



# All about that trait: Examining extraversion and state anxiety during the SARS-CoV-2 pandemic using a machine learning approach

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## ABSTRACT

We examine the longitudinal relation between extraversion and state anxiety in a large cohort of New York City (NYC) residents using a linguistic analytical machine learning approach. Anxiety, both state and trait, and Big Five personality traits were predicted using micro-blog data on the Twitter platform. In total, we examined 1336 individuals and a total of 200,289 observations across 246 days. We find that before the onset of SARS-CoV-2 in NYC (before 1st March 2020), extraverts experienced lower state anxiety compared to introverted individuals, while this difference shrinks after the onset of the pandemic, which provides evidence that SARS-CoV-2 is affecting all individuals regardless of their extraversion trait disposition. Secondly, a longitudinal examination of the presented data shows that extraversion seems to matter more greatly in the early days of the crisis and towards the end of our examined time range. We interpret results within the unique SARS-CoV-2 context and discuss the relationship between SARS-CoV-2 and individual differences, namely personality traits. Finally, we discuss results and outline the limitations of our approach.

## 1. Introduction

From 2020 to 2021, in what remains an ongoing public health crisis, SARS-CoV-2 spread across the globe. In what became known as the most devastating worldwide crisis in history, the vast majority of the individuals were instructed to work from home (WFH) and socially distance themselves from friends, family, and co-workers (Mervosh et al., 2020). With headlines such as “we are all in this together” flooding social media, there is solace in knowing that everyone is in a similar situation and is sharing similar emotions of frustration, anxiety, and lack of social connection with others. Yet, some scholars have speculated that these emotions might not have been experienced equally across the population (McCleskey & Gruda, 2020). For example, some suggested that imposed socialization restrictions might have impacted extraverts more than introverts (Folk et al., 2020) and that extraversion may play a key role in understanding individuals' adjustment to the SARS-CoV-2 pandemic (Gruda & Ojo, 2021). Hence, introverts (i.e., individuals who score low on extraversion) might have been less likely to experience negative emotions, such as anxiety, during the SARS-CoV-2 crisis. Put differently, could low levels of extraversion protect against experiencing increased levels of anxiety during this pandemic? This paper makes a first step in addressing this research question.

First, we investigate the role of extraversion in predicting state anxiety before and throughout the SARS-CoV-2 crisis. To do so in a large sample of 1336 individuals with 2,259,186 micro-blogs on the Twitter platform, resulting in 200,289 daily observations, we apply two machine learning algorithms to predict (state) anxiety over time and Big Five personality scores. Secondly, we examine this relationship on a day-by-day basis from the onset of the SARS-CoV-2 pandemic in New York City. Finally, we showcase and relate results to previous literature.

## 2. Extraversion and well-being

Extraversion is composed of several sub-facets, including “sociability, gregariousness, assertiveness, engagement in activity, sensation seeking, and susceptibility to positive affect” (Dauvier et al., 2019, p. 3). Extraverted individuals seek out social activities and interaction, experience high positive affect, and generally act more assertively around others, and respond more vigorously to reward cues in their social environment (Smillie et al., 2015). In general, extraverted individuals “are more disposed to encounter objectively pleasant events and display more positive thoughts” (Dauvier et al., 2019, p. 4). Previous work indicates that the link between extraversion and personal well-being likely relies on extraverts' preference for social interactions (Anglim et al.,

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2020). Hence, it seems likely that extraverts' larger social network, might provide a buffer to negative affect, especially in times of crises or great uncertainty (Folk et al., 2020). Therefore, it seems that a preference for aloneness, behavior which is more closely related to introverted individuals, is associated with higher anxiety, depression, and emotion dysregulation (Nguyen et al., 2018).

However, although these findings have held up in various previous works (e.g., Zelenski et al., 2014), the current SARS-COV-2 crisis is different from previous exogenous shocks since it is a "socially distant" health crisis. As such, this particular crisis has resulted in a large decrease in social face-to-face connections to others, behavior that is closely related to extraverted individuals (Folk et al., 2020). Hence, the current crisis provides a unique setting, in which the potential advantages of high introversion, previously primarily associated with negative health outcomes, might serve as a protective mechanism against specific health outcomes such as state anxiety.

### 2.1. Extraversion and anxiety during the SARS-COV-2 pandemic

Concerning the association between extraversion and anxiety-related experiences, Zelenski and Larsen (2002) found that extraverted individuals expect positive future events more frequently. However, these findings have been contested by others (e.g., Jylhä & Isometsä, 2006). We argue that additional research is required to better understand the link between extraversion and anxiety, in particular in the context of the current exogenous shock caused by the SARS-COV-2 pandemic and its required social distancing behavior protocols. These new behaviors are largely atypical for both introverts and extraverts and are likely associated with increased anxiety.

Anxiety is typically described as feelings of tension, worry, and apprehension (Spielberger et al., 1983). It is important to distinguish between the two main types of anxiety. On the one hand, state anxiety describes the temporary experience of anxiety, usually triggered by an ongoing or upcoming event, e.g. an employee's upcoming presentation in front of their co-workers is likely to trigger feelings of anxiety ahead of time. On the other hand, some individuals experience anxiety frequently over time, without a specific trigger marking the onset of anxiety. This type of anxiety is often referred to as trait anxiety. Trait anxiety, as the term suggests, is considered a stable disposition towards recognizing and interpreting stimuli as threatening.

Although previous studies are a good starting point in examining the relationship between state anxiety and extraversion, the current SARS-COV-2 crisis is different from previous crises. Not only do individuals have to cope with increased uncertainty and anxiety about their own and their families' personal and economic future, but they also have been forced to cope with a significant drop in social interactions, including interactions at work. Most companies have directed their workforce to solely WFH for the near future with no end in sight for many employees, who now must balance work obligations with family and personal obligations, all from home.

Previous literature has shown that prolonged deprivation of social contacts significantly reduces feelings of connection and is associated with poor mental health (Sun et al., 2020). Social isolation affects all individuals, regardless of individual differences. However, extraverted individuals, who habitually seek out social interactions are more likely to be impacted by an environment that discourages social interactions, compared to their more introverted counterparts. In general, introverts tend to have fewer social connections (and therefore interactions) than extraverted individuals (Srivastava et al., 2008). Hence, concerning the current social isolation crisis, we would expect introverts (i.e., individuals who score low on extraversion) to be disposed to better cope with their initially changing environment and imposed social distancing requirements, and therefore experience less state anxiety than their extraverted counterparts (i.e., individuals who score high on extraversion).

## 3. Methodology

Linguistic-based text analytics or linguistic analytics exploits information about the syntax and semantics of a language as well as lexicons, to extract important information from textual data. For instance, while Gruda et al. (2020), Gruda, Karanatsiou, Mendhekar, Golbeck, & Vakali, (2021), Gruda, Karanatsiou, Hanges, Goldbeck, & Vakali, (2021), and Karanatsiou et al. (2020) applied linguistic-based text analytics on Twitter data to detect traits such as narcissism and attachment, Ojo and Rizun (2019) employed linguistic markers found in negative free-text comments provided by hospital service users to determine the frequency and intensity of the associated negative experience. In addition, more recent work by Gruda and Ojo (2021) and Gruda, Ojo & Psychogios (2021) have also demonstrated that mental health signals can be identified from publicly available Twitter data.

In this work, we build on two machine learning-based linguistic analytics algorithms to achieve our research goals. The first algorithm is the state and trait anxiety prediction algorithm described in Gruda and Hasan (2019) and Gruda & Hasan, (2018), while the second algorithm constitutes the IBM Watson Personality Insights algorithm (Gliozzo et al., 2017) for inferring Big Five personality traits and associated facets. We apply these algorithms to a sample of 2,259,186 million tweets from 1336 user accounts of NYC residents.

Detailed descriptions of our approach and the two aforementioned algorithms as part of the overall analytics and computational process implemented in our study are provided in Supplementary Materials. However, an overview of our approach is provided in Fig. 1.

## 4. Results

Pairwise correlations are provided in Table 1.

### 4.1. Extraversion and state anxiety before and after the onset of the SARS-COV-2 pandemic

Firstly, we examine the effect of extraversion on state anxiety between two different periods, namely "before corona" (BC) and "after corona" (AC) cases were first recorded in NYC, i.e. before and after 1st March 2020. To ensure a balanced dataset, for comparison, the period BC is defined from 30th October 2019 – 29th February 2020, while the period AC is defined from 1st March 2020 to 2nd July 2020. Both periods correspond to a range of 123 days, respectively. The results are reported in Table 2 below.

Model 1 (M1; Table 2) includes the independent variable, namely extraversion, as well as controls (remaining Big Five personality traits, and time). Including time as a variable in our model allows us to control for time-specific effects on the various days reflected in our dataset as an unexpected variation or special events (such as an increase in cases, new restrictions, etc.) might affect our outcome variable. In Model 2 (M2; Table 2) we introduce an additional control variable, namely trait anxiety, and in Model 3 (M3) we introduce our BC-AC (dummy) variable. Finally, in Model 4 (M4), we examine the interaction between extraversion and our before and after COVID-19 dummy variable (i.e., BC-AC). Results show a positive relationship between state anxiety and the interaction of extraversion and BC-AC (M4,  $b = 0.09$ ,  $SE = 0.01$ ,  $z = 7.77$ ,  $p < .001$ ). To understand this main interaction further, we graph the result accordingly in Fig. 2 ( $\pm 1$  SD).

A simple slopes test ( $\pm 1$  SD) shows a significant difference between introverts and extraverts in the pre-SARS-COV-2 period (simple slope =  $-0.15$ ,  $SE = 0.02$ ,  $z = -6.77$ ,  $p < .001$ ). After the onset of SARS-COV-2 (i.e., AC), results showed a smaller difference between introverts and extraverts (simple slope =  $-0.06$ ,  $SE = 0.02$ ,  $z = -2.48$ ,  $p = .013$ ).

For more comprehensive insights, we conduct a longitudinal examination of the relationship between extraversion and state anxiety.

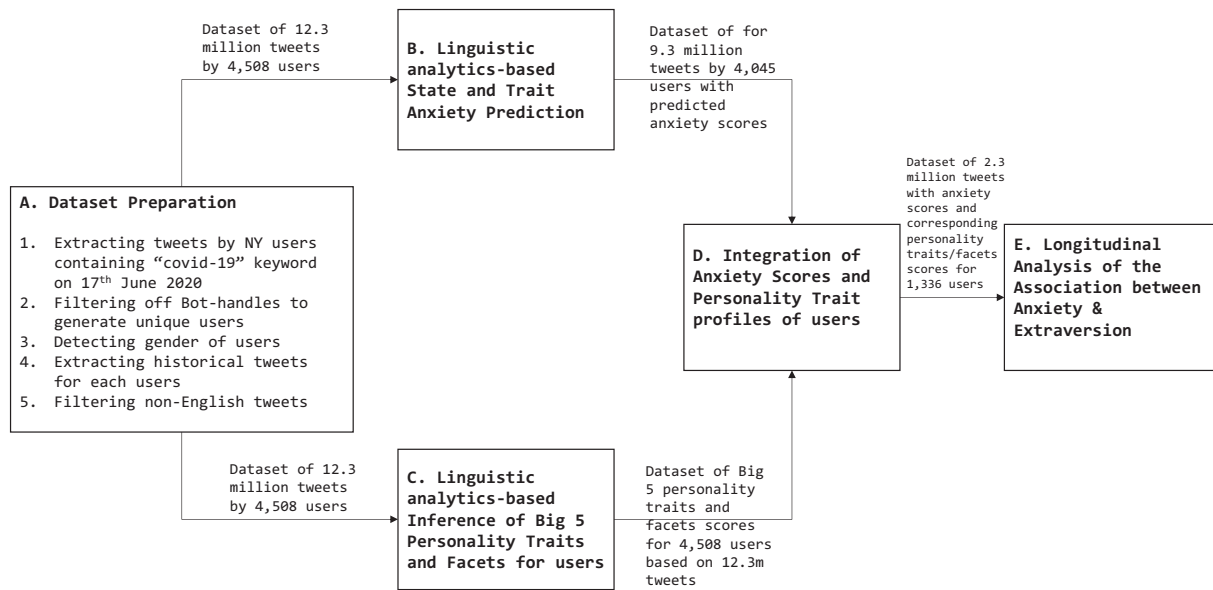


Fig. 1. Overall analytical process.

Table 1  
Pairwise correlations of (predicted) variables.

Variables	M	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) State anxiety	2.33	0.25							
(2) Trait anxiety	2.31	0.13	0.42***						
(3) Openness to experience	0.59	0.14	0.01***	0.02***					
(4) Conscientiousness	0.48	0.19	-0.14***	-0.29***	0.24***				
(5) Extraversion	0.37	0.14	-0.27***	-0.58***	0.16***	0.59***			
(6) Agreeableness	0.46	0.14	-0.20***	-0.43***	0.47***	0.68***	0.64***		
(7) Neuroticism	0.50	0.18	0.13***	0.28***	-0.21***	-0.89***	-0.72***	-0.66***	
(8) Gender	0.64	0.48	-0.03***	-0.04***	0.00***	0.02***	0.01***	0.03***	-0.05***

Note: Gender = female (0) and male (1); \*\*\*  $p < .001$ ,  $n = 1336$  individuals (200,289 observations).

Table 2  
Relationship between extraversion and state anxiety (BC-AC).

	M1	M2	M3	M4
Openness to experience	0.18 (7.26)	0.06*** (3.59)	0.06*** (3.59)	0.06*** (3.60)
Conscientiousness	-0.17*** (-4.85)	0.01 (0.46)	0.01 (0.43)	0.01 (0.38)
Extraversion	-0.58*** (-19.49)	-0.10* (-4.29)	-0.10*** (-4.33)	-0.15*** (-6.77)
Agreeableness	-0.25*** (-6.94)	-0.06** (-2.86)	-0.06** (-2.87)	-0.06** (-2.89)
Neuroticism	-0.39 (-10.09)	-0.02 (-0.89)	-0.02 (-0.93)	-0.02 (-1.00)
Trait anxiety		0.74 (32.74)	0.74 (32.75)	0.74*** (32.76)
BC-AC			0.02*** (9.10)	-0.01** (-2.71)
BC-AC X extraversion				0.09*** (7.77)
Time	0.00*** (25.17)	0.00*** (25.54)	0.00*** (8.52)	0.00*** (8.55)
Constant	-2.87*** (-12.42)	-5.11*** (-21.58)	-2.33*** (-6.55)	-2.32*** (-6.53)
R <sup>2</sup> (between)	0.45***	0.79***	0.79***	0.79***

Note: Before COVID-19 (BC; 30th Oct. 2019 – 29th February 2020) = 0, After COVID-19 (AC; 1st March 2020 – 22nd June 2020) = 1; unstandardized coefficients; robust standard errors; z-statistic in parentheses; between-R<sup>2</sup> = amount of variance between separate panel units accounted for in the model; \*\*\*  $p < .001$ , \*\*  $p < .01$ ;  $n = 200,289$  observations, 1336 individuals.

#### 4.2. Extraversion and state anxiety over time

To understand the relationship between extraversion and state anxiety, we must take into account the changing nature of the ensued crisis as a result of SARS-CoV-2 (see Fig. 3). For example, it is likely that as daily infections, hospitalizations and deaths increased (or decreased), the relationship between extraversion and anxiety likely changed as well. We, therefore, build a model to account for changes over time between our two variables of interest (Table 3).

Instead of comparing anxiety differences between introverts and extraverts post an arbitrary beginning of SARS-CoV-2 (e.g., the day SARS-CoV-2 was declared a pandemic vs. the day the first case of SARS-CoV-2 was recorded in NYC vs. the day quarantine restrictions were issued in NYC), in this model we treat time (i.e., days of SARS-CoV-2) as a continuous variable. This allows us to graph the relationship between extraversion and state anxiety for every day of the SARS-CoV-2 pandemic while accounting for experienced anxiety on all previous days. Therefore, we consider the full range of available data in this dataset (i.e., from 30th October 2019 – 2nd July 2020). In addition, we also control for the same variables as before, namely all Big Five personality traits, trait anxiety, and time.

Results show that, overall, the relationship between state anxiety and the interaction between extraversion and days of SARS-COV-2 is positive and significant (Table 3;  $b = 0.00$ ,  $SD = 0.00$ ,  $z = 5.71$ ,  $p < .001$ ). We note that the reported interaction effect (i.e.,  $b = 0.00$ ,  $p < .001$ ), are the result of several factors. First, in this model time is treated as a continuous variable across a large period of time, namely 123 days. Second, all personality traits in this paper, including extraversion, were coded to

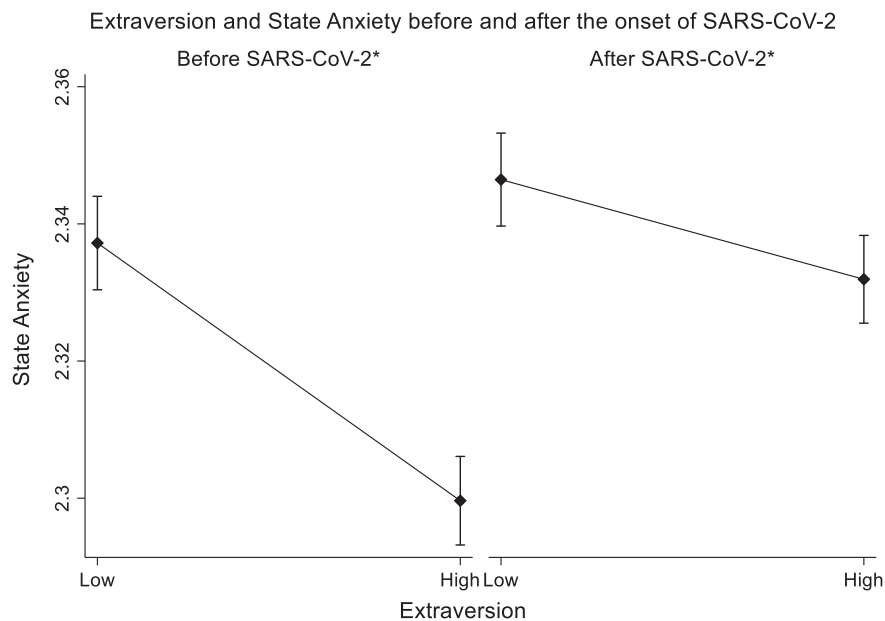


Fig. 2. Regression model predicting state anxiety (before/after COVID-19\*)

Note: \* = announcement; Before the onset of the SARS-COV-2 pandemic (30th Oct. 2019 – 29th February 2020) – After the onset of the SARS-COV-2 pandemic (1st March 2020 – 2nd July 2020); Figure includes respective 95% Confidence Intervals, n = 200,289 (1336 individuals).

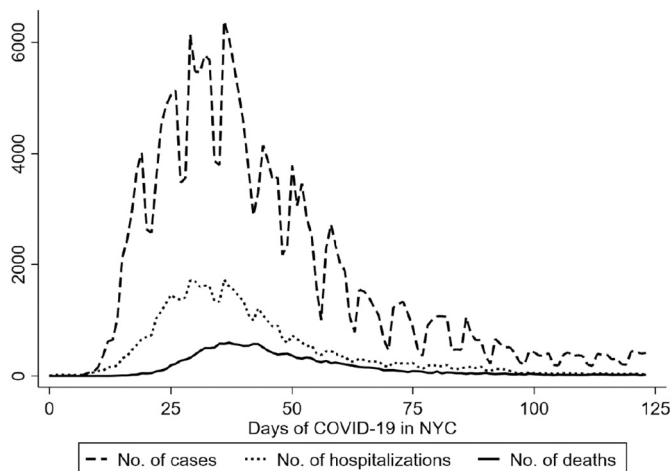


Fig. 3. Number of cases, hospitalizations and deaths due to SARS-CoV-2 in New York City.

have values between 0 and 1, which also affects the reported interaction coefficient. Third, the sample on which the reported interactions are based is also quite large (i.e., 200,289 observations).

To understand this interaction further and to help facilitate the interpretation of results, we graph results over time in Fig. 4. To ensure the readability and interpretability of results, we provide results using five-day intervals. Given that in this analysis we examine specific daily changes of anxiety we chose meaningful scores of extraversion (i.e., 5th and 95th percentile) at which to evaluate slopes to illustrate the difference between low vs. high levels of extraversion and state anxiety, instead of graphing one standard deviation above the mean (the “pick a point” approach; Rogosa, 1980). Doing so allows us to view results across the entire spectrum of extraversion, instead of focusing on average values (e.g.,  $\pm 1$  SD), and is in alignment with previous literature (Dawson, 2014).

As shown in Fig. 4, before the onset of SARS-CoV-2 extravert residents of NYC experienced much lower levels of anxiety compared to

Table 3

Longitudinal analysis of extraversion and state anxiety during the SARS-CoV-2 pandemic.

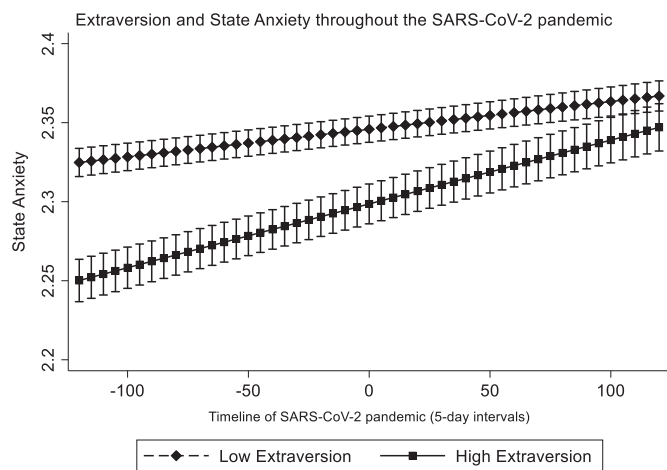
	State anxiety			
	b	SE	z	[95% confidence interval]
Openness to experience	0.06***	0.02	3.60	0.03 0.09
Conscientiousness	0.01	0.02	0.42	-0.03 0.05
Extraversion	-0.10***	0.02	-4.60	-0.15 -0.06
Agreeableness	-0.06**	0.02	-2.87	-0.10 -0.02
Neuroticism	-0.02	0.02	-0.94	-0.07 0.02
Trait anxiety	0.74***	0.02	32.73	0.70 0.78
Time	0.00*	0.00	2.54	0.00 0.00
Time × extraversion	0.00***	0.00	5.71	0.00 0.00
Constant	0.65***	0.07	9.82	0.52 0.78
R <sup>2</sup> (between)	0.79***			

Note: Time = Days of SARS-CoV-2 pandemic (i.e., continuous variable); Day 0 (1st March 2020, first case recorded in New York City), Day 123 (2nd July 2020); between-R<sup>2</sup> = amount of variance between separate panel units accounted for in the model; unstandardized coefficients; robust standard errors; \*\*\*  $p < .001$ , \*\*  $p < .01$ , n = 200,289 observations, 1336 individuals.

introverts on the same day (e.g., simple slopes test on Day -120:  $b = -0.16$ ,  $SD = 0.02$ ,  $z = -6.91$ ,  $p < .001$ ). However, as the crisis ensued, extraverts' anxiety quickly “caught up” with introverts' anxiety levels (e.g., simple slopes test on Day 100:  $b = -0.05$ ,  $SD = 0.02$ ,  $z = -2.13$ ,  $p = .033$ ). From Day 108 onward, results show no significant difference in experienced anxiety in introverts compared to extraverts (simple slope:  $b = -0.05$ ,  $SD = 0.026$ ,  $z = -1.94$ ,  $p = .052$ ). This trend continues until the last day in our dataset.

### 5. Discussion

Previous research (e.g., Cheng & Furnham, 2003) has shown a positive (negative) association between extraversion and health outcomes such as happiness (and anxiety). While these associations seem to be stable and consistent in general, in this paper we argued that this association might need to be reexamined in the context of the SARS-COV-2 pandemic. This study takes a step in that direction.



**Fig. 4.** Association between extraversion and state anxiety over time  
 Note: Time = -123 days before the onset of the SARS-CoV-2 pandemic in New York (1st March 2020) to 123 days after the onset of SARS-CoV-2 pandemic in New York City (2nd July 2020); Low/High Extraversion = 5th and 95th percentile of scores;  $n = 200,289$  observations, 1336 individuals.

We make two main contributions. First, we examine the relationship of extraversion on state anxiety over time in a large sample of 1336 individuals with a total of 200,289 daily observations. Concerning the conducted time comparison (BC-AC), we find that before the SARS-COV-2 pandemic, highly extraverted individuals exhibited lower state anxiety compared to more introverted individuals. These results are in line with previously mentioned studies, which took place years before the current pandemic. With the first detection of SARS-COV-2 cases (in NYC), we find that both highly extraverted and introverted participants exhibited increased state anxiety, compared to an equal period before the crisis began. Indeed, we find no significant difference between extraverted and introverted individuals in the examined post-SARS-COV-2 period. However, the change in state anxiety between the two examined periods is significantly higher in extraverted users, compared to introverted users. Hence, it seems that being more introverted is associated with a lower, initial increase in anxiety levels in response to the SARS-COV-2 pandemic.

Second, we also examined the link between extraversion and state anxiety on a day-to-day basis (Day -123 – Day 123) and found a positive relationship between extraversion and state anxiety. A closer examination of these results indicated that the relationship between extraversion and state anxiety can vary considerably over time, with introverts less impacted by the onset of the SARS-CoV-2 pandemic at the beginning of the crisis; as the crisis ensued extraverts' anxiety began to increase drastically, with no anxiety differences between introverts and extraverts by Day 108. It could be that as the onset of the crisis began, introverts did not share the same worries as their extraverted counterparts. For example, extraverted individuals could have been more likely to worry about not being able to be as socially active as they used to be before restrictions on physical meetings, etc. become the new reality. However, as the crisis continued and restrictions remain in place, both introverts and extraverts experienced increased state anxiety levels compared to baseline.

The current pandemic provides a distinctive setting to study the effects of context, in particular concerning mental health outcomes such as anxiety. And with the looming health crisis also comes an economic crisis, which has left many individuals furloughed or unemployed (Cajner et al., 2020). Naturally, most individuals' outlook on their future at this point would be tainted by anxiety, worry, and uncertainty, especially since the barrier between work and life has been removed and employees can no longer easily separate their working lives from their personal lives. Our presented findings underline the importance of

context and environment when studying the impact of personality traits on anxiety and other health outcomes.

The presented results speak to two important implications. First, SARS-CoV-2 may be significantly exacerbating mental health problems that could perhaps result in a second-degree anxiety epidemic if the SARS-CoV-2 situation persists (e.g., Long COVID-19). Our work highlights the need for planning to accommodate the possibility of increased demand for mental health services while keeping in mind that many events may lead to increased population anxiety levels. Anxiety is certainly not limited to pandemics.

Second, given the SARS-CoV-2 work implications, i.e., working from home when possible, organizations could provide additional trait-specific opportunities for (virtual) socialization experiences (i.e., targeting extraverts) or available time-periods employees can use for self-reflection or other related activities (i.e., targeting introverts). Organizations need to accept that their employees behave and cope with anxiety differently and might need to accommodate employees differently based on their personality or other demographics (e.g., the existence of at-home child-care, etc).

In addition to the anxiety caused directly by the SARS-CoV-2 crisis, anxiety is likely also associated with changed work circumstances, i.e., working from home (WFH). While WFH was a large-scale organizational response to living through the crisis and protecting workers, WFH is not always a viable option for workers, especially in cities like New York City where renting is expensive and large work-from-home spaces are likely limited. Based on our research, we suggest organizations consider the indirect mental health consequences of limited work-from-home space, and urge them to provide workers with workplace alternatives, where possible, to limit the extent to which work circumstances increase workers' anxiety levels.

## 6. Limitations and future research

Our presented study is not without limitations. Firstly, our results need to be considered in line with other events that might have contributed to the results we outline in this paper. For example, the protests and civil unrest in response to the killing of George Floyd at the end of May might have added to the already increased anxiety levels of both introverts and extroverts. Similarly, other personal events, unrelated to SARS-COV-2, during the examined timeframe, might also have increased anxiety levels of several individuals in our dataset. Future research could consider the individual as well as the cascading impact of these events on individuals' mental health.

Secondly, to ensure that the exogenous shock was felt by all participants in our sample at the same time, we restricted our analyses to one location we restricted our data collection efforts to one location. However, we recognize that a few weeks after NYC was initially declared the epicenter of the pandemic, the epicenter in the US shifted to other states. Hence, future research could examine whether the found results are replicable in other states across the US or worldwide.

Finally, we recognize that the data on which this study relies is limited in two ways. First, we acknowledge that the examined data is found data, meaning this data are a result of the design of digital services and devices, data retention and access policies of the Twitter platform (Howison et al., 2011) as well as the motives of users' of such platforms (Jungheer, 2018). Hence, the examined data is pre-processed data by users who intended to communicate to the public. Secondly, the examined data is merely a sample of the overall examined population (i.e., residents of NYC) who are active on Twitter. Given that Twitter users tend to be younger, better educated, and more publicly vocal than the average population (Jungheer, 2018), the examined data is limited in that it is likely not fully representative of the overall population of interest, namely residents of NYC. While we acknowledge these limitations, the mechanism behind the emergence of the association between ground truth datasets and predicted scores has been well established in past research (Gliozzo et al., 2017; Gruda & Hasan, 2019). Also, both

algorithms either were built on very large participant samples (i.e., IBM Watson Personality Insights algorithm is based on a sample of 1,000,000 participants) or have been validated on large user samples in the past (i.e., anxiety algorithm was validated using 3.3 million tweets). This provides us with confidence regarding the validity and reliability of the respective personality and anxiety measurement and assessment. We encourage future research to examine the association between extraversion and state anxiety longitudinally using other methods as well, including natural experiments (Bond et al., 2012).

## 7. Conclusion

With the current SARS-COV-2 crisis impacting individuals around the world, social media represents a unique opportunity to study the interplay of exogenous shocks and individual differences, such as anxiety and personality, over time. This is especially advantageous as the continuous analysis of user data can help identify particularly crucial points in time during which anxiety peaks. In this study, we longitudinally examine the dynamic relationship between extraversion and state anxiety in a large sample of individuals using a machine learning approach. Our analysis provides insights into how individual differences impact the experience of anxiety on a day-to-day basis while living through the greatest pandemic in recent history.

## CRedit authorship contribution statement

**Dritjon Gruda:** Conceptualization, Methodology, Formal analysis, Writing – original draft. **Adegboyega Ojo:** Data curation, Software, Formal analysis, Writing – review & editing.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.paid.2021.111461>.

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