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Utilizing the Visual Working Memory Paradigm Based on the "Global-First" Topological Approach to Optimize Psychiatric Disorders Diagnosis and Differentiation

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Abstract

Current diagnostic methods present major challenges in accurately diagnosing and differentiating psychiatric disorders. Due to the key role of visual working memory (VWM) for cross-diagnosis research on information processing deficits, we developed a new VWM paradigm based on the "global-first" topological visual perception theory to detect different psychiatric disorders among age groups. In young groups, significant differences in accuracy were observed between topological change and no-shape-change (all $p < .05$) in bipolar disorder (BD) and schizophrenia (SCZ) at different sequence values, and non-topological change was noted between the other two conditions when the size of the test graphic set in 3 in chronic-SCZ ($p_{3\text{-same}} = .000/p_{3\text{-non-topo}} = .003$). The accuracy of the no-shape-change in depression differed from that of topological change when the size of the test graphic was set at 4 ($p = .002$). In older adults, the accuracy of non-topological change is different from the other two conditions in depression when the size of the test graphic set is 3 ($p_{same} = .0314/p_{topo} = .0390$). Our new VWM paradigm demonstrates potential as a complementary diagnostic tool for psychiatric disorders, with preliminary evidence of sensitivity to disease-specific cognitive deficits. While classification accuracy [Area Under Curve (AUC) > 0.70–0.98] suggests clinical utility, further validation against traditional diagnostic instruments (e.g., DSM-5 criteria, symptom scales) is required to establish its role in clinical practice.

Keywords

psychiatric disorder, paradigm, visual working memory, global-first, topological visual perception, visual perception deficits

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Introduction

Psychiatric disorders not only result in significant physiological and psychological suffering but are also associated with substantial cognitive and functional impairments. The considerable phenomenological and pathophysiological overlap among psychiatric disorders emphasizes the need for cross-diagnostic research (Gaebel et al., 2020). Current guidelines for the treatment of psychiatric disorders predominantly depend on patient self-reports, collateral information from others, and clinician assessments. While these methods inform clinical decision-making, they frequently lead to misdiagnoses (Gaebel et al., 2020). Studies have demonstrated that relying solely on patient history yields an accuracy rate of just 62%, with the misdiagnosis rate for depression (DEP) reaching as high as 65.9% (Vermani *et al*., 2011). Although advances in imaging and neurobiology have provided significant breakthroughs, no testing method has yet replaced scale assessments as the "gold standard" for psychiatric diagnosis (Jiang et al., 2024; Maier et al., 2024). The absence of validated objective markers remains a major obstacle in the accurate diagnosis of mental health conditions.

Visual working memory (VWM) forms the basis of almost all high-level cognitive processes, enabling the storage, manipulation, and utilization of limited visual information (Baddeley, 2012). Impairments in working memory associated with mental illness significantly affect patients' cognitive function, self-monitoring, and attention, as widely reported in the literature (Butler et al., 2008; *Kurylo* et al., 2007). VWM is widely regarded as a central cognitive domain in cross-diagnostic research on information processing impairments (Insel et al., 2010). Quantifying the degree to which VWM capacity is constrained across psychiatric disorders is an important step toward screening and differentiation of disease.

The definition of the basic unit of VWM capacity remains a classic and unresolved problem, often conceptualized through the notion of a "chunk" (Miller, 1956). Although existing studies, utilized VWM paradigms involving color-shape/position tasks have achieved methodological progress for psychiatric diagnosis and classification across age groups (Barnes-Scheufler et al., 2021; Liu et al., 2021; Parra et al., 2009). The above researches exhibit critical limitations by primarily analyzing local geometric features (e.g., collinearity/parallelism) while neglecting holistic graphic variations. This reductionist approach generates ambiguous change patterns and obscure diagnostic distinctions. To address these limitations, developing a new foundational theoretical model of visual cognition and identifying appropriate psychological variables are essential for creating an effective auxiliary method for disease staging.

The traditional definition of perceptual objects, originating from Gestalt principles, emphasizes intuitive yet ambiguous characteristics. Chen's seminal topological property perception theory of "global-first" argues that perceptual objecthood fundamentally derives from topological invariance—holistic identity preserved through shape transformations (Chen, 1982, 2005). Geometric invariance, defined by topology, underpins perception and serves as a key psychological variable for assessing the cognitive impacts of brain diseases. The hypothesis provides a novel framework to study how topological attributes influence the perception of object damage in patients with psychiatric disorders within the context of VWM.

We integrated the concept of perceptual objects into VWM using the "global-first" topological property perception theory, approached from the perspective of topology. To achieve this, we designed a test sequence with three conditions (no-shape-change, non-topological change, and topological change) to identify patients with psychiatric disorders across different age groups (Barnes-Scheufler et al., 2021; Lin et al., 2020; Wei et al., 2019, 2021). Considering the differences in visual information processing abilities among patients of different age groups, we have set 2 different sizes of test graphics, namely 2 or 3 (older adult participants) and 3 or 4 (young participants), due to the past experiments (Wei et al., 2021).

This study introduces the novel application of the topological interference effect of VWM, based on the "global-first" topological visual perception theory, to explore differences across different age groups and types of psychiatric disorders. The objective of our study is to enhance the differentiation of psychiatric conditions across different age groups, support psychiatrists in accurately diagnosing and screening mental disorders, and inspire innovative approaches to developing diagnostic and treatment strategies.

Methods

Participants

This study was approved by the Ethics Committee of the First Affiliated Hospital of Anhui Medical University (No. 2017-43) and was performed in accordance with the Declaration of Helsinki of 1975, as revised in 2013. Written informed consent was obtained from all participants or their legal guardians.

Patients aged 55 to 85 years with emotional disorders—were recruited from the First Affiliated Hospital of Anhui Medical University. In contrast,

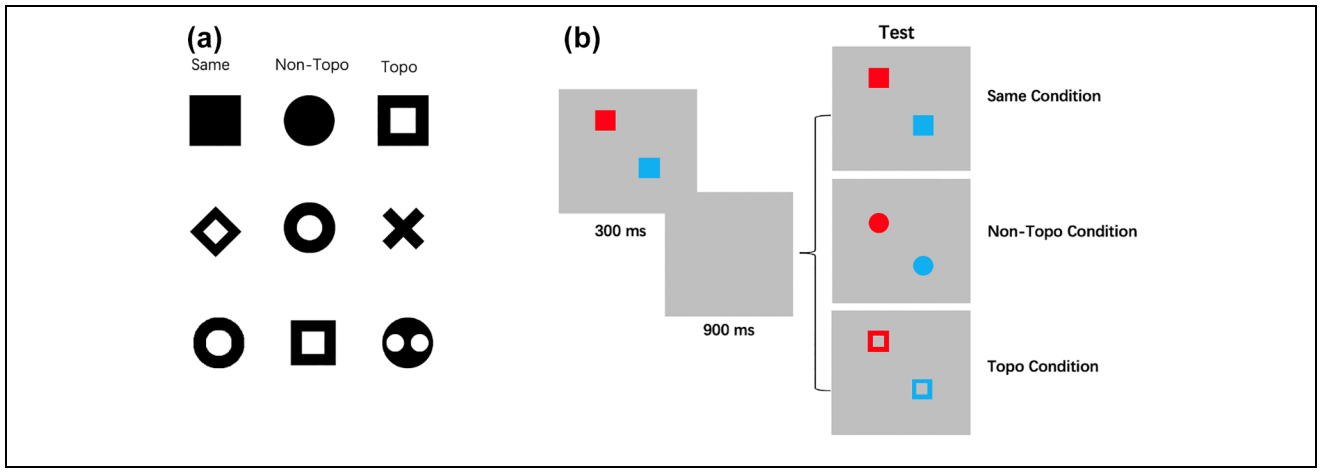

Figure 1. (a) Schematic Depiction of the Stimulus Groups for Experiments and (b) Schematic Description of Experiments, the No-Change Pattern Was Presented in the First Display, and the No-Shape-Change, the Non-Topological Change, or the Topological Change Pattern Was Presented in the Second Display Randomly.

patients aged 18 to 40 years with various psychotic conditions were recruited from the Center of Mental Health of Anhui Province and the First Affiliated Hospital of Anhui Medical University. Diagnoses of emotional and psychiatric diseases were made according to the International Classification of Diseases, Tenth Revision criteria by a consultant neurologist in conjunction with a multidisciplinary team prior to recruitment. In addition, 27 college students and 29 healthy older adult individuals were recruited as control participants.

Patients were excluded if they had a history of uncorrected vision problems (e.g., blindness, cataract, glaucoma, and retinal detachment), language production problems, neurological disorders (e.g., epilepsy and strokes), or substance use disorders. Older adults with severe cognitive impairment were also excluded from the study due to their condition. Different types of psychiatric patients of varying ages were only administered conventional medical therapy, and all complied with the medication regimen. No physical intervention was performed in any group of participants. In addition, no interventions were administered to the young or older adult control groups.

Materials

Stimuli were presented individually in a well-illuminated, acoustically insulated room on a 19-inch CRT monitor (refresh rate of 100 Hz) with a resolution of 1024×768 pixels, using MATLAB (MathWorks, Natick, MA, USA) 2013a with Psychophysics Toolbox extensions. All participants were seated approximately 70 cm from the computer screen.

Visual working memory task involved a $9.8° \times 7.3°$ region on a gray background, presented at a viewing distance of 70 cm for all stimuli. Each item, randomly positioned within the background of a given array, was separated from others by at least 2° (center-to-center). Seven highly discriminable colors were randomly selected for each square using RGB values: black (0, 0, 0), red (255, 0, 0), green (0, 255, 0), blue (0, 0, 255), yellow (255, 255, 0), and magenta (255, 0, 255), white (255, 255, 255). Each color, both in the memory array and test arrays, appeared no more than twice. Each stimulus subtended a visual angle of $0.95° \times 0.95°$. Three groups of stimulus patterns, including different topological transition patterns, were used in the experiment, as illustrated in Figure 1a. In addition, non-topological changes involving significant shape deformations and various local feature changes were carefully controlled throughout the experiment. Although they appeared quite different, these stimulus figures were topologically equivalent.

The experimental setup is illustrated in Figure 1b. Each trial began with a 500 ms fixation point to signal the start of the trial. Following this, a 300 ms sample display containing different numbers of colored items was presented, followed by a 900 ms blank interval. Finally, a test array was displayed on the screen until a response was provided. Memory items were set at 2 or 3 and 3 or 4, depending on the different age groups, with seven unique colors appearing only once per trial. Each condition consisted of 24 trials, resulting in a total of 144 trials per participant. Participants were instructed to explicitly determine if color changed between the memory and test arrays while ignoring changes in shape, as attending to shape changes could impair their performance. Responses were collected using two alternative forced-choice responses on a response keyboard at the end of each trial.

Table 1. Accuracy of Visual Working Memory in Young Patients With Psychiatric Disorders Under Various Conditions.

Condition		Size = 3			Size = 4		
		No-shape-change	Non-topo	Topo	No-shape-change	Non-topo	Topo
Group	YC	0.89 ± 0.07	0.90 ± 0.07	0.87 ± 0.07	0.90 ± 0.05	0.90 ± 0.08	0.88 ± 0.05
	DEP	0.89 ± 0.07	0.89 ± 0.08	0.87 ± 0.08	0.86 ± 0.08	0.84 ± 0.09	0.82 ± 0.08
	GAD	0.91 ± 0.07	0.88 ± 0.07	0.86 ± 0.07	0.85 ± 0.10	0.84 ± 0.09	0.83 ± 0.08
	BD	0.88 ± 0.06	0.89 ± 0.08	0.83 ± 0.10	0.82 ± 0.10	0.79 ± 0.10	0.74 ± 0.12
	First-episode SCZ	0.85 ± 0.09	0.85 ± 0.07	0.74 ± 0.13	0.82 ± 0.08	0.78 ± 0.09	0.65 ± 0.11
	Mild SCZ	0.85 ± 0.10	0.79 ± 0.11	0.71 ± 0.11	0.77 ± 0.11	0.73 ± 0.11	0.64 ± 0.11
	F	2.249	8.095	19.967	6.171	10.610	32.870
	p_c	0.37*	.000***	0.000***	0.000***	0.000***	0.000***
	ηp^2	.066	.190	.366	.151	.235	.487

Note. BD = bipolar disorder; DEP = depression; GAD = general anxiety disorder; SCZ = schizophrenia; YC = young control. Data is expressed in Mean ± SD.

[c]Bonferroni is used for multiple comparative corrections.

*$p < .05$. ***$p < .001$.

Statistical Analysis

Repeated-measures ANOVA was used to analyze the accuracy in the VWM experiments under two memory load conditions: item sizes were set at 2 or 3 (elder group) and 3 or 4 (young group). These conditions involved three types of VWM stimuli (no-shape-change, non-topological change, and topological change) across different groups.

All data were analyzed using SPSS software (version 22.0; Statistical Package for the Social Sciences; IBM Corp., Armonk, NY, USA). Graphs were plotted using GraphPad Prism 7 software (GraphPad Software, Inc., San Diego, CA, USA). All statistical tests were two-tailed, and a *p*-value of 0.05 was considered statistically significant.

Results

Test 1. VWM Task Results of Young Patients With Psychiatric Disorders

A total of 180 participants (including 34 participants with depression [DEP], 28 participants with generalized anxiety disorder [GAD], 27 participants with first-episode SCZ, 32 participants with chronic SCZ with a course of less than 10 years, 32 participants with BD, and 27 young controls [YCs]) were obtained during this part of the test, with the accuracy results for each group detailed in Table 1 and Figure 2. Analysis of the YC group revealed no statistically significant differences in accuracy within the group under the current experimental conditions ($p > .05$).

When the size of test graphics is set to 3, a significant main effect of the shape-change condition was observed in the BD group ($F = 8.463$, $p = .007$, partial $\eta^2 = .214$). The accuracy in the topological-change condition was significantly lower than that in the other two conditions ($p_{same} = .007/p_{non\text{-}topo} = .005$). However, no significant differences were found in accuracy between the non-topological-change and no-shape-change condition ($p > .05$). Similar results were also observed in the group of first-episode SCZ ($F = 12.112$, $p < .001$, partial $\eta^2 = .318$). The accuracy in the topological-change condition was significantly lower than that in the other two conditions under graphic size at 3 ($p_{same} = .001/p_{non\text{-}topo} = .001$), whereas no significant differences were found in accuracy between the non-topological change and no-shape-change condition ($p > .05$). The main effect of shape change was also evident in the chronic SCZ group ($F = 27.511$, $p < .001$, partial $\eta^2 = .478$). The accuracy of topological change was lower than both non-topological change and no-shape-change conditions ($p_{same} < .001/p_{non\text{-}topo} < .001$), whereas a significant difference was also observed in accuracy between non-topological changes and no-shape-change ($p_{same/non\text{-}topo} = .002$). No significant intra-group differences were found in other groups ($p > .05$).

When the number of graphics is set to 4, the main effect of the shape-change condition was also significant in the BD group ($F = 6.244$, $p = .003$, partial $\eta^2 = .168$). Further study revealed the accuracy in the topological-change condition was significantly lower than that in the no-shape-change ($p_{same} = .008$), whereas a differential trend between non-topological change and topological change can be observed ($p_{non\text{-}topo} = .111$). A significant main effect was also observed in the first-episode SCZ group ($F = 37.298$, $p < .001$, partial $\eta^2 = .589$). Significant differences were observed between the accuracy in topological change and that in the other two conditions ($p_{same} < .001 / p_{non\text{-}topo} < .001$),

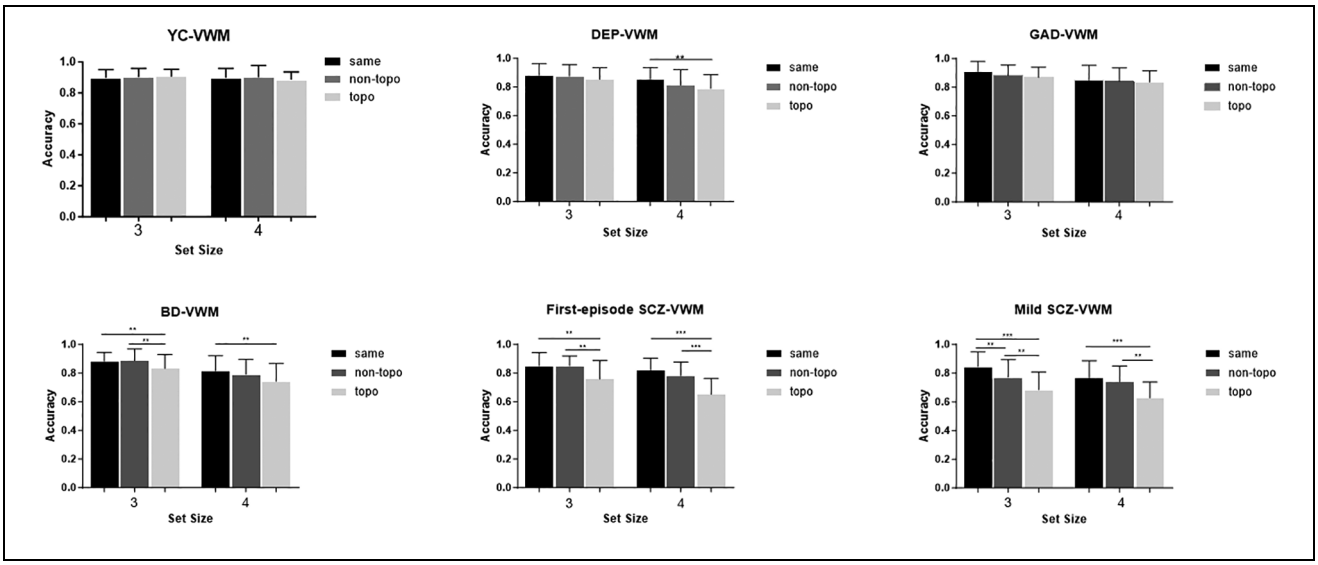

Figure 2. The Differences of VWM Levels in Different Size Conditions Compared to Different Groups of Young Participants With Psychiatric Disorders.
*$p < .05$. **$p < .01$.

whereas no significant differences were found in accuracy between the non-topological change and no-shape-change condition ($p > .05$). Evident main effect of shape change was also observed in the chronic SCZ group ($F = 23.988$, $p < .001$, partial $\eta_4^2 = .444$). Further analysis revealed significant differences in accuracy under the topological-change condition in the chronic SCZ group ($p_{same} < .001/p_{non\text{-}topo} = .005$), whereas no significant difference was found in accuracy between non-topological changes and no-shape changes ($p > .05$). Within the DEP group, a significant difference in accuracy was found between the topology change condition and the condition of the unchanged graphics for the size is 4 ($p = .002$). Conversely, the GAD group showed no statistically significant differences under the no-shape-change conditions ($p > .05$).

As detailed in Table 1, differences among various groups were analyzed, revealing a significant shape-change*group interaction effect when the size of test graphics is set to 3 ($F(5, 173) = 16.362$, $p_3 < .05$, partial $\eta^2 = .321$). Post hoc analyses showed significant differences between the two groups of SCZ and the other groups of participants (all $p < .05$). Further analysis reveals that the accuracy of participants with chronic SCZ on tasks involving no-shape-change graphics was lower than that of participants with GAD ($p = .025$). The accuracy of participants with chronic SCZ was significantly lower than that of other groups on non-topological change ($p < .05$), while the accuracy among the other groups showed no significant differences ($p > .05$). Conversely, under conditions involving topological change, the accuracy of participants with SCZ in both groups significantly differed from that of all other groups (all $p < .05$).

When the number of test graphics is set to 4, repeated-measures analysis of variance was used to compare the accuracy of different change conditions under the same size of memories among groups, and the interaction effect was significant ($F(5, 173) = 25.870$, $p < .001$, partial $\eta^2 = .428$). Post hoc analyses revealed that the accuracy of the two groups of SCZ was different from DEP, GAD, and YC groups, whereas only the chronic SCZ group demonstrated a significant difference with BD. The BD group also exhibited significant inter-group differences with DEP, GAD, and YC. Further study found that the accuracy of chronic SCZ was also significantly lower than YC, DEP, and GAD in no-shape-change condition (all $p = .000$); Under the condition of non-topological change, the accuracy of the YC group was significantly higher than that of participants with mental disorders in each group ($p < .05$), and the accuracy of GAD was also significantly higher than chronic SCZ ($p = .000$); In topological-change condition, the accuracy of chronic SCZ group was significantly lower than that of all the test groups except the first-episode SCZ (all $p < .05$), and the correct rate of the first-episode SCZ was significantly lower than that of BD ($p = .007$), DEP ($p = .000$), GAD ($p = .000$), and YC ($p = .000$). The accuracy of YC is also different from that of DEP ($p = .006$) and BD ($p = .000$).

As shown in Figure 3, we based our paradigm testing on the different set sizes of different groups. The AUC

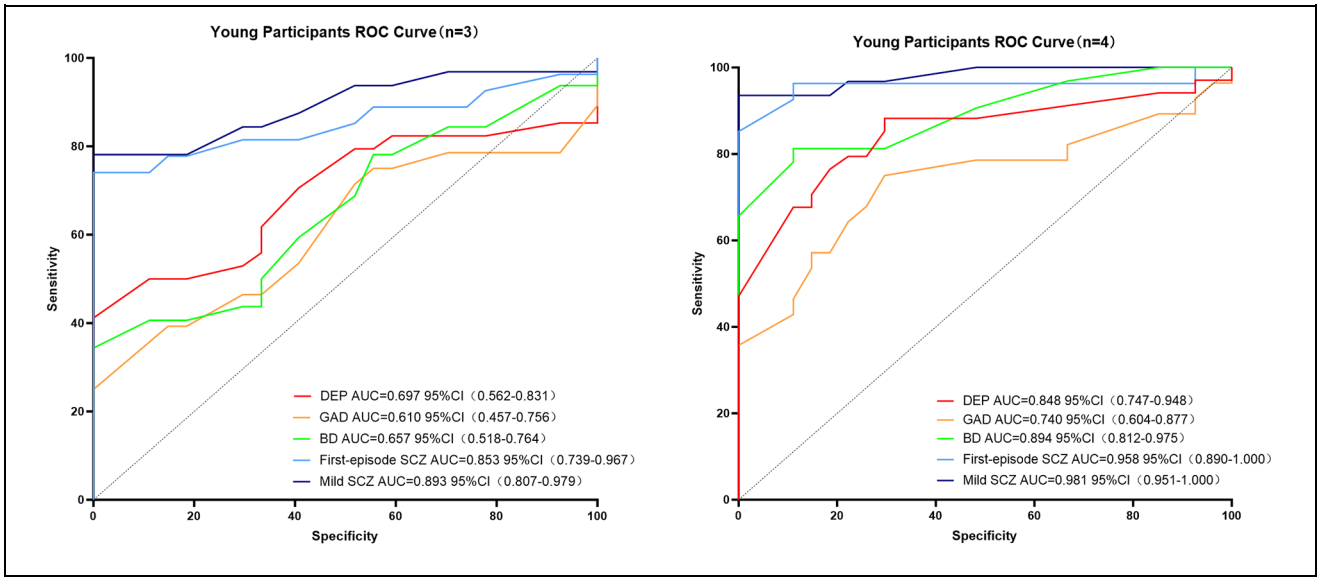

Figure 3. Receiver operating characteristic (ROC) Curve Analysis for the Psychiatric Disorders Evaluation of VWM Paradigm in Young Participants When the Size of Graphics is 3 and the Size of Graphics is 4.
Note. VWM = visual working memory.

Table 2. The Accuracy of Visual Working Memory in Older Adult Patients With Emotional Disorders Under Various Conditions.

Condition		Size = 2			Size = 3		
		No-shape-change	Non-topo	Topo	No-shape-change	Non-topo	Topo
Group	HE	0.93 ± 0.07	0.89 ± 0.11	0.86 ± 0.09	0.82 ± 0.12	0.79 ± 0.11	0.76 ± 0.11
	Elder-DEP	0.91 ± 0.06	0.87 ± 0.08	0.82 ± 0.08	0.84 ± 0.07	0.79 ± 0.07	0.74 ± 0.07
	Elder-GAD	0.91 ± 0.07	0.88 ± 0.07	0.82 ± 0.14	0.83 ± 0.09	0.80 ± 0.09	0.76 ± 0.10
	MCI	0.89 ± 0.08	0.87 ± 0.08	0.84 ± 0.11	0.77 ± 0.10	0.73 ± 0.09	0.70 ± 0.09
	F	1.084	0.332	0.966	3.405	3.863	2.964
	p_c	.359	.803	.411	.020*	0.11*	0.35*
	ηp^2	.027	.009	.024	.081	.091	.071

Note. HE = healthy older adults; MCI = mild cognitive impairment; DEP = depression; GAD = grand anxiety disorder; Data is expressed in Mean ± SD.
[c]Bonferroni is used for multiple comparative corrections.
*$p < .05$.

of first-episode SCZ (AUC: 0.853, 95% CI [0.739, 0.967]) and mild SCZ (AUC: 0.893, [0.807, 0.979]) on the test set ranged over 0.70 when the size of test graphics is 3. When the set size is 4, the AUC of all groups set ranged over 0.70, with both the mild SCZ group (AUC: 0.981, [0.951, 1.000]) and first-episode SCZ (AUC: 0.958, [0.890, 1.000]) emerging over 0.95. The performance of the BD also persistently ranked over 0.85 (AUC: 0.894, [0.812, 0.975]).

Test 2. VWM Task Results of Older Adult Participants With Psychiatric Disorders

A total of 120 participants (including 25 participants with DEP, 24 older adults with GAD, 42 participants with mild cognitive impairment [MCI], and 29 healthy older adults [HE]) were collected for this test. The accuracy results for each group are summarized in Table 2 and illustrated in Figure 4.

When the size of test graphics is set to 2, significant main effects can be observed in the HE ($F = 16.963$, $p = .001$, partial $\eta^2 = .377$), older adults DEP ($F = 12.640$, $p = .001$, partial $\eta^2 = .345$), older adults GAD ($F = 9.004$, $p = .001$, partial $\eta^2 = .281$), and MCI group ($F = 13.002$, $p = .001$, partial $\eta^2 = .241$). Post hoc comparisons revealed a significant difference in accuracy between topological change and no-shape-change was observed across groups (all $p < .05$), whereas the trend of difference in accuracy toward non-topological change and topological change in MCI group ($p_{\text{non-topo}} = .059$) and DEP group ($p_{\text{non-topo}} = .041$).

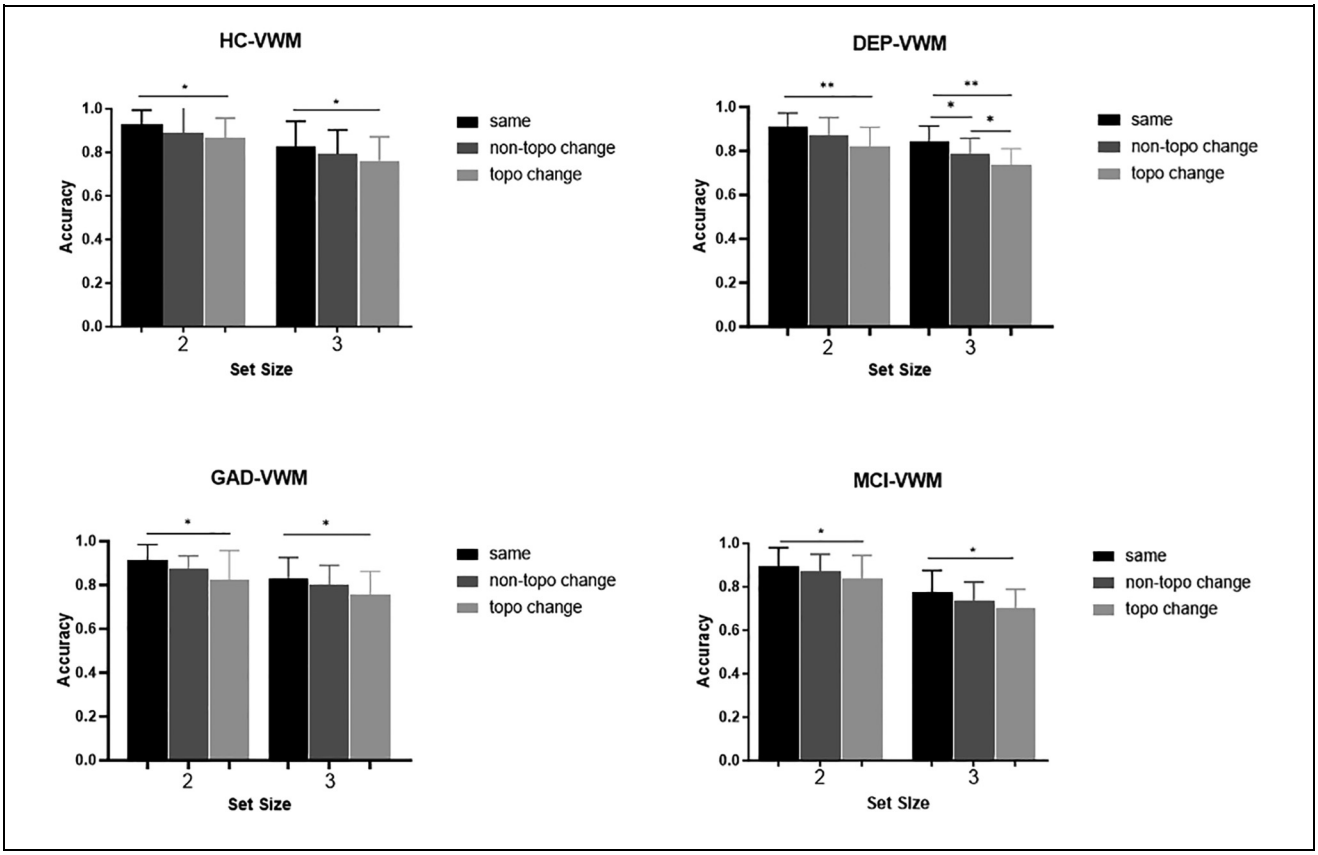

Figure 4. The Differences of VWM Levels in Different Size Conditions Compared to Different Groups of Older Adults With Emotional Impairment,
*$p < .05$. **$p < .01$.

The main effect of shape change was significant in each group for the size is 3 ($F = 6.880$, $p < .001$, partial $\eta^2 = .151$). Post hoc comparisons revealed significant intra-group effects in the HE ($F = 16.963$, $p = .024$, partial $\eta^2 = .125$), older adults DEP ($F = 15.797$, $p < .001$, partial $\eta^2 = .397$), older adults GAD ($F = 3.727$, $p = .032$, partial $\eta^2 = 0.397$), and MCI group ($F = 7.369$, $p = .001$, partial $\eta^2 = .152$). A significant difference in accuracy between topological change and no-shape-change was observed across groups (all $p < .05$). In the older adults DEP group, a significant difference in accuracy under the non-topological change condition was found compared to both the no-shape-change and topological-change conditions ($p_{same} = .0314/p_{topo} = .0390$). In addition, the MCI group exhibited a trend of difference in accuracy toward non-topological change and topological change ($p_2 = .0502/p_3 = .1188$).

When the number of test graphics is set to 3, significant differences among the four groups were observed in pairwise group comparisons ($F(3, 116) = 6.880$, $p < .001$, partial $\eta^2 = .151$). Post hoc analyses showed significant differences between the MCI and the other groups of older participants (all $p < .05$), whereas no significant differences were observed between the other groups of older participants. In contrast, no significant differences were found between the groups for the size is 2.

We additionally plotted the AUC graphs to utilize model prediction data constituted by variables from an older adult group, which is illustrated in Figure 5. We additionally plotted the AUC graphs to utilize model prediction data constituted by variables from the older adult group. It is noticed that the AUC of MCI on the internal test set ranged over 0.70 when the size of test graphics is 3 (AUC: 0.706, 95% CI [0.577, 0.836]), whereas other groups set ranged below 0.70 under various size conditions. No AUC in groups was found over 0.70 for the size of test graphics is 2.

Discussion

Our study advances the conventional VWM change-detection paradigm by rigorously controlling the influence of graph properties in defining perceptual objects. We adopted a new VWM paradigm inspired by the

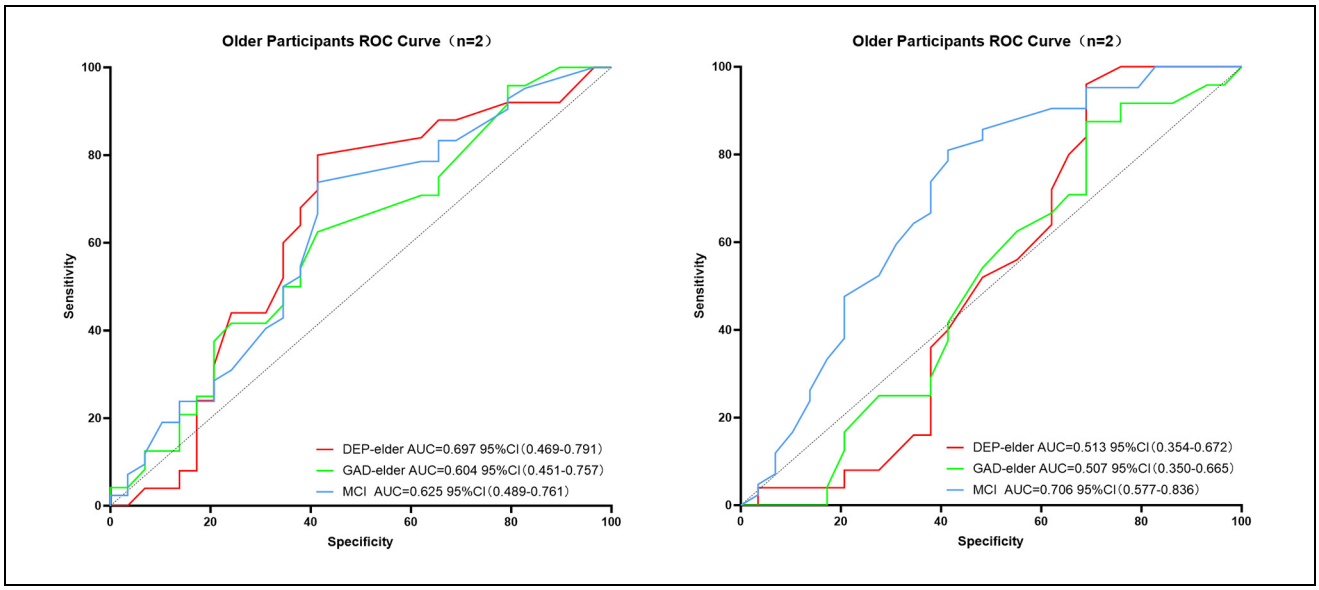

Figure 5. ROC Curve Analysis for the Older Adults Evaluation of VWM Paradigm in Different Groups When the Size of Graphics is 2 and the Size of Graphics is 3.

"global-first" topological visual perception theory to evaluate VWM performance across psychiatric disorders and age groups. This approach aimed to enhance the accuracy of differential diagnoses for psychiatric conditions across varying age demographics. The main findings of the study include: (a) A pronounced topological interference effect was observed between groups with SCZ and BD. (b) Older adults with DEP exhibited heightened sensitivity to non-topological changes, which will be elaborated upon separately.

Participants With BD and SCZ Have Greater Interference of Topological-Change

This is the first study to evaluate VWM abilities across a range of psychiatric disorders using a paradigm based on the "global-first" topological visual perception theory. In this phase of the research, stimuli were presented for 0.3 s, with either three or four stimuli shown, to investigate how these parameters influence VWM performance in mental disorders.

Our study found a statistically significant difference in accuracy levels for BD under topological changes compared to both no-shape-change and non-topological conditions. However, no significant difference in accuracy was observed between non-topological change and no-shape-change conditions when the size of the presented stimuli is 3 or 4, aligning with our hypothesis. These findings were consistent across both first-episode and chronic SCZ groups. Building on our previous study, we propose that changes in topological properties cause object separation, disrupting the correspondence between objects and their VWM representations. This explains the decline in accuracy under the topological conditions of the three groups of subjects mentioned above (Bian et al., 2024; Zhou et al., 2010). Notably, the accuracy of the topological changes in BD and SCZ under the current set conditions was significantly lower than that of the YC group. Prolonging the image presentation time revealed a significant repetition advantage, further emphasizing the markedly reduced memory capacity in the BD and SCZ groups relative to the YC group. These results align with previous studies on working memory dysfunction in these two diseases, which also reported substantial reductions in memory capacity in these participants with BD compared to YCs (Barch & Smith, 2008).

Our study revealed that topological interference significantly impacted BD and SCZ, particularly when the visual display set of 4, where it was notably stronger in both the first-episode and chronic SCZ compared to BD. These findings are consistent with previous studies on working memory dysfunction in these disorders, which demonstrate greater working memory impairment in SCZ than in BD (Barch & Sheffield, 2014; Hamilton et al., 2009; Hill et al., 2013). This suggests that participants with SCZ may experience more pronounced topological visual impairment than those with BD, offering potential insight into differentiating between BD and SCZ in clinical diagnoses.

Chronic SCZ may also exhibit differences in the accuracy of non-topological and topological conditions, although this pattern is subtle. To date, no studies have directly explained this phenomenon. We believe that this

may be related to the limited number of trials included in our analysis. However, it is plausible that participants with chronic SCZ experience pronounced deficits in local geometric visual perception due to ongoing brain damage. These impairments could hinder their ability to discern non-topological changes. However, further investigation is required to confirm the hypotheses.

We artificially reduced the number of stimulus graphics and the time of stimulus presentation, finding no significant difference in the accuracy of the YC group across various conditions. This outcome aligned with our hypothesis that extending the stimulus presentation time would enhance YC working memory processing during the presentation period, thereby effectively distinguishing healthy participants from those with BD and SCZ. Similar patterns were observed in the DEP and GAD groups. We believe that the above results are due to the relative reduction in the number of stimulus graphics and the significant increase between stimulus presentations, which led to the stimulus directly activating semantic memory from perception without intermediate processing in VWM (Della Sala et al., 2010).

Older Adults Participants With DEP Have Greater Interference of Non-Topological-Change

Our previous research indicates that when items in the second storage array diverge from the topology attribute of the first storage array, the resulting object with an altered topology replaces the original, disrupting object continuity and diminishing the repetition benefit effect(Wei et al., 2021, 2024). Conversely, moderate changes to the second storage array's characteristics did not significantly impact the repetition benefit effect on color memory in healthy young adults (Wei et al., 2019). However, we found that the memory tolerance of older adult participants was significantly reduced, with a significant repetition dominance effect observed only when the image presentation time was substantially prolonged. These findings align with the results from our previous study (Wei et al., 2021).

In contrast, when the second storage array exhibited moderate feature changes, the color memory of the healthy older adult participants was also influenced, although this effect was less pronounced (Wei et al., 2019). This finding aligns with our previous study. In addition, another study conducted by our team suggests that while object continuity persists despite significant non-topological changes, older adult individuals experience difficulty in recognizing changes. This limitation is due to their perceptual deficits in local geometric visual perception, which explains why non-topological changes disrupt the repeated dominance effect in this population (Meng et al., 2019).

The accuracy of older adults in DEP with non-topological changes in the test sequence was statistically significant when compared to their accuracy under the no-shape-change condition. In addition, a distinct difference was observed in the accuracy rates between topological and non-topological changes. This discrepancy may be attributed to pronounced perceptual deficits in local geometric visual perception, which persist even when object continuity remains unchanged, making it difficult for DEP to identify non-topological change patterns (Meng et al., 2019). Interestingly, the accuracy of older adults with DEP under the condition of an unchanged graph with no-shape change was comparable to that of healthy older adult individuals and older adult patients with GAD. However, statistical differences were noted in the correct rate of non-topological changes of patients with DEP compared to their accuracy under no-shape-change and topological change conditions. In contrast, no significant differences were found between older adult healthy participants and participants with GAD across these conditions. While the small sample size may have influenced these findings to some extent, it appears that older adults in the DEP group experience greater topological interference effects than the other two groups. This finding could have positive implications for screening for DEP among older adults in the community.

We observed similar results in patients with MCI and older adult patients with DEP. Although the difference in the trend between topological and non-topological interference in the MCI group was not evident, we do not believe that older adults with DEP are more influenced by topological changes. On the one hand, considering that our relatively limited trials have a certain impact on the final accuracy, some studies have found that there is a certain working memory compensation in MCI. These studies indicate no significant difference in bilateral prefrontal cortex activation between participants with MCI and HE under low task loads. However, neural compensation in the form of overactivation becomes evident in MCI with a moderate task load (Lin et al., 2020; Ung et al., 2020). Given the observed significant group differences between DEP and MCI, it is necessary to conduct further trials to establish whether there is a difference in topological interference effects between the two groups.

This study has some limitations. We preselected different subgroups based on normal cognition or existing diagnoses, which may not fully reflect the standard clinical decision-making or community screening process faced by professional psychiatrists and community doctors. In addition, only 144 trials of the paradigm were used to detect patients, resulting in a relatively small sample size for each condition. The accuracy and errors

of individual trials may have affected the final result. A key limitation of the current study is its exclusive focus on VWM without parallel investigation of verbal working memory. While our paradigm demonstrates diagnostic utility for psychiatric disorders, the absence of comparative data on verbal working memory restricts our ability to fully characterize domain-general cognitive deficits. This omission may limit the generalizability of our findings, as verbal working memory impairments are well-documented in conditions such as SCZ and depression. Future studies should incorporate dual-task paradigms to disentangle modality-specific versus global working memory deficits.

Conclusion

Our model captures the differences in VWM expression and changes caused by different psychiatric disorders across age groups. While the topological paradigm shows promise as an objective biomarker for cognitive deficits, its clinical adoption requires further validation in multicenter trials with direct comparisons to gold-standard diagnostic methods (e.g., structured clinical interviews and neuropsychological batteries). If replicated in broader cohorts, this approach could complement existing tools to enhance diagnostic precision across age groups.

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