Face Masks Disrupt Holistic Processing and Face Perception in School-Age Children

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Research Highlights

- In the era of COVID-19, face masks are necessary to enable safe reopening of schools.
- Face perception abilities of school-age children were evaluated for masked and non-masked faces.
- Masks hindered face perception abilities in children more than in adults.
- Masks altered holistic processing of faces across age groups.

Abstract

Face perception is considered a remarkable visual ability in humans, which is subject to a prolonged developmental trajectory. In response to the COVID-19 pandemic, mask-wearing has become mandatory for adults and children alike. However, previous research indicates its adverse effects on face recognition abilities in adults. The current study sought to explore the effect of masks on face processing abilities in school-age children given that face perception is not fully developed in this population. To this end, children (n = 72, ages 6-14 years old) completed the Cambridge Face Memory Test – Kids (CFMT-K), a validated measure of face perception performance. Faces were presented with or without masks and across two orientations (upright/inverted). The inclusion of face masks led to a profound deficit in face perception abilities. This decrement was more pronounced in children compared to adults, despite adjustment of task difficulty across the two age groups. Additionally, children exhibited reliable correlations between age and the CFMT score for upright faces for both the mask and no-mask conditions. Finally, as previously observed in adults, children also showed qualitative changes in the processing of masked faces. Specifically, holistic processing, a hallmark of face perception, was disrupted for masked faces, as suggested by a reduced face-inversion effect. Together, these findings provide evidence for substantial quantitative and qualitative alterations in the processing of masked faces in school-age children.

Keywords: face perception, holistic processing, COVID-19, inversion effect, masks

Introduction

Faces are among the most significant visual stimuli in human perception. A quick glance at a person's face reveals a plethora of socially relevant information, including their race, age, gender, and emotional state (Tsao & Livingstone, 2008). In response to the COVID-19 pandemic, governments around the world have mandated mask-wearing in public spaces in an effort to curb virus transmission (Canada, 2020). Mask-wearing became mandatory for children and adults alike and was presented as a necessary step to enable the safe re-opening of educational institutions. Recent research has demonstrated that masks hinder face processing abilities in adults, including the ability to perceive the identity of faces (Carragher & Hancock, 2020; Freud et al., 2020) and their emotional expression (Calbi et al., 2021), and to recognize voices (Mheidly et al., 2020). It is yet unknown whether and to what extent masks impair face recognition abilities in children.

Typical human face perception is characterized by a holistic processing style, which emphasizes processing the face as an entire unit rather than relying on its specific features (Farah et al., 1998). Previous research has shown a relationship between face perception abilities and the degree of holistic processing in adults. In particular, face recognition accuracy was found to be correlated with different measures of holistic processing of faces (Wang et al., 2012; Richler et al., 2011). The importance of holistic processing for face perception is further emphasized by neuropsychological evidence from both acquired and congenital prosopagnosia, where impairments in face perception abilities are accompanied by severe impairments in holistic processing (Avidan et al., 2011; Ramon et al., 2010; Tanzer et al., 2013). Indeed, even in typical observers, experimental manipulations that disrupt holistic processing, such as face inversion

(Face Inversion Effect, FEI; Yin, 1969; but see Richler et al., 2011) and face alignment (Composite Effect; Young et al., 2013), lead to a robust decrement in face perception abilities.

Face masks conceal the lower half of the face (e.g., the mouth and nose area), making it difficult to process the faces in a holistic manner. In accordance with the terminology suggested by Maurer and colleagues (2002), masks can interfere with the detection of first-order relations that define faces (for example, two eyes above a nose and mouth), with the integration of those features into a coherent gestalt, and with the processing of the second-order, fine-grained spatial relations between the features. Consistent with this logic, a number of studies showed reduction in face recognition performance due to disruptions in holistic processing with partially occluded faces (Carragher & Hancock, 2020; Kret & De Gelder, 2012). A recent study from our lab conducted during the COVID-19 pandemic similarly found that face masks interfere with holistic processing and lead to a reduced face inversion effect (Freud et al., 2020).

Despite the wealth of research on the correspondence between holistic processing and face perception in adults, the developmental trajectory of this correspondence has not been directly addressed. Previous studies reported that children's face perception abilities generally develop slowly, improving precipitously between the ages of four to 11 (Bruce et al., 2000; Geldart et al., 2002) but only showing adult-like levels in performance in adolescence, after years of experience differentiating faces (Carey et al., 1980; Mondloch et al., 2002). Other studies, however, show evidence of adult-like holistic face processing in children as young as four years of age (Cassia et al., 2009; de Heering et al., 2007; Meinhardt-Injac et al., 2017; Pellicano & Rhodes, 2003). Nevertheless, it is generally understood that face perception mechanisms are already present at birth and mature quickly throughout childhood, with improved in adulthood being the result of the development of cognitive factors that support face perception, such as memory and attention (McKone et al., 2012; see Weigelt et al., 2014).

Given a gradual refinement in face perception abilities from early childhood to adolescence, we predicted that children will be more adversely affected by face masks than adults, with face recognition abilities expected to improve with age. We also predicted that face mask will alter holistic processing in children as was previously observed for adults. To test these predictions, we used the Cambridge Face Memory Test – Kids (CFMT-K; Dalrymple et al., 2012), which is considered a reliable test of face recognition abilities in children. In this test, children are asked to recognize children's faces across increasing levels of difficulty. We generated an adjusted version of the test that includes face masks and compared performance in children who completed the masked version of the test with those who completed the unmasked (standard) version. To examine whether any reduction in face perception is accompanied by a qualitative change in holistic face processing, we constructed upright and inverted versions of the CFMT-K and administered them to both groups of children.

Methods

Participants

Seventy-two participants (33 females) with a mean age of 10.7 (SD = 2.3, range 6-14) were recruited using snowball sampling during the period of November/December 2020. Participants were randomly assigned to the mask/no-mask condition and were compensated for their time ($10 CAD Amazon gift card for 15 mins). Thirty-seven participants (19 females) with a mean age of 10.6 (SD = 2.5, range 8-10) were randomly assigned to the masked condition and thirty-five participants (14 females) with a mean age of 10.7 (SD = 2.1, range 7-10) were randomly assigned to the non-masked condition. All participants and their parents/legal guardians provided informed consent prior to participating in the experiment.

A group of 495 adult participants with a mean age of 26.3 years (SD = 8.7, range = 18-66) was recruited online during the period of January 2021. Participants were randomly assigned to the mask/no-mask condition and were compensated for their time (~$6 CAD for 25 minutes).

The experiment was performed in accordance with the protocol approved by the ethic review board. Data and analysis code are available on the Open-Source Framework (https://osf.io/t89dh/) under CC-By Attribution 4.0 International license.

Materials

The CFMT-K was used to assess face perception abilities (Dalrymple et al., 2012). The CFMT-K is based on the adult version of the task (Duchaine & Nakayama, 2006). Unlike the adult version, the CFMT-K is shorter and uses children's faces instead of adult faces. The CFMT-K includes three phases (total of 48 trials) with increasing levels of difficulty. Prior to the beginning of the task, participants are presented with a practice trial with one target cartoon face shown from three different viewpoints, followed by a three-alternative forced-choice task (3-AFC). The first phase (easy) involves learning to recognize four unfamiliar male faces from three different viewpoints (right, front, left) and subsequently testing recognition of these faces in a three-AFC. The second phase (medium) involves a refresher of the four targets presented together from one viewpoint (frontal) followed by testing from novel viewpoints and different lighting conditions. The third phase (difficult) is similar to the second phase but includes test images with added visual noise. The adult version of the CFMT is identical in structure to the

CFMT-K, except for the use of adult faces instead of children's faces and an additional two targets (total of six target faces; total 72 trials).

Participants were randomly assigned to one of two groups. The first group completed the original CFMT (faces without masks), while the second group completed a modified version of the CFMT in which an identical face mask was added to all faces. To explore the processing style of faces with and without masks, each participant completed the test twice, once with upright faces and once with inverted faces. Block order (upright/inverted) was counterbalanced between participants.

Procedure

The CFMT-K was built using jsPsych, an open-source JavaScript plugin library (de Leeuw, 2015), and was hosted on Pavlovia (https://pavlovia.org/). The parents of the children were contacted first via email to obtain consent for their child's participation. Participants completed the experiment at home and were emailed an experiment link which they could access at any time to complete the experiment. Participants were instructed to complete the experiment independently; for children under the age of 10, parents/legal guardians were encouraged to help their children read the experiment instructions. Participants were randomly assigned to one of two groups. The first group completed the CFMT-K with non-masked faces, while the second group completed a modified version of the CFMT-K in which an identical face mask was added to all faces (Figure 1). To explore the processing style of faces with and without face masks, each participant completed the task twice, once with upright faces and once with inverted faces. Block order (upright/inverted) was counterbalanced between participants. Accuracy scores (0-48) for the upright and inverted faces were computed and served as the dependent variable. Data was processed using Python and statistical analyses were conducted using JASP (*JASP Team*, 2020).

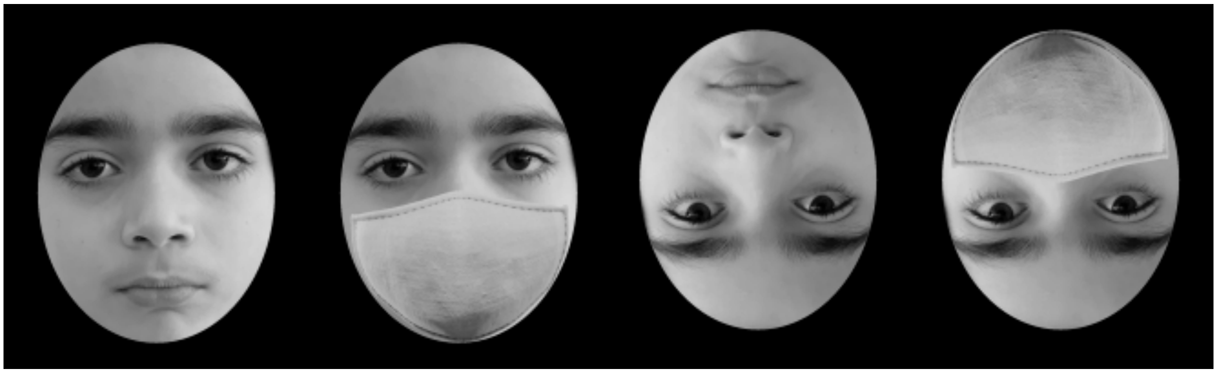

Figure 1. Examples of masked and unmasked faces similar to those used in the experiment. Faces were presented in upright and inverted orientations to evaluate differences of processing style associated with inversion and mask wearing. The picture was taken and published with permission from the child and their legal guardians.

Results

We explored the extent to which face masks impaired face recognition abilities. To this end, participants completed the CFMT-K with upright and inverted faces (within-subject) while the faces were either masked or non-masked (between-subjects). Participant sex/gender also served as between-subject variables, as previous research has documented an advantage in face recognition abilities in female participants (Herlitz & Lovén, 2013).

Figure 2A shows the group averages across conditions on the CFMT-K. We found a robust alteration in face recognition abilities for masked compared to non-masked faces, such that for upright masked faces there was a decrease of about 20% in the CFMT-K score. Consistent with previous studies, a strong inversion effect was observed for the no-mask condition. This effect was also observed for the masked condition, albeit to a lesser degree.

A repeated measures ANOVA was conducted with mask type (mask/no-mask) and orientation (upright/inverted). We found a main effect of mask [$F_{(1,68)}$= 14.31, p<.001, η_p^2=

0.17]. The mask effect was accompanied by a strong inversion effect [$F_{(1,68)}$= 55.31, p<.001, η_p^2 = 0.44] reflecting the well-documented advantage for upright faces.

Importantly, these main effects were qualified by a two-way interaction between face orientation and group [$F_{(1,68)}$= 5.38, p<.05, η_p^2= 0.07]. Planned comparison showed that the face inversion effect (FIE) was evident for both non-masked [mean FIE: 8.05 points; $F_{(1,68)}$ = 31.74, p<.001] and masked faces [mean FIE: 4.13 points; $F_{(1,68)}$ = 23.16, p<.001], but it was significantly smaller for the latter, pointing to a qualitative difference in the processing style of masked faces. In particular, the magnitude of the inversion effect is suggested to reflect the extent of holistic processing of faces, hence a reduced inversion effect reflects a shift toward a more local/analytical processing style (Farah et al., 1995). Importantly, the reduced inversion effect for masked faces could not be attributed to a floor effect, as performance for inverted masked faces was well above chance level (average score for inverted mask faces = 24, SD = 6; One-sample t-test against chance level (16) - $t_{(36)}$ = 4.86, p <.001, η_p^2 = 0.79).

An additional main effect of sex/gender was found, with females outperforming males [$F_{(1,68)}$ = 7.44, p<.01, η_p^2= 0.09; Figure 2B]. This result is consistent with some of the previous literature (e.g., Rehnman & Herlitz, 2006; but see Grüsser et al., 1985 for different results). We further elaborate on this topic in the discussion.

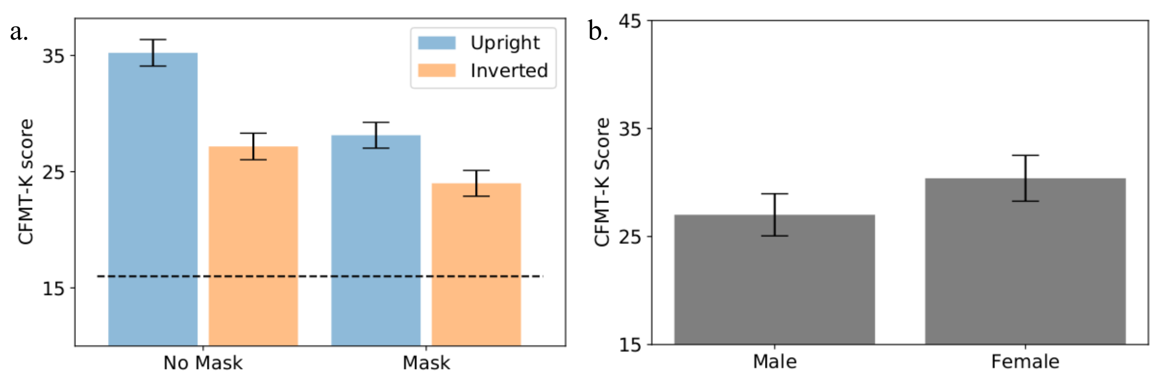

Figure 2 – (a) Results of the CFMT-K experiment for non-masked and masked faces across orientations. The dashed horizontal line represents chance level (CFMT-K score of 16). Performance was significantly impaired for masked faces. An inversion effect was found for masked and non-masked faces, but it was significantly reduced for masked faces. Error bars represent the 95% confidence interval for the main effect of group (mask/no mask). (b) Average performance of males and females on the CFMT-K. Females showed better face recognition abilities than males. Error bars represent the 95% confidence interval for the main effect of gender.

Children's age and face recognition abilities

To explore whether face recognition abilities in children improve with age, a correlation between age and CFMT-K scores for masked and non-masked upright faces was calculated. In line with previous literature, face recognition abilities were positively correlated with age, such that older children performed better on the CFMT-K (masked faces: $r_{(35)} = .57$, $p < .001$); non-masked faces: $r_{(33)} = .35$, $p < .001$) (Figure 3). Despite the numerical differences, these correlations were not statistically different [$Z = 1.15$, $p > .1$].

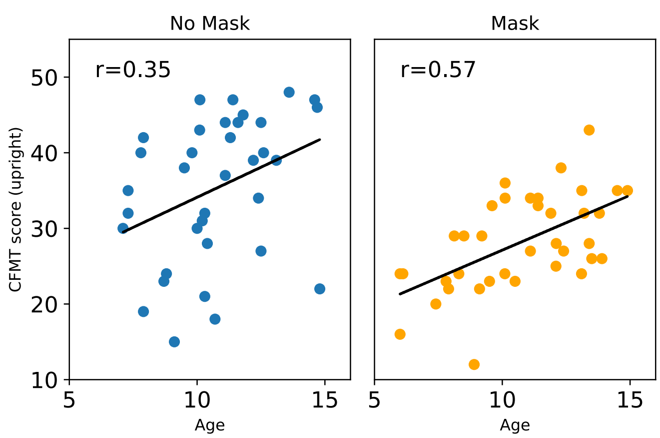

Figure 3 – Correlation between age and CFMT-K scores for upright non-masked (left) and masked (right) faces. A significant positive correlation between age and face recognition abilities was found for both conditions, such that face recognition abilities improve with age.

Notably, as mask type (mask/no mask) was manipulated as a between-subjects variable, we could not directly assess the correlation between age and the mask effect. Thus, we split the children into two age groups (11 years and younger and older than 11) and conducted an

ANOVA with age group as an additional between-subjects variable. This analysis revealed a robust main effect of age-group with better performance for older children [$F_{(1,68)} = 21.07$, $p < .001$, $\eta_p^2 = 0.23$] and a two-way interaction between age-group and orientation [$F_{(1,68)} = 5.27$, $p < .05$, $\eta_p^2 = 0.072$], such that a greater inversion effect was found for older children. This finding might serve as an indication that holistic processing mechanisms are subject to a protracted developmental trajectory.

Importantly, however, we did not find any evidence [$F < 1$] for differences in the effect of mask across the age groups [young children – 19.7%, older children – 22.4% for upright faces]. This result suggests that while face perception abilities are subject to a prolonged developmental trajectory, the mask effect is relatively constant across age groups during childhood.

Children's and adults' face recognition performance

Finally, we compared children's face recognition abilities to that of a group of 495 adults sampled in January 2021. Adult participants completed the CFMT with adult upright and inverted masked and non-masked faces. Notably, the CFMT-K adjusts the difficulty of the test between age groups. Hence, the comparison between adults and children can uncover potential differences in the mask effect while controlling other variables. Since adults and children completed different versions of the CFMT, we used percent accuracy (rather than absolute CFMT score) as the dependent variable for this analysis.

A repeated measures ANOVA with age group (adult/child), mask type (mask/no mask) and orientation (upright/inverted) was conducted. First, we found that the overall accuracy rate was similar across the two age groups [$F_{(1,563)} < 1$], confirming that the difficulty level was adjusted across the two tests (i.e., CFMT / CFMT-K). Importantly, we found a two-way interaction between mask type and age group [$F_{(1,563)} = 4.82$, $p < .05$, $\eta_p^2 = 0.008$], reflecting a greater mask effect for children (20.1%, upright faces) compared to adults (13.6%, upright faces) (Figure 4). This finding might suggest that children are more susceptible to the visual alterations embedded in masked faces. Finally, we found an additional two-way interaction between mask type and orientation [$F_{(1,563)} = 36.44$, $p < .001$, $\eta_p^2 = 0.06$], mirroring the greater inversion effect for non-masked faces. This effect was similar across the age groups, as the three-way interaction was not significant [F < 1], suggesting that in both groups holistic processing was disrupted by face masks to a similar extent (Figure 4).

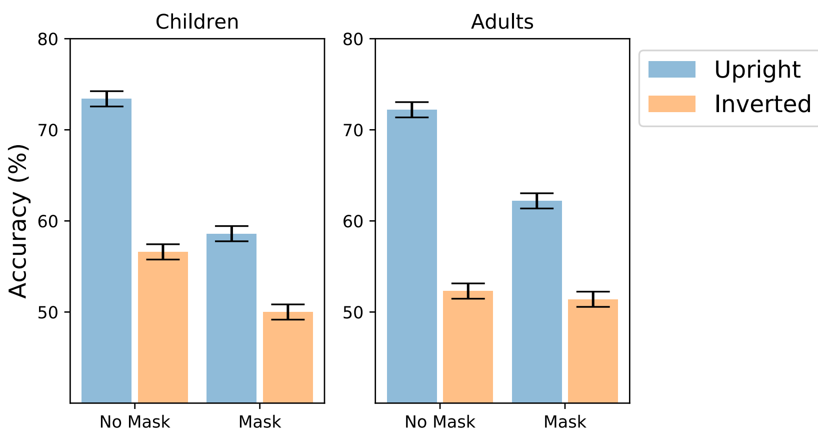

Figure 4 - Results of adults' and children's CFMT performance for non-masked and masked faces across orientations. The mask effect found in children was larger than the effect documented in adults. (see text for details). An inversion effect was found for masked and non-masked faces, but it was significantly reduced for masked faces. Error bars represent the 95% confidence interval for the main effect of group (mask/no mask).

Discussion

Face masks have been accepted as an important tool to minimize the spread of COVID-19 and are thus prevalent in everyday social interactions. Here, we evaluated whether school-age children demonstrate a similar impairment in face perception abilities caused by face masks as previously found in adults (Carragher & Hancock, 2020; Freud et al., 2020). We have documented quantitative and qualitative changes in face processing abilities for masked faces in children. We found that face masks led to a robust decrease in face processing abilities measured by the reliable and well-established CFMT-K. This quantitative reduction was accompanied by a reduced inversion effect for masked faces, suggesting a qualitative change in the way masked faces are processed.

When compared to adults, children showed a greater mask effect (20.1% compared to 13.6% for adults), suggesting greater susceptibility to visual alterations caused by face masks. The reduction of the FIE for masked faces was similar in the young and older children groups, suggesting that holistic face processing is similarly disrupted in these two age groups. Together, these results suggest that face processing abilities in children are highly susceptible to the inclusion of face masks. Below we discuss plausible mechanisms that could account for the observed changes in the processing of masked faces.

Reduced holistic processing for masked faces

A critical finding in the current experiment is the reduction of the face inversion effect for masked faces in children. Specifically, for non-masked faces we found a decrease of 8.05 points in the CFMT-K score for inverted faces, while a smaller inversion effect of 4.13 points was found for masked faces. The inversion of a face makes it difficult to extract configural relationships between face features (Farah et al., 1995; Freire et al., 2000; Yin, 1969); therefore, the twofold smaller inversion effect for masked faces can be taken as evidence that holistic face processing is largely reduced, though not entirely abolished. Thus, the processing of masked faces relies more heavily on the available features rather than on configural or holistic information.

The inversion effect is typically suggested to reflect a reduction in holistic processing and greater reliance on sequential, spatially restricted processing of face features (Rossion, 2009).

This view can account for the smaller inversion effect for upright masked faces, as these faces are processed in a less holistic manner, resulting in reduced face perception abilities. For the inverted masked faces, the effect of the mask is less evident due to feature processing being spatially limited, thus leading to a reduced face inversion effect.

A similar alteration in face perception and holistic processing is found when children of one race view faces of a different race (i.e., “the other race effect”; Mondloch et al., 2007; Kuefner et al., 2010). Reduced face recognition performance in these studies was interpreted as evidence for reduced holistic processing of other race faces. Together, these findings provide evidence for the co-occurrence of a reduction in face perception abilities and a disruption of holistic face processing.

Interestingly, the face inversion effect increased for older children, presumably reflecting a greater degree of reliance on holistic processing in this group. Hence, if the mask effect solely reflects a disruption in holistic processing, a plausible prediction would be that younger children should exhibit a reduced mask effect. However, this was not the case, as the mask effect remained stable across children’s ages. This pattern of results suggests that the mask effect is more likely to reflect a reduction in both holistic and featural processing. The relative contribution of each of those components might change throughout development.

Sex/gender differences in face perception abilities

An additional finding in the current experiment was better face recognition performance for female compared to male children. Superior face perception abilities in females has been extensively documented in adult participants (Bai et al., 2015; Bobak et al., 2016; Freud et al., 2020; McBain et al., 2009); however, findings in the developmental literature are less consistent.

One study has reported a strong overall face recognition advantage for female children, with a magnified effect for own-sex faces (Rehnman & Herlitz, 2006); however, others have found only a minimal effect of sex/gender on face perception, with girls performing better on old/new and face inversion tasks (Zhu et al., 2010).

One limitation of the present study is the exclusive use of male faces in the CFMT-K. It is possible that greater sex/gender diversity in the face stimuli set would result in an even greater sex/gender difference between males and females than currently observed, given documented face recognition advantages for own-sex faces (Rehnman & Herlitz, 2006). Future studies should use the CFMT-K with a combination of male and female faces to explore sex/gender differences in face recognition.

Conclusion

The current study provides novel evidence for quantitative and qualitative changes in the processing of masked faces in children. Changes in face recognition performance and alteration along the processing style of partially occluded faces could have significant effects on children's social interactions with their peers and their ability to form important relationships with educators. Previous research in adults has already demonstrated the detrimental effect of reduced face perception abilities on one's level of social confidence and quality of life (Lane et al., 2018). Given the recent proliferation in mask-wearing due to the COVID-19 pandemic, future research should explore the social and psychological ramifications of wearing masks on children's performance.

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