Cognitive network science reconstructs how experts, news outlets and social media perceived the COVID-19 pandemic

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ABSTRACT

This work uses cognitive network science to reconstruct how experts, influential news outlets and social media perceived and reported the news “COVID-19 is a pandemic”. In an exploratory corpus of 1 public speech, 10 influential news media articles on the same news and 37,500 trending tweets, the same pandemic declaration elicited a wide spectrum of perceptions retrieved by automatic language processing. While the WHO adopted a narrative strategy of mitigating the pandemic by raising public concern, some news media promoted fear for economic repercussions while others channelled trust in contagion containment through semantic associations with science (e.g. “flatten the curve”), a strategy found also in other studies. In Italy, the first country to adopt nationwide lockdown, social discourse perceived the pandemic with anger and fear, emotions of grief elaboration, but also with trust, a useful mechanism for coping with threats. Whereas news mostly elicited individual emotions, social media promoted much richer perceptions, where negative and positive emotional states coexisted, but also where trust mainly originated from politics-related jargon rather than from science. This indicates that social media linked the pandemics to institutions and their intervention policies. The above emotions strongly influence people’s risk-averse behaviour and mental/physical wellbeing, as reviewed here in view of recent work about COVID-19. Cognitive network science opens the way to unveiling and understanding emotional framings and perceptions of news, with relevance for better understanding information flow during a global health crisis with little human coding.

Keywords: COVID-19, computational cognitive science, semantic networks, text mining, social media mining, emotions.

Word Count: 5596 (including references and figure captions).

INTRODUCTION

On March 11 2020 the World Health Organization (WHO) declared COVID-19 a pandemic. Simultaneously, a secondary *infodemic* of COVID-19 news flooded information systems, overwhelming large audiences with a deluge of content about the COVID-19 spread (Cinelli et al. 2020). In addition to this infodemic of fake news, even fact-checked articles reported a wide variety of contrasting views about the pandemic, e.g. diminishing the threat posed by

the pathogen, creating alarm about the impact of novel coronavirus over the economy or trying to convey the importance of social distancing for containing virus spreading. This massive proliferation of multiple views about the novel coronavirus overwhelmed large audiences with limited attention, ultimately promoting anxiety and inhibiting people from understanding the exact and correct dynamics of the pandemic (cf. Garfin et al. 2020).

In order to reduce anxiety and stress, identifying the contents promoted by this “battle of ideas” is urgently needed, also given how semantic and emotional content can deeply influence how we perceive and respond to massive events (Stella et al. 2018, Gallotti et al. 2020, Garfin et al. 2020).

This manuscript outlines how recent tools from computational cognitive science (Stella 2020, Siew et al. 2019) can crucially reconstruct how experts, news media and social media perceived and discussed the COVID-19 pandemic. Theoretical grounding is provided by semantic frame theory, which indicates that the meaning attributed in language to individual words or concepts is fundamentally built over conceptual associations with other concepts (Fillmore 2001, De Deyne et al. 2017, Vitevitch 2019). Hence, meaning cannot be attributed to words/concepts in isolation but rather require access to their *semantic frame*, i.e. the set of concepts linked to a given conceptual entity as occurring in language. Understanding the cognitive reflection attributed by individuals to the real world in terms of perceived meaning depends, therefore, on the semantic frame in which concepts are entwined together, e.g. in a text “pandemic” being conceptually related to other jargon like “disease”, “spreading” and “pathogen” means that the text author(s) framed “pandemics” as a phenomenon related to disease diffusion. Conceptual relationships might be of different types, like word co-occurrences (see also the interesting historical investigation of “risk” in Li et al. 2020) or syntactic/semantic links (like words specifying each other in a sentence or possessing the same meaning, see also Stella, 2020). Semantic frames arise from the associative structure

of language and contain both semantic and emotional content (Plutchik, 2001 and Vitevitch 2019). Recent research pointed out how different populations can reconstruct semantic frames containing very different emotions around the very same concept, e.g. high school students linking “maths” to anxiety-eliciting words and researchers associating “maths” to creativity-related positive jargon (cf. Stella et al. 2019). The identification of the emotional content of a given portion of language is called *emotional profiling* and it has been recently applied also to the investigation of online perceptions of COVID-19 (Stella et al. 2020, Lwin et al. 2020, Aiello et al. 2020).

This manuscript combines semantic frame theory with emotional profiling in order to reconstruct the plurality of views and emotions on the COVID-19 pandemic that were presented to millions of individuals by: (i) the authoritative WHO declaration of March 11 2020, (ii) influential news media reporting such declaration and (iii) online social media.

The structure of the paper includes a Methods section, outlining the linguistic datasets and the network analysis used here, followed by a Results section, reporting on the semantic frames and emotional profiles across 8 basic emotions (cf. Mohammad and Turney, 2010) of all the above declarations/articles/social media discourse. A Discussion section comments on the plurality of semantic views found in this exploration. The Discussion also interprets such results in light of relevant theories from cognitive science and other studies about the psychological impact of COVID-19 in relation to anxiety management, grief elaboration and psychological distress.

MATERIAL AND METHODS

This exploratory study focused about how the COVID-19 was perceived by different information channels and investigated a corpus including three different sources of textual

data: 1 speech transcript (WHO declaration), 10 news media articles on the same news (i.e. reporting the WHO declaration) and 37,500 tweets from social media (discussing the COVID-19 pandemic in the immediate aftermath of the WHO declaration). Notice that the requirement for articles to be on the same news crucially reduced the sample size of investigated texts.

This section outlines relevant information about the datasets and methods used in the main text.

Speech transcript and news media articles

The main analysis investigated the structure of linguistic knowledge as expressed in texts. The 10 news media analysed here were identified as influential by using a Google query as implemented in Mathematica 11.3. The Google query “COVID-19 WHO pandemic” on April 1 2020 provided the top-ranked ten articles reported in Table 1, mostly produced between 10 and 12 March 2020. Notice that all investigated articles were:

1 - Produced, published and updated between March 10 and March 22, which is the immediate aftermath of the WHO declaration of COVID-19 outbreaks being a pandemic (dated March 10 2020). 9 out of 10 articles were produced and updated between March 10 and March 12, guaranteeing a temporal coherence of the considered dataset, i.e. a collective of articles being produced within the same time window of the investigated Twitter dataset (see also the next section in the Methods);

2 - As reported in their titles, all the investigated articles focused on the same news of COVID-19 being declared a pandemic by WHO. This is an important indicator that the considered news articles did not focus on local happenings but rather analysed and interpreted the COVID-19 pandemic in light of the WHO declaration. This guarantees that the considered articles had also a topical coherence, all focusing on the WHO declaration and on COVID-19 being characterised as a pandemic.

Media ID and Link	News Outlet	Article Title
Media 1	ABC News	What the WHO pandemic declaration means.
Media 2	CNBC	World Health Organization declares the coronavirus outbreak a global pandemic
Media 3	National Geographic	Coronavirus is officially a pandemic.
Media 4	Times	World Health Organization Declares COVID-19 a 'Pandemic.'
Media 5	Telegraph	Coronavirus outbreak declared a pandemic: what does it mean, and does it change anything?
Media 6	NewScientist	Covid-19: Why won't the WHO officially declare a coronavirus pandemic? (Updated 11 March)
Media 7	BBC	Coronavirus: What is a pandemic and why use the term now?
Media 8	Channel News Asia	Threat of coronavirus pandemic now 'very real': WHO
Media 9	Washington Post	WHO declares a pandemic of coronavirus disease covid-19
Media 10	Business Insider	The coronavirus is officially a pandemic.

Table 1: News media articles investigated in this study, with online links and labels (Media 1-10).

Social media tweets

This analysis featured 37,500 Italian trending tweets gathered by Complex Science Consulting through the Twitter-approved account @ConsultComplex between March 11 and March 17 2020. All the investigated tweets had to feature the hashtag #pandemic together with one of the following hashtags: #coronavirus, #COVID-19, #COVID. Only tweets identified as trending by the Mathematica 11.3 “Popular” flag in the Twitter crawler ServiceConnect[] were considered in this analysis. The analysis focused on Italy given its resonance across the media due to the dramatic escalation of COVID-19 contagions in

March 2020. A different dataset was also crawled by Complex Science Consulting within the same time period and investigated separately by Stella et al. (2020).

Notice that despite the social media focusing over the discourse in Italy, the investigated tweets were influenced by the WHO declaration too and they were gathered in the next few days after the declaration itself, so that social discourse cannot be considered independent from the views portrayed in news articles. Establishing a direct causal link between exposure to news articles and social media reactions goes beyond the scope of this explorative study and it represents a delicate research question that started being successfully explored only in recent studies (cf. Schmidt et al. 2020 and Gozzi et al. 2020). Instead, this investigation focuses on comparing the semantic frames and emotional perceptions about the COVID-19 pandemic in the aftermath of the WHO declaration across different online sources.

Forma mentis networks as knowledge graphs extracted from text

This manuscript adopted the recent framework of forma mentis networks as already introduced and tested in previous works (Stella et al. 2019, Stella 2020). Forma mentis networks are knowledge graphs representing the mental lexicon, a cognitive system storing linguistic information and driving word acquisition and use (Vitevitch 2019, Siew et al. 2019). Representing conceptual associations between words as a network of nodes (words) and links (syntactic/semantic associations), textual forma mentis networks (TFMNs) extract both knowledge and affective patterns as embedded in text by a given author's mind. Syntactic relationships were extracted by using the language models available in TextStructure[], a command implemented in Mathematica 11.3. Semantic relationships indicating meaning overlap (i.e. two words/concepts being synonyms) were retrieved by using WordNet 3.0 in English and its Italian translation (cf. Bond and Paik, 2012). All words in texts were stemmed in order to represent different inflected forms with the same concept (e.g. "talking", "talked" and "talks" all representing "talk"). English words were stemmed by using the WordStem[]

function implemented in Mathematica 11.3. In Italian, words were stemmed by using the Snowball C stemming algorithm as implemented in R. Italian words were translated in English for easier visualisation.

Emotional Profiling and Cognitive Datasets

Combined with the NRC Emotion Lexicon by Mohammad and Turney (2010), TFMNs can identify the emotional profile of a given concept in a collection of texts. The emotional profile of a concept here was defined as the number of words eliciting a given emotion associated/linked to a given concept, as performed also in previous studies (Stella et al. 2020, Stella 2020, Stella 2020b). Negations were considered by associating antonyms to negated words (e.g. “not” linked to “love” was replaced by both “love” and “hate” in emotional profiling). The NRC Emotion Lexicon in Italian was obtained from the English one by adopting a consensus translation with services including Google Translate, Bing Translator and DeepL. Where at least two out of three translator services provided the same translation for a word, that one was used. In all other cases translation was human coded by the author. On a random sample of 200 words, the accuracy of translation was estimated to be 93%. This required also an additional human coding of the translation, checking for and correcting mistakes according to the author’s expertise.

The null model for emotional profiles was random word sampling from the NRC lexicon. This was necessary as the original NRC lexicon features more words eliciting certain emotions and fewer words eliciting other emotional states, so that richness of words by itself might be an artefact of the underlying dataset if no null model is considered (see also Stella et al. 2020). Z-scores were computed between the empirical emotional profiles of “pandemic” and a distribution of 1000 random samples. The confidence interval relative to a 0.05 significance level was adopted as neutrality range, i.e. a range where no emotional pattern was identified.

RESULTS

Semantic frames and emotions as attributed in the processed texts highlight interesting patterns on how the COVID-19 pandemic was announced by WHO and discussed by news outlets and social media users.

Investigating the knowledge and emotions in the whole WHO declaration

Figure 1 visualises the WHO declaration of “COVID-19 is a pandemic” in terms of a knowledge graph, a textual *forma mentis* network representing the mindset (in Latin *forma mentis*) portrayed in the declaration in terms of concepts (nodes) linked by semantic and syntactic relationships (cf. Methods). Larger nodes are relative to concepts with a higher closeness centrality (see Newman 2018), i.e. connected by fewer links to all other concepts in the network. Since previous studies indicated how closeness in *forma mentis* networks captures semantic prominence (see Stella 2020), the knowledge graph indicates how the WHO declaration mainly revolved around “country”. Other prominent concepts (i.e. high in closeness centrality) were “we”, “not”, “take”, “case”, “change”, “tell” and “numbers”, indicating that the speech adopted a first-person narrative revolving around countries and the change (of the pandemic) due to the registered numbers of cases. This is not surprising but comes as a confirmation that a network metric (closeness centrality) can identify key aspects of an apparently unstructured piece of text (in this case the WHO declaration of COVID-19 being a pandemic).

In addition to this reality check, the knowledge graph can also conveniently convey a visual representation of words and semantic frames. For instance, in Figure 1 words are clustered in communities as identified by a Louvain algorithm (cf. Newman 2018). Communities are defined as network regions made of tightly interconnected nodes and in a *forma mentis* network a community can provide contextual knowledge describing the meaning attributed to

concepts across sentences (cf. Stella 2020). By considering the community including “pandemic” one can notice that the WHO speech presented the concept of a pandemic to the general audience in relationship to “health”, “change”, “crisis” and even “economy”: WHO presented the pandemic as a challenging crisis not only for global health but also for the economy. Positive terms like “protect”, “together” and “calm” appeared within the same community of “pandemic” and indicate a tendency for the speech to call for calmness and a communal protection against such crisis.

The overall emotional profile of the speech is reported in Figure 1 (bottom, right). The words adopted in the WHO declaration elicited strong emotional patterns of fear, anger and sadness but also levels of trust higher than random expectation. Combinations of fear and sadness indicate concern, according to Plutchik’s wheel of emotions (Plutchik, 2001), but what about the combination of positive and negative emotions? The co-existence of concern and trust indicates a clear narrative strategy pursued by WHO in their speech: to clearly explain the dangers posed by the COVID-19 emergency to the general public, while subsequently adopting also trustful language focusing on how to face the crisis itself.

Investigating knowledge and emotions around “pandemic” across texts

Forma mentis networks were built not only for the WHO declaration but for all the considered articles and aggregated tweets. Rather than investigating the whole networks, attention was given to the individual semantic frames, i.e. the network neighbourhoods, of “pandemic” across texts. Figure 2 (top) reports the semantic frames and emotional profiles of “pandemic” in the WHO declaration, within two of the 10 investigated articles and within social discourse. Figure 2 (bottom) provides the complete spectra of emotional profiles across all the investigated media.

The other semantic frames and emotional profiles reported here are the most dissimilar from the WHO's one. News media 4 provided a highly polarised perception of "pandemic", combining fear-inducing links to "threat" with more trustful concepts about the future, a combination indicating submission, apprehension and passive acceptance of COVID-19 being a pandemic. Instead, news media 7 depicted a more neutral and trustful frame for the COVID-19 pandemic, using neutral jargon, explaining the epidemiological definition of a pandemic and conveying emotions of trust into "changing the curve", a widespread motto for fighting COVID-19. These patterns were absent in the original WHO declaration and have thus to be considered as cognitive alterations attributed to the way individual journalists framed the news "COVID-19 is a pandemic" compared to what was originally declared by WHO. It should be stressed that these alterations emerge from a purely quantitative modelling of texts and do not require any human coding or reading of the underlying texts.

Social media strongly debated over the COVID-19 pandemic. Here attention was given to Italy, the first European country struck by COVID-19 and reacting with a national lockdown (see Stella et al. 2020). In 37,500 Italian tweets (see Methods), "pandemic" spawned a social discourse featuring contrasting, affect-polarising concepts like "help", and "hope" together with "risk" and "attack". The resulting emotional profile was strongly trustful, dominated by a positive awareness of the coronavirus and the need to offer assistance against it, but also mixed with patterns of fear (against the risks of the pandemics), anger (against a global threat) and anticipation (for a better future).

Anger and fear are both natural evolutionary mechanisms for coping with threats (Plutchik, 2001) and also natural responses in elaborating grief about a negative event, as indicated by the Kübler-Ross model (Kübler-Ross and Kessler 2005). These emotions are therefore expected when perceiving a pandemic and were also strongly detected in other studies focusing on different datasets related to social discourse about the COVID-19 pandemic

(see Aiello et al. 2020). Interestingly, in here grief-related emotions attributed to “pandemic” were found to be dominated by more positive ones, expressing awareness and willingness to act upon the recently declared health emergency. In this way, the perception of the “pandemic” itself is quantitatively found to be way richer in positive/trustful concepts than the framing portrayed by WHO.

DISCUSSION AND CONCLUSIONS

The same event can be described in text through different semantic frames, eliciting different emotions and perceptions. The real challenge in AI is quantifying and reconstructing these frames without human coding and in absence of training data. This manuscript tested knowledge modelling via cognitive network science as a quantitative way for automatically identifying key concepts and their emotional perceptions in texts, e.g. articles and social media messages. The semantic and emotional frames reconstructed here around the news “COVID-19 is a pandemic” open quantitative ways for tracking how COVID-19 was discussed by experts, news media and social networks.

Fear, anger and trust about the pandemic were detected in news outlets and social media reaching large audiences. It is crucially important to keep track of any massive release of information vehiculating these emotions, since the latter can strongly influence individuals’ perception, mental well-being and real-world behaviour (cf. Lerner 2001, Plutchik 2001, Staufenbiel et al. 2013, Moron and Biolik-Moron 2020). As recent studies from computational social science pointed out (cf. Kramer et al. 2014), both negative and positive emotions can give rise to emotional contagion over social media, a phenomenon where emotions pass from user to user by the mere act of reading a post/message portraying a certain emotional profile and without any real-world experience giving grounding to the emotions being transmitted. Hence, emotional contagion over social media can infect unaware audiences

and potentially destabilise public opinion about the COVID-19 crisis (cf. Cinelli et al. 2020). A recent investigation on the reopening after lockdown found that online users on Twitter tended to retweet more those messages richer in fear-eliciting jargon (Stella 2020b), further indicating the possibility for fear-eliciting content to give rise to emotional contagions of fear.

According to cognitive science, contagions of fear and anger would have different repercussions. Responding to threats with anger greatly inhibits risk perception (cf. Lerner, 2001), leading to resisting risk-reduction policies (e.g. lockdown or social distancing). Instead, fear heightens risk perception thus leading to more risk-averse behaviour (cf. Lerner, 2001). However, prolonged states of fear are detrimental for correctly identifying threats and induce higher levels of cortisol, which impair both mental wellbeing and the immune system (Staufenbiel et al. 2013). Hence, a deluge of fear-inspiring semantic frames, like the ones found in some news media in this exploratory study, might have concrete repercussions over the COVID-19 contagion, influencing people's immune systems and bolstering their susceptibility to pathogens. The exact quantification of this relationship between COVID-19 fear levels and health susceptibility remains an open question for future research. However, it should be noted that fear can also assume a positive role in hampering the pandemics. Harper and colleagues (2020) recently found that moderate levels of fear were functional in promoting public health compliance and boosting positive behavioural changes (e.g. social distancing) aimed at containing the contagion in a sample of 324 people. This positive role played by fear in motivating for people to adopt a more responsible behavior aligns with the moderate levels of fear found in the semantic frame of "pandemic" in the WHO declaration, providing further support to the narrative expedient adopted by WHO of raising concern about the novel coronavirus with concerned jargon related to epidemics and including also mitigation measures.

Trust was identified in the semantic frames of “pandemic” as discussed by social media and some news outlets. The reconstructed semantic frame reported here indicated how news outlets channelled trust through scientific knowledge, a “scientific explanation” strategy useful for improving individuals’ awareness about the mechanisms driving the pandemic and its containment. Recent studies also outlined how eliciting trust is a good strategy not only for reducing the incidence of fear and anger but also in order to boost compliance with regulations and responsible health behaviour (Khemani 2020). The “scientific explanation” strategy was not found in the semantic frames extracted from social media discourse, where trust-eliciting concepts were not linked to scientific jargon but were rather connected to “politics”. This confirms that trust can indeed come from different sources, as also channelling feelings of trust towards politics can make large audiences comply with public health orders like respecting social distancing (Khemani 2020, Sibley et al. 2020). Notice that higher levels in trust towards science and politics, as outlined here with this study, were also found by previous investigations targeting populations under recent lockdown caused by the COVID-19 (cf. Sibley et al. 2020 and Stella et al. 2020).

Tracking the levels of perceived trust around the COVID-19 pandemics and identifying the sources of such trust, be it scientific knowledge or politics, is a crucial challenge for better understanding compliance with regulations. In fact, audiences with little trust in the institutions can mine the credibility of governments, both fostering divisive politics and hampering nationwide adoption of strategies for pandemic containment (Khemani 2020).

It should be noted that trust and fear are not direct opposites. According to the Atlas of Emotions (Plutchik, 2001) trust and awareness can turn anger into a constructive motivation towards facing the threat or source of anger itself, in this case the COVID-19 pandemic. This interconnectedness suggests a highly nuanced perception of social media users towards facing the COVID-19 pandemic, as also found within other studies focusing over Twitter data

(Lwin et al. 2020 and Stella et al. 2020) and other social media platforms (Cinelli et al. 2020, Aiello et al. 2020).

The above points outline a complex landscape of real-world implications for the different emotional perceptions of the COVID-19 pandemic. The current semantic/emotional frames can be a valid compass for navigating such landscape, with some limitations. This exploratory study considers only textual information, thus neglecting other types of communication through visual or verbal cues. Nonetheless, the plurality of perceptions quantified here, in a statistically robust way, indicate how already processing only textual sources might provide richly complex semantic frames and emotional profiles about how the COVID-19 pandemic is perceived, discussed and reported to large audiences.

Another limitation of this study was neglecting how potential automated accounts might have biased social discourse. Recent investigations (Stella et al. 2018, Pozzana and Ferrara, 2020) found that social bots, i.e. user accounts piloted by an automatic software, were quite capable of influencing human behaviour by fostering negative, conspiratorial and anxious perceptions in online platforms. Applying the same tools of cognitive network science explored and tested here to the investigation of the semantic frames produced by social bots represents an interesting future research direction.

Besides the above limitations, the main advantage of cognitive network science is its ability to capture linguistic associations, semantic frames and emotions in a transparent way, enabling a visualisation of conceptual associations in texts and without requiring training data for machine learning.

Future research should build upon cognitive network science for a better understanding of social media, possibly in synergy with other promising and successful automatic approaches to knowledge modelling (cf. Brito et al. 2020, Lucking et al. 2020, Choi et al. 2020, Murray et

al. 2020 and Gozzi et al. 2020). Access to large-scale corpora of news media articles would enable prompt identification of outlets promoting distorted mindsets (“COVID-19 is just a flu”) or panic-inducing misinformation. A richer understanding of the context promoting negative perceptions should be pursued also in the analysis of political debate, like in (Brito et al. 2020), where cognitive networks can unveil how political parties or politicians discuss the COVID-19 emergency. The current methodology can also identify how people perceive health risks and concrete symptoms of COVID-19, complementing recent powerful analyses extracting the symptoms of novel coronavirus from social discourse (Murray et al. 2020) and complementing interesting dynamical patterns of grief elaboration and COVID-19 recently unearthed in social platforms by Aiello and colleagues (2020).

In this time of uncertainty, about the evolution of the coronavirus pandemic and the impact of lockdowns, having a clear, misinformation-free perception of the COVID-19 pandemic is fundamental (cf. Larson 2020). The cognitive network science framework outlined in this work can tackle this challenge, effectively capturing and reproducing a plurality of views promoted about the COVID-19 pandemic. Access to such information opens new ways for policy makers to act based on how large audiences perceive the COVID-19 pandemic and its repercussions.

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AUTHOR DISCLOSURE STATEMENT

The author reports no conflict of interest in connection with the current work.

FUNDING INFORMATION

The author received no financial support for the research, authorship, and/or publication of this article.