Schizophrenia

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Unexpected higher resilience to distraction during visual working memory in schizophrenia

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This study investigates the computational mechanisms underlying visual working memory (VWM) deficits in schizophrenia (SZ) under distraction. Combining 60 SZ patients and 61 demographically matched healthy controls (HC), we employed a modified delayed-estimation task with varying set sizes (1/3) and distractor numbers (0/2). Results showed universally impaired VWM performance in SZ across conditions, though distraction did not disproportionately worsen their deficits. Using the variable precision model, we found that distractors significantly increased resource allocation variability (reflecting heterogeneity in attentional resource distribution) in HC, but not in SZ. This counterintuitive pattern suggests SZ patients' VWM processes are less perturbed by external distractions, potentially linked to reduced flexibility in cognitive control. Our findings highlight the nonlinear interplay of multiple cognitive dysfunctions in SZ, where their combined effects exceed simple additive models, offering new insights into the mechanistic complexity of cognitive deficits in the disorder.

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INTRODUCTION

Visual working memory (VWM) is a central cognitive ability that allows for the temporary storage and manipulation of information[1,2]. VWM deficits have been widely documented in people with schizophrenia (SZ), and are proposed to underlie a range of cognitive impairments in SZ[3–7]. Importantly, VWM is associated with different symptom dimensions in SZ and may act as a predictive factor of functional outcomes and disease development[8,9], while underlying mechanisms remain unclear. Existing theories suggest that impaired sensory processing at the encoding stage of working memory is one of the candidate mechanisms of behavioral deficits[10]. Indeed, our sensory systems are often confronted with an immense amount of information that far exceeds our processing capacity[11–13]. This capacity limitation requires a selection process that prioritizes task-relevant information and filters out task-irrelevant information to optimize performance. This is particularly important when salient distractors are present and interfere with target processing. Resistance to distraction (RTD) has been shown to be associated with several other cognitive functions, including working memory[14], endogenous and exogenous attention[15], perceptual and value-based decision making[16], response inhibition[17], and cognitive control[18]. In addition, atypically poor resilience to distraction (i.e., distractability) has been found in several psychiatric disorders, including ADHD[19], autism[20], and depression[21].

Atypical distractibility has long been hypothesized to be one of the major cognitive deficits in SZ[22–26]. A standard approach to studying RTD is to introduce distractors into some cue-based attention tasks. However, the existing empirical results are highly controversial[27,28]. One possibility is that the cues and instructions in these tasks were simple and 100% valid. Simple cues make tasks easier and require less attentional control. In contrast, when tested on highly demanding attentional tasks, SZ show deficits in suppressing salient distractors[29,30]. These findings suggest that distractibility deficits are present in SZ and may be more pronounced in the presence of highly salient distractors.

Recent advances in the basic science of VWM indicate that behavioral performance on VWM tasks is mediated by multiple factors, and the concept "precision" has been emphasized in various computational models[31,32]. With the classical mixture model decomposing VWM factors into capacity and precision, researchers have shown reduced memory capacity but intact memory precision in SZ compared to healthy controls (HC)[33]. However, contradictory evidence also persists[34]. By using the variable precision (VP) model, we have previously found that poorer VWM performance in SZ is associated with larger resource allocation, beyond the decreased-capacity theory[35]. The VP model[36] assumes that VWM resources can be allocated as a continuous variable. And it estimates three aspects of VWM: the amount of resources at different target size levels, the variability of resources allocated across items, and the variability induced by behavioral choice. It has been shown that the VP model can best describe the VWM performance in SZ[35]. Moreover, from a computational perspective, distractors may reduce memory capacity and/or impair memory precision. Unfortunately, few studies have attempted to combine VWM deficits and distractibility and examine their interaction effect. Two unanswered questions remain: (1) whether SZ have distractibility deficits in VWM; (2) if so, which VWM component(s) are affected by such distractibility deficits.

In this study, we aimed to combine the classical distraction and VWM experimental paradigm to investigate both functions simultaneously in SZ. To this end, we modified a standard VWM task—the color delay-estimation task. In the color delay-estimation task, subjects must remember the colors of all

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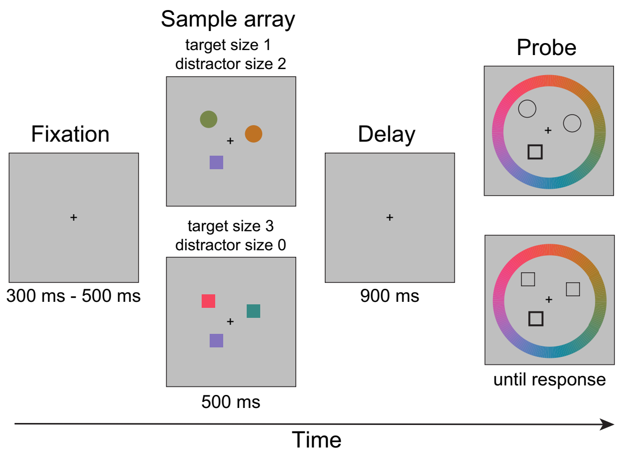

Fig. 1 The modified color delay-estimation task. This figure illustrates two example trials from the experiment. In the experiment, each trial begins with a fixation point presented for 300–500 ms (with a step of 50 ms). In the example array, one or three targets (squares in this example), together with zero or two distractors (circles, a 2 × 2 design), are presented on the screen for 500 ms. Subjects were instructed to remember the colors of one of the shapes in the sample array. After a 900-ms delay, the outlines of the items would appear in their original location, and one of the target shapes would be cued. Subjects are asked to recall and report the color of the target by clicking on the colored wheel using a computer mouse.

presented items and reproduce the color of a cued item after a short delay. In our modified version (Fig. 1), subjects were instructed to remember only a subset of the presented items (i.e., targets) and to ignore other items (i.e., distractors). We manipulated target size and distractor size independently to control for VWM load and distraction level. In addition, we used the VP model[36] to explicitly quantify the distraction effect during the computational process of VWM. If individuals with SZ experience greater difficulty with distractibility, this deficit may lead to two potential outcomes. First, as demonstrated in our previous study[35], atypical VWM processing in SZ is primarily characterized by increased variability in the allocation of memory resources. We hypothesize that the introduction of distractors may further amplify this variability in resource allocation. Second, a long-standing hypothesis posits that the presence of distractors may directly reduce the amount of resources allocated to target items[37,38]. We further hypothesize that the addition of distractors will reduce memory resources, as reflected by resource-related parameters in the VP model.

METHODS

Ethics statement

All experimental protocols were approved by the institutional review board of East China Normal University. All research was conducted in accordance with relevant guidelines and regulations. Informed written consent was obtained from all participants.

Subjects

Sixty clinically stable SZ and 61 HC were recruited for this study. All SZ met the DSM-IV criteria for SZ and were receiving antipsychotic medication (2 first-generation, 43 second-generation, and 15 both). The Brief Psychiatric Rating Scale, the Scale for the Assessment of Negative Symptoms, and the Scale for the Assessment of Positive Symptoms were used to assess symptom severity. HC were recruited through advertisements. All HC were screened to exclude current diagnosis of Axis 1 or 2 disorders, substance dependence or abuse, or family history of psychosis. All subjects are right-handed and have normal vision and color vision. Two groups of subjects were matched for age and educational level. Demographic and clinical information is identical to our previous study[35].

Stimuli and task

The experiment was adapted from previous studies investigating VWM precision and distractibility[39,40], including those focused on SZ[28,33]. Most behavioral models of VWM precision are based on variants of this delay-estimation task[31]. Two common manipulations—target and distractor numbers—are used to assess the effects of memory load and distraction level on VWM performance.

The experiment was conducted on the platform of MATLAB 8.1 and Psychtoolbox 3. Subjects were seated at a distance of 50 cm from an LCD monitor. Each trial began with a fixation cross presented at the center of the screen for a randomly selected time [300, 350, 400, 450, 500 ms]. Then, a set of colored shapes (squares and/or circles) was presented on the screen for 500 ms within an invisible circle with a radius of 4°. Four conditions were used in this experiment: target size 1/3 × distractor size 0/2. Half of the subjects were instructed before the start of the experiment to remember colored squares (i.e., targets) and to ignore colored circles (i.e., distractors) for the whole experiment and vice versa. Colored squares were 1.5° × 1.5° in visual angle and colored circles were 1.5° in visual angle in diameter. The item array was shown for 500 ms, followed by a 900 ms delay period with only the fixation cross on the screen for memory retention. Then, an equal number of outlined shapes were presented at the same locations as the items shown in the item array. One of the outlined shapes was bolded, indicating that the target item at that cued location was to be recalled. Meanwhile, a randomly rotated color wheel with inner and outer radii of 7.8° and 9.8°, respectively, was displayed on the screen. Subjects were instructed to recall and report the color of the bolded item by clicking on the color wheel with a computer mouse. Accurate recall of the color was desired, and the response time was unlimited. The 180 colors used in this experiment were selected from a circle (centered at $L = 70$, $a = 20$, $b = 38$, with a radius of 60) derived from the CIE Lab color space. The center of the circle was chosen to maximize its radius and, consequently, the discriminability of the colors. Each color on this color wheel is indexed by a value between $[0, 2\pi]$. All participants completed a block of 80 trials for each condition, and the order of conditions was counterbalanced across subjects. This task was originally proposed by Dr. Weiwei Zhang and Dr. Steve Luck in their seminal paper[32]. With over 1961 citations, this paradigm is widely regarded as a classical VWM task, and nearly all behavioral computational models of VWM are based on it.

Data analysis

The data with no distractor has been presented in our previous study[35]. The comprehensive analysis of the distraction effect in this paper is new.

Variable precision model. The VP model was initially proposed by van den Berg et al.[36,41]. The VP model proposes that the mean VWM resource levels decline as the target size assigned to individual items is not only continuous but also variable across items and trials. This variability in resource assignment results in trial-by-trial recall errors. Moreover, the VP model also explicitly isolated the variability of behavior choice (e.g., motor or decision noise), which was ignored by most previous models in VWM.

For each item, the memory resources recruited J is defined as Fisher information $J = \kappa \frac{I_1(\kappa)}{I_0(\kappa)}$, where I_0 and I_1 are modified Bessel functions of the first kind of order 0 and 1, respectively, with the

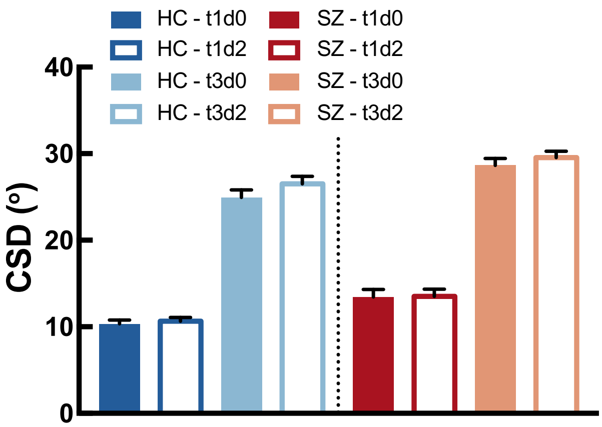

Fig. 2 General memory load and distraction effects in both groups. A higher CSD indicates poorer performance. Increasing memory load and the distractor level worsen performance in both groups. Also, SZ generally showed worse VWM performance than HC. Furthermore, distractors only affect VWM performance at high memory load (target size = 3). Error bars represent ±SEM across subjects. The letter "t" in the legend indicates "target size" and "d" indicates "distractor size". For example, "t1d0" indicates target size = 1 and distractor size = 0.

concentration parameter K. In the VP model, because J varies across items and trials, it is further assumed to follow a Gamma distribution with a mean of $\bar{J}$ and scale parameter τ. Moreover, since the mean VWM resource decreases with target size N (Fig. 3A), we assume that the relationship between $\bar{J}$ and N can be written in a power-law fashion $\bar{J} = \bar{J}_1 * N^{-a}$, where $\bar{J}_1$ is the initial resources when only 1 item ($N = 1$) should be remembered in VWM and α is the decay exponent.

The model also assumes that the subject's internal representations of stimuli are noisy and follow a von Mises distribution. Thus, the distribution of sensory measurement (m) given the input stimulus (s) can be written as:

$$p(m|s) = \frac{1}{2\pi I_0(\kappa)} e^{KCOS(m-s)} = VM(m; s, k) \quad (1)$$

and we further assumes that subjects' reported color ($\hat{S}$) shat also follows a von Mises distribution with the choice variability κ_r:

$$p(\hat{s}|m) = \frac{1}{2\pi I_0(k_r)} e^{k_r \cos(\hat{s}|m)} = VM(\hat{s}; m; k_r) \quad (2)$$

Taken together, there are four free parameters: $\bar{J}_1$, α, τ, and κ_r in the VP model.

Model fitting

We fit the model separately for each subject. Because J is a variable across items and trials, we sampled it 10,000 times from the Gamma distribution with mean $\bar{J}$ and scale parameter τ. We then used all these samples to calculate response probability in each trial.

We used the BADS optimization toolbox in MATLAB to search for the best-fitting parameters that maximize the likelihood of responses. To avoid the issue of local minima, we did the optimization process 20 times with 20 different initial seeds. The parameters with the maximum likelihood were used as the best-fitting parameters for a subject and were further used in the statistical process.

The model fitting codes are publicly available via: https://github.com/ruyuanzhang/VWMmodels.

Power analysis

Since our study aimed to compare a large family of models, and we had no prior knowledge of their fitting efficiency (e.g., parameter recovery), it was challenging to estimate statistical power and determine the appropriate sample size before conducting the experiment. Therefore, we referred to the sample sizes used in previous studies within this research area. Our sample size is among the largest in this line of research[27,28,33,42–46].

RESULTS

SZ makes larger recall errors than HC

We set four experimental conditions (target size 1/3 × distractor size 0/2) for each group. In the modified color delay-estimation task, performance on a trial, denoted as "recall error," was defined as the angular difference between the true color and the reported color of the cued item in the circular color space. For each subject, circular standard deviations (CSDs) of recall errors in each experimental condition were calculated separately as indices of VWM performance.

A 2 × 2 × 2 ANOVA was performed with CSDs as the dependent variable (Fig. 2), target size (1/3) and distractor size (0/2) as the within-subject variables, and group (SZ/HC) as the between-subject variable. We observed main effects of target size ($F(1,119) = 935.650$, $p < 0.001$, partial $\eta^2 = 0.887$) and distractor size ($F(1,119) = 8.909$, $p = 0.003$, partial $\eta^2 = 0.070$), indicating that behavioral performance decreased in both groups as memory load and distraction level increased. These results also suggest that our experimental manipulation successfully induced the classical load and distraction effects. A group difference was also found ($F(1,119) = 12.716$, $p < 0.001$, partial $\eta^2 = 0.097$), and we confirmed an overall worse VWM performance of SZ than HC, a result consistent with many previous studies showing VWM deficits in SZ[3–6]. We also found a significant interaction between target size and distractor size ($F(1,119) = 4.486$, $p = 0.036$, partial $\eta^2 = 0.036$). Post hoc analysis showed that distractors worsened VWM performance in the high target size condition (i.e., target size = 3, $p = 0.004$), whereas no distractor effect was found in the low target size condition (i.e., target size = 1, $p = 1.000$).

The key question we asked here was whether the distractors selectively impaired VWM processing in SZ. If so, we should expect an interaction effect between distractor size and group, as adding distractors could lead to greater performance impairments in SZ compared to HC. However, we did not find such an interaction effect ($F(1,119) = 0.820$, $p = 0.367$, partial $\eta^2 = 0.007$), indicating that adding distractors worsened performance in both groups and that such a distraction effect was not specific to SZ. The similar deficits of apparent distractibility also call for more in-depth computational modeling to disentangle the contributions of multiple factors. Moreover, previous studies have suggested that distractibility deficits in SZ may be more pronounced when the task becomes more challenging (e.g., higher memory load). However, no other significant interaction effect was found with respect to the group variable (target size × group, $F(1,119) = 0.139$, $p = 0.710$, partial $\eta^2 = 0.001$; target size × distractor size × group ($F(1,119) = 0.137$, $p = 0.712$, partial $\eta^2 = 0.001$)). These results are consistent with previous studies[27,28,47] showing that SZ generally show worse VWM performance than HC, but the memory load and distraction effect manifest similarly in both groups.

Distractors elevate resource allocation variability in HC but not in SZ

The above analyses focused only on the CSD—a summary of statistics describing the variance of the recall error distributions in each experimental condition. To further analyze the data, we used the VP model (see "Methods")—a Bayesian observer model that describes the generative process of a behavioral choice in the delay-estimation task. The VP model has two major strengths. First, unlike the CSD as a summary statistical variable, the VP model is a probabilistic model that uses the data in each trial without losing any information. Second, and more importantly, the VP model explicitly defines some key VWM components and characterizes the full generative process of the VWM task. Therefore, we can quantify the distraction effect on these VWM components.

Here we introduce the details of the VP model. First, the VP model estimates initial resources when only one target is present. Second, the memory resources allocated to each target decrease as a power function of target size, and this decreasing trend can be described by the decay exponent. Third, the power function only specifies the average resource at each target size level. The actual resources allocated to each item vary and follow a Gamma distribution, with the variance defined as resource allocation variability. The resources allocated to each item determine the precision of the sensory measurement (i.e., memory representation) of the item. Fourth, given the noisy representation, there exists choice variability that describes the uncertainty from the internal sensory representation to the outcome behavioral choice. We estimated the four parameters (i.e., initial resources, decay exponent, resource allocation variability, and choice variability) on each subject and separately at two distractor size levels.

We performed a 2×2 ANOVA with distractor size as the within-subject variable, group as the between-subject variable, and the four estimated parameters of the VP model as the dependent variables. We observed a main effect of group on resource allocation variability ($F(1,119) = 9.863$, $p = 0.002$, partial $\eta^2 = 0.077$), showing an overall higher resource allocation variability in SZ compared to HC (Fig. 3D). This result is consistent with our previous work[35]. The main effect of group was not significant for the other three parameters. In particular, we did not observe a significant main effect of initial resource and decay exponent, two factors that control the amount of memory resources. Intuitively, these results suggest that SZ may have the same amount of memory resources, but they distribute the resources across the targets in a very heterogeneous manner.

We also found a main effect of distractor size on initial resource ($F(1,119) = 5.559$, $p = 0.020$, partial $\eta^2 = 0.045$) and a marginally significant main effect on decay exponent ($F(1,119) = 3.882$, $p = 0.051$, partial $\eta^2 = 0.032$). We speculate that adding distractors greatly increased the task difficulty and consequently forced subjects to internally use more resources to remember the targets. There were no main effects of distractor size on choice variability ($F(1,119) = 3.528$, $p = 0.063$, partial $\eta^2 = 0.029$) and resource allocation variability ($F(1,119) = 2.862$, $p = 0.093$, partial $\eta^2 = 0.023$). Note that these main effects were present in both groups.

More importantly, to examine the distraction effect, it is crucial to examine the interaction effect between group and distractor size. If SZ have deficits in distractibility, we should expect that adding distractors would induce significantly greater disruptions to VWM processing in SZ compared to HC. Indeed, we observed a significant interaction effect between group and distractor size ($F(1,119) = 5.062$, $p = 0.026$, partial $\eta^2 = 0.041$) (Fig. 3D) on resource allocation variability. However, post hoc analysis suggested that adding distractors only increased resource allocation variability in HC ($p = 0.036$) but not in SZ ($p = 0.999$). Note that, as demonstrated in our previous work[35], increased variability in resource allocation leads to worse performance (i.e., larger CSD of recall errors), which is consistent with the current results showing that adding distractors significantly worsens behavioral performance. This is surprising given that increased distractibility has long been proposed as a core executive function deficit in SZ. On the contrary, here we found a more pronounced distraction effect in HC rather than in SZ, suggesting a relatively higher RTD in SZ. We did not find such an interaction effect for any of the other three parameters (initial resource, $F(1,119) = 2.042$, $p = 0.156$, partial $\eta^2 = 0.017$; decay exponent, $F(1,119) = 0.236$, $p = 0.628$, partial $\eta^2 = 0.002$; choice variability, $F(1,119) = 0.430$, $p = 0.513$, partial $\eta^2 = 0.004$).

DISCUSSION

VWM and distractibility have long been recognized as core executive functions. Despite the widely documented behavioral deficits of SZ in these two domains, little is known about the computational mechanisms underlying these deficits. This is due to two major obstacles: (1) few studies have attempted to integrate two cognitive functions within the same experimental paradigm; (2) computational models that describe the internal processes have been lacking. To address these issues, we modified the classic VWM delay-estimation task to deliberately incorporate distractors and used the VP model to disentangle several key VWM components. We set up two distractor conditions (distractor size 0/2) and used the VP model to estimate the VWM components separately in these two conditions. We made two main observations: (1) the variability of allocation memory resources was generally larger in SZ; (2) adding distractors increased resource allocation variability in HC but not in SZ. These results highlight the importance of resource allocation variability in mediating VWM performance and demonstrate an unexpectedly higher resilience to distraction during VWM in SZ.

The finding of increased resource allocation variability is of unique significance for understanding VWM deficits in SZ. This finding was systematically evaluated in our previous work[35]. In that study, we compared several influential models in VWM literature and examined the results between SZ and HC. We found that the only difference between the two groups lies in resource allocation variability, not in the amount of memory resources. Importantly, higher resource allocation variability induces larger recall errors (i.e., worse VWM performance) in this delay-estimation task[35]. Note that larger recall errors may also arise from color perception deficits rather than from a VWM deficit in SZ. Both our work[35] and Gold et al.[33] have shown that individuals with SZ exhibit color perception deficits in this task; however, these deficits alone cannot fully account for the observed VWM impairments. This perception-based account has recently become an important topic in VWM research. Schurgin et al.[48] proposed joint modeling of behavioral data on the delay-estimation task and the perceptual similarity judgment task. In this framework, recall errors can be simply modeled by a perceptual sensitivity to different colors and a simple memory strength factor. Unlike previous computational models that only focused on delay-estimation or change detection tasks, the approach by Schurgin et al.[48] emphasizes the joint modeling of working memory (i.e., delay-estimation task) and perceptual sensitivity (i.e., perceptual similarity judgment task), providing novel insights into the limits of working memory. This idea is also supported by recent neural population models to reconcile the discrete and continuous account[49]. Computational investigations[50,51] also showed that the neural population model corresponds to the behavioral model proposed by Schurgin et al.[48]. Overall, these new advances in VWM research provide several fresh ideas about the neural underpinnings of VWM.

This result suggests that SZ has the same amount of mean resources as HC at each target size level, but the resources assigned to individual items have greater variability around this mean. For example, suppose that, given three targets, both SZ and HC have r units of mean resource for each target. But the actual resources assigned to each item vary around this mean value (i.e., $r + 0.1$, $r - 0.2$). SZ exhibits overall larger variability (e.g., $r + 3$, $r - 2$) than HC (e.g., $r + 0.3$, $r - 0.2$). Note that this mechanism is fundamentally different from increased attentional lapses or general deficits in filtering distraction. Increased attentional lapses

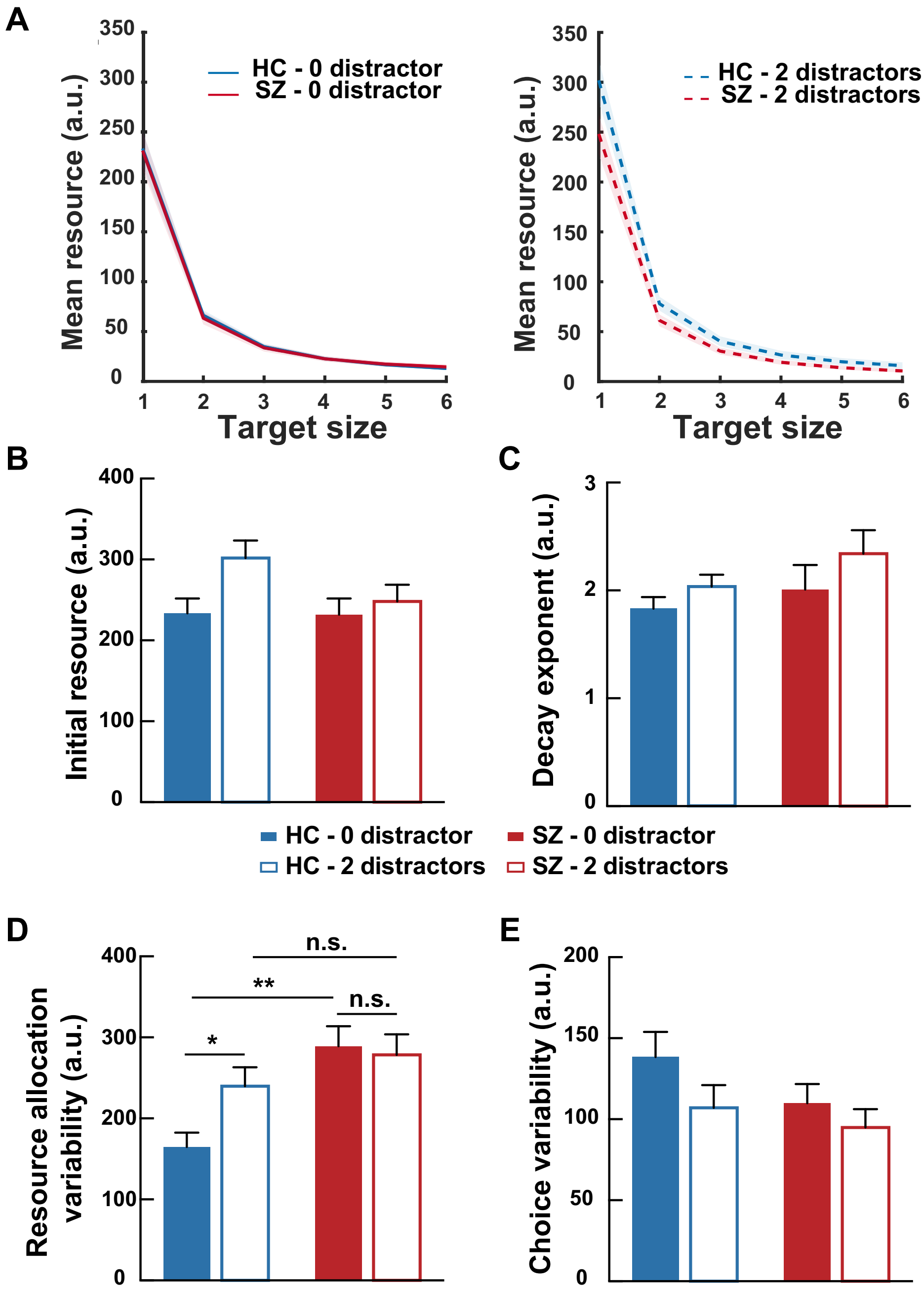

Fig. 3 Effects of group, target size, and distractor size on the four fitted parameters of the VP model. A The mean resources as a function of target size, generated by the fitted initial resource (**B**) and decay exponent (**C**) values. **D**, **E** The fitted resource allocation variability and choice variability, respectively. The main group effect was found only in resource allocation variability (**D**). Specifically, SZ showed overall greater resource allocation variability than HC, and adding distractors increased the resource allocation variability only in HC but not in SZ, indicating that SZ are more resistant to distraction than HC. No group × distractor size interaction was observed for initial resource, decay exponent, and choice variability. Shaded areas in (**A**) and error bars in (**B**–**E**) denote ±SEM across subjects. Significance symbol conventions are $*p < 0.05$; $**p < 0.01$; n.s. non-significant.

will lead to more guessing trials, and the general deficits in filtering distraction will allow more resources to be allocated to distractors. Thus, these mechanisms predict an overall reduction in mean resources in SZ. However, we did not observe significant group differences in memory resources (Fig. 3A).

The unexpectedly enhanced RTD in resource allocation variability provides a new perspective for understanding distractibility in SZ. We confirmed that the behavioral performance of SZ is generally worse than that of HC, a well-established finding in many previous studies[3–6]. However, in the analyses of behavioral performance, we observe significant effects of memory load and distraction, but both effects manifest similarly in both groups. There was no stronger distraction effect specific to SZ. Most previous studies employed a similar approach and only focused on behavioral performance. Here, we took a further step and examined the distraction effect on individual VWM computational components. Results showed that adding distractors significantly increased the resource allocation variability only in HC but not in SZ. This is the main contribution of our work. Our approach allows us to provide a deeper mechanistic interpretation rather than just reporting the quantitative behavioral deficits in SZ. The lack of a significant difference in resource allocation variability across distraction levels in SZ seems somewhat inconsistent with the observed worse performance in the high distraction condition. However, while we have previously shown that increased resource allocation variability leads to worse VWM performance, we also note that this relationship is not linear. VWM performance is influenced by additional factors such as initial resource allocation and decay exponent. Our current approach involves fitting the VP model separately to data from the two distraction conditions and then examining differences in the estimated parameters. An alternative approach, as pursued by Ni and Ma[52] and Shen and Ma[53], would be to incorporate the distraction effect directly into the generative process. This would allow for model comparisons and provide a framework for evaluating different theories. We suggest that future work could explore this alternative approach in greater detail.

At first glance, the greater RTD in VWM resource allocation suggests a cognitive advantage in SZ. However, it could also imply less flexible cognitive control in SZ. For example, it has been shown that SZ tend to allocate their VWM resources more intensely and narrowly than HC[43], a phenomenon called "hyperfocusing." If SZ allocate too many resources to a small set of visual objects, they may have difficulty flexibly switching to new objects. Hyperfocusing might be particularly pronounced in VWM tasks because one of the key features of VWM is the ability to flexibly and dynamically maintain representations of multiple objects. The mechanism of hyperfocusing could explain both the increased resource allocation variability and higher RTD in SZ. In our task, involuntary hyperfocusing means that memory resources are overly allocated to a small subset of targets, while other targets are ignored. Given that resource allocation variability is already high among targets, adding distractors may not significantly influence resource allocation. However, HC tend to allocate resources more evenly across targets, so the introduction of distractors disrupts this even distribution, making it more heterogeneous. Note that the "side effect" of hyperfocusing might be the lack of ability to flexibly switch resources between targets and distractors[54]. Atypical dynamic executive control abilities have also been found in other special populations, such as aging[55,56], ADHD[57].

What are the neural mechanisms underlying VWM deficits and distraction effects in SZ? A recent study identified the superior intraparietal sulcus as a cortical region that controls resource allocation variability[58]. Atypical neural processing in this region has also been found in SZ patients[59]. On the other hand, the distraction effects on neural processing have been widely found in attention and cognitive control networks[60]. In particular, SZ showed abnormal neural processing in the presence of distractors, and cortical activity in high-level brain regions (i.e., dorsolateral prefrontal cortex) correlates with negative symptoms[61]. However, no study has combined the VWM and distractor paradigms and measured neural activity in SZ. It is also unclear how other computational components of VWM are implemented in the brain. Future studies may need to combine computational modeling, neural measurements, and behavioral testing to systematically address this issue. We acknowledge that the large-scale comparisons of computational models may post challenges to estimate the sample size for this type of study because different models may have different levels of fitting efficiency and parameter recovery. We emphasize that our sample size is among the largest in this line of research. More computational work is needed to rigorously test the validity of these models.

In summary, in this study, we combined the standard VWM and distractor paradigms to examine the distraction effect during VWM in both SZ and HC. We replicated the standard memory load and distraction effects in both groups. We also found generally poorer VWM performance in SZ. However, we did not observe a significantly higher distraction effect in SZ. Further modeling analyses revealed that distractors increased resource allocation variability during VWM in HC but not in SZ. This unexpectedly higher resilience to distraction in SZ sheds new light on the cognitive deficits in SZ.

DATA AVAILABILITY

Data and codes will be made available on request.

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COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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