5-2023

Do executive functions buffer against COVID-19 fear and stress? A latent variable approach

Tina Li Yi NG
Singapore Management University, tina.ng.2019@socsc.smu.edu.sg

Nadyanna M. MAJEED

Verity Yu Qing LUA
Singapore Management University, verity.lua.2021@msps.smu.edu.sg

Andree HARTANTO
Singapore Management University, andreeh@smu.edu.sg

Do executive functions buffer against COVID-19 stress?

A latent variable approach

Tina L. Y. Ng[1] · Nadyanna M. Majeed[1,2] · Verity Y. Q. Lua[1] · Andree Hartanto[1]

Abstract
Levels of COVID-19 stress have soared worldwide as a result of the pandemic. Given the pernicious psychological and physiological effects of stress, there is an urgent need for us to protect populations against the pandemic's psychological impact. While there exists literature documenting the prevalence of COVID-19 stress among various populations, insufficient research has investigated psychological factors that might mitigate this worrying trend. To address this gap in the literature, the current study seeks to examine executive functions as a potential cognitive buffer against COVID-19 stress. To do so, the study adopted a latent variable approach to examine three latent factors of executive functions and their relation to COVID-19 stress among a sample of 243 young adults. Structural equation models showed differential associations between COVID-19 stress and the latent factors of executive functions. While the latent factor of updating working memory was associated with attenuated COVID-19 stress, task switching and inhibitory control were not significantly associated with COVID-19 stress. These results further our understanding of the critical processes of executive functions and highlight the nuanced link between executive functions and pandemic-related stress.

Keywords COVID-19 stress · Executive functions · Structural equation modelling

Since the onset of the COVID-19 pandemic, people around the world have had to cope with huge life disruptions, from local lockdowns and international travel restrictions, to changes in educational and work activities. Levels of stress around the world have risen in tandem, for instance in China, Singapore, Spain, Turkey, and the US (Bareeqa et al., 2021; Fitzpatrick et al., 2020; Ornell et al., 2020; Özmen et al., 2021; Rodríguez-Rey et al., 2020; Shorey et al., 2020). These trends are concerning because of the detrimental psychological and physiological effects that stress has been shown to widely exert. Stress does not just reduce wellbeing and life satisfaction (Hatun & Kurtça, 2022; Passavanti et al., 2021), but also amplifies susceptibility to infectious diseases (Cohen et al., 1993; Cohen & Williamson, 1991) while at the same time reducing vaccine efficacy (Madison et al., 2021). Despite increased attention to studying the prevalence of COVID-19 stress (e.g., Mahmud et al., 2021; Salari et al., 2020), few studies have identified risk factors that could inform targeted interventions. Protecting populations against the psychological effects of COVID-19 remains highly relevant during the post-pandemic period not solely because pandemics are far from once-in-a-lifetime events (Taylor, 2022), but also because the prevalence of mental health disorders is expected to rise over time with the pandemic's long-term ramifications (Colizzi et al., 2022; Kathirvel, 2020; Łaskawiec et al., 2022; Tandon, 2020; Taylor et al, 2020). These include, but are not limited to, the pandemic's effects on the economy, social relationships and individual health (Łaskawiec et al., 2022).

To this end, researchers have identified some factors associated with the amelioration of COVID-19 stress. However, these have been largely confined to the socioemotional domain. For instance, factors such as resilience (Hatun & Kurtça, 2022; Kavčič et al., 2021), optimism (Arslan et al., 2021; Leung et al., 2021) and religiosity (DeRossett et al., 2021; Khoo et al., 2021; Krok et al., 2021) have been

✉ Tina L. Y. Ng
tina.ng.2019@socsc.smu.edu.sg

✉ Andree Hartanto
andreeh@smu.edu.sg

[1] School of Social Sciences, Singapore Management University, 10 Canning Rise, Level 5, Singapore 179873, Singapore

[2] National University of Singapore, Singapore, Singapore

established as buffers against COVID-19 stress. In contrast, there remains a paucity of research investigating cognitive factors that could protect against these negative outcomes.

One promising cognitive factor is executive functions, a multifaceted construct of higher-order cognitive processes responsible for controlling and regulating thoughts and actions to achieve a goal (Miyake et al., 2000). There is a broad consensus that three core processes make up executive functions (Diamond, 2013; Lehto et al., 2003; Miyake et al., 2000). The first of these is *updating working memory*, referring to the ability to keep information in mind and update current contents with new information. The second is *inhibitory control*, which is the ability to inhibit thoughts or prepotent responses in order to selectively attend to information and engage in goal-directed rather than habitual action. The last is *cognitive flexibility*, referring to the ability to flexibly shift between cognitive rules or modes of thought. These processes are central to numerous critical aspects of human functioning (Diamond, 2013). For instance, greater proficiency in executive function tasks has been associated with better mental (Lawson et al., 2015; Paelecke-Habermann et al., 2005; Penadés et al., 2007) and physical health (Crescioni et al., 2011; Ng & Hartanto, 2022; Riggs et al., 2010), stronger social relationships (Eakin et al., 2004; Riggs et al., 2006) as well as success at work and school (Bailey, 2007; Borella et al., 2010; Gathercole et al., 2004). Recent research has also demonstrated the centrality of executive functions to emotional reactivity and emotion regulation (e.g., Hartanto & Yang, 2022; Obradovic, 2016; Stawski et al., 2010; Ursache, 2013; Williams et al., 2009). However, this has yet to be applied in the specific context of COVID-19 stress.

There are two possible reasons why executive functions could serve as a potential buffer against COVID-19 stress. Firstly, executive functions could support individuals in dampening their immediate emotional response to pandemic-related stressors such as lockdown measures or new strains of the disease. Evidence supporting this notion is seen from studies demonstrating that individuals with higher levels of executive functions experience dampened psychological and physiological responses to stress inductions such as the Trier Social Stress Test (Grimm et al., 2021; Hendrawan et al., 2012; Larsson et al., 2007). For example, in Hendrawan et al.'s (2012) study, participants with higher levels of executive functions experienced lower acute stress reactivity as indicated by lower levels of state anxiety, negative mood, salivary cortisol, and skin conductance. Such results are likely the result of the strong associations between executive functions and the frontal lobes of the brain, areas critical to the processes of arousal, autonomic control, endocrine regulation, and emotional processing, all of which contribute strongly to stress regulation (Williams

et al., 2009). Hence, executive functions may play a promising role in mitigating the severity of COVID-19 stress by modulating one's immediate emotional reaction to COVID-19 stressors.

Secondly, executive functions could attenuate COVID-19 stress by promoting adaptive emotional regulation. Research has demonstrated positive associations between executive functions and the frequency of engaging in central emotional regulation strategies that attenuate stress (Liu et al., 2019; Shore et al., 2017) such as cognitive reappraisal (McRae et al., 2012). In the specific context of COVID-19, reappraisal interventions have been shown to reduce negative emotions and increase positive emotions in response to the COVID-19 pandemic (Daniels et al., 2021; Wang et al., 2021). Cognitive reappraisal involves reframing emotional experiences in a way that allows individuals to modulate their emotional reactions to them (Khoo et al., 2021). For instance, instead of viewing stay-at-home measures as mandatory lockdowns, one could instead view them as opportunities to spend time with family at home, thereby minimizing the stress and anxiety faced in response (Hofmann, 2009; Xu et al., 2020). Better executive functions would facilitate the adoption of these adaptive emotional regulation strategies since they form their underlying mechanisms (Ochsner & Gross, 2005; Opitz et al., 2012; Schmeichel et al., 2008). For reappraisal to occur, executive functions are needed to suppress negative appraisals of the experience, focus on more desired ones and also maintain these goal-relevant appraisals in the face of changing circumstances (Schmeichel & Tang, 2015). As such, better executive functions would protect against COVID-19 stress by encouraging the employment of adaptive emotion regulation strategies.

Taken together, the current study aims to examine the protective role of executive functions on COVID-19 stress. Drawing from the literature on executive functions and emotional regulation, we hypothesized that individuals with higher levels of executive functions would exhibit lower levels of COVID-19 stress. We operationalized executive functions as three latent factors based on the unity/diversity framework (Miyake et al., 2000) which posits that the regulatory processes of executive functions are correlated but also separable. Bearing in mind the common issue of task impurity in executive function research (Burgess, 2004; Hartanto & Yang, 2020; Miyake et al., 2000) whereby studies show insignificant intercorrelations between executive function tasks due to measurement errors and the inclusion of non-executive function processes, the present study employed a latent variable approach of executive functions to examine the protective effects of executive functions on COVID-19 stress. COVID-19 stress was operationalized by the seven items of the Fear of Covid-19 Scale (Ahorsu et al., 2020) as well as the five subscales of the COVID-19

Stress Scales (Taylor et al., 2020), which include (1) fears of danger and contamination, (2) compulsive checking and reassurance seeking against pandemic related threats, fears regarding the consequences of the pandemic such as (3) socioeconomic consequences, (4) xenophobia and (5) traumatic stress symptoms.

We hypothesized that all three latent factors of executive functions would predict lower levels of COVID-19 stress, even after controlling for demographic factors of age, sex, race, household income, subjective socioeconomic status and trait anxiety.

Method

Participants

The sample consisted of 243 young adults from a university in Singapore (see Table 1 for descriptives). Data collection

took place from June 2021 to August 2021, as part of a larger study investigating daily experiences and executive functioning (see Goh et al., 2023; Ng et al., 2022). Data collection coincided with the country's semi-lockdown "Phase 2 Heighted Alert" and subsequently, the partially-relaxed "Phase 3 Heightened Alert" phases of the COVID-19 pandemic (Ministry of Health Singapore, 2023). Approval for data collection was obtained from the Institutional Review Board at the authors' university, and participants provided informed consent to participate in the study in return for compensation of up to SG$70.

Measures

Trait anxiety

Levels of trait anxiety were measured using the trait anxiety subscale of Spielberger's State-Trait Anxiety Inventory

Table 1 *Descriptive Statistics of the Sample*

	N	M (SD)	Observed Range	Theoretical range	Reliability [e]
Demographics					
Sex (% female)	243	76.13%			
Age (years)	243	22.13 (1.63)	19–29		
Ethnicity (% minority)	243	25.10%			
Household income [a]	243	2.98 (1.43)	1–6	1–6	
Subjective socioeconomic status [b]	243	6.10 (1.25)	2–10	1–10	
Trait anxiety	243	2.39 (0.47)	1.20–3.70	0–4	0.89
Fear of COVID-19	243	13.88 (5.15)	7–29	7–35	0.86
COVID-19 stress overall	243	0.75 (0.57)	0.00-2.75	0–4	0.95
COVID-19 stress subscales					
Danger and contamination	243	1.11 (0.82)	0.00–4.00	0–4	0.93
Socioeconomic consequences	243	0.47 (0.78)	0.00–4.00	0–4	0.97
Xenophobia	243	0.68 (0.81)	0.00–4.00	0–4	0.93
Traumatic stress	243	0.18 (0.44)	0.00-2.83	0–4	0.94
Compulsive checking	243	0.92 (0.71)	0.00-3.33	0–4	0.81
Executive functions					
Updating					
Colour accuracy [c]	236	0.53 (0.19)	0.07-0.98	0–1	0.94
Letter accuracy [c]	242	0.71 (0.15)	0.05-0.97	0–1	0.94
Number accuracy [c]	241	0.69 (0.22)	0.09 – 1.00	0–1	0.97
Inhibitory Control					
Simon [d]	240	7.38 (1.70)	3.72–12.34	1–20	0.79
Flanker [d]	239	6.72 (1.81)	4.07-20.00	1–20	0.85
Stroop [d]	234	6.91(1.35)	3.87–11.82	1–20	0.75
Task Switching					
Animacy-locomotion [d]	235	6.94 (1.38)	4.52–15.11	1–20	0.75
Colour-shape [d]	235	7.23 (1.90)	3.92-20.00	1–20	0.68
Magnitude-parity [d]	233	7.86 (2.46)	4.08-20.00	1–20	0.88

Note. [a] Household income was measured on a six-point scale where 1 = less than $2000 per month and 6 = more than $20,000 per month, with intervals of $3999 between points. [b] Subjective socioeconomic status was measured with Adler et al.'s (2000) ladder scale. [c] technical faults and participant data resulted in some incomplete data. [d] Data was omitted due to participants performing exceedingly poorly on the task(s) in question. [e] Internal reliability for measures of COVID-19 stress were calculated using Cronbach's alpha, and internal reliability for measures of executive functions were determined by the Spearman-Brown corrected split-half reliability.

Fig. 1 Measurement models for the four latent variables. *Note*. Diagram **(a)** illustrates the measurement model for executive functions and diagram **(b)** the measurement model for COVID-19 stress. Circles represent latent variables while boxes represent manifest variables. Single-headed arrows connecting the latent variables to the manifest variables denote standardized factor loadings. Single-headed arrows directed toward the manifest variables represent error terms. Double-headed arrows represent correlations between latent variables. Higher scores for both task switching and inhibitory control reflect poorer task switching and inhibitory control performance respectively, whereas higher scores for updating tasks reflect better updating working memory.
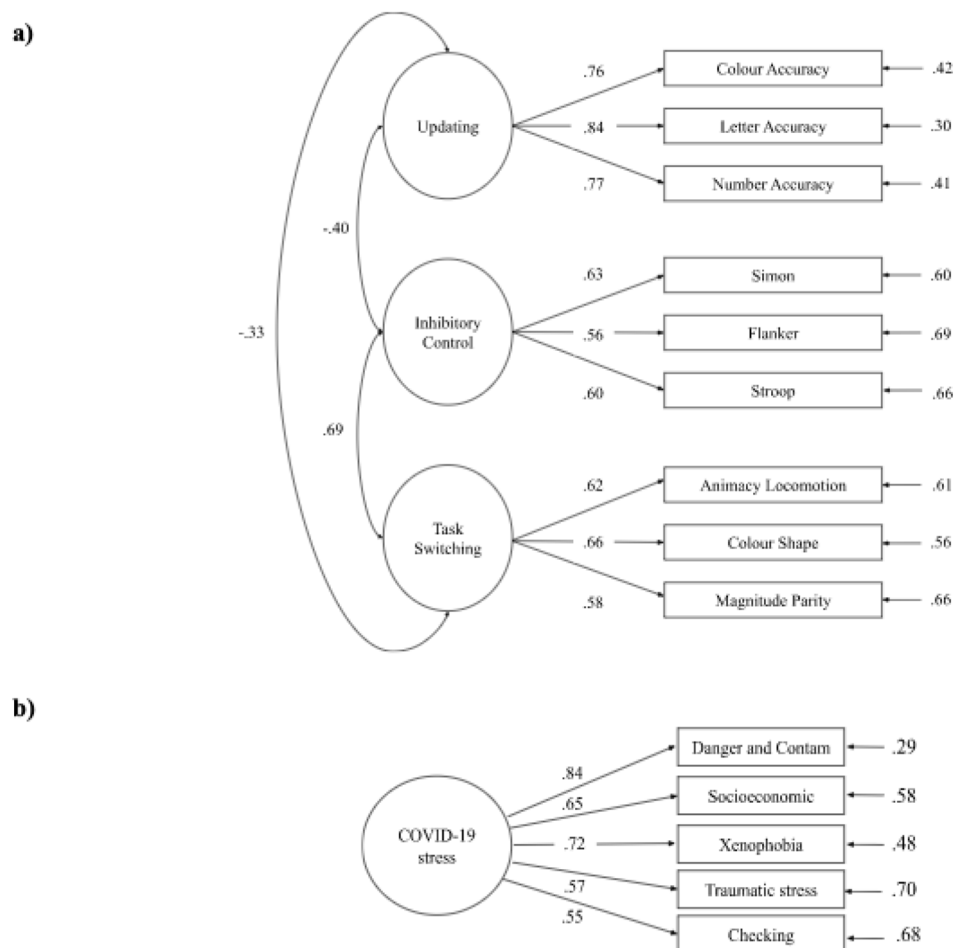
(STAI; Spielberger et al., 1983). The inventory measures state anxiety and trait anxiety, split into subscales consisting of 20 items each. The trait anxiety subscale has been demonstrated to possess good psychometric properties (e.g., Aguirre et al., 2022; Perpiñá-Galvañ et al., 2011; Van Wijk, 2014). Participants were asked to rate how well items such as "*I worry too much over something that doesn't really matter*" and "*I am calm, cool and collected*" described them on a scale from 1 (*Almost never*) to 4 (*Almost always*). Overall scores were derived from the average of all individual items and ranged from 0 to 4, where higher scores represented more intense levels of trait anxiety.

COVID-19 stress

Levels of COVID-19 stress were assessed using Taylor et al.'s (2020) COVID Stress Scales, which comprise 36 items spread across five subscales of various stress or anxiety related responses. The literature is replete with studies validating the measure's psychometric robustness (e.g., Abbady et al., 2021; Adamczyk et al., 2021; Milic et al., 2021; Noe-Grijalva et al., 2022), including population-representative

samples from Canada ($N=3479$) and the United States ($N=3375$; Taylor et al., 2020). The five subscales include measures of various COVID-19-related stress and anxiety symptoms, namely (1) fears of danger and contamination (12 items), (2) compulsive checking and reassurance seeking against pandemic related threats (6 items), along with fears regarding the consequences of the pandemic such as (3) socioeconomic consequences (6 items), (4) xenophobia (6 items) and (5) traumatic stress symptoms (6 items). Participants rated how frequently they experienced worries related to COVID-19 from a scale of 0 (*Never*) to 4 (*Almost always*). Scores were averaged for each subscale to obtain subscale scores,[1] as well as across all 36 items to form a composite index of COVID-19 Stress, where $0 = Not$ *stressed about COVID-19* and $4 = Highly$ *stressed about COVID-19*.

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[1] Supplemental analyses using each sub-scale separately (available in ResearchBox #749) yielded relatively similar results to those reported later in the manuscript.

Fear of COVID-19

We implemented Ahorsu et al.'s (2020) Fear of COVID-19 Scale as another measure of COVID-19 stress. This scale has been shown to demonstrate good psychometric properties and has been widely validated across studies from various countries (e.g., Lin et al., 2021; Midorikawa et al., 2021; Reznik et al., 2021; Pilch et al., 2021). The Fear of COVID-19 scale consists of seven items capturing an individual's fear response to the virus (e.g., "*My hands become clammy when I think about coronavirus-19*", "*I cannot sleep because I'm worrying about getting coronavirus-19*"). Participants responded to the items on a scale from 1 (*Strongly disagree*) to 5 (*Strongly agree*). Overall scores were constructed through a summation of the individual items, such that the lowest possible score of 7 reflected *low fear of COVID-19* and the highest possible score of 35 reflected *severe fear of COVID-19*.

Updating working memory

To assess updating working memory, we utilized measures sourced from von Bastian et al. (2015), which were designed based on Miyake et al.'s (2000) widely cited Keep-Track tasks. The tasks have been validated in numerous studies as an indicator of updating working memory (e.g., Bharti et al., 2020; Friedman et al., 2008, 2016; Ito et al., 2015; Young et al., 2018; Zhao et al., 2013).

Colour keep-track task

Participants were first shown five coloured shapes (circle, square, triangle, diamond and hexagon). They then went through nine updating steps, where some shapes were presented in colours different from the original. The task required participants to recall the colour that each shape had been last presented, and choose the correct option from a list of 10 choices. To ensure that the initial set of stimuli had been encoded, recall was probed immediately after the initial coding for five out of 25 trials. Participants were scored by the number of correctly solved items divided by the total number of items done across 25 trials.

Letter keep-track task

Participants were shown five letters displayed in five separate boxes. Participants then went through nine updating steps, whereby the letter in one of the boxes would change. The task required participants to recall the most recent letter for each box, and choose the correct option from a list of 10 choices. To ensure that the initial set of stimuli had been encoded, recall was probed immediately after the initial

coding for five out of 25 trials. Accuracy was scored by the number of correctly solved items divided by the total number of items done across 25 trials.

Number keep-track task

Participants were shown four digits presented in different colours (red, blue, green and orange). Participants then went through nine updating steps, whereby the value of each digit would change. The task required participants to choose the most recent number that corresponded to each colour. To ensure that the initial set of stimuli had been encoded, recall was probed immediately after the initial coding for five out of 25 trials. Accuracy was scored by the number of correctly solved items divided by the total number of items done across 25 trials.

Inhibitory control

All tasks assessing inhibitory control were sourced from von Bastian et al. (2015). These include the well-validated Simon Task (Simon, 1969), Flanker Task (Eriksen & Eriksen, 1974) and Stroop Task (Stroop, 1938). These measures have been shown to induce strong incongruency effects and has been very widely cited as indicators of inhibitory control (e.g., Basu, 2022; Breitling-Ziegler et al., 2021; Cespón et al., 2016; Friedman et al., 2008, 2016; Hartanto et al., 2023; Ito et al., 2015; Lu & Proctor, 1994; Sanders et al., 2018).

Simon task

Participants were shown a coloured circle on either side of the screen. The task required them to denote the colour of the circle they saw by pressing either the left arrow key (for green) or right one (for red). In congruent trials, the correct arrow key press was on the same side as the circle's screen position which served as a distractor (i.e., red circle on the right, or green circle on the left). Whereas in incongruent trials, the correct arrow key press was on the opposite side of the circle's screen position (i.e., red circle on the left, or green circle on the right). Participants went through practice trials before commencing 144 trials, where 75% of the trials were congruent and 25% incongruent.

Flanker task

Participants were shown a string of seven characters (letters or symbols) positioned in the middle of the screen. The task required them to decide if the central letter was a vowel or consonant, and respond by pressing either the left arrow key (when the central letter was a vowel), or the right one (when the central letter was a consonant). Surrounding the central

letter were other characters which, during congruent trials, were of the same group (i.e., all vowels or consonants, e.g. "AAAEAAA" or CCCPCCC"). Whereas for incongruent trials, the central letter and the distractors were of different groups (e.g. "AAABAAA" or CCCACCC"). There were also neutral trials with distractors that did not correspond to any arrow key press (e.g., "###B###"). Participants went through practice trials before commencing 144 trials, which were equally distributed across congruent, incongruent and neutral ones.

Stroop task

Participants were shown a string of seven characters (integers between one to four or non-numeric symbols) positioned in the middle of the screen. The task required them to count and record the number of characters shown. During congruent trials, the integer characters were identical to the number of characters displayed (e.g., "55555") whereas for incongruent trials, the integer characters differed from the number of characters displayed (e.g., "33"). For neutral trials, the distractors were composed of non-numeric symbols that did not correspond to any arrow key press (e.g., "##"). Participants went through practice trials before commencing 144 trials, which were equally distributed across congruent, incongruent and neutral ones.

Task switching

Measures of task switching ability were sourced from von Bastian et al. (2015), which were derived from Monsell's (2003) task switching paradigm. The tasks have been shown to produce reliable switch costs and has been validated by a plethora of studies as an indicator of task switching proficiency (e.g., Friedman et al., 2008, 2016; Ito et al., 2015; Vasta et al., 2017; Vermeylen et al., 2022; Wang & Egner, 2022; Zhang et al., 2012).

The tasks required participants to classify stimuli according to specific rules. Each task involved two sorting rules (i.e., animacy and size classification for the Animacy-Locomotion Switching Task, colour and shape classification for the Colour-Shape Switching Task and magnitude and parity classification for the Magnitude-Parity Switching Task). Within each task, there could be single-rule blocks, where participants sorted the stimuli by only one rule (e.g., animacy or size) or mixed-rules blocks, where the two rules switched unpredictably. Each task was composed of two single-rule blocks (e.g., animacy classification followed by size classification), one mixed-rules block, then two single-ruled blocks in reverse order (e.g., size classification followed by animacy classification). Within the mixed-rules blocks, half of the trials were repetition trials (where the same rule had

to be applied for two consecutive trials), while the other half were switch trials (where the rule changed between trials). Participants went through practice trials before commencing 128 trials of each task.

Animacy-locomotion switching task

Participants were presented with line drawings of either objects or animals. Among these drawings, there were animals and objects that were smaller than a soccer ball (e.g., a snail or a pen), and those that were larger (e.g. an elephant or a car). The task required participants to classify these stimuli according to their animacy (living or non-living) or size (smaller or larger than a soccer ball) by pressing either the left (for animate or smaller objects) or right arrow key (for inanimate or larger objects).

Colour-shape switching task

Participants were presented with 64 simple geometrical shapes, of which 32 were round and 32 were angular. Among each shape type, half of them were green and the other half were blue. The task required participants to classify the stimulus according to either its colour (green or red) or shape (circle or triangle), by pressing either the "d" key (for red or circle) or "k" key (for green or triangle).

Magnitude-parity switching task

Participants were presented with digits between one to nine, excluding five. The task required them to classify these digits either by magnitude (smaller or greater than five) or by parity (even or odd) by pressing either the left (for even digits or those less than five), or right arrow key (for odd digits or those greater than five).

Procedure

The study was divided into two sections separated by a minimum of eight days and a maximum of 13 days for all participants. Both sections took place online, where participants were monitored by trained research assistants via Zoom. In the first section, participants declared their informed consent, provided their demographic information (e.g., age and income) as well as completed self-report measures of trait anxiety and COVID-19 stress. In the second section, participants completed measures of executive functions administered via Tatool (von Bastian et al., 2013). The section started with measures of updating working memory (the Colour Keep-Track Task, Letter Keep-Track Task then the Number Keep-Track Task), followed by measures of

inhibitory control (the Simon, Flanker then Stroop task). Lastly, participants completed measures of task switching ability (the Animacy-Size Switching Task, Colour-Shape Switching Task and subsequently the Magnitude-Parity Switching Task).

Analysis plan

Pre-processing of executive function tasks

While measures of updating working memory were scored by the number of accurately solved items divided by the total number of items, the scoring of tasks assessing inhibitory control and task switching involved a binning procedure which we ran prior to our analyses. This involved combining speed and accuracy into a single score. This data pre-processing has been widely recommended due to its ability to improve the construct validity and reliability of executive function tasks beyond that of pure latency or accuracy scores (Draheim et al., 2016).

Adopting Draheim et al.'s (2016) method, each participant's "baseline" score was first determined based on their mean reaction times on accurate congruent trials in inhibitory control tasks or correct repeat trials in task switching tasks. Subsequently, a new score, termed the *interference effects* for inhibitory control tasks or trial-based *switch costs* for task switching trials, was obtained by subtracting each participant's baseline score from their accurate incongruent trials (for inhibitory control tasks) or correct repeat trials (for task switching tasks). This reflects the deviation in speed from their usual reaction time when they responded to accurate incongruent trials. The interference effects were then ranked ordered across participants, based on deciles, and bin values ranging from 1 (fastest 10%) to 10 (slowest 10%) were assigned. As for inaccurate trials, these were assigned a bin value of 20 regardless of actual reaction time. Each participant's final bin scores were calculated based on their mean bin score across all incongruent or switch trials, where a lower bin score reflected stronger performance.

Latent variable analyses

Confirmatory factor analyses (CFA)

Following the binning procedure, we conducted CFA to investigate whether the factor structures proposed for the variables of executive functions and COVID-19 stress showed a good fit to the current data (Mertens et al., 2021). CFA also enabled us to statistically extract the common variance behind the same underlying latent construct, thereby facilitating the removal of measurement errors and spurious

non-executive function processes specific to each task. We estimated the three latent variables of executive functions (i.e., updating working memory, inhibitory control and task switching) from a sum of nine tasks, where there were three tasks per latent variable. To manifest updating working memory, the three Keep-Track Tasks were used, which assessed accuracy in updating numbers, letters and colours. Meanwhile, binned interference effects on the inhibitory control tasks (i.e., Simon task, Flanker task and Stroop task) were used to manifest inhibitory control. Finally, binned switch costs on the task switching paradigms (i.e., Animacy-Size Switching Task, Colour-Shape Switching Task and Magnitude-Parity Switching Task) were used to manifest task switching ability. Each latent variable was allowed to correlate freely with the other two latent variables.

Confirmatory factor analyses was also conducted for the COVID-19 stress-related constructs. Fear of COVID-19 was manifested by the seven items of the Fear of COVID-19 Scale and COVID-19 stress was manifested by the five sub-scales of the COVID-19 Stress Scales, with overall COVID-19 stress as a higher order factor.

Structural equation modelling (SEM)

Following the confirmatory factor analyses, we utilized SEM to identify the latent factors that could explain the associations between the different manifest variables (Mertens et al., 2021), as well as to identify the higher-order latent factors addressing the relationships between our manifest variables and their respective latent variables (Mertens et al., 2021). We estimated structural equation models where the latent variable of COVID-19 stress was regressed on the three latent factors of executive functions. We included both unadjusted and adjusted models for COVID-19 stress, where adjusted models included six covariates, namely age, race, sex, household income, subjective socioeconomic status and levels of trait anxiety.

Model fit

A variety of indices were used to establish model fit. Better fit was indicated by lower values of Akaike's information criterion (AIC), Bayesian information criterion (BIC), standardized root mean-squared residual (SRMR), and root mean square error of approximation (RMSEA), whereas higher values of Bentler's comparative fit index (CFI) and Tucker-Lewis index (TLI) denoted better fit. Our judgement of good model fit was based on established cut-offs, whereby an excellent model fit would be indicated by CFI > 0.95, TLI > .95, SRMR < 0.080 (Hu & Bentler, 1999), as well as RMSEA < 0.060 (Browne & Cudek, 1992).

Transparency and openness

The study's design and analysis plan were not pre-registered. Relevant data and analytic code have been made publicly available on Researchbox (#749; https://researchbox.org/749). All analyses were conducted in R version 4.0.3 (R Core Team, 2020) using lavaan version 0.6.7 (Rosseel, 2012) set to mimic Mplus for all calculations (Muthén & Muthén, 2012). Descriptives were extracted using psych version 2.1.9 (Revelle, 2022). Any missing data was managed by full-information maximum likelihood parameter estimation.

Results

Measurement models

Our measurement model for executive functions produced excellent fit metrics (CFI = 0.95, TLI = 0.92, SRMR = 0.063, RMSEA = 0.066), in agreement with the three-factor model of executive functions proposed by Miyake et al. (2000). All manifest variables loaded significantly onto their respective latent variables (ps < 0.001) and the latent variables produced significant latent correlations with one another. Better performance on tasks of updating working memory was associated with better performance on tasks of inhibitory control ($r = -.40$, $p < .001$) and task switching ability ($r = -.33$, $p = .005$), whereby lower scores for inhibitory control and task switching denoted better performance. Similarly, scores on inhibitory control and task switching were positively correlated ($r = .69$, $p < .001$).

Although the measurement model for COVID-19 stress produced a high RMSEA (RMSEA = 0.152), it produced acceptable fit indices on other metrics (i.e., CFI = 0.93, TLI = 0.85, SRMR = 0.047). Furthermore, each manifest variable loaded significantly onto its latent variable of interest (ps < 0.001). However, the measurement model for Fear of COVID-19 was poor (CFI = 0.80, TLI = 0.70, SRMR = 0.080, RMSEA = 0.226). As such, we dropped Fear of COVID-19 from our main analysis. Model fit statistics and the summary of results can be found in Appendix D and E respectively of our supplementary analyses.

Figure 1 below presents the measurement models and Table 2 presents the specific model fit metrics.

Structural models

The unadjusted and adjusted structural equation models for COVID-19 stress similarly had near excellent fit indices, whereby CFI > 0.80, TLI > 0.80, SRMR < 0.080.

However, only the adjusted structural equation model for COVID-19 stress produced good fit in terms of RMSEA (RMSEA < 0.060), whereas that of the unadjusted model was higher than our established cutoff (RMSEA = 0.071). A summary of the results for the structural models is presented in Table 3.

COVID-19 stress

Updating working memory was negatively associated with COVID-19 stress in both unadjusted and adjusted models (unadjusted: $\beta = -0.33$, $z = -3.42$, $p = .001$; adjusted: $\beta = -0.31$, $z = -3.36$, $p = .001$), suggesting that better performance on tasks measuring updating working memory was associated with moderately lower COVID-19 stress. Scores on tasks measuring inhibitory control and task switching were not significantly associated with levels of COVID-19 stress (ps ≥ 0.140; see Table 3). The results of our structural equation models are presented in Fig. 2 below.

Discussion

Efforts at protecting populations against COVID-19 have largely targeted the pandemic's direct effects, such as infection control and treatment of the disease itself (Ahorsu et al., 2020; Dong et al., 2020; Swain & Kumar, 2021). However, addressing the pandemic's indirect effects, such as those on mental health, merits attention given the deleterious consequences of failing to do so (Cohen et al., 1993; Cohen & Williamson, 1991; Hatun & Kurtça, 2022; Passavanti et al., 2021). While a large bout of research has investigated the prevalence of COVID-19 stress in the population (Fitzpatrick et al., 2020; Özmen et al., 2021; Rodríguez-Hidalgo et al., 2020), comparatively little has looked into the factors that protect populations against it. To supplement this paucity of research, the current study employed a latent variable approach to examine the associations of three latent factors of executive functions with COVID-19 stress among a sample of 243 young adults in Singapore. We hypothesized that all three latent factors of executive functions would be associated with lower levels of COVID-19 stress. Overall, we found that the three latent factors of executive functions were differentially associated with the pandemic's psychological impacts. Several findings were noteworthy.

Our results suggest that updating working memory exhibits protective effects on levels of COVID-19 stress. This finding validates our initial hypothesis, where we posited that higher competency in updating working memory tasks would be associated with lower levels of COVID-19 stress. This association could be explained by the fact that

Table 2 *Summary of Model Fits*

Model	df	χ^2	p for χ^2	AIC	BIC	SRMR	RMSEA	CFI	TLI
Measurement models									
Executive functions	24	49.53	0.002	4727.80	4832.60	0.058	0.066	0.95	0.92
Fear of COVID-19	14	188.33	<0.001	4046.67	4120.02	0.080	0.226	0.80	0.70
COVID-19 stress	5	32.93	<0.001	2240.34	2292.73	0.047	0.152	0.93	0.85
Structural equation models									
Outcome: COVID-19 stress									
Unadjusted	71	157.27	<0.001	6953.05	7120.72	0.064	0.071	0.91	0.89
Adjusted	149	249.25	<0.001	6948.12	7136.74	0.060	0.053	0.89	0.88

Note. AIC = Akaike's information criterion; BIC = Bayesian information criterion; SRMR = standardized root mean-squared residual; RMSEA = root mean square error of approximation; CFI = Bentler's comparative fit index; TLI = Tucker-Lewis index. Better fit is indicated by lower AIC, BIC, SRMR and RMSEA values and higher CFI and TLI values. The unadjusted model includes measures of COVID-19 stress. The adjusted model additionally includes the covariates of age, race, sex, household income, subjective socioeconomic status and levels of trait anxiety

updating working memory enables individuals to maintain their pursuit of emotion regulation goals in the face of changing circumstances (Pruessner et al., 2020; Schmeichel & Tang, 2015). For instance, the continued monitoring and updating of working memory content could help individuals persevere in applying emotion regulation strategies such as cognitive reappraisal (Schmeichel & Tang, 2015), a strategy that has been shown to robustly minimize negative emotions and boost positive ones amidst the COVID-19 pandemic (Wang et al., 2021).

In contrast, we found no association between COVID-19 stress with task switching and inhibitory control. This mirrors the broad findings of the literature surrounding executive functions and emotion regulation, where emotion regulation has most consistently associated with updating working memory (Groves et al., 2022; Gyurak et al., 2009, 2012; McRae et al., 2012; Schmeichel & Tang, 2015; Sperduti et al., 2017; Toh & Yang, 2022) but not task switching or inhibitory control. We posit that the robust relationship between emotion regulation and updating working memory is the result of the fact that our emotions, more often than not, are a reflection of what we pay attention to and hold in our working memory (Pe et al., 2015). Consequently, the ability to update the contents of working memory would likely play a significant role in emotional regulation, and therefore explain why we only found associations between COVID-19 stress and updating working memory. Another plausible explanation for our results can be found in the facilitative role of inhibitory control in emotional suppression (Schmeichel & Tang, 2015) – an avoidance emotional regulation strategy that has been shown to be maladaptive in responding to stress and negative emotions (Carlson & Wang, 2007; Schmeichel & Tang, 2015; von Hippel & Gonsalkorale, 2005). Inhibitory control is frequently associated with the ability to repress the exhibition of socially inappropriate emotional behaviours, including the expression of anger and anxiety (Kochanska et al., 2000; Schmeichel & Tang, 2014), disgust (von Hippel & Gonsalkorale, 2005) and disappointment (Kieras et al., 2005). This ability might be maladaptive in responding to stress, however, as emotional suppression exacerbates arousal and reduces opportunities to habituate to emotional stimuli (Gross & Levenson, 1997; Lynch et al., 2001), a process important to reducing feelings of anxiety and distress (Amstadter, 2008; Litz et al., 2000; Lynch et al., 2001). This could partly explain the null associations between inhibitory control and COVID-19 stress. Therefore, it could be that the link between executive functions and COVID-19 stress is primarily driven by the process of updating working memory, thereby explaining our observed results.

Taken together, these results shed light on the nuanced associations between executive functions on COVID-19

Table 3 Summary of Results

Outcome	Updating			Task Switching			Inhibitory Control		
	β	b (SE)	p	β	b (SE)	p	β	b (SE)	p
COVID-19 stress									
Unadjusted	**-0.33**	**-0.92 (0.27)**	**0.001**	0.18	0.08 (0.07)	0.250	-0.13	-0.05 (0.06)	0.418
Adjusted	**-0.31**	**-0.87 (0.26)**	**0.001**	0.14	0.06 (0.07)	0.353	-0.06	-0.02 (0.06)	0.685

Note. $N = 243$. β = standardized regression coefficients, $b (SE)$ = unstandardized regression coefficient (standard errors). Bolded values indicate statistical significance ($p < .05$) while non-bolded values indicate statistical non-significance ($p \geq .05$)

stress. Structural equation models showed that lower levels of COVID-19 stress were associated with greater competency in tasks of updating working memory, but no association was found with performance on measures of task switching and inhibitory control. Our research suggests that individuals with lower levels of executive functions might be exposed to a heightened risk of COVID-19 stress and its detrimental effects (Hatun & Kurtça, 2022; Passavanti et al., 2021; Madison et al., 2021), pointing to the necessity of targeted interventions (Holmes et al., 2020). This is especially critical in the current post-pandemic stage, given that the prevalence of mental health disorders such as post-pandemic stress disorder is expected to rise as a result of the pandemic's long-term effects (Kathirvel, 2020; Łaskawiec et al., 2022; Tandon 2020; Taylor et al., 2020).

Despite the theoretical and practical contributions made by this study, our findings are not without caveat. First, the study's cross-sectional nature limits our ability to ascertain the directionality of the relationship between COVID-19 stress and executive functions. While there are strong theoretical reasons to believe that executive functions could ameliorate COVID-19 stress, it is similarly plausible for COVID-19 stress to have debilitating effects on executive functions (Castanheira et al., 2021; Kira et al., 2021). As such, future studies should consider utilizing a time-lagged study design in order to better establish the directionality of this relationship.

Second, our assessments for executive function were conducted after assessments of COVID-19 stress. Despite this lack of temporal precedence in our measurements, however, it is unlikely that participants' executive functions would change in a short time period of less than two weeks. Evidence supporting this lies in the fact that individual levels of executive functions have been shown to be relatively stable during major changes in the lifespan developmental profile, including late adolescence, early adulthood, and old age (Ferguson et al., 2021; Friedman et al., 2016).

Third, the generalizability of our findings to other demographic groups can be considered as another limitation. Age for instance has been found to be significantly associated with levels of COVID-19 stress (Andrade et al., 2022; Quadros et al., 2021) across studies of diverse cohorts. Thus, our sample of young adults between 19 and 29 years may not fully capture the effects of executive functions on COVID-19 stress for all age cohorts. Future research should therefore endeavour to test the impact of executive functions on COVID-19 stress among other population groups to more comprehensively understand this potential buffer.

Finally, poor model fit limits the interpretability of our results for the Fear of COVID-19. Although the Fear of COVID-19 scale has been widely validated across studies from different countries (e.g., Lin et al., 2021; Midorikawa

a)
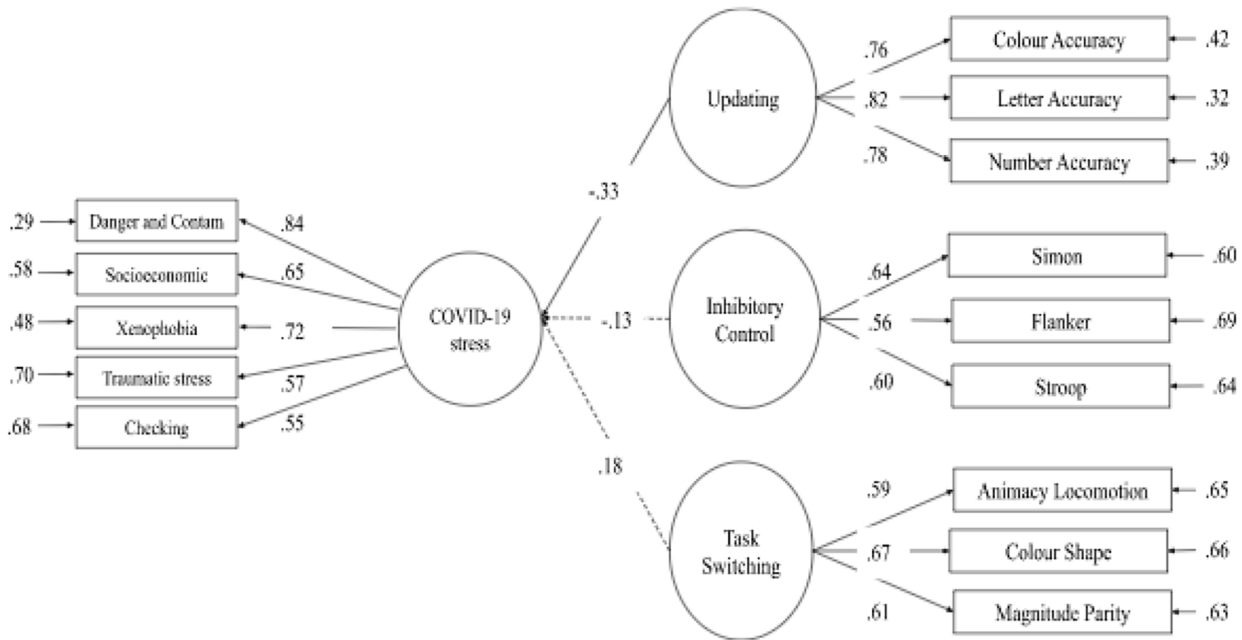
b)
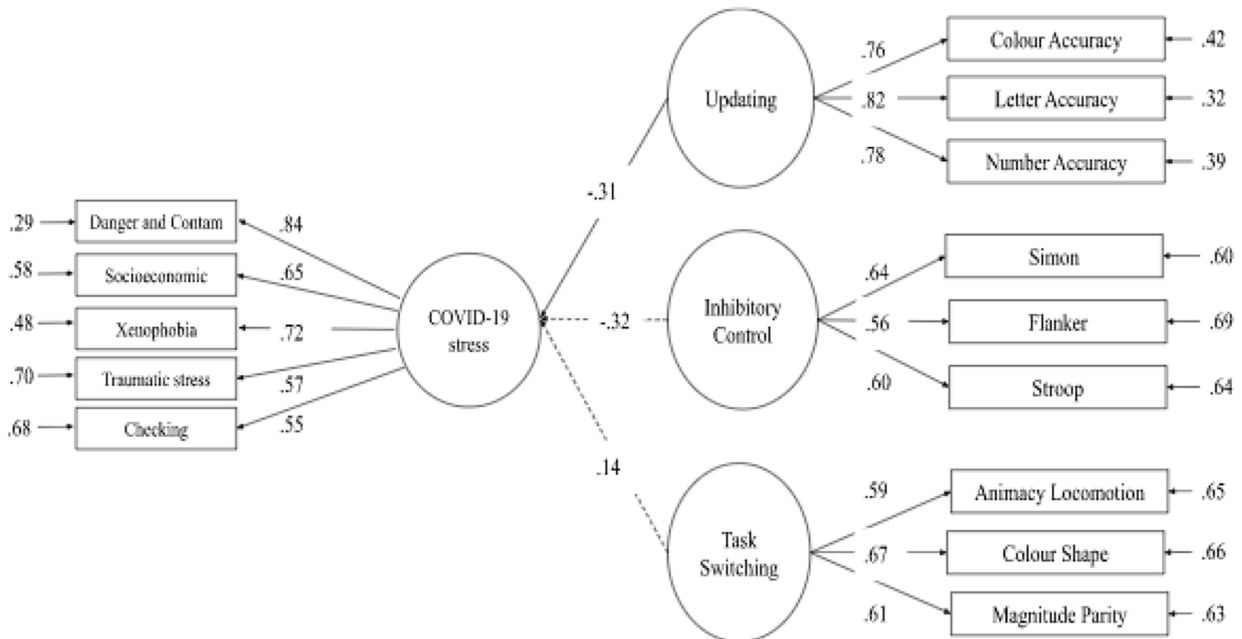
Fig. 2 Unadjusted and adjusted structural equation models of COVID-19 stress regressed against executive functions. *Note*. The top diagram illustrates the unadjusted model of COVID-19 stress regressed against executive functions while the bottom illustrates the adjusted model. The unadjusted model includes measures of COVID-19 stress whereas the adjusted model additionally includes the covariates of age, race, sex, household income, subjective socioeconomic status and levels of trait anxiety. Circles represent latent variables while boxes represent manifest variables. Single-headed arrows connecting the latent variables to the manifest variables denote standardized factor loadings, and single-headed arrows directed toward the manifest variables represent error terms. Solid lines connecting COVID-19 stress to each of the executive functions represent significant regression paths ($p < .05$) while dotted lines represent non-significant regression paths ($p \geq .05$). Higher scores for both task switching and inhibitory control reflect poorer task switching and inhibitory control performance respectively while higher scores for updating reflect better updating working memory. The three latent variables of executive functions were allowed to correlate freely with one another but latent intercorrelations are not presented in this diagram.

et al., 2021; Reznik et al., 2021; Pilch et al., 2021), we posit that the scale demonstrated poor fit to our data from Singapore possibly due to the country's proactive implementation of COVID-19 response strategies. Early implementation of COVID-19 measures has been shown to significantly reduce fear at a population level (Pakpour et al., 2021) and Singapore's fight against the spread of COVID-19 has been internationally recognized for its efficiency in crisis management, for instance in detecting and isolate new cases (The Straits Times, 2021). Another possible reason for the poor model fit for the Fear of COVID-19 can be conjectured by analysing the COVID-19 stress scales. We posit that our structural models for COVID-19 stress fit well with our data because the COVID-19 Stress Scales capture a wider range of COVID-19-related stressors. Besides the fear of infection from COVID-19, the scale also assesses other worries, including those related to xenophobia and traumatic stress symptoms (Taylor et al., 2020). Given that studies conducted among Singaporean samples found that xenophobia was the only prominent fear among Singaporeans amidst COVID-19, compared to low levels of concern for the risk of infection and other stressors like socioeconomic status or compulsive checking (Ang et al., 2022), the poor model fit for the Fear of COVID-19 is likely the result of this fear not having been very prominent among our sample. As such, future studies seeking to investigate the relations between COVID-19 fear and executive functions might replicate the study in other countries where the fear of infection might have been more prominent as a result of different responses to the pandemic.

To the best of our knowledge, this was the first study to investigate executive functions as a protective factor against COVID-19 stress. Results of our study demonstrated differential associations between executive functions and the pandemic's psychological effects. These results further our understanding of the critical processes of executive functions and highlight the nuanced link between executive functions and pandemic-related stress.

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