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ENHANCING PSYCHOLOGICAL HEALTH THROUGH BIOPHILIC DESIGN: THE INFLUENCE OF SEA VIEWS ON UNDERGROUND OCCUPANTS.

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Abstract: Occupying underground spaces can be associated with poor psychological health. This is due to the unique constraints of the environment, which typically include isolation from the outside world, risk of poor ventilation, and anxiety related to potential safety risks within these spaces. While exposure to nature, such as sea views, is associated with positive psychological health outcomes, little is known if similar effects can be achieved by integrating sea view elements as visual stimuli in underground spaces. In this study, we investigated the impact of virtual sea views on psychological health and cognition by exposing participants to a simulated static sea view, a dynamic sea view, and a control room with no sea view. Participants completed cognitive tasks under each condition, and their subjective emotional responses were collected using questionnaires. Wilcoxon signed-rank test was used to compare participants' health state for each virtual scenario before and during the cognitive tests. Kruskal-Wallis tests were applied to conduct inter-group comparisons. The results from the psychological state assessment showed that static and dynamic sea views can protect against negative emotional shifts. For the cognitive tests, the inverse efficiency score assessment revealed superior efficiency across different tests for different environmental conditions. Further analysis using the Mann-Whitney test with Bonferroni correction suggests that both static sea view (IES = 2.22) and non-sea view conditions (IES = 1.06) were effective for the Stroop test (working memory). However, the IES scores favor the non-sea view control group.

Keywords: Psychological Health, Biophilia, Sea view, Virtual Reality, Underground Space

1. INTRODUCTION

The mounting pressures from rapid urban growth have led to a paradigm shift in urban development, with planners utilizing underground spaces to augment available developmental space. By increasing developable space, governments can better accommodate the growing population, meet their evolving needs, and pursue sustainability goals [1]. However, this paradigm shift in urban development faces a major hurdle in gaining social acceptance. Underground spaces pose unique indoor environmental challenges for human occupancy, which include the risk of suboptimal ventilation, limited daylight, lack of connection to nature, and a sense of isolation from the outside world [2]. Hence, enhancing the health and perception of underground space occupants remains a topical issue in the academic literature.

Human health is a multidimensional construct encompassing physical, psychological, and social dimensions [3]. As the development of underground spaces expands to include workspaces where occupants reside and work for extended periods, the psychological dimension has emerged as a particularly contentious issue to be addressed in underground space design [4]. According to Ringstad [5], occupants of underground spaces tend to face heightened anxiety due to perceived health and safety risks. In some cases, people's cultural values frame the underground as inhospitable [5]. Such barriers highlight the need to mitigate indoor environmental stressors and reshape perceptions of underground spaces.

Beyond this, productivity, a critical business metric, may be adversely affected by declines in the health of underground workers.Thus, it is prudent to examine workers' cognitive functioning when assessing overall health status [6,7]. In this context, stress reduction theory explains how exposure to nature (e.g., greenery, natural waters)

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can lead to the restoration of psychological health following stress or trauma [6]. Similarly, Schertz and Berman [8] posit that exposure to nature-based interventions promotes restorative states, reducing stress and enhancing cognition. In this line of inquiry, researchers have examined the impact of blue spaces on human health, highlighting their potential to support psychological health and cognitive restoration (e.g., [9],[10],[11]).

As defined by Grellier et al. [12], blue spaces are “outdoor environments, either natural or manmade, that prominently feature water and are accessible to humans either proximally (being in, on or near water) or distally/virtually (being able to see, hear, or otherwise sense water)”. To date, evidence from some studies suggests that exposure to sea views offer a promising approach to improving psychological health by alleviating stress [10] and depression [13]. Nevertheless, a previous systematic review of the state of art of research on exposure to blue spaces and psychological health states revealed very limited studies to date [13]. Accordingly, this study aims to contribute to the knowledge base on the impact of blue spaces on human psychological health and cognition by investigating their effect as visual stimuli in the novel, understudied underground space environment. The study aimed to evaluate the psychological effects of integrating sea view elements into underground spaces, informing design strategies that enhance the psychological health and cognition of underground occupants.

2. THEORETICAL FRAMEWORK: BLUE SPACES AND POSITIVE AFFECT

Severin et al. [14] characterized sea views as therapeutic landscapes. Therapeutic landscapes have physical and social features that promote physical, psychological, and even spiritual well-being. Growing empirical evidence demonstrates that exposure to blue spaces like the sea views, rivers, and lakes yields significant benefits for human psychological health ([14], [15]). The evidence documented to date spans several mechanisms, including driving physical activity (e.g. swimming, walking), social cohesion (i.e. a place of engagement in social relationships), and emotional regulation due to their therapeutic nature [15]. Using exposure to the sea as a case study, Severin et al. [14] identified several pathways through which emotional regulation may occur via sea views. These include feelings of awe driven by the sea’s vastness and power, a sense of mental freedom by releasing challenging thoughts, feelings, and emotions, a break from the fast-paced urban environment that serves as psychological safe-havens, and allowing individuals to experience emotional vulnerability without judgment. Thus, while the therapeutic benefits of sea view exposure are acknowledged, little is known if the integration of sea views as design elements in underground spaces can similarly mitigate the psychological health concerns associated with occupying underground spaces. Therefore, to fill this gap, a virtual reality experiment was conducted to investigate the impact of two types of sea views (static sea view and dynamic sea view) and a control, non-sea view scenario on the psychological health and cognition of underground occupants. To the best of our knowledge, this study is the first to examine the health impacts of blue spaces on individuals occupying underground environments. It adds to the existing literature by extending the focus beyond psychological health to include cognitive effects, highlighting their relevance in enhancing the quality of underground workspaces. Accordingly, and guided by the theoretical framework and prior empirical findings, the following hypotheses were proposed:

H1: Individuals exposed to a sea view will report higher levels of positive psychological well-being compared to those without.
H2: Individuals exposed to a sea view will demonstrate better cognitive performance than those without.

3. METHOD

3.1. Experiment design

Three immersive virtual office environments were developed using 3D Max and Unity software. Fifty-five participants (26 males, 29 females) were recruited via posters and emails. The participants were randomly assigned to three groups to experience three different virtual office environments: static sea view (wallpaper = 19), dynamic sea view (motioned, n = 20), or non-sea view control (n = 13). The mean body mass index (BMI) of these participants was 21.92 kg/m², which was considered a healthy level [16].

Participants' emotional states were assessed based on six indicators: calmness, tension, upset, relaxation, contentment, and worry. The study required the participants to complete four tasks in the virtual environment. The tasks were the go/no-go visual task, Stroop test, n-back test and calculation test. The tasks served as proxies, providing insight into a person’s response inhibition [17], cognitive flexibility [18], working memory [19], and numerical processing, respectively. First, the participants reviewed and signed a consent form after which they completed a questionnaire survey to record their basic information and how they felt before exposing them to the underground virtual world. We also screened for caffeine consumption, their level of physical activity and medications prior to the experiment. The participants donned the VIVE Pro 2 headset, and images were enhanced for clarity by adjusting an interpupillary distance (IPD) knob. Virtual reality (VR) is acknowledged to enhance experimental control by enabling systematic manipulation of indoor environments, minimizing confounding variables and allowing for immersive simulations of natural settings [20,21]. In addition, studies leveraging the capability of VR have demonstrated its effectiveness in delivering emotionally impactful visual stimuli, with statistically significant differences observed between treatment and non-treatment groups across various experimental contexts [21,22].

A brief tutorial was conducted to familiarize participants with the controls and interactions in the VR environment. Next, we confirmed that the participants did not experience any motion sickness or discomfort. Using a job interview scenario, participants were required to complete four cognitive tests. Following the completion of the experiment, we confirmed that the participants did not experience any discomfort and provided them with a coupon as a token of appreciation.

Figure 1. *Virtual Office Environment*

3.2. Measurements

The visual reaction time test required participants to promptly click a "press" button when a green dot popped up on a virtual computer monitor, ignoring all other colored dots. In the Stroop test, several colored words with their respective meanings were displayed on a virtual computer monitor. The goal was for participants to recognize the word whose color was inconsistent with its meaning (e.g., the participant was expected to click the yellow-colored word "Blue"). For the n-back test, participants quickly clicked "press" when the current number matched the one presented two trials earlier. Regarding the calculation test, participants completed simple calculations encompassing addition, subtraction, multiplication, and division. To assess participants' psychological state, the study employed the State-Trait Anxiety Inventory (STAI). Although some researchers argue that individual differences (such as personality type, gender, and prior spatial experiences) combined with the inherent subjectivity of human perception, may introduce bias in environmental perception studies that use questionnaires, the use of subjective evaluations was deemed feasible and valuable. This is because human judgments of spatial environments tend to follow statistically consistent patterns despite such individual variability (e.g., [23,24,25]).

3.3. Data analysis

The Shapiro-Wilk test revealed that the dataset was not normally distributed hence non-parametric tests were employed. The visual distribution of the data was first presented using box plots. Descriptive statistics and the Wilcoxon signed-rank test were used to compare the changes in participants' psychological health before and during the cognitive tests. The aim was to evaluate whether the visual impression of the space impacted the participants' psychological health perceptions (emotions). Task performance was analyzed using the inverse efficiency score (IES), and subsequently, the Kruskal-Wallis test was used to compare cognitive performance between different groups of participants. IES was adopted following recommendations by Townsend and Ashby [26] on its ability to provide comprehensive insight by combining both the speed of task completion and the accuracy involved. In IES analysis, greater efficiency is reflected by a lower IES, reflecting one's ability to combine both speed and accuracy in performing a given task. Following the proposal of Bruyer and Brysbaert [27], IES was calculated using the formula;

$$\text{Inverse efficiency score} = \frac{\text{Task Time}}{\text{Accuracy}} \tag{1}$$

Where;

$$\text{Accuracy} = \frac{\text{Ntrue}}{\text{Ntrue} + \text{Nfalse} + \text{Nmissing}} \tag{2}$$

4. RESULTS AND DISCUSSIONS

4.1. Assessment of Emotional States

The analyzed dataset revealed that the three spatial scenarios (static sea view, dynamic sea view, and non-sea view control group) influenced the participants psychological health differently. In determining time reference points, T0 represented the baseline condition prior to exposure to any virtual environment. T1 represented the moment subjects began the cognitive tests, while T2 represented the end of the cognitive tests. Figures. 2-7 show the participants' psychological state in the different scenarios (i.e., T0-1 and T1-2).

The Wilcoxon signed-ranks tests revealed that with the exclusion of two metrics (feeling upset and feeling worried), the remaining emotional metrics reached statistical significance in one or two groups. Hence the analysis focused exclusively on those emotional metrics that showed significant differences. Table 1 presents these directional effects visually, with the following key patterns emerging:

Calmness

Wilcoxon signed-ranks tests revealed a statistically significant decrease in self-reported calmness in the control group between timepoints T1 and T2 (Z=-2.68, *p<0.01). For the static and dynamic sea view groups, no difference in time points T1 and T2 were observed, although that of the dynamic sea view group reached statistical significance (Z = -2.23, *p* < 0.05). The statistically significant result could be attributed to the Wilcoxon test's sensitivity to consistent subtle shifts in individual responses, rather than a change in the group's overall central tendency. Thus, some individuals perceived their calmness levels differently at the end of the cognitive test thereby influencing the sensitivity to the ranked pairwise changes.

Tension

Wilcoxon signed-ranks tests indicated a statistically significant increase in self-reported tension between T1 and T2 for both the control group (Z = -2.750, *p* < 0.01) and the static sea view group (Z = -2.448, *p* < 0.05). No significant change in tension was found in the dynamic sea view group (Z = -0.73). A visual inspection of the box plot however indicates a positively skewed distribution of tension scores for the dynamic group between T1 and T2.

Relaxation

Whereas relaxation levels in the static sea view group remained unchanged, a decline was noted in the dynamic sea view group. This shift was however not statistically significant. On the other hand, a statistically significant decrease in self-reported relaxation was observed in the control group between T1 and T2 (Z = -3.27, *p* < 0.01).

Contentment

For the dynamic and static sea view groups, no statistically significant changes in contentment were found between T1 and T2 (Dynamic: Z = -0.63; Static: Z = -1.10). However, a statistically significant result was found for the control group (Z = -2.26, *p* < 0.05). Despite this statistical finding, the median contentment score for this group was identical at T1 and T2. Visual analysis of the box plots indicated a wider interquartile range and longer whiskers at T2 compared to T1, suggesting the statistically significant result could be due greater variability in responses of some participants.

Discussion of emotional state results

The analyzed dataset revealed that both static and dynamic sea views buffered against psychological decline across various metrics (ref. Fig, 2,3 and 4). This finding provides deeper insight into the protective, and not merely restorative, potential of nature exposure ([7],[28]). Thus, the presence of natural elements like sea views in confined underground spaces may lie in its capacity to prevent a decline rather than promote psychological health. While the treatment groups in most cases maintained baseline levels, the control group exhibited a significant increase in tension and decreased in calmness and relaxation. This pattern aligns well with Stress Reduction Theory ([7],[28]).

Furthermore, the results indicated that the static and dynamic sea view groups exhibited different psychological health effects. While both maintained pre-test calmness, the dynamic view also prevented a significant rise in tension. Although this effect did not reach statistical significance, a larger sample might provide conclusive evidence. On the other hand, the static sea view group exhibited a rise in tension, although, this increase was less pronounced than that observed in the control group. This suggests that static sea view provides a partial buffer compared to the control.

Further analysis, guided by Russell's [29] Circumplex Model of Affect, revealed the mechanics of this protective effect. According to Russell's [29] model, emotions like calmness (pleasant, low-arousal) and tension (unpleasant, high-arousal) are conceptual opposites. Thus, two opposite emotions cannot be felt at the same time. Consistent with this model, the dynamic sea view maintained stable levels of calmness and tension levels, whereas the control group exhibited a decline in calmness and an increase in tension. These patterns validate the effectiveness of dynamic sea views in sustaining calmness and reducing tension.

As summarized in Table 1, the results suggest that static and dynamic sea views offer protective benefits against negative emotional shifts, with dynamic exposure demonstrating marginally stronger effects. This underscores the nuanced role of natural stimuli in emotional regulation. However, due to the inconsistent effects of sea view exposure on restoration and positive emotions, we reject Hypothesis H1.

Figure 2. *Calmness*

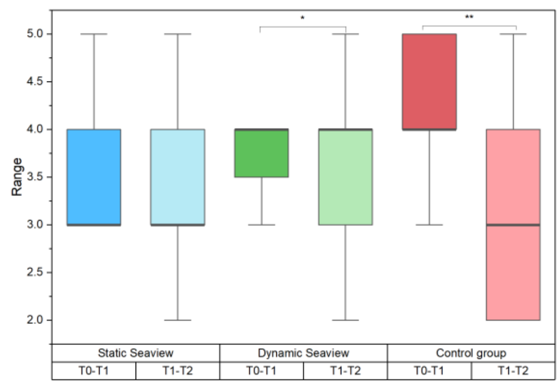


Figure 3. *Tension*

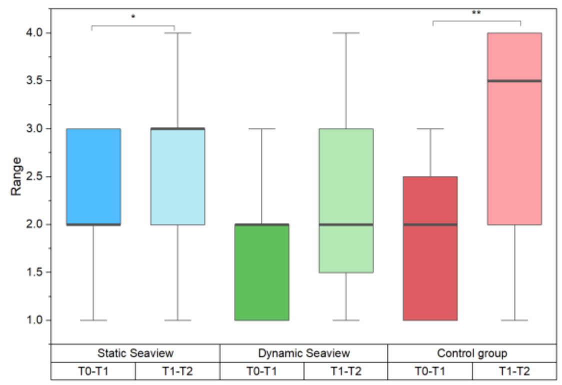


Figure 4. *Relaxation*

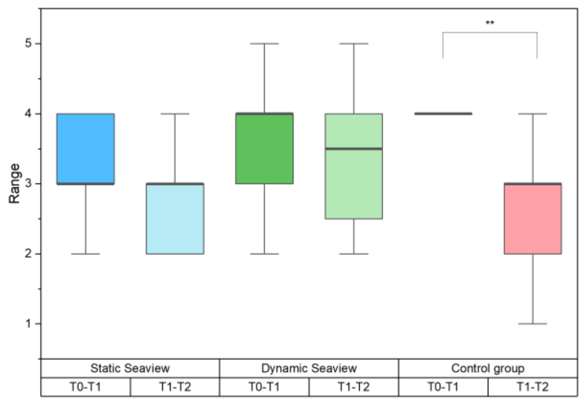
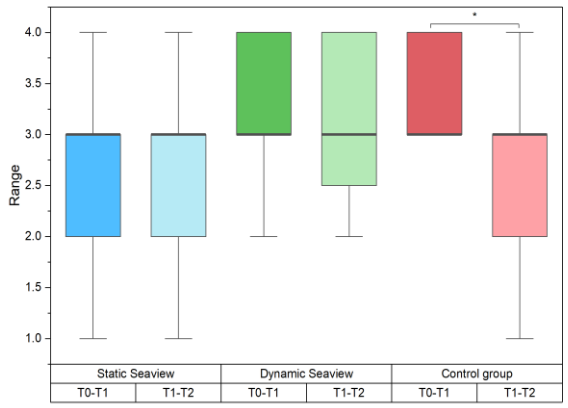


Figure 5. *Content*



*p <0.05, ****p<0.01** Statistically significant

Descriptive Emotional Impact Matrix

Emotional state	Static sea view	Dynamic sea view	Control group
Calmness	—	—	↓ **
Tension	↑*	—	↑**
Upset	—	—	↑
Relaxation	—	↓	↓**
Contentment	—	—	—
Worry	—	↓	—

Key: ↑ improvement, — no change, ↓ decrease, *p <0.05, **p<0.01 Statistically significant

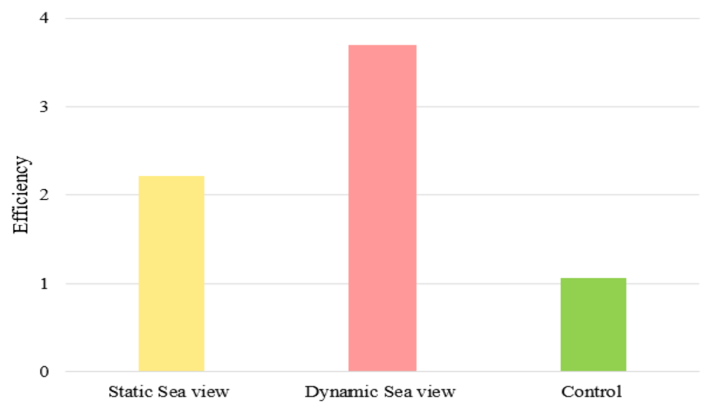
4.2. Cognitive Assessment: Task Performance

Participants' performance across four cognitive tasks (go/no-go, Stroop, n-back, and calculation) was analyzed using the inverse efficiency score, Kruskal-Wallis results and Mann-Whitney tests.

4.2.1. Inverse Efficiency Scores

Inverse Efficiency Scores (IES) were used to assess both accuracy and speed, with lower scores indicating better performance. The inverse efficiency analyses indicated that all scenes yielded distinct advantageous performance alongside some drawbacks. First, participants performed better on the n-back test (cognitive flexibility) under static sea view. For dynamic sea view, the participants performed better in the go/no-go task (response inhibition), n-back test (cognitive flexibility) and the calculation test (numerical processing). In the Control group, the participants performed better in the Stroop test (working memory). However, the Kruskal-Wallis test revealed that amongst all the tasks, only results from the Stroop test (working memory) reached statistical significance (p = 0.026).

Figure 6. *Stroop test**



(Lower IES = Better Performance), *p < 0.05 Statistically significant
Best performance Medium Least

4.2.2. Mann-Whitney with Bonferroni correction

Following the identification of a significant difference across the groups on the Stroop test, a post-hoc analysis using Mann-Whitney tests with a Bonferroni-adjusted alpha of 0.05/3 (0.0167) was conducted for pairwise comparisons to determine which groups differed. Three analyses were run; Static vs. Dynamic, Static vs. Control and Dynamic vs. Control. The test revealed statistically significant differences in Stroop's tests for static sea view versus dynamic sea view, and dynamic sea view versus the control group. Static sea views (IES= 2.22) were superior to dynamic sea views (IES=3.70) suggesting a suitability of static sea view for tasks requiring working memory. Also, the Stroop test in the non-sea view control environment (IES= 1.06) yielded superior performance compared with that taken in the dynamic sea view environment (IES=3.70). Notably, no significant difference was found between the Stroop test results of the static sea view and the control group. This suggests that both environments are effective although, the control group had a lower IES of 1.06 compared to the static sea view's 2.22. Therefore, Hypothesis 2 is not supported.

Mann-Whitney tests with Bonferroni correction

Pairwise Comparison	p-value
Static Sea view vs. Dynamic Sea view	0.011*
Static Sea view vs. Control	0.659
Dynamic Sea view vs. Control	0.012*

Bonferroni threshold ($p^* < .0167$).

5. CONCLUSION

This study examined the impact of simulated sea view scenarios (static, dynamic, control) on psychological enhancement and cognition of underground occupants via virtual reality. The results suggest that the presence of sea views (static and dynamic) may overall protect the emotional state of underground occupants compared to the control group, although further studies with larger samples are needed for further validation. Nevertheless, these preliminary results align with existing qualitative research highlighting the positive emotional impact of blue spaces [14,30]. Regarding cognitive performance, the Mann Whitney test with Bonferroni corrections indicated that both static sea view and non-sea view conditions (control group) were conducive for tasks involving working memory. This insight suggests that the integration of sea views in underground space may be dependent on the functional use of the space. Future studies should also examine how the functional use of space may mediate the psychological and cognitive effects of sea view elements. Also, researchers could replicate this study with larger samples and could utilize advanced neuroscience behavioral technologies like eye tracking to unveil the interaction of study participants with the visual elements within a virtual world. Furthermore, a qualitative approach could reveal whether the integration of blue spaces such as the dynamic blue space may inadvertently evoke a longing to be outside or frustration in participants confined to a constrained space. Previous research on coastal blue spaces has highlighted that, in certain cases, individuals with traumatic associations to coastal settings may not experience the intended restorative benefits, suggesting that personal history and context can significantly shape responses to blue space exposure [31].

In conclusion, this study demonstrates that integrating sea views into underground spaces can protect occupants from psychological deterioration, with dynamic exposures offering a marginally superior benefit. For architects and designers, this suggests that dynamic digital displays of nature could be a valuable strategy for windowless or underground spaces. Future research should investigate longer exposure times and incorporate physiological measures to further elucidate the mechanisms behind this protective effect.

6. ACKNOWLEDGMENT

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