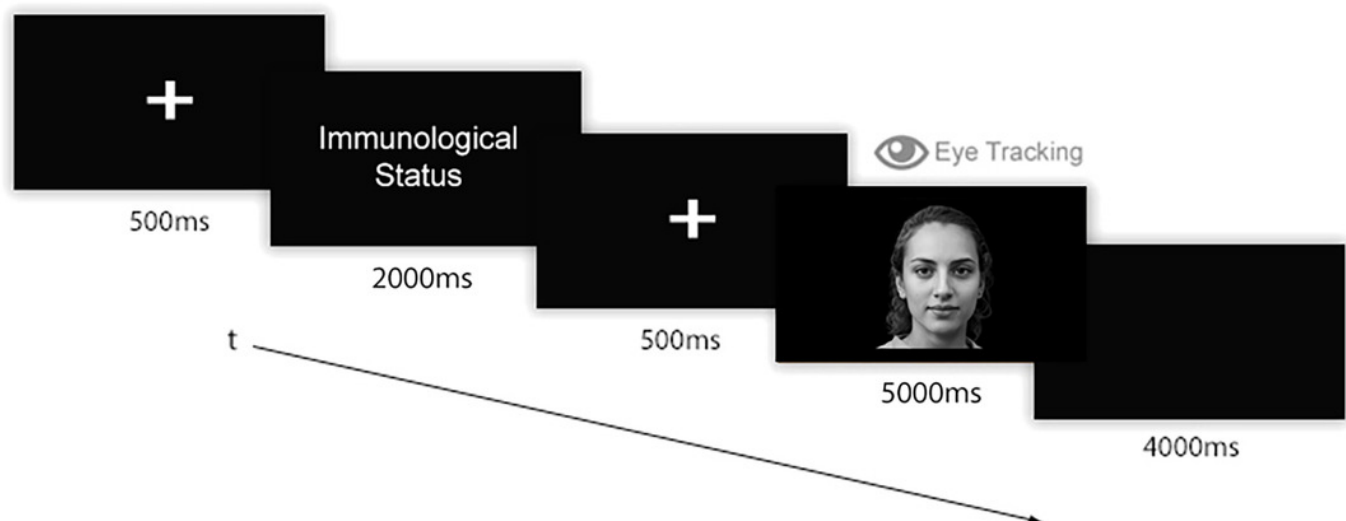



Figure 3

Face AOIs considered in the study

We analysed how participants looked at two distinct AOIs of the faces involved in the study. The first AOI was associated with the eyes (i.e., "Eye AOI"). The second AOI referred to the mouth (i.e., "Mouth AOI"). Both AOIs remained stable in terms of size, spatial position, and proportions across the stimuli.

Figure 4

Face exploration heatmaps

Example of heatmaps related to how all participants explored faces of individuals that could be presented as (A) COVID-19 free, (B) Sick with COVID-19, or (C) Recovered from COVID-19. Time window: 5000ms.

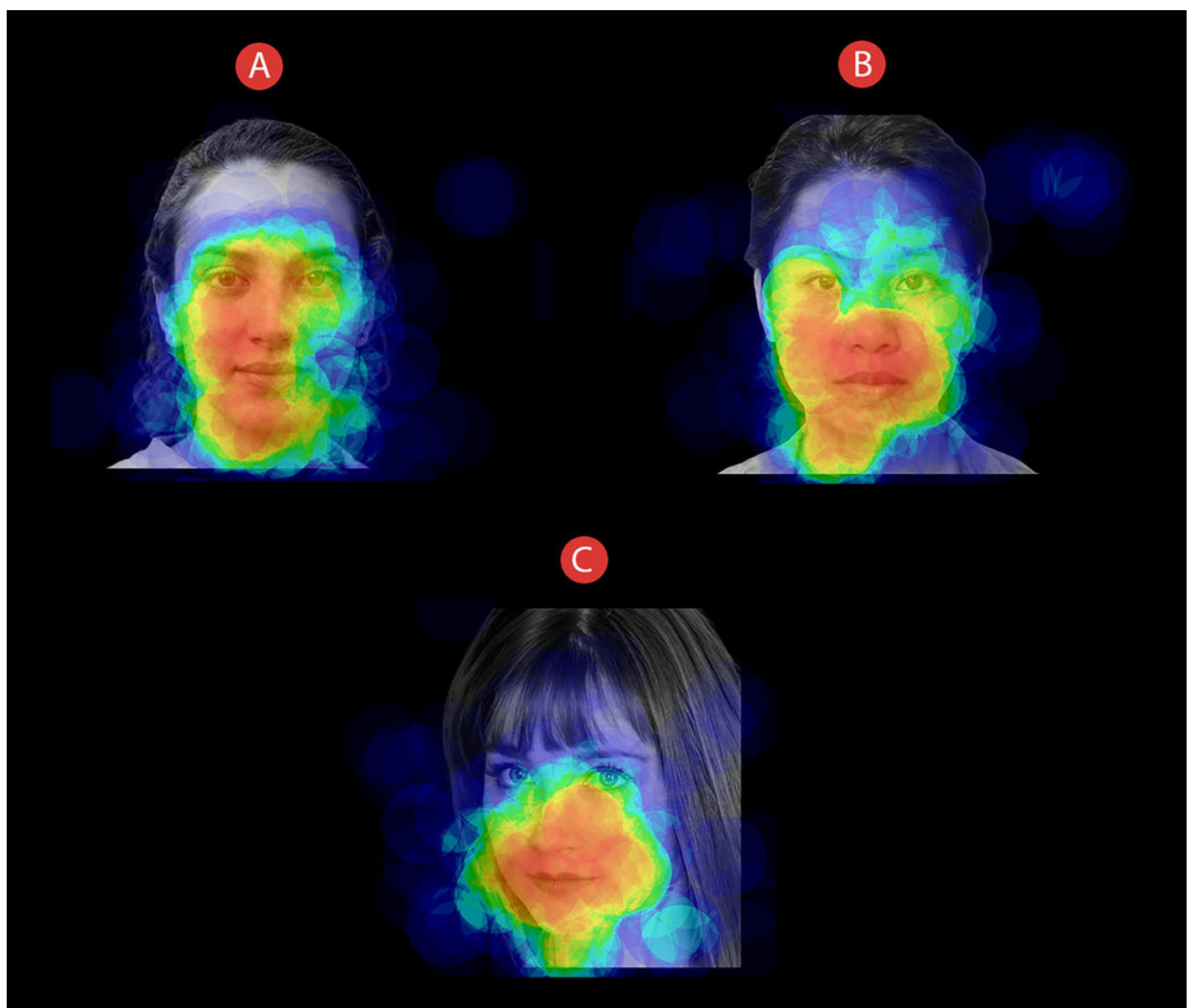
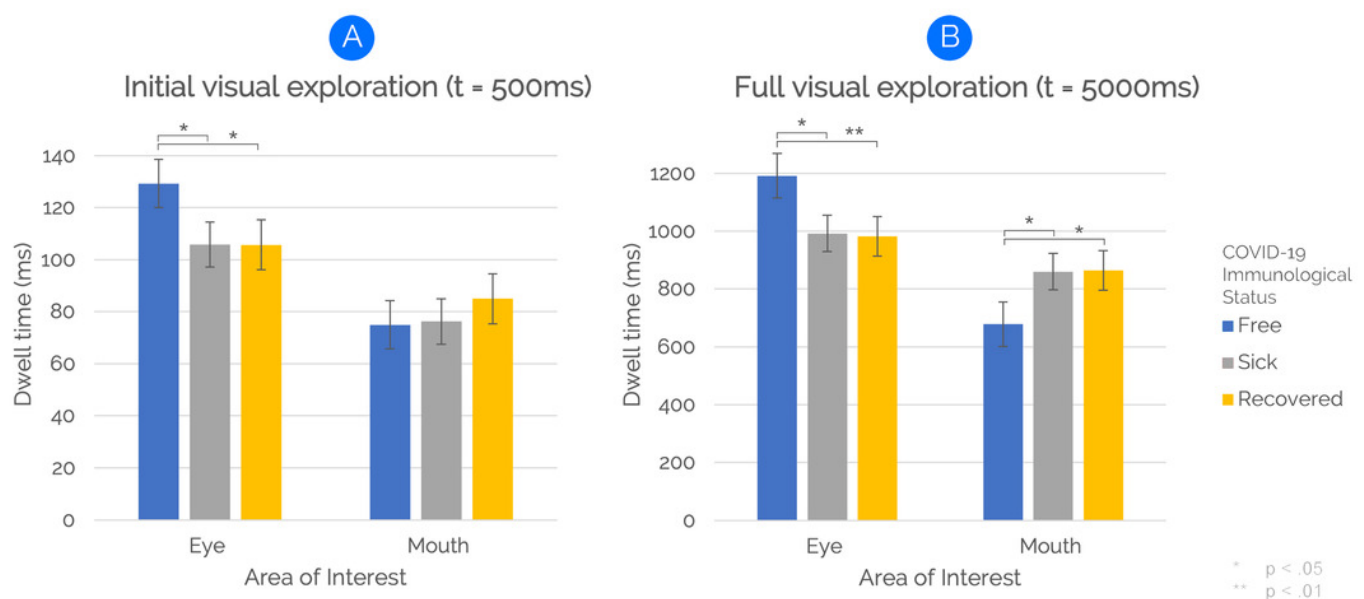



Figure 5

The effect of COVID-19 Immunological Status on face visual exploration

Participants looked at the eyes of individuals presented as "COVID-19 Free" longer than at those of individuals presented as "Sick with COVID-19" or "Recovered from COVID-19" for both time windows of analysis (A and B). Additionally, the full exploration analysis (B) revealed that mouth areas of both sick-wih-COVID-19 and recovered-from-COVID-19 faces were fixated longer than COVID-19-free ones. Vertical bars denote .95 confidence intervals, computed by adopting a simpler solution to Loftus & Masson (1994) provided by Cousineau (2005).

Initial visual exploration (500ms)

Eye-tracking data (sampling rate: 20Hz) related to participants' initial visual exploration.

	AOIs – Dwell Time (SD)	
Immunological Status	*Eyes*	*Mouth*
COVID-19 FREE	129,26 (86,06) ms	74,97 (59,44) ms
SICK WITH COVID-19	105,86 (80,4) ms	76,23 (56,11) ms
RECOVERED FROM COVID-19	105,71 (83,36) ms	84,96 (68,19) ms

Full visual exploration (5000ms)

Eye-tracking data (sampling rate: 20Hz) related to participants' full visual exploration.

	AOIs – Dwell Time (SD)	
Immunological Status	*Eyes*	*Mouth*
COVID-19 FREE	1191,48 (790,63) ms	678,25 (403,02) ms
SICK WITH COVID-19	991,99 (670,22) ms	859,96 (391,528) ms
RECOVERED FROM COVID-19	982,39 (710,69) ms	864,87 (424,02) ms

Post-experimental Interview results

Item		
COVID-19-related information	**Yes (%)**	**No (%)**
2.1 I am currently COVID-19 positive	1 (2)	48 (98)
2.2 I got sick of COVID-19, but now I'm cured and negative	3 (6.1)	46 (93.9)
2.3 In my circle of acquaintances, someone got sick of COVID-19	42 (85.7)	7 (14.3)
2.4 In my circle of acquaintances, someone has died from COVID-19	14 (28.6)	35 (71.4)
Risk Perception	**M**	**SD**
3.1 How risky is it for you coming into contact with a COVID-19 patient?	5.45	1.51
3.2 How likely is it for you coming into contact with a COVID-19 patient?	5.06	1.45
3.3 How much can you control the possibility of coming into contact with a COVID-19 patient?	4.27	1.30
3.4 Are you afraid of coming into contact with a COVID-19 patient?	4.82	1.72
3.5 Do you know what the consequences of coming into contact with a COVID-19 patient are?	6.33	0.92
3.6 How serious might be consequences you could have when coming into contact with a COVID-19 patient?	5.43	1.17
COVID-19-related behaviours		
4.1 Used the mask	5.86	.35
4.2 Used gloves	2.06	1.25
4.3 Used the hand sanitizer	5.18	1.03
4.4 Kept a distance of at least one meter from other people	5.06	.92
4.5 Avoided crowded places	5.33	0.80
4.6 avoided meeting friends/relatives	4.41	1.35
COVID-19-related intentions		
5.1 Use the mask	5.94	0.32
5.2 Use gloves	2.63	1.32
5.3 Use the hand sanitizer	5.47	0.77
5.4 Keep a distance of at least one meter from other people	5.33	0.80
5.5 Avoid crowded places	5.53	0.68
5.6 Avoid meeting friends/relatives	4.39	1.10

Risk perception factor analysis

Risk perception factor analysis (extraction method: principal component analysis with varimax rotation). Component 1 has been named *Severity*, Component 2 *Probability* and Component 3 *Knowledge*.

	Components		
Risk Perception Items	*1*	*2*	*3*
3.1	.87	.09	-.04
3.4	.76	-.18	.17
3.6	.68	.48	.11
3.3	.13	-.80	.22
3.2	.15	.76	.12
3.5	.09	-.03	.98

Pearson's correlation coefficients among the PEI scales and gaze-behavioural data

Notes: * = p < .05, ** = p < .01.

Item	Severity	Probability	Knowledge	COVID-19-related behaviours	COVID-19-related intentions
Severity	-				
Probability	.13	-			
Knowledge	.19	-.09	-		
COVID-19-related behaviours	.17	-.02	.27	-	
COVID-19-related intentions	.23	-.01	.27	.84**	-
MFT COVID-19-FREE EYES 500ms	-.29*	-.06	-.03	-.22	-.13
MFT COVID-19-FREE MOUTH 500ms	.22	.03	.02	-.06	.00
MFT COVID-19 SICK EYES 500ms	-.19	.03	-.09	-.14	-.06
MFT COVID-19 SICK MOUTH 500ms	.15	-.01	-.05	-.22	-.08
MFT COVID-19 RECOVERED EYES 500ms	-.08	.03	.02	-.03	.07
MFT COVID-19 RECOVERED MOUTH 500ms	.18	.01	-.06	-.23	-.17
MFT COVID-19-FREE EYES 5000ms	-.17	-.09	-.01	-.17	-.07
MFT COVID-19-FREE MOUTH 5000ms	.18	.11	-13	-.06	.02
MFT COVID-19 SICK EYES 5000ms	-.14	.03	.07	.01	.11
MFT COVID-19 SICK MOUTH 5000ms	.04	.04	-.04	-.11	-.02
MFT COVID-19 RECOVERED EYES 5000ms	-.10	-.08	-.05	-.02	.07
MFT COVID-19 RECOVERED MOUTH 5000ms	.41**	.07	.08	-.13	-.10