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Effects of COVID-19-related stay-at-home order on neuropsychophysiological response to urban spaces: Beneficial role of exposure to nature?

Agnieszka Olszewska-Guizzo [a,b,*], Anna Fogel [c], Nicolas Escoffier [b], Roger Ho [d]

[a] Institute for Health Innovation & Technology (iHealthtech) MD6, 14 Medical Drive, #14-01, 117599, Singapore
[b] NeuroLandscape Foundation, Suwalska 8/78, 03-252, Warsaw, Poland
[c] Singapore Institute for Clinical Sciences, Agency for Science, Technology and Research, 12 Science Drive 2, Tahir Foundation Building #12, 117549, Singapore
[d] Department of Psychological Medicine, Yong Loo Lin School of Medicine, The National University of Singapore, NUHS Tower Block, Level 9 1E Kent Ridge Road, 119228, Singapore

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ABSTRACT

Background: The COVID-19 pandemic has had severe negative effects on populations worldwide. The seriousness of the pandemic necessitated local and even national lockdowns. In Singapore a national lockdown with aStay-at-Home Order (SHO) lasted for over 7 weeks. The impact of the pandemic and of the long SHO period on neuropsychophysiological functioning remains unknown. Studies prior to the pandemic highlighted the beneficial role of nature exposure on mental health and well-being, although this has not yet been explored in the post-pandemic world. This is the first study to investigate the longitudinal changes in (1) brain frontal alpha asymmetry (FAA; neuroelectric marker of approach-related motivation), (2) depressive mood and (3) symptoms, and (4) emotional response to videos of various urban spaces from before COVID-19 to immediately after the SHO in Singapore was over. Finally, we examined whether higher vs lower exposure to nature during the SHO moderated changes over time.
Methods: The sample included 25 healthy adult Singaporeans (56% female, $M_{age} = 40.4$ y, $SD = 17.8$), who attended two electroencephalography (EEG) lab sessions, within a year before the COVID-19 pandemic (T1) and immediately following the SHO (T2). The participants viewed 9 fixed-frame videos, filmed before the pandemic, from 3 urban public spaces (Busy Downtown, Residential Green, Lush Garden) on the roll-up screen. They rated their emotional response (arousal, valence) after each video and completed Becks Depression Inventory-II (BDI-II) as a measure of depressive symptoms, Profile of Mood Scale (POMS), as a measure of momentary mood, and self-reported the frequency and duration of their nature visits during the SHO.
Results: Linear mixed models were fitted to examine changes over time, and effect moderation by amount of nature exposure during the SHO. The results showed decrease in FAA ($p < 0.001$), increase in depressive symptoms ($p = 0.046$), and a trend for marginal increase in momentary mood disturbance ($p = 0.097$) after the SHO. Importantly, people with high nature exposure during SHO had greater decrease in FAA over time ($p = 0.005$) than those with low nature exposure, FAA scores decreased the most for Residential Green. Valence and Arousal did not change over time, but Arousal towards Busy Downtown decreased among high nature exposure individuals ($p = 0.002$).
Conclusions: Post SHO, brain activity and responsiveness to landscapes changed, and showed a general reduction in positive emotions and increased depressive symptoms among participants. The higher nature exposure during the SHO did not help mitigate this depressive symptoms, as previous research would suggest. This can be due to the modified quality of nature exposure during lockdown, which highlights the importance of high quality nature experience in cities and the provision of diversified visual exposures. Potential neuropsychophysiological consequences of SHO should be considered by policy makers in the post-COVID-19 world.

* Corresponding author. NeuroLandscape Foundation, Suwalska 8/78, 03-252, Warsaw, Poland.
E-mail addresses: a.o.guizzo@neurolandscape.org (A. Olszewska-Guizzo), n.escoffier@neurolandscape.org (N. Escoffier).

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1. Introduction

The global outbreak of a novel coronavirus disease starting in 2019 (COVID-19) caused serious issues subsequently followed by a range of preventative measures, including national quarantines with stay-at-home orders (SHO). The mental health implications of the latter in relation to the environmental aspect of living in big cities are largely unknown.

In the face of a growing number of infections and a lack of effective therapies, governments introduced a range of measures in early 2020 to slow down the spread of the disease, including social distancing, mass testing, closure of schools, businesses and temporary SHOs, commonly called lockdowns (Cascella et al., 2020; Ferguson et al., 2020). While several major epidemics have occurred in recent decades (e.g., SARS, MERS), the suddenness and scale of the COVID-19 impact on everyday life is unprecedented in modern history. The mental health burden caused by the pandemic, while not yet scientifically established, has been estimated as very large on a global scale (Pfefferbaum & North, 2020; World Health, 2020).

To date, multiple online surveys conducted at one time point reported moderate to severe rates of depression and anxiety (Grover et al., 2020; Ozamiz-Etxebarria et al., 2020; Wang et al., 2020a), psychosocial strain (Ammar et al., 2020; Rehman et al., 2020), symptoms of post-traumatic stress disorder (PTSD) (Wang et al., 2020b), increasing suicidal ideation (O'Connor et al., 2020) and decreased life satisfaction (Ammar et al., 2020). On the contrary, one study from the Philippines suggested no significant effect on mental health of the community during lockdown (Estacio, Lumibao, Reyes, & Avila, 2020). There are fewer longitudinal studies comparing the mental health of people before and after the COVID-19 pandemic. For example, nationwide surveys found that in the US the prevalence of adult depression rates was 3-fold higher during than before the COVID-19 pandemic (Ettman et al., 2020), and in the UK prevalence of clinically concerning mental distress during the COVID-19 pandemic was higher than had been predicted for that quarter (Pierce et al., 2020). The increased depression during the pandemic was also reflected in approximately 10 times more calls to emergency hotlines for people in emotional distress as compared to previous years (Firozi, 2020; Phua, 2020). This raised concerns about the risk of suicides, but no conclusive statistics have been presented on this matter to date (Reger, Stanley, & Joiner, 2020; Sher, 2020). Furthermore, much less is known about the mental health implications of home confinement and its environmental aspect with special focus on urban populations.

1.1. Potential psychological mechanisms

COVID-19 home confinement is usually discussed in regards to social isolation – loneliness and lack of social connectedness (Galea et al., 2020; Pasion et al., 2020). Humans as social species are dependent on stable social bonds, so the isolation poses a serious risk to their health, leading to increased mortality rates (Cacioppo & Hawkley, 2003; Holt-Lunstad et al., 2015). Another aspect of home confinement is the environmental isolation linked to sensory deprivation resulting from a limited diversity of environmental exposures, including nature exposure, especially in urban settings. Studies from prisons, which can broadly be considered psychologically analogous sensory-deprived settings, have clearly documented that living in these conditions for prolonged periods of time can lead to trauma and major psychological distress (Hocking, 1970; Leiderman, 1962), including appetite and sleep disturbances, depression, anxiety, panic, irritability, paranoia, negative attitudes, hypersensitivity and cognitive dysfunction (Haney, 2003). The effects of isolation and confinement on mental health and well-being were also studied in participants of year-round polar expeditions who experienced prolonged lockdown in their cabins over extreme winters, with very limited human interaction and an extremely barren landscape. Research shows that the psychological consequences of such lockdowns are akin to those in prisoners, coined "cabin fever" (Ledbetter, 1974).

1.2. Nature exposure in the city and mental health

The urban environment is characterized by a high concentration of built (manmade) elements and infrastructures, high population density, soil and air pollution, noise, low level of biodiversity, and scarcity of natural ecosystems. These factors form the sum of environmental exposures detrimental to human welfare and mental health (Tost et al., 2015). Peen et al. in their meta-analysis found that prevalence of any mental illness is 38% higher in urban compared to rural areas (Peen et al., 2010). At the same time, a growing body of evidence confirms the salutogenic effects of nature exposure on mental health and well-being on urban residents (van den Berg et al., 2007; Gascon et al., 2015; Hartig et al., 1991; Nath et al., 2018; Olszewska-Guizzo et al., 2020). Urban environments separate people from nature and limit nature exposure, making those who live in cities more at risk of developing mental illness. One of the most prominent theories explaining the salutogenic potential of natural environments is the Attention Restoration Theory (ART) according to which, nature exposure can restore depleted attention capacity (Kaplan, 2001; Kaplan & Kaplan, 1989). The sense of *being away* from the city chaos and involuntary attentiveness to natural phenomena are the main reasons for ART being specifically relevant to urban dwellers.

The SHO on the other hand poses the risk of further amplifying the negative mental health impacts associated with city life, similar to those observed in prisoners or polar expeditions. While this has not yet been supported by peer-reviewed research, a large cross-country online survey conducted during the COVID-19 lockdown across European cities showed that people reported missing the freedom of spending time in nature and nature observation during home confinement (Ugolini et al., 2020).

In multiple experimental, cross-sectional and qualitative studies, contact with nature has been shown to help with the restoration of depleted attention capacity (Hartig et al., 1991; Kaplan & Kaplan, 1989), the reduction of mental fatigue, emotion regulation and stress reduction (Ulrich et al., 1991), an increase in positive mood and cognitive performance (Berman et al., 2008) and even slower cognitive aging (Sia et al., 2020). Our earlier electroencephalographic (EEG) studies demonstrated that even passive contact with natural environments induced a pattern of brain activity called Frontal Alpha Asymmetry (FAA), whereby the right hemisphere displays greater alpha power than the left (Olszewska-Guizzo et al., 2018, 2020). This brainwave pattern has been associated with positive approach and motivation towards perceived stimuli and is indicative of positive emotions. This points to FAA as a significant neurophysiological marker to investigate when assessing the impact of the SHO. Combined with well-known questionnaire measures, it is likely to reflect both the emotional and mood response to the SHO and the changing response tendencies towards green spaces in this period, while further illuminating relevant neural mechanisms.

1.3. Study aims

The aim of this study is to fill the current gaps in the literature on our understanding of the impact of the SHO on the neuro-psycho-physiological functioning of healthy adults. It aims to do that by utilizing both validated questionnaires and a relevant EEG marker, the FAA. Furthermore, in line with the previous literature suggesting that exposure to nature may have a beneficial impact on mental health, we intend to explore whether contact with nature and perception of natural environments during home confinement can mitigate the impact of the SHO on mental health and well-being. Various nature-based activities, such as landscaping and horticulture, have been successfully introduced to help with mental health among healthy elderly adults (Ng et al., 2018), and even prison populations, under the so-called "Green Prison Programme", which has shown promising results on mental health (Linden, 2015). However, to date, no study has investigated the potential of certain environmental exposures in mitigating the negative impact of SHO on mental distress. This is the first study to date to investigate this question by examining the neuropsychophysiological measures of mental health and well-being before and after the SHO.

The study was conducted in Singapore, which has a particularly interesting context, because 100% of its population lives in an urban area (Agency, 2020) on 709.2 km^2 of land. It is a country with one of the highest population densities (8358 people/km^2) and one of the lowest land area per capita on earth (126m^2/person) (City Population. Availabe), thus offering the opportunity to explore the study aims in extreme urban conditions.

1.4. Hypotheses

We explored the differences between pre- and post-SHO on self-reported and physiological markers of depression and mood, as well as on perception of urban public spaces, with special consideration for urban green spaces. The experiment utilized a within-subject design, in which outcomes were collected both before the pandemic and immediately after the SHO.

We tested the following hypotheses:

H1). We predicted an increase in depressive symptoms over time, namely:

a) Decrease in approach-related motivation towards public space videos as measured with frontal alpha asymmetry (FAA)
b) Increase in the severity of depressive symptoms measured with the BDI-II questionnaire
c) Increase in the momentary Total Mood Disturbance (TMD), measured with the Profile of Mood States (POMS) questionnaire.

H2). We also predicted that an increase in depressive symptoms (FAA, BDI-II, POMS) would be moderated by nature exposure during the lockdown. Participants who had greater nature exposure during the SHO would show lower depressive symptoms and mood disturbance compared to those with lower nature exposure.

H3). Given that people were mainly confined to their homes, we predicted that they would have a more emotional response to the sightings of outdoor spaces. We therefore predicted that they would report an increase in arousal (the strength of emotion) and valence (degree of positivity) towards videos with urban green spaces and a decrease towards videos of built up spaces.

2. Methods

2.1. Participants

Twenty-five healthy individuals (14 females) aged between 21 and 74 (M = 40.4, SD = 17.94) were included in the study. They were recruited from a pool of 58 healthy individuals, who took part in a larger study on the impact of nature on neuro-functioning, prior to the pandemic (T1). T1 data collection was completed by January 20, 2020, 78 days before the start of SHO in Singapore on April 7, 2020. All 58 T1 participants were re-invited for participation in the subsequent study, after the SHO ended on June 1, 2020. Twenty-five consented to participate (none were later excluded), 17 of 58 agreed to complete only the online forms, and 16 of 58 declined to participate or did not respond. Non-responders did not differ from the analytical sample in age, ethnicity, education level, nature exposure or gender (all $ps > 0.50$) and there was a non-significant trend for non-responders to show slightly higher depressive scores (BDI; M = 9.40, SD = 7.93) as compared to the analytical sample (M = 6.44, SD = 6.74; p = 0.10). The time interval between T1 and T2 data collection ranged from 145 to 487 days (M = 341.32, SD = 104.2 days).

All participants reported right-handedness and had normal or corrected to normal vision. Procedures were reviewed by the National University of Singapore Ethics Committee and obtained ethics approval (NUS-IRB_S-20-12). Participants took part in the study voluntarily and provided informed consent.

2.2. Stay-at-home order in Singapore

The first COVID-19 related restrictions affecting public space use were announced on January 20, 2020 by the Ministry of Health, introducing body temperature screening at the entrance to selected public spaces (World Health, 2020). The SHO, referred to as the "circuit breaker" in government communications, lasted for 56 days (from 7 April until 1 June).

During this time, people were advised to leave home only for essential reasons (e.g., grocery shopping, medical care) and to wear a mask at all times while outside their homes. Most of the industry and schools switched to remote work from home. All places of worship, non-essential shops, and entertainment establishments were closed, and restaurants only opened for take-away. Travelling overseas for leisure or business was highly restricted. People were not to gather with family or friends who did not live in the same household. Access to green and public spaces was possible, but limited to certain areas and functions (e.g., playgrounds and seating areas were blocked). Additionally, a range of restrictions to minimize contact in green spaces, such as the closing of the beaches, car parks and food outlets. All measures were strictly enforced, with legal repercussions ranging from financial fines to imprisonment, loss of residency rights and expulsion for foreign residents (see Supplementary Materials for details). Thousands of Social Distancing Ambassadors were recruited to monitor and ensure compliance with the law. Taken together, these measures resulted in everyday activities and environmental exposures of Singaporeans being largely limited to the home environment and their closest neighborhood.

2.3. Stimuli

Participants were presented with video material consisting of still-frame videos of nine scenes of urban spaces in Singapore: three scenes from the Lush Garden, three scenes from the Residential Green, and three scenes from the Busy Downtown area (Fig. 1). All videos were recorded before the COVID-19 pandemic (people within the video were not wearing masks, parks were without restrictions or cordons). All videos were 20 s long, recorded with a Sony™ HDR-TD30 camcorder with a frame size of 1920 × 1080 pixels, 50 frames per second and 16:9 aspect ratio in TS(AVC) ("*.m2ts") format. The video files were then converted to MP4 format supported by presentation software (compression rate 50:1), using VideoProc 3.2 (Digiarty Software Inc.) All videos were comparable in terms of luminance (M = 124.0, SD = 7.1) and root mean square contrast (M = 52.6, SD = 3.4) and were not processed further to avoid low-level influence on attentional processing (Hart et al., 2013).

Nine videos of three urban sites formed three experimental conditions varying by the level of green vs built-up (man-made) elements, and number of people visible within the view (only Busy Downtown included people).

The videos were displayed on a 108 × 178 cm roll-up screen, placed 200 cm from the participant's eyes (Fig. 2), spanning approximately 30° of their visual field. Videos were projected using the HD29Darbee Optoma Home Theatre Full HD projector with 1080p (1920 × 1080) screen resolution. Videos were displayed with the natural sound as recorded together with the visuals, using standard PC audio speakers placed near the projector, behind the participant's chair. During the experiment, a daylight imitating lamp (with the light hue of 5500K) was

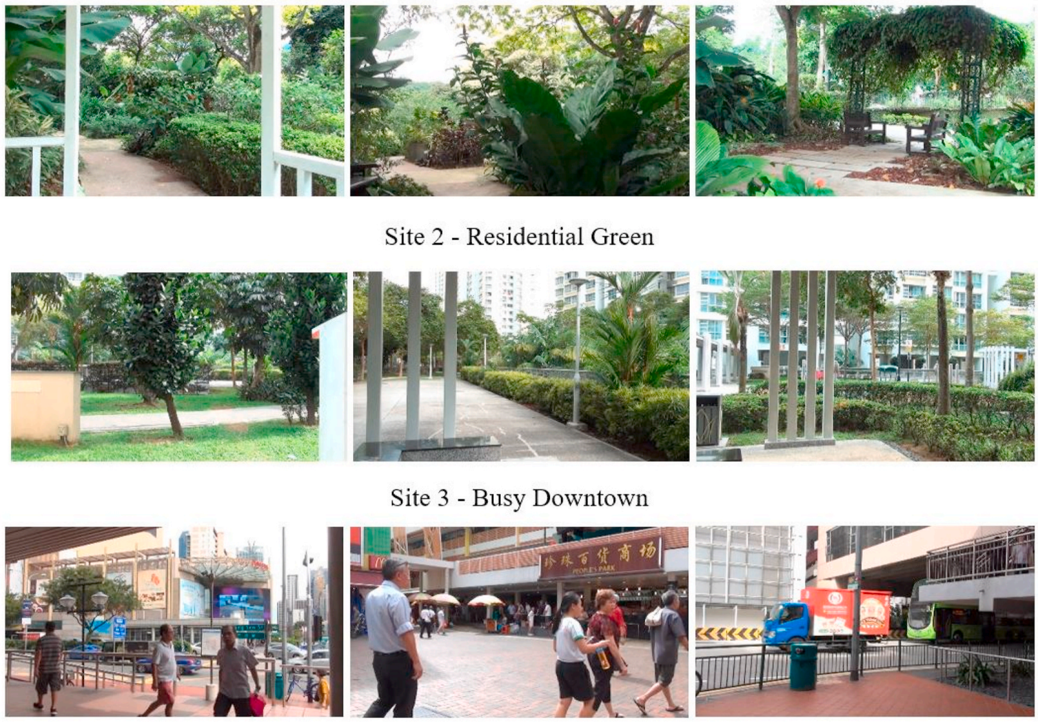

Fig. 1. Photographic representations of video stimuli presented to participants during the experiment.

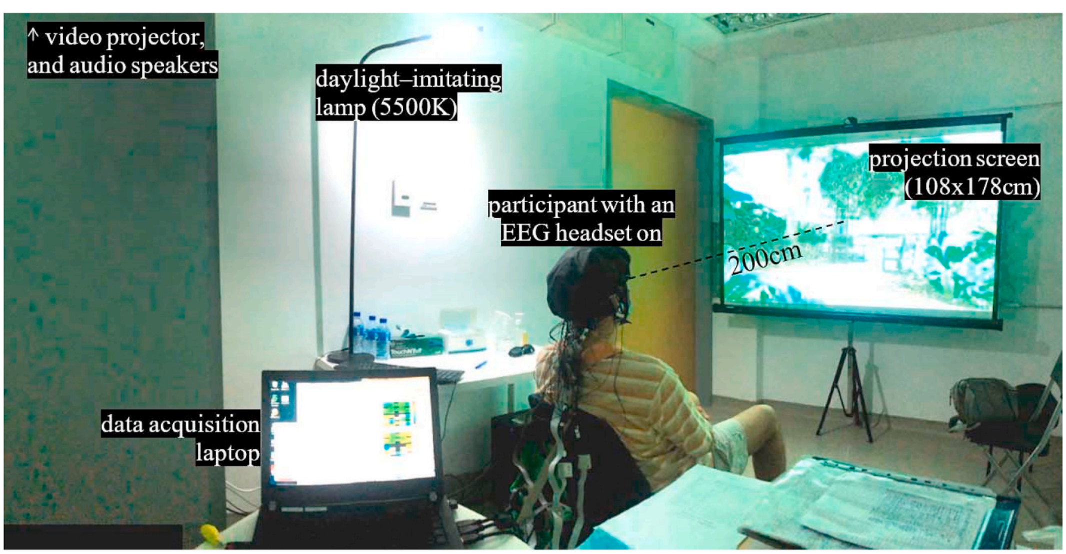

Fig. 2. Experimental laboratory setup.

on.

2.4. Questionnaires

Profile of Mood States questionnaire (POMS). A self-reported momentary mood questionnaire that provides an overall score Total Mood Disturbance (TMD) (Shacham, 1983). It contains a list of 40 names of feelings. Subjects self-report on each using a 5-point Likert scale. Higher scores indicate more intensive emotion. The final output of POMS is a TMD score. The higher the score, the more disturbed the mood.

Self-Assessment Manikin (SAM). A non-verbal pictorial assessment that was employed to assess the valence (i.e., pleasantness) and the degree of arousal associated with participants' affective responses to each landscape video (Bradley & Lang, 1994). The scale had five pictograms for valence and five for arousal and ranged from −2 to 2 points. A higher valence score indicates more positive emotion towards the stimuli and a higher arousal score indicates higher intensity of that emotion towards the stimuli.

Beck Depression Inventory (BDI-II). A 21-item multiple choice self-reported questionnaire measuring the severity of depression (sensitivity 81%, specificity 91%) (Beck et al., 1996). Questions refer to feelings experienced during the two weeks prior to and including the assessment day. Subjects circle one of four to seven statements under each item, which have assigned scores of 0, 1, 2 or 3 points. The total BDI-II score from 0 to 13 denotes minimal depression, 14 to 19 – mild depression, 20 to 28 – moderate depression and 29 to 63 – severe depression.

Other questionnaires. Only at T2, nature exposure during the SHO was assessed using two questions on the frequency and duration of visits to nature areas, defined as parks, gardens or nature reserves. Additionally at T2, two 5-point Likert scale items assessed the degree of discomfort experienced from mask wearing during the experiment (*How much discomfort do you experience from wearing the mask?*) and stress related to contracting coronavirus during the experiment (*How safe from contamination have you felt during this session?*). These were followed by a short standard socio-demographic questionnaire (both T1 and T2, see Fig. 3).

2.5. Procedures

The participant first read the study information sheet and signed the informed consent form before completing the POMS questionnaire. They were then seated in a chair, had their scalp cleaned at the electrode locations with an alcohol swab, and were fitted with an elastane-fabric cap with EEG electrodes (antiCAP, Brain Products GmbH, Munich, Germany).

At T2, the experimenter and participants followed the university COVID-19 safety regulations that involved wearing a mask for the duration of the experiment, keeping social distance of 1.5 m between the participant and experimenter, except for setting up the EEG, given that the experimenter remained in the lab room during the entire protocol. Additionally, the experimenter wore disposable gloves and disinfected all surfaces and equipment after each participant.

T1 and T2 data collection took place in the same room at the National University of Singapore premises, and followed the same procedure with some necessary modifications arising from COVID-19 sanitary precautionary measures – see Fig. 3. During the experiment, all electronic devices in the room were switched off, except necessary data collection equipment. Room temperature and humidity level were kept constant at T1 and T2 and across all participants. When the setup ended, the participants were instructed to refrain from talking or moving for the duration of the experiment and were asked to passively watch the landscape views displayed on the screen in front of them. The experiment started with a recording of baseline resting state activity while participants watched a light-grey empty screen for 1 min. This was followed by the main stimuli presentation, which comprised nine 20 s landscape videos, repeated three times each in a randomized order by the presentation software – Psychopy 3 (2002–2018 Jonathan Peirce, UK (Peirce et al., 2019)) (Fig. 3). Each video was preceded by a 15 s fixation cross (2° of visual angle). The stimuli presentation segment lasted for 14.5 min.

After stimuli presentation, the data acquisition cap was removed and participants completed the SAM, BDI-II, Nature exposure and Socio-demographic questionnaires. The whole procedure for both T1 and T2 (including explanations, consent taking, setup, experiment, removal, and questionnaires) was completed within 50 min. Fig. 2 shows the experimental laboratory setup.

2.6. EEG data recording and processing

The EEG signal was recorded using a 16-channel V-amp amplifier (Brain Products GmbH, Munich, Germany) equipped with dry active electrodes mounted on an elastic cap according to the modified 10/20 system. Electrode impedance was kept below 100 kΩ throughout the experiment, which is considered an acceptable value for dry electrodes (Ferree et al., 2001). Signal was recorded at 500 Hz.

Data were processed offline in Brain Analyzer 2 software (Brain Products GmbH, Munich, Germany). The raw signal was filtered with a 50 Hz notch filter, a low-pass at 40 Hz and a high-pass at 0.5 Hz (all were zero phase shift Butterworth filters, order 2). Channels were referenced to an average reference of 16 electrodes and visually inspected for noisy or missing channels. Topographic interpolation of noisy or lost channels was performed where necessary. Ocular artefacts (eye blinks and eye movement) were captured by Independent Component Analysis (ICA) and removed from the data. The signal was epoch time-locked to the video onset (0–20 s), and resting baseline data split into matching 20 s long epochs. All data underwent Fast Fourier Transform and were output as power. Power values were then averaged over each condition and alpha band power extracted between 8 and 13 Hz and averaged.

To compute the FAA index, channels' alpha values were first baseline

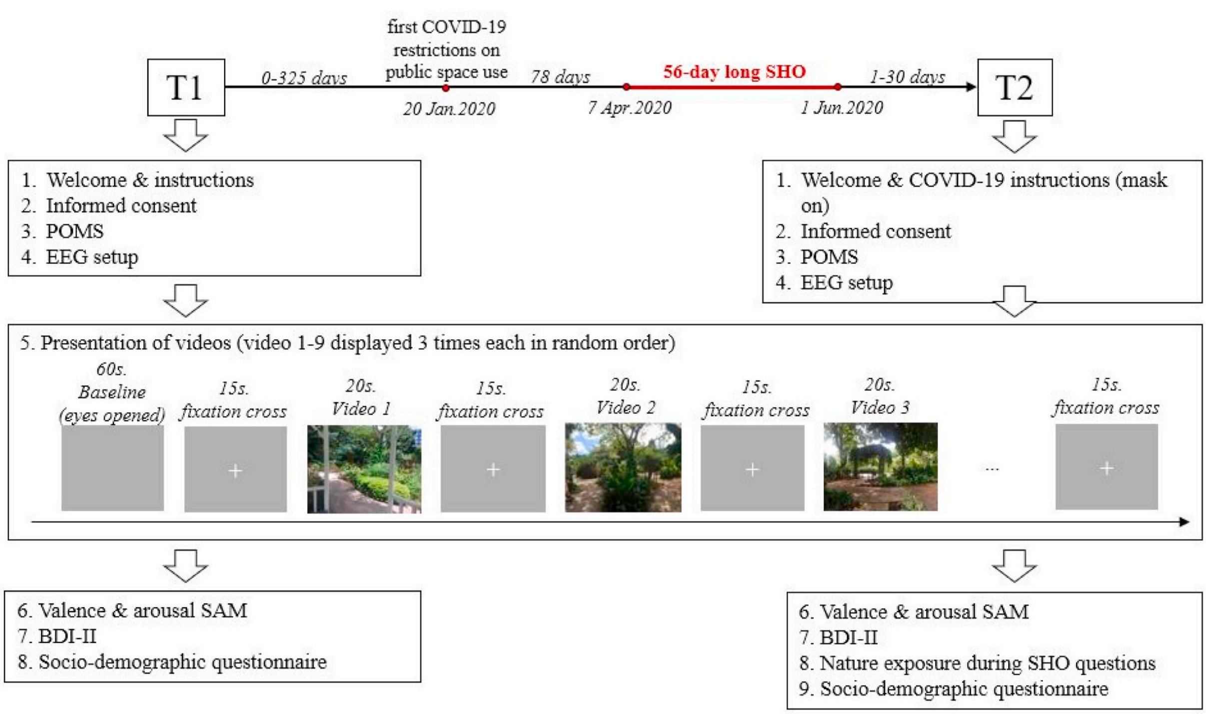

Fig. 3. Timeline between T1 and T2 and experiment design at each of the time-points.

corrected (condition minus baseline) (Bailey et al., 2018; Coelli et al., 2015, pp. 1512–1515). Then, frontal alpha power on the left (LF, comprising AFF5h) was subtracted from the right (RF, comprising AFF6h) as RF – LF (Beck et al., 1996; Peirce et al., 2019). Positive FAA values are indicative of greater alpha power on the right frontal hemisphere as compared to left and negative of greater alpha power on the left frontal hemisphere compared to the right. Higher relative FAA values indicate positive approach motivation as opposed to the withdrawal from stimuli (Harmon-Jones & Allen, 1997).

2.7. Statistical analyses

The index for nature exposure pre- and post-COVID-19 was computed based on the reported frequency of attendance and duration of visit to nature. It was computed as minimum reported minutes per week, e.g. for an individual reporting going daily for 15–30 min, computation yielded 7*15 min = 105 min weekly. Participants were then median split into two groups (lower and higher exposure).

Data was modelled using Linear Mixed Models (LMM) with random effects and compound symmetry covariance matrices, which were estimated using restricted maximum likelihood. All analyses were conducted in SPSS V.23, and an alpha level of 0.05 was used as an indicator of statistical significance. Separate models examined changes in BDI, FAA, POMS, and Valence and Arousal (as outcome variables) over time and a potential effect moderation by degree of Nature Exposure during the SHO. Main effect of Time was used as a predictor in all analyses to examine changes over time (H1, H3) across all three variables of interest.

For analysis of FAA, the model included the main effects of Time and Landscape Type (Landscape), and 2-way interactions Time*Landscape, Time*Nature Exposure and the 3-way interaction Time*Landscape*Nature Exposure. The main effects of Time and Landscape were used to examine changes in FAA over time (Time) and a general bias towards certain Landscape types (Landscape), independent of time. Interaction between Time*Landscape was computed to examine whether changes over time varied by landscape type. Interaction between Time*Nature Exposure was computed to examine whether nature exposure moderated changes in FAA over time independently of landscape type, and a 3-way interaction between Time*Landscape*Nature Exposure examined whether nature exposure moderated changes over time to specific landscape types.

For the analysis of BDI and POMS, models included the main effect of Time, and the interaction Time*Nature Exposure, to examine changes in outcome variables over time and potential moderation effect by Nature Exposure. Modelling the main effect of Nature Exposure was also not justified theoretically due to the time-variant nature of the outcome variables, i.e. impact of Nature Exposure during SHO was irrelevant for Time 1 measurements. Due to the small sample size, main effects of Nature Exposure were not modelled to preserve the degrees of freedom. LMM were fitted to examine changes in arousal and valence over time.

For Valence or Arousal analyses (H3), the model predictors were Time, Landscape and Time*Landscape interaction, to examine changes over time, potential bias by Landscape Type, and changes over time with moderation effect by Landscape Type.

3. Results

Sample characteristics are described in Table 1. The participants were mainly university-educated Singaporean citizens. The majority lived in a 3-person household, in a 3-room (2 bedrooms) accommodation or larger.

3.1. Frontal alpha asymmetry (FAA)

The results showed a significantly higher FAA at T1 (M = 25.7, SE = 6.9) compared to T2 (M = 0.8, SE = 6.8) indicating a reduction in FAA over time ($F(1,398.1) = 20.02$, $p < 0.001$) (Fig. 10). This was independent of the Landscape (interaction $F(2, 386.8) = 0.3$, $p = 0.74$). Nature Exposure significantly moderated changes in FAA over time ($F(2,43.0) = 6.0$, $p = 0.005$). The results are presented in Fig. 4. Among those with high nature exposure, FAA decreased over time. FAA remained the same over time among those with low nature exposure.

Landscape did not have a significant effect on FAA ($F(2, 386.8) =$

Table 1
Characteristics of the sample presented as total number and percentage of the sample.

Variable	Participants (n = 25)
Age	
Youth (18–24)	6 (24%)
Adults (25–64)	15 (60%)
Seniors (65+)	4 (16%)
Gender	
Male	11 (44%)
Female	14 (56%)
Vision	
Normal	7(28%)
Glasses	18 (72%)
Citizenship	
Citizen	16 (64%)
Non-citizen	8 (8%)
Education	
Below tertiary	5 (20%)
University	20 (80%)
Household size	
1	2 (8%)
2	0 (0%)
3	13 (52%)
4	3 (12%)
≥5	7 (28%)
Rooms number	
1	2 (8%)
2	0 (0%)
3	10 (40%)
≥4	13 (52%)
Nature exposure during SHO	
High (>60 min/week)	13 (52%)
Low (0 ≤ 60 min/week)	12 (48%)
Discomfort from mask wearing	
High to very high	5 (20%)
Low to moderate	20 (80%)
Fear of infection during exp.	
High to very high	4 (16%)
Low to moderate	21 (84%)

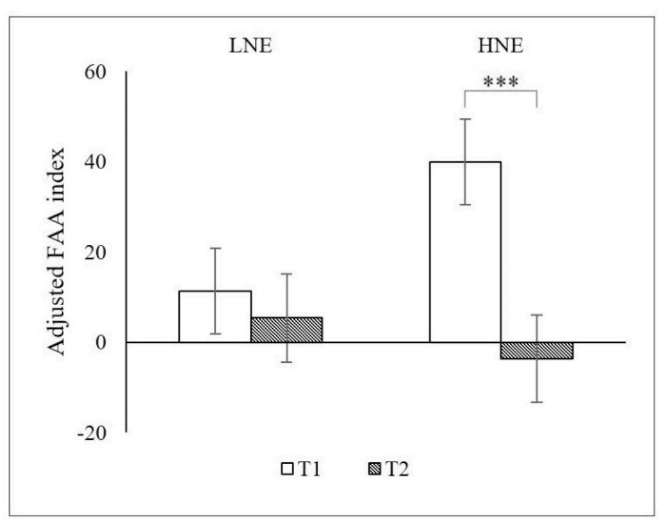

Fig. 4. Changes in adjusted FAA value (Mean ± SE) as a function of Time (before/after SHO) and Nature Exposure during SHO (LNE – low nature exposure, HNE – high nature exposure). *Note: ***p < 0.001.*

0.40, $p = 0.66$), nor did it significantly moderate the effects of Nature Exposure on FAA ($F(4, 386.8) = 0.10$, $p = 0.98$), although the largest decrease in FAA was observed for the videos of Residential Green areas (Fig. 5).

3.2. Becks Depression Inventory II (BDI-II)

BDI score was significantly lower at T1 ($M = 6.4$, $SE = 1.5$) compared to T2 ($M = 8.8$, $SE = 1.5$), indicating an increase in depressive symptoms over time ($F(1,23) = 4.4$, $p < 0.046$) (Fig. 10). Nature Exposure did not significantly moderate this effect ($F(2,23) = 1.6$, $p = 0.22$). However, an examination of T2 data indicated that participants with lower nature exposure during the SHO had a higher BDI score at T2 (Fig. 6).

3.3. Profile of Mood States (POMS)

There was a marginally significant increase in Total Mood Disturbance (TMD) over time ($F(1,25) = 3.09$, $p = 0.091$) (Fig. 10), with a trend for lower scores at Time 1 ($M = 87.8$, $SE = 3.08$) as compared to Time 2 ($M = 92.3$, $SE = 3.08$) (Fig. 7). This effect was not significantly moderated by the degree of Nature Exposure ($F(2,25) = 1.14$, $p = 0.34$).

3.4. Valence and Arousal in responses to videos

Valence. Valence in response to videos did not show significant change over time ($F(1,124.1) = 0.08$, $p = 0.77$). There was a significant main effect of Landscape ($F(1, 124.1) = 228.2$, $p < 0.001$). The model indicated that overall valence was the highest for the Lush Garden and the lowest for Busy Downtown (Fig. 8a). Change over time was not moderated by the Landscape ($F(2,124.1) = 0.18$, $p = 0.84$) and this was not further modified by Nature Exposure ($F(6,73.1) = 0.42$, $p = 0.86$), see Fig. 8b.

Arousal. Arousal in response to videos did not show significant change over time ($F(1,25.2) = 2.23$, $p = 0.15$). The model indicated that overall arousal was significantly lower for Residential Green ($M = -0.40$, $SE = 0.13$) compared to Lush Garden ($M = 0.26$, $SE = 0.13$) or Busy Downtown ($M = -0.01$, $SE = 0.13$; $F(2,99) = 11.58$, $p < 0.001$). The mean differences between Lush Garden and Busy Downtown were marginally different ($p = 0.053$) (Fig. 9a). Significant interaction between Time and Landscape indicated that change in arousal over time depended on the type of landscape ($F(2, 99.6) = 4.02$, $p = 0.021$). Arousal to Busy Downtown decreased over time, while for Residential Green or Lush Garden, it increased over time (Fig. 9b). Importantly, this change in arousal to different landscapes over time varied by nature exposure during the SHO ($F(6,49.1) = 4.19$, $p = 0.002$). Arousal to Busy downtown decreased only among those with high nature exposure (Fig. 9b).

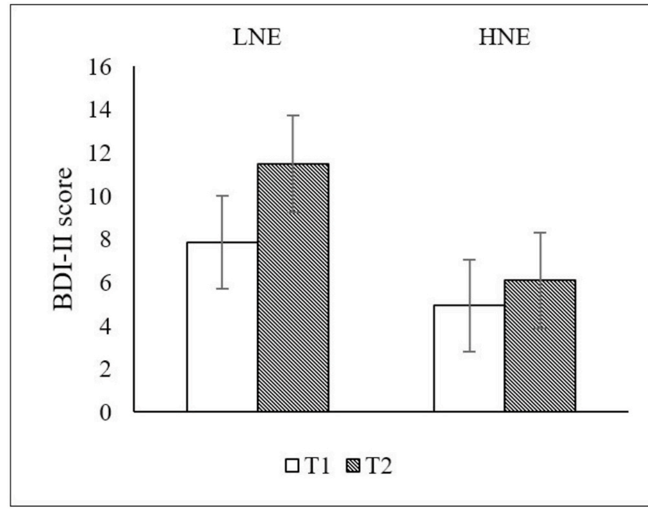

Fig. 6. Changes in the BDI-II scores (Mean ± SE) as a function of Time (before/after the SHO) and Nature Exposure during the SHO, (LNE – low nature exposure, HNE – high nature exposure).

4. Discussion

This study investigated the longitudinal changes in mental health outcomes in a population of healthy adults before and after the COVID-19-related SHO in Singapore. Both physiological (brain activity) and self-reported data were compared before the SHO started and soon after it ended. In this study, a special emphasis was put on exploring potential environmental influences on mental health outcomes during the SHO.

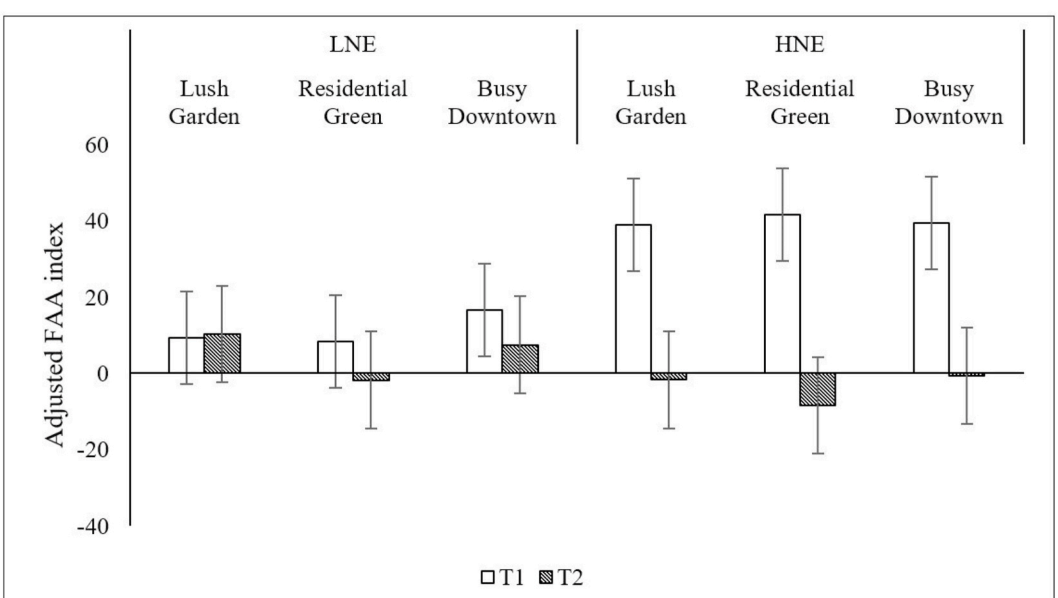

Fig. 5. Changes in the FAA (Mean ± 95%CI) in response to different urban landscapes over time, for two groups of people a) low nature exposure (LNE) and b) high nature exposure during the SHO (HNE).

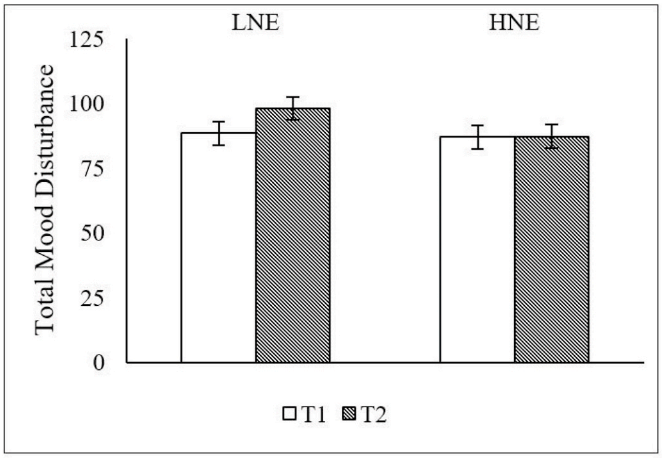

Fig. 7. Changes in the TMD (Mean ± SE) over time relative to the level of Nature Exposure during the SHO (LNE – low nature exposure, HNE – high nature exposure).

4.1. Did depressive symptoms increase during the SHO?

We demonstrated that there was an increase in depressive symptoms over time measured through both questionnaires and neurophysiological markers. At T2, soon after the SHO, brain activity pattern associated with positive emotions, the FAA in response to presented videos, was significantly lower than at T1. We also observed that the self-reported BDI-II scores, which measure the severity of depressive symptoms in the previous two weeks, were significantly higher at T2 than at T1. Moreover, the total mood disturbance measured with POMS, the momentary mood assessment, was higher at T2 than at T1, but at a marginal level of statistical significance (see Fig. 10). These findings suggest that after the SHO participants were more depressed, had lower mood at the time of the experiment, and perceived the stimuli with a less positive approach than before.

The observed changes in the alpha brainwave oscillations in response to the videos suggested overall less positive emotions and lower approach-related motivation after the SHO compared to before. The decrease in the FAA observed in the sample is particularly interesting. Decreased FAA is related to more alpha brainwaves on the left frontal cortex (i.e., greater relative right frontal activity). Traditionally, it has

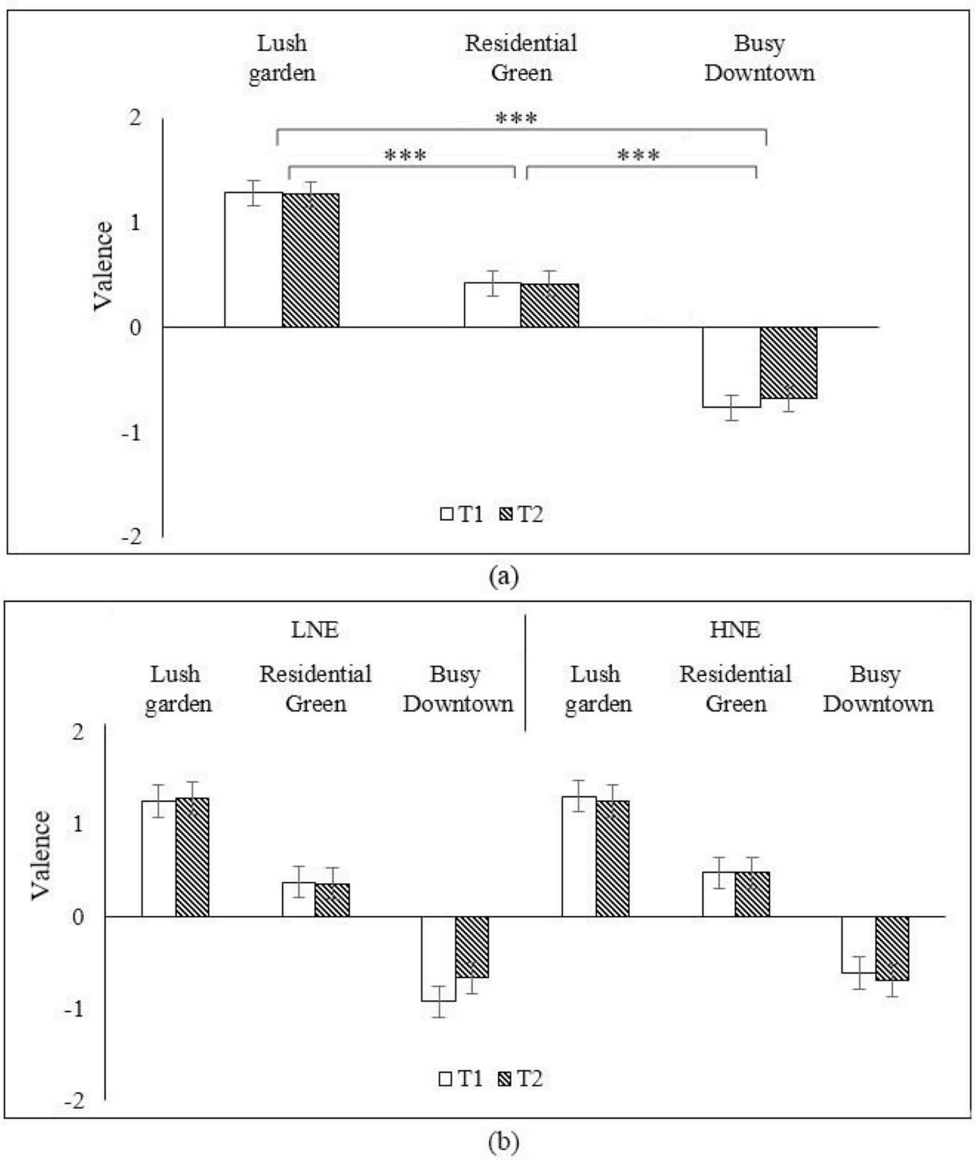

Fig. 8. Change of valence over time a) in response to videos of different sites and b) as a function of the level of Nature Exposure (Mean ± SE). *Note: ***p < 0.001.*

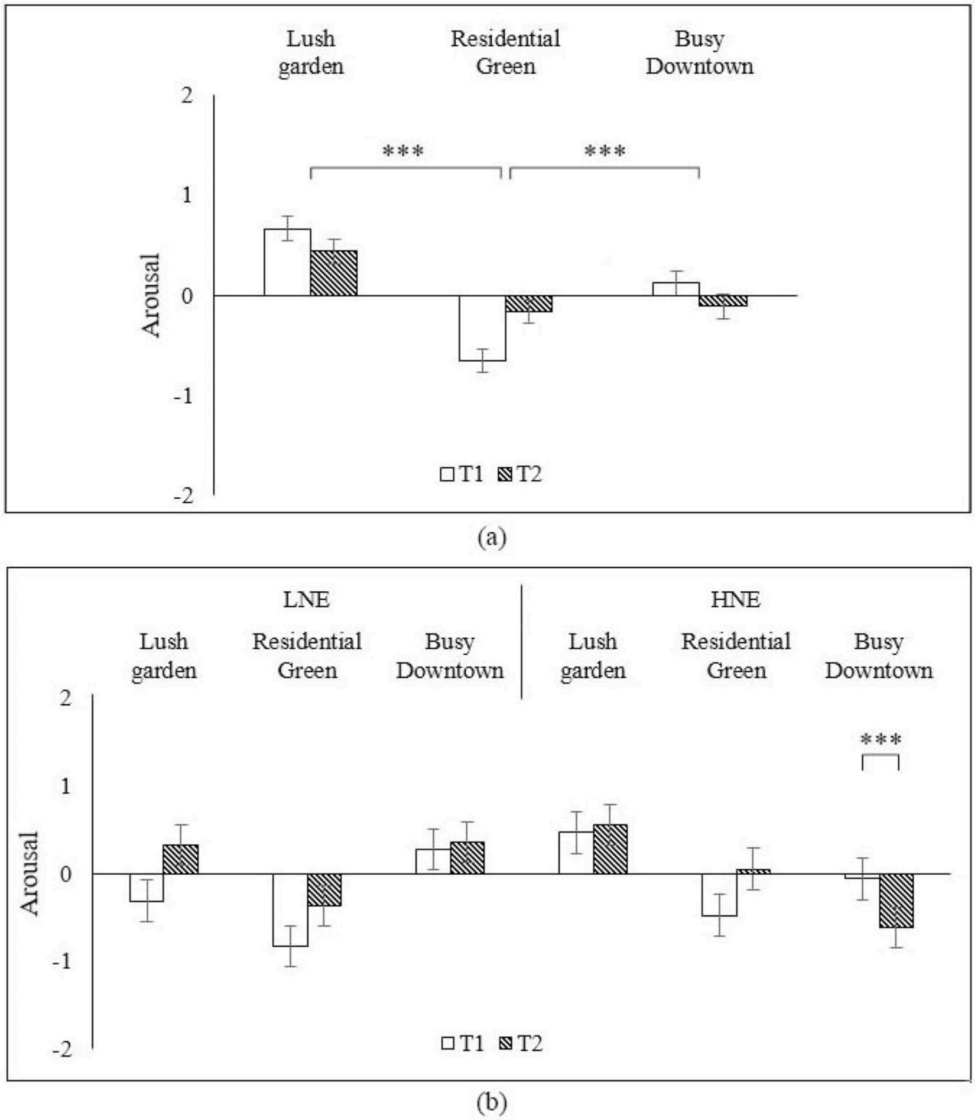

Fig. 9. Change in arousal over time a) in response to videos of different sites and b) depending on the level of Nature Exposure (Mean ± SE). *Note: ***p < 0.001*.

been linked to a withdrawal/avoidance system, such that it represents negative affect/avoidance (Davidson, 1994, 1998; Davidson et al., 1979; Harmon-Jones & Allen, 1997). Because of this, low FAA score was broadly discussed as a potential marker of depression. In our study, the decrease in FAA is consistent with the increase in self-reported measures of depressive symptoms (including avoidance) and might constitute its neurophysiological underpinnings.

Increased depressive symptoms soon after the SHO were expected based on the previous body of research on prisoners (Haney, 2003; Hocking, 1970; Leiderman, 1962) and "cabin fever" (Ledbetter, 1974) as well as the recently conducted COVID-19 online surveys (Wang et al., 2020a; Grover et al., 2020; Ozamiz-Etxebarria et al., 2020; Ammar et al., 2020; Rehman et al., 2020; Wang et al., 2020b; O'Connor et al., 2020; Estacio et al., 2020). AfterA experiencing drastic lifestyle changes by being confined to their homes for over seven weeks showed more depressive symptoms than before. The average BDI-II scores of tested individuals were not of clinical concern (still within the minimal depression range), but they signal an increase in the overall depressive symptoms and in the prevalence of clinically relevant depression at the population scale. The participants also reported more disturbed momentary mood after the SHO. However, the effect was not as strong as with the BDI-II. This could be due to the fact that while the BDI measures a more stable and persisting mood/symptoms with participants reporting their feelings from the last two weeks, POMS measures momentary mood. It is possible that even leaving the house for a short while to take part in this study had beneficial effects on the participants' moods as measured by POMS, while overall mental burden was nonetheless reflected in the more stable measure of the BDI. Together, the findings from FAA, BDI-II and TMD analyses consistently demonstrate a decline in mood and mental health related to prolonged SHO, social isolation and stimuli deprivation.

Beyond the FAA role as a marker of emotional processing, these findings suggest new hypotheses regarding possible causes for the effect of SHO on response to outdoor spaces. Previous studies have associated the decreased FAA we observed here with limited supervisory control over emotions (Gable et al., 2015) and with diminished reactivity to reward (Morgan et al., 2013). This highlights these aspects of cognitive functioning as possible contributing causes for the effects we report. Notably, the sanitary situation as well as the drastic nationwide lifestyle changes during the SHO have generated atypical mood and emotional responses to all outdoor spaces overall, notwithstanding the lush green spaces. These would have overwhelmed the emotion supervisory control systems indexed by the FAA, with the associated inability to cope having knock-on effects on depression and mood scores for all stimulus types.

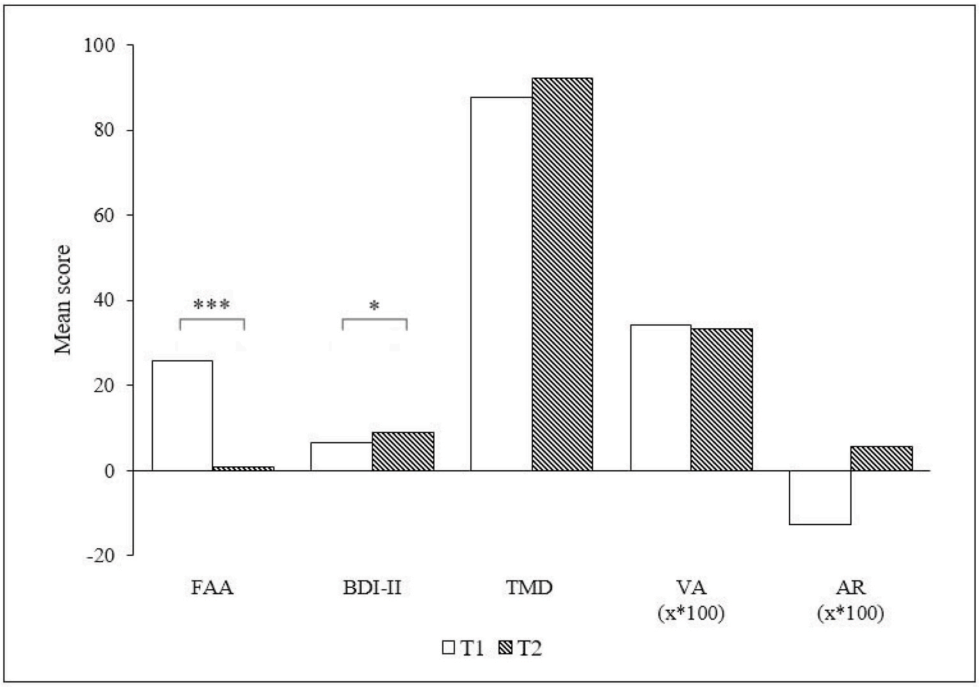

Fig. 10. Change in the depressive mood symptoms before and after the SHO, measured with: FAA (alpha asymmetry in the anterior cortex of the brain in response to videos of urban public spaces, associated with positive emotions), BDI-II (self-reported depressive symptoms), TMD (self-reported mood disturbance), VA (Valence – level of positive/negative emotions towards videos of urban public spaces), AR (Arousal – intensity of emotions towards videos of urban public spaces). *Note: ***p < 0.001, *p < 0.05.*

Second, the situation likely generated ambivalent attitudes towards outdoor spaces as these were simultaneously a potential source of relief, yet posed potential sanitary and legal risks. This would be reflected in impaired processing of the reward associated with outdoor spaces emerging as the decreased reward sensitivity reflected by the FAA. We initially expected that the neurophysiological response would vary depending on the stimulus type; however, this was not the case. The FAA was lower at T2 compared to T1, independent of the landscape type. These response patterns in the EEG open new avenues for a better understanding of the mechanism of nature deprivation, specifically in the case of complex risk/reward patterns such as during a pandemic.

4.2. Did nature exposure during the SHO moderate depressive symptoms?

We also hypothesized that exposure to nature during the SHO would moderate changes in mental health outcomes over time. The self-reported time spent in nature per week had a significant effect on the FAA, but not on BDI-II or TMD scores. Interestingly, the effect of nature exposure on the FAA in response to videos was opposite to what we expected: participants who reported high nature exposure during the SHO showed significantly lower FAA scores than those with low nature exposure. It seems that individuals who spent more time in nature during the SHO responded to all videos with less positive emotions and approach than those who spent less time in nature during the SHO. This may be due to more approach-related motivation to outdoors videos in those who did not go out much during the SHO. We might also speculate that people who spent more time in nature during the SHO, showed less of an approach tendency, because videos of the outside were not as attractive as their actual, although limited, experience of nature during the SHO.

Previous research shows that contact with nature has a beneficial effect on mental health and well-being of people in urban areas. In addition, active or passive contact with nature has been shown to mitigate the negative mental impact of confinement in prisons (Linden, 2015). However, the current study does not support previous evidence – high nature exposure reported by Singaporeans during the SHO did not contribute to mitigating the risk of depression. This could be due to relatively low levels of reported depression - it is possible that among people with higher depressive scores, or those with clinically relevant depression, the degree of nature exposure would be a moderating factor. Also, it must be considered that visits to parks, gardens and nature reserves during COVID-19 were very different from those before the COVID-19 situation. As shown in the Supplementary Materials, many functions of the parks, gardens and nature reserves were not accessible, limiting the visit to only passing through the area (in groups limited to household members and wearing a mask if not engaged in sport activities) and without the possibility of stopping to spend more time in one spot (seating, picnicking, playing team games, etc.). During the SHO, there was also much more green space visitors than usual, resulting in greater crowds in those spaces. Research on the use of green urban spaces for mental health promotion emphasizes the importance of green spaces that *invite for rest and relaxation* by providing appropriate seating areas where one can relax and contemplate nature (Olszewska et al., 2016)—conditions that were not met in Singapore parks due to the COVID-19 restrictions. Moreover, following the Attention Restoration Theory (ART), the feeling of *being away* from everyday struggles is essential to enable the salutogenic, restorative effect of nature (Kaplan & Kaplan, 1989; Olszewska et al., 2016). Before COVID-19 such *being away* meant reorientation from the city noise and overload of stimuli; during the pandemic — distancing oneself from the struggles of lockdown. During the SHO, however, green spaces cordoned off with red tape and paths crowded with mask-wearing people could not have been the most relaxing places, as they only reminded visitors of the challenging time of the pandemic. Also, mask-wearing itself could have caused more sweating and/or breathing difficulties, especially in Singapore's tropical climate, which potentially degraded the overall nature experience to something less than would normally be expected (Scarano et al., 2020).

Furthermore, we have no information about the quality of green spaces visited by the participants. A recent Singaporean study showed the weakness of the linear relationship between the amount of greenery and the General Health Questionnaire scores (Zhang et al., 2017), suggesting that other aspects beyond quantity may play a role in the salutogenic potential of urban nature. We can presume that the nature exposure required to yield positive mental health outcomes, such as less depressive symptoms and improved mood, should not only be based on the frequency and duration of the green space visit, but also on the quality of that experience and quality of the space's features. Given the growing body of research on how contemplative landscapes (specific attributes of the landscape scenes within a Contemplative Landscape Model) are beneficial for mental health (Olszewska-Guizzo et al., 2018, 2020), the level of contemplativeness of the view could also play an important role. For example, we have recently demonstrated that spaces with more contemplative features (long distance views, presence of archetypal elements, natural asymmetry, among other features) induce higher FAA compared to spaces with fewer contemplative features (Olszewska-Guizzo et al., 2020), suggesting that the lack of effects of nature on depressive symptoms found in the current study may be only relevant for exposure to urban green spaces of lower quality.

4.3. Did the emotional response to urban spaces change after the SHO?

Finally, we tested the changes in emotional response towards the three types of urban landscapes: Lush Garden, Residential Green and the Busy Downtown. We expected that, as compared to T1, T2 arousal and valence would increase in response to the green spaces and decrease in response to the busy urban spaces. This hypothesis was only partially supported. There was a difference in the valence of the emotional response, but it differed between spaces, not between T1 and T2. Participants reported the most positive emotions towards the Lush Garden, moderately-positive towards the Residential Green and most negative emotions towards the Busy Downtown area, both before and after SHO. They also reported significantly lower scores for arousal towards the Residential Green space at both times, indicating that their moderately-positive feelings about this kind of space was the least intensified. There was no change in valence and arousal towards these spaces over time, indicating that their reaction to these spaces was not affected by the SHO.

A targeted analysis focusing on the Busy Downtown indicated that, for these spaces, arousal changed over time as a function of nature exposure during SHO. People who reported higher nature exposure reported a significant drop in arousal in response to busy urban downtown, indicating decreased negative emotional reactivity towards these spaces after the SHO. This may be due to the fact that during the SHO they missed busy downtown exposures and city-life, and suggests they may be more keen to return to spend time in these areas than people with low exposure to nature. It also highlights the need for diversity of exposures, which was lacking during the SHO.

Regarding different urban spaces, we also observed lower FAA scores at T2, and lower Valence scores at both times for the Residential Green. This was not observed for the Lush Garden condition, which represents a less tended natural area without any buildings in the view. This suggests that even though Residential Green areas contain natural elements, and are technically considered green spaces, their potential to induce positive mood may be limited. This may be caused by too much exposure to residential places during the SHO, and mental distress linked to themby residents. This further supports and emphasizes the need for knowledge about the quality of green spaces and the quality of nature experience in the city, rather than solely focusing on their quantifiable aspects (amount of green, duration and frequency of exposure).

We observed a change in the self-reported or neurophysiological perception over time for Residential Green and for the Busy Downtown, likely dictated by the specificity of the SHO. However, Lush Garden was one condition towards which the perceptions did not change over time across the metrics used. This suggests that lush nature continuously provides potential restorative, soothing experiences for urbanites, even during the pandemic.

The main contribution of this study is the demonstration in a longitudinal within-subjects design of the effect of the SHO on the mental health of Singaporeans. It did so using both self-reported behavioral methods and physiological brain imaging methods, which all clearly showed the scale of effect of decline in mental health outcomes related to the COVID-19 lockdown. One limitation of the study was a relatively small sample size dictated by the reluctance for participation due to the fears of COVID-19. It is also unknown to what extent the sample was representative of the Singaporean population. Nevertheless, the presented evidence was sufficiently powered to reach statistical significance, and multiple age and social groups were represented in the study.

More research is needed in the area of urban green space design and its potential to generate the positive mental health and well-being outcomes required to meet the needs of progressively declining mental health in urban populations. Further research should directly measure the impact of specific types and characteristics of nature exposure on mental health.

5. Conclusions

This is the first study to show that the Stay-at-Home Order may have contributed to a decline in mental health in healthy Singaporeans, and their change in physiological response towards public urban spaces. We have demonstrated that compared to assessments conducted before the Covid-19 pandemic, after the Covid-19-related SHO, participants self-reported more severe depressive moods and showed reduced Frontal Alpha Asymmetry, akin to negative affect, withdrawal and reduced responsiveness to reward in response to urban spaces. This brain response was independent of the landscape type, suggesting a general decrease in cognitive functioning. The findings emphasize the importance of a diversity of environmental exposures as well as the role of the quality of nature exposure beyond mere quantity. The provision of fully-functioning green urban spaces even in the times of pandemic, i.e. allowing social isolation, rest and relaxation in nature, forgetting about the pandemic struggles, may be the key for improved well-being of urbanites post-COVID-19. Future lockdowns with potential stay at home orders should be planned with regards to declining mental health and the heightened risk of depression, and with consideration to the availability of high-quality nature exposure in urban populations.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2021.101590.

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