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The effect of face masks on sign language comprehension: performance and metacognitive dimensions

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ABSTRACT

In spoken languages, face masks represent an obstacle to speech understanding and influence metacognitive judgments, reducing confidence and increasing effort while listening. To date, all studies on face masks and communication involved spoken languages and hearing participants, leaving us with no insight on how masked communication impacts on non-spoken languages. Here, we examined the effects of face masks on sign language comprehension and metacognition. In an online experiment, deaf participants (N = 60) watched three parts of a story signed without mask, with a transparent mask or with an opaque mask, and answered questions about story content, as well as their perceived effort, feeling of understanding, and confidence in their answers. Results showed that feeling of understanding and perceived effort worsened as the visual condition changed from no mask to transparent or opaque masks, while comprehension of the story was not significantly different across visual conditions. We propose that metacognitive effects could be due to the reduction of pragmatic, linguistic and *para*-linguistic cues from the lower face, hidden by the mask. This reduction could impact on lower-face linguistic components perception, attitude attribution, classification of emotions and prosody of a conversation, driving the observed effects on metacognitive judgments but leaving sign language comprehension substantially unchanged, even if with a higher effort. These results represent a novel step towards better understanding what drives metacognitive effects of face masks while communicating face to face and highlight the importance of including the metacognitive dimension in human communication research.

1. Introduction

Since the outbreak of the COVID-19 pandemic, face-masks have become pervasive in face-to-face communication. Psychological

Abbreviation: FoU, Feeling of understanding.

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research has shown that they constitute an obstacle to the linguistic dimension of speech perception, limiting access to auditory and visual cues that normally allow correct processing of linguistic information. Face masks alter the frequency and intensity of the voice passing through their tissues, filtering high frequencies, which are essential for the correct identification of consonants (see, e.g., Corey et al., 2020). In addition, opaque face masks conceal the lips of a talker, breaking the integrity of audio-visual integration that supports spoken language processing in face-to-face communication. This leads to poorer listening performances, regardless of the level of voice filtering (Thibodeau et al., 2021).

Face masks also have an impact beyond spoken language comprehension, as they can influence metacognitive judgements. Metacognition is our ability to think about our cognitive processes (Flavell, 1979), and it has a substantial impact on our behavior. Correct evaluation of our perceptual and cognitive difficulties is a prerequisite for enacting adequate strategies to overcome them. With face masks, listening becomes more effortful, and our perceived confidence in the spoken message becomes less certain. Studies that have examined listening to masked talkers, in quiet or in different levels of noise, have shown that voice distortions generated by the mask or even the absence of visual cues from the lips alone, produce an increase in perceived effort (Giovanelli et al., 2021; Brown et al., 2021) and a decrease in perceived confidence in what is heard (Giovanelli et al., 2021; Thibodeau et al., 2021).

Although studies on the impact of face masks on language and communication remained limited to spoken languages in hearing individuals, recent works have started to examine if sign language experience in deaf people could result in different skills when processing emotional cues from the face. Comparing the performance of hearing and deaf people in recognizing faces expressing happiness at different intensity levels, Amadeo and colleagues (2022) found that deaf signers rate faces as more emotional compared to hearing controls when faces are unmasked. However, when a face mask is applied the signers' ability to recognize happiness decreases, especially when the emotion is low-level and subtle (Amadeo et al., 2022). The authors attributed this result to the preference of deaf signers in paying increased attention to the lower part of a face and fixate on it more than on the upper part when compared to hearing people, as already documented by Mitchell et al. (2013). Evidence suggesting that deaf signers perceive more intensely facial information than hearing controls when processing emotional valence in faces with and without mask also emerged from a between-experiment comparison reported in Lau et al. (2022).

However, to date, no studies have directly examined to what extent covering the lower part of the face with masks could impact sign language comprehension. Linguistic research has shown that sign languages are natural human languages that rely on a combination of visual information resulting from hands, face, and body movements (Klima and Bellugi, 1979; Volterra, Roccaforte, Di Renzo & Fontana, 2022). The parameters pertaining to the hands are their configuration, movement and location, as well as palm orientation. Additionally, linguistic information is associated with the posture of the trunk and movements from the upper (eyes and eyebrows) and lower (lips, jaw, and mouth) parts of the face. For instance, combined movements of eyes and brows can convey relevant signals in discriminating between open vs. closed questions. Similarly, lip, jaw and mouth movements could also serve the role of modifiers that extend and specify the meaning expressed by the manual components of a sign (Boyes-Braem and Sutton Spence, 2001; Branchini and Mantovan, 2020). In addition, mouthing can also have a disambiguation role in distinguishing among signs which share the same manual components, for example the LIS sign for "butter" and that for "marmalade" are manual homonyms, but they differ for the mouthing involved in performing the signs (Rinaldi, Roccaforte and Volterra, in press.). The role of mouthing in distinguishing between manual homonyms and between polysemic signs has been cross-linguistically observed for several sign languages (Bisnath, under review).

In the present study, we set out to investigate to what extent sign language comprehension is affected by face masks. We examined this question both in terms of performance and in terms of metacognitive assessment of comprehension abilities. To this aim, we asked deaf signers to watch a story in Italian Sign Language (Lingua dei Segni Italiana, LIS). The story was divided into three parts: one was signed with no obstacle on the signer's face (no mask condition); one was signed with a fully opaque surgical mask covering the lower part of the face (opaque mask condition); one was signed with a face mask containing a transparent window (transparent mask condition). For each part of the story, we measured sign language comprehension (as an index of performance), plus feeling of understanding, perceived effort and perceived confidence in the response (as indices of metacognitive assessment).

We predicted that occluding the face with a mask could impact on performance as well as on metacognitive judgements. This outcome could result from the fact that sign comprehension relies on linguistic and *para*-linguistic information from the face, as evidenced by the higher gaze fixation patterns showed particularly by expert deaf signers towards on or near the eyes when looking at sign language productions, with respect to non-expert deaf signers who, in turn, fixated on or near the mouth (Emmorey et al., 2009). Hence, occluding information provided in the area between the eyes and the chin should increase cognitive demands and consequently impact on both language processing and metacognitive assessments of comprehension.

2. Methods

2.1. Participants

Sixty participants with severe to profound bilateral deafness (mean age: 37.45 years, SD: 11.29, age range: [18–67], 25 males) took part in the study. All participants gave their informed consent before the start of the online experiment, which was conducted according to the criteria of the Declaration of Helsinki (1964, amended in 2013) and according to the University of Trento Ethic Committee (number of Protocols: 2021–008).

All participants were fluent in Italian Sign Language by self-report, albeit with varying sign proficiency. The majority of them reported LIS as mother tongue (41.6%), while the remaining reported Italian (33.3%) or Italian and LIS (23.3%) as mother tongue. Less than half (43.3%) also used another language, either oral or signed. Most participants were exposed to Italian Sign Language between

0 and 10 years of age (61.6%), 16.6% after the age of 10, and about 20% only after 20 years of age. In terms of frequency of LIS use, almost all participants (95%) self-rated their use with "Very often" or "Often" (every day or at least three days a week). A large number of participants (85%) reported a degree of hearing loss at the better ear from "Profound" to "Severe". Deafness onset was described as

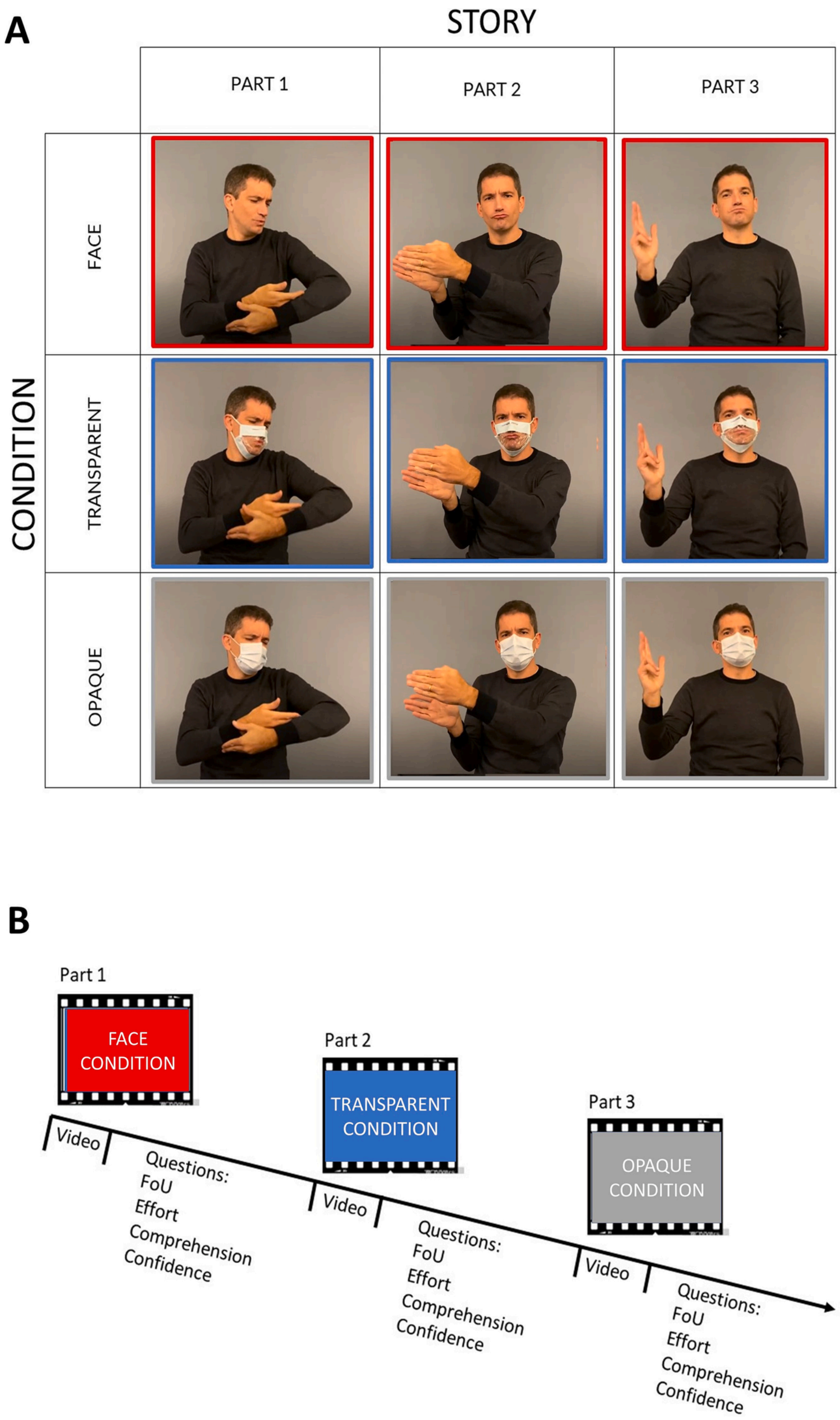

Fig. 1. Panel A shows all the story parts signed in all visual conditions. Note that the order of the visual conditions was counterbalanced across participants. Panel B shows a schematic representation of the comprehension task (FoU: Feeling of Understanding).

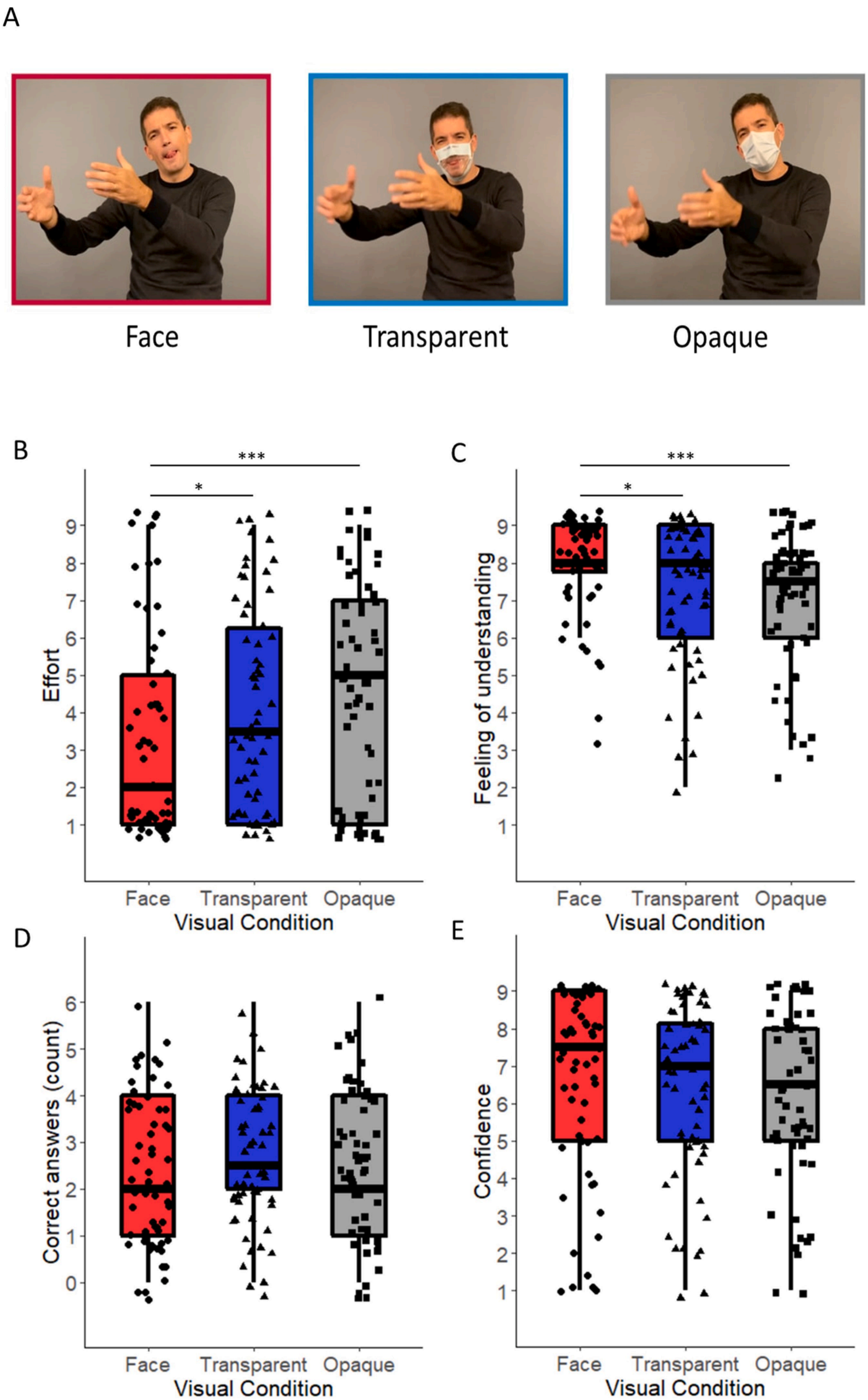

Fig. 2. Panel A shows the narrator signing "little bowl" in the three different visual conditions. Panels B, C, D and E show how Effort, FoU, Number of correct answers and Confidence changed across visual conditions.

congenital in 68.3% of the cases. The vast majority (91.6%) of participants received the diagnosis of deafness between birth and 6 years of age. Nearly half of the participants (48.3%) reported using hearing aids, while only 4 of them reported having a cochlear implant (6.6%). The remaining 45% did not currently use any device. A considerable part of participants (85%) underwent speech therapy in their lives, and the 51.6% reported to have deaf parents and/or siblings. For more information, see the sample description in Supplementary Tables S1 and S2.

2.2. Stimuli

Based on the format of Goldilocks and the three bears story, three deaf research assistants developed a narrative in Italian Sign Language (LIS). In the signed narrative numerous dialogues between characters and descriptions of the different environments in the story (e.g., countryside, house) have been included. In addition, signs referring to size and shape of the objects, some of them result ambiguous without seeing the actions performed by the mouth (e.g., the sizes of the three bowls, that are little, medium and big, respectively, since in the narrative all the bowls have been signed with identical manual parameters, also in terms of space used and movement; Fig. 2A shows the narrator in signing the little bowl in the three different visual conditions), lexical signs which can be correctly guessed only seeing both their manual and facial components (e.g., the sign specifically used in the narrative for CHIMNEY is hardly distinguishable from the sign for FIRE without seeing the mouthing) have been included.

The story was then divided into three parts of similar length, and each part was signed by the same deaf native signer in three different conditions: without any face mask, with a transparent face mask, with an opaque face mask. Although the signer (L.L.) was aware of the aims of the study, we took particular care in monitoring that he reproduced each part of the story identically under the three visual conditions. Specifically, each part of the story has been carefully checked by two authors of this paper (G.G & T.L) who are experts in Italian Sign Language, to ensure that the signer had not significantly altered manual and non-manual components in the masked conditions.

Duration of part 1 was approximately 1.14 min (no-mask: 1.16; opaque mask: 1.13; transparent mask: 1.13); duration of part 2 was approximately 2.04 min (no-mask: 2.08; opaque mask: 2.02; transparent mask: 1.58); duration of part 3 was approximately 1.10 min (no-mask: 1.11; opaque mask: 1.11; transparent mask: 1.08).

For each part, six questions with four answer alternatives for each question were produced. Most of the questions do not refer to the literary content of the story, but rather to descriptions of the environment, spatial placement of elements, dialogues, and details that in sign language are specified through mouth actions. The story, the questions, as well as all the answer alternatives to choose from, were thought and developed directly in LIS, without any previous mediation of Italian language. Some examples and description of questions and possible answers in Italian Sign Language can be retrieved at osf.io/arde8.

2.3. Procedure

The experiment was carried out using the Qualtrics© platform. When the experiment started, participants received the overall description of the task in Italian Sign Language and in written Italian and gave their informed consent. They first completed a questionnaire about relevant information on their linguistic background and deafness (see the section Participants for more details). After this phase, they started the comprehension task in Sign Language. The task comprised three parts of the story, signed in LIS. In every part of the story the signer was visible either without mask, or wearing a surgical mask, or wearing a transparent mask (from now on, the visual conditions; see Fig. 1).

The order of the visual conditions was counterbalanced across participants by creating six different versions of the comprehension task. In this way, we ensured that: for every participant, each visual condition was associated with only one of the three parts of the story; the three parts of the story were seen by the same number of participants in their three different visual conditions; and that the order of the conditions covered all possible combinations. Participants were informed that each part of the story could be seen only once and therefore to pay maximum attention during video presentation.

After each part of the story, participants answered two questions, one assessing their feeling of understanding (FoU; "now that you have seen this part of the story, how much do you think you have understood?") and the other rating their perceived effort ("now that you have seen this part of the story, how much was it effortful? How much effort did it cost you?"), both expressed on a Likert scale from 1 to 9, where 1 corresponded to feeling of very little comprehension and to low effort, and 9 corresponded to feeling of very much comprehension and to high effort, for FoU and Effort respectively.

That done, after each part of the story, comprehension and confidence were rated through 6 questions. Participants had to choose the right answer between four alternatives and then report their perceived confidence in the answer given on a Likert scale from 1 to 9 ("When you choose the answer, how did you feel? How much are you sure of your answer?"), where 1 corresponded to low confidence, and 9 corresponded to high confidence.

The study was carried out online to reach more participants. To monitor the ongoing experimental procedure we recorded the overall duration of the experiment and we directly asked participants if they encountered any technical problem while performing the task. Participants for whom duration was excessive (e.g., they completed the experiment in two different days, or they took more than 120 min to complete the experiment) or participants that reported technical errors in loading the videos (story parts, questions, alternative answers) were excluded from the analysis and replaced.

2.4. Analyses

The subjective assessment of perceived effort to complete the task (Peelle, 2018) and the FoU were calculated as the medians of rating expressed at the end of each part of the story. Scores ranged from 0 to 9, for both perceived effort (1 = low effort; 9 = high effort) and FoU (1 = very little; 9 = very much).

Performance scores were computed as the average count of correct answers to the questions that followed each part of the story (from 0 to 6). Similarly, confidence was calculated as the median of ratings expressed when answering each question (from 1 to 9, 1 = low confidence, 9 = high confidence). These scores were computed separately for each visual condition. The confidence rating refers to a subjective measure of awareness that represents how much people think they have chosen their answers by guessing or not (Dienes, 2008; Dienes and Seth, 2010; Norman et al., 2011; Thiede et al., 2003).

All data were analyzed using R studio (R Core Team, 2013). We ran non parametric Friedman and Wilcox tests. Raw data can be retrieved from osf.io/arde8.

3. Results

3.1. Effort and feeling of understanding

Effort in watching the story and feeling of understanding, as measured after each part of the story but before comprehension questions, were studied as a function of the three visual conditions. Perceived effort was significantly less in the condition without mask (3.27 ± 2.77) compared to both watching the signer using the transparent mask (4.13 ± 2.78, $V = 149.5$, $p = 0.01$) and the opaque mask (4.60 ± 2.80, $V = 140.5$, $p < 0.001$). The transparent and opaque mask conditions did not differ from one another ($V = 341$, $p = 0.17$; *Chi-square*: 13.74, $p = 0.001$). Similarly, participants felt they understood more during the condition without mask (7.93 ± 1.38) as compared to both the transparent mask (7.22 ± 1.88, $V = 647.5$, $p = 0.01$) and opaque mask conditions (6.97 ± 1.83, $V = 848$, $p < 0.001$), while transparent and opaque mask condition did not impact differently this feeling ($V = 624.5$, $p = 0.21$; *Chi-square*: 12.94, $p = 0.002$) (see Table 1 and Fig. 2B and 2C).

3.2. Comprehension performance and confidence

Participants' comprehension was tested with multiple choice questions, after watching the video and judging effort and feeling of understanding. The visual condition (without mask, transparent mask and opaque mask) did not significantly impact on performance (Chi-square: 0.69, p = 0.71; Fig. 2D). Instead, the measure 'confidence' approached statistical significance (Chi-square:4.86, p = 0.09), with trend for higher confidence values in the condition without mask (6.60 ± 2.51), and smaller confidence for the transparent mask (6.37 ± 2.33) and particularly for the opaque mask (6.18 ± 2.23; Fig. 2E).

4. Discussion

In the present study, we aimed to assess if hiding the lower part of the face with different types of masks influence sign language comprehension, both in terms of performance and metacognitive assessment. Due to the tendency of signers (particularly those who are most expert) to have a high rate of fixations in the area near the eyes while communicating, and since face-masks (partially or completely) occlude information originating from the middle-low part of the face, we expected a negative impact of face masks both on understanding performance and metacognition. Contrary to our prediction, our findings show that face masks, either opaque or transparent, do not have a substantial impact on sign language comprehension performance. This could reflect the preserved accessibility to other visual components of the signs (e.g., eyes, eyebrows, zygomaticus muscles, manual parameters, and head and trunk movements). Yet, a clear impact of face masks on metacognitive variables emerged: both the feeling of understanding and the perceived effort were affected by the mask, irrespective of whether it was opaque or transparent. A similar trend emerged also for the confidence measure. This shows that masks can selectively impact on metacognition even when performance remains substantially unchanged, resulting in a dissociation between actual performance and metacognitive effects on sign language communication.

This dissociation opens the possibility to examine the metacognitive effects of face-masks at the net of performance outcomes. Specifically, they suggest that metacognitive judgements on comprehension may not just reflect the quality of linguistic content processed, but rather the subjective assessment of the integrity of face-to-face communication. Parallel lines of investigation have documented that face-masks impact also on face recognition and recognition of emotional expression (Marini et al., 2021; Carbon, 2020; Marini et al., 2022; for a review see Pavlova and Sokolov, 2022). In this scenario, metacognitive effects of face-masks could

Table 1
Means with standard deviation for performance and metacognitive variables as a function of visual condition.

	Face	Transparent Mask	Opaque Mask
Effort	3.27 ± 2.77	4.13 ± 2.78	4.60 ± 2.80
FoU	7.93 ± 1.38	7.22 ± 1.88	6.97 ± 1.83
Correct Answers	2.42 ± 1.61	2.68 ± 1.44	2.52 ± 1.50
Confidence	6.60 ± 2.51	6.37 ± 2.33	6.18 ± 2.23

result from altered availability of face-cue signals for communication rather than just limited access to language. In the specific case of our study, the reduction of linguistic and *para*-linguistic components of sign language (i.e., the movements of mouth and lips), is not sufficient to dramatically affect performance, but it is enough to impact on feeling of understanding, perceived effort, and confidence.

Which specific aspects of the face-to-face interactions are most relevant for metacognitive assessment of communication remains an open question. One first possibility is that the metacognitive effects we observe result from the increased difficulty in reading emotions. This specific effect of face-mask has been documented in adults, with or without deafness (Amadeo et al., 2022). Even if our participants were not asked to recognize the emotion the signer was expressing, it is possible that they spontaneously read the signer's face in terms of "what is this person expressing to me?". Difficulties in these automatic processes could result in a feeling of uncertainty which, however, is more tied to missing emotional face cues rather than missing linguistic information.

A second possibility is that metacognitive effects could result from the difficulty in attributing attitudes to someone communicating with us. As social animals, we tend to attribute attitudes and intentions based on how a face looks like and on other characteristics, such as the way it moves (Todorov et al., 2015; Uleman et al., 2008). The same linguistic message can be delivered implying different attitudes, like serious or sarcastic, trustable or untrustable, based on our interlocutor communicative signals. For instance, previous studies already demonstrated that face masks alter our ability to attribute trustworthiness (Marini et al., 2021) or competence (Bennetts et al., 2022) to a face. Not being able to derive attitudes from a face could thus represent an anomalous situation in a face-to-face interaction, which could influence our judgments of understanding and effort.

A third possibility is that the effects of face-mask on metacognition are driven by the experienced reduction in sign language prosody. In spoken languages, different tones and different rhythms are used to express different meanings of a phrase. For instance, the way in which we intonate a phrase could make a difference between an affirmation and a question (for a review see Cole, 2015). Prosody is also used to signal the focus in a phrase, changing its suggested meaning. For example, in the phrase "Luke introduced Anna to Linda" we can put the accent on the name "Luke" to make our interlocutor focus on the person who introduces, or we can put the accent on the name "Anna", to focus on the person who has been introduced. On the basis of the focus, we can give different emphasis and different suggested meanings to the same phrase. In sign languages, prosody is represented by non-manual features (Dachkovsky and Sandler, 2009), which include face expressions and configurational movements of face parts. Occluding part of the facial features could thus generate uncertainty about what the signer is communicating beyond the linguistic meaning of his message.

This latter interpretation may be partly disconfirmed by the fact that, specifically for sign language prosody, the upper part of the face (eyes and eyebrows in particular) is most relevant and it remains visible even if the interlocutor is wearing a face-mask. Yet, it remains to be ascertained if processing of the single facial features not occluded by the mask may be influenced by the disruption of the holistic face processing (i.e., the tendency to process faces as a configurational object). This possibility is suggested by studies showing that face-masks reduce the face inversion effect (i.e., an index of configurational face processing) both in adults and school-age children (Freud et al., 2020; Stajduhar et al., 2022; but see Fitousi et al., 2021 for opposed findings). Even if there is no consensus in past literature, in our study the lack of significant differences in FoU and perceived effort between transparent and opaque masks conditions seems in line with the disruption of holistic processing account. Specifically, the presence of a visual obstacle, fully opaque or partially opaque, could have disrupted the configurational nature of the face alike, explaining the similar effect on metacognition.

Another possibility is that face-masks, either opaque or transparent, reduce our ability to share emotions and to experience empathy in face-to-face communication. A study by McCrackin et al. (2022) involving hearing participants, showed how transparent face-masks allow better understanding of emotional states when compared to opaque masks, but seem to have similar detrimental effects on emotional sharing, decreasing perceived empathy. Similar conclusions have been drawn in studies on face mimicry (i.e., the tendency to imitate the expressive display of someone else's face), in which face-masks reduced perceived emotional intensity and feeling of interpersonal closeness, especially for happy faces (Kastendieck et al., 2022).

To sum up, our results are compatible with theoretical approaches that conceptualize human language as an instance of much broader skill, that is sharing of communicative intentions through social signals. If we cannot derive pragmatic features of a conversation, it could impact on our metacognitive judgments about it, even when our comprehension is actually unchanged.

Note that when studying the impact of face-masks on spoken languages, dissociating the effect of reduced non-linguistic and paralinguistic face cues from those of reduced linguistic cues is considerably more challenging. In spoken languages the impact of face-masks on linguistic information is unavoidable, with substantial reduction of both auditory and visual information. Face-masks materials have a great influence on human voice intensity features, with attenuations up to 18 dB in the higher frequencies (for a review see Pörschmann et al., 2020). These attenuations impact especially on consonants perception, affecting word recognition and, in turn, speech understanding (Zhou et al., 2022). In addition, face-masks hide the lower face, impacting on speech understanding even when the auditory signal is unfiltered (Giovanelli et al. 2021). In spoken languages, lips and mouth act as an anticipatory cue that enhances the processing of the auditory signal. This visual information seems able to restore the auditory spectrum of what is poorly heard (Plass et al., 2020). Given the huge detrimental effect of face-masks on the ability to process speech, we cannot exclude the possibility that metacognitive effects are completely driven by a lack of understanding instead of a reduced access to non-linguistic or *para*-linguistic face cues normally visible during a face-to-face communication.

The scenario may instead be different for sign languages. When considering the perspectives that describe sign languages from a multilinear point of view (e.g., Volterra et al., 2022), it is noteworthy that the configurations of the mouth and of the lips of the signers carry on various types of linguistic information which can be either very specific or redundant with respect to the meaning expressed through the other articulators (eyes, eyebrows, cheeks, manual parameters, movement of the head and of the trunk). Thus, for the perceiver of a sign language message it remains possible to obtain linguistic cues from the multiple active articulators that are still accessible in signing despite the signer wearing a face-mask. For example, the meaning of BIG-BED can be expressed in sign language not only through one of the specific mouth configurations associated with big things (e.g., placing the upper dental arch on the lower lip), but also through the wider manual movement, the raised eyebrows, the opened eyes. Likewise, the meaning of SMALL-BED can be expressed not only through one of the specific mouth configurations associated with small things (e.g., protruding the tongue), but also through the shorter manual movement, the lowered eyebrows, the tightened eyes, the contraction of the upper zygomatic muscles (for more details about multimodal expression of evaluative morphology, see Petitta, Di Renzo and Chiari, 2015). In this view, the semantic redundancy, allowed and to some extent ensured by the multilinear characteristics of sign language productions, could have limited the loss of information (due to the reduction of linguistic information available) and this could explain why the performance remained substantially unaffected in the three different visual conditions, although the higher effort and the lower confidence reported by participants in the mask conditions. In our experiment we have carefully checked that the signer had not modified the manual components of the signs, as well as the non-manual ones which were not hindered by the mask in the different conditions. However, it is worth noting that in daily communication among deaf people wearing a mask, the signers may compensate for the loss of information (whether consciously or not consciously) by amplifying the features of the sign they know are visible by the addressee. For example, the signer could emphasize the indicators to convey BIG that are produced with the hand and/or with the eyes when they have a mask on. This phenomenon is relevant and has occurred more frequently since the use of the masks became very common. Future research could focus on this specific self-regulatory aspect, ideally comparing it with strategies that may occur in spoken languages (e.g., raising the volume of the voice or stressing specific aspects of the prosody).

Another possibility is that deaf participants could have filled the gap of the mask conditions by retrieving (or interpolating) the information that was partially or completely hidden by the masks, taking advantage of the overall context. However, this process is not costless and, indeed, the perceived effort was higher in the mask conditions with respect to the no-mask condition, probably also because in the former there was a great amount of information that participants have been forced to interpolate. This is in line with studies that examined college deaf students' allocation of visual attention in classrooms, which demonstrated that they looked away from signing teachers or interpreters for about 50% of the time (Matthews and Reich, 1993). This behavior appears to be common among deaf students, whilst it seems to be unusual among hearing interpreters involved in similar tasks (Marschark, Pelz, Convertino, Sapere, Arndt & Seewagen, 2005) and could be explained at least in two ways: (1) because of their enhanced visuospatial skills, deaf signers are able to look away from classroom communication and quickly reorient attention to a novel target, thus probably without losing too much information (e.g., Bavelier et al., 2001; Proksch and Bavelier, 2002; Pavani and Bottari, 2012), (2) deaf signers are able to look away from classroom communication without losing too much information because they have greater "filling in the gaps" abilities. To this end, it could be useful to explore the role of eventual variables that could explain the inter-individual variability shown by participants in this study.

This interpretation is also reminiscent of the work of Pavel et al. (1987) on American Sign Language which degraded the stimulus through visual blurring in central or peripheral parts of the visual field (see also Tartter and Fischer, 1982 and Fischer and Tartter, 1985, quoted in Bochner et al., 2011, p.1306). They found that intelligibility is more degraded when the blurring was in the center of the visual field compared to the periphery. They also observed that proficient users were able to fill the gaps using top-down processes at the cost of increased effort. While in the present work the visual obstacle was only limited to mouth and lower-face movements, in Pavel et al. (1987) central blurring disturbed all parts of the signed message. In addition, individual ASL signs were used, all isolated from context. This task appears to be very different from understanding the meaning of a narrative as here. Moreover, the signs were performed without lip movement or other facial expression, i.e., the part of the face hidden by the mask in our experiment. Nonetheless, participants might have used similar top-down processes to compensate for missing parts of the sign, possibly by inferring them through the use of other sign components.

Two limitations of the present work are worth discussing. First, it should be noted that the lack of effects on performance in the current study could depend upon the specific nature of the experimental task we used. Specifically, we used a story whose overall context was partially predictable. Future studies should use tasks in which sign understanding cannot rely on a general semantic context. Another limitation worth considering concerns the inclusion of participants that likely differed in sign proficiency. While all participants were recruited among a community of sign language users, who self-rated their LIS use as "often" or "very often", their actual sign language competence was not assessed directly in the present study. Evidence that sign proficiency differed between participants emerges in the variability observed in the 'face' condition, where no impediment was present. A proportion of participants appear to have struggled in this condition, reporting high effort and low confidence in their *meta*-cognitive scores, and failing most of the comprehension questions. Future studies should investigate this aspect further, with the prediction that the higher the LIS competence (as assessed in an independent LIS comprehension test) the less the effect of the visual conditions on performance and *meta*-cognitive assessment. Along a similar line of reasoning, it would be interesting to examine our research question in hearing LIS users (i.e., CODAs or sign language interpreters). This population could employ different attentional mechanisms compared to their deaf counterparts, with effects on their understanding ability. They may employ different resources and strategies to fill the information gaps caused by the face-mask compared to deaf signers.

5. Conclusions

We found that face-masks can impact sign language processing by impacting on the metacognitive dimension of understanding, even when performance remains substantially unaffected. We suggest that the reduced availability of linguistic and *para*-linguistic cues coming from lips and mouth movements could generate difficulties in social and emotional attributions and in understanding without effort what is being communicated. Difficulties in both linguistic and pragmatic dimensions of face-to-face communication could drive the observed metacognitive effects of face-masks. Our results have implications also on past literature on face-masks effects, which has always considered impacts of face-masks on linguistic and non-linguistic dimensions of face-to-face communication separately. Future research should consider the effects of face-masks on verbal and visual dimensions of communication in the same experimental design.

CRediT authorship contribution statement

Elena Giovanelli: Conceptualization, Methodology, Software, Data curation, Writing – original draft. **Gabriele Gianfreda:** Conceptualization, Methodology, Investigation, Resources, Writing – review & editing. **Elena Gessa:** Conceptualization, Software, Data curation, Writing – original draft. **Chiara Valzolgher:** Conceptualization, Methodology, Formal analysis, Writing – original draft. **Luca Lamano:** Resources. **Tommaso Lucioli:** Resources. **Elena Tomasuolo:** Conceptualization, Writing – review & editing. **Pasquale Rinaldi:** Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration. **Francesco Pavani:** Conceptualization, Methodology, Writing – original draft, Supervision, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Raw data can be retrieved from osf.io/arde8.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.concog.2023.103490.

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