Resource or slot model in visual working memory: Are they different?

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Summary

The ‘slot model’ and ‘resource model’ are two well-established theories used to explain working memory (WM) organization. With newer computational models suggesting that WM may not strictly conform to one model, this study aimed to understand the relationship between these models. By implementing correlational assessments of subject performances in two different tasks (analog recall paradigm with sequential bar presentation and delayed match-to-sample task (DMS) with checkerboard stimuli which are representative for resource and slot models, respectively), our study revealed significant correlations between WM performance (measured by DMS tasks) with recall error, precision, and sources of error (measured by sequential paradigm). Overall, the findings emphasize the importance of considering both models in understanding WM processes, shedding light on the debate between slot and resource models by demonstrating overlap in elements of both models.

Main text

Working memory is a limited short term storage for temporary information retention and manipulation which plays a critical role in multiple cognitive functions.[1] The two main theories that describe WM include the ‘slot model’ and the ‘resource model’. According to the slot model, WM capacity comprises a fixed number of predefined slots that creates a binary condition for information recall. In contrast, the resource model, advocates for the dynamic allocation of memorized items in the memory resources, wherein memory precision decreases as the number of memorized items increase.[2, 3]

While different WM paradigms were used to assess slot and resource models, newer computational models claim that WM is not always confined within one of these traditional

models, but rather has stimulus specific features and is not a solitary process.[4] Stimulus specific evidence suggest that strict categorization of visual WM between slot and resource models are less reflective of experimental data and a stimulus specific bias theory is more relevant.[5] With the goal to understand the correlation between WM precision and capacity, this study was conducted.

A total of 30 healthy subjects (7 females, 26.56 ± 4.61 years old, from 21 to 37) participated in the analog recall task with sequential bar presentation and DMS task with checkerboard which is demonstrated in Fig. 1A and B. By conducting a Spearman's correlation analysis, we found that subjects' performance in the DMS task was negatively and significantly correlated with the mean recall error in the sequential task ($r = -0.60$, $p < 0.001$, Fig. 1C). We also found that performance in the DMS task was positively correlated with the precision of the sequential task ($r = 0.60$, $p < 0.001$, Fig. 1D). Furthermore, we found that while performance of the DMS task was positively correlated with target proportion ($r = 0.59$, $p < 0.001$, Fig. 1E), it was negatively correlated with swap error ($r = -0.55$, $p < 0.003$, Fig. 1F). Performance did not show a significant correlation with uniform error ($r = -0.22$, $p = 0.23$, Fig. 2G). A similar pattern was observed when we calculated the correlation between performance in DMS task for each delay, and recall error, precision, target proportion, swap error, and uniform error (Fig. S1A-E).

We also found that the performance in DMS task was more correlated with the recall error of the third presented bar ($r = -0.59$, $p < 0.002$), than the second ($r = -0.56$, $p < 0.002$), and first bar ($r = -0.57$, $p < 0.001$, Fig. S1A). The same pattern was observed for precision (3rd: $r = 0.7$, $p < 0.001$; 2nd: $r = 0.46$, $p < 0.01$; 1st: $r = 0.45$, $p < 0.02$, Fig S1B).

The debate between the slot and resource models, each with unique properties have been an everlasting conversation in WM assessment. More recent theories, such as the categorical

resource model, have emerged, incorporating elements from both traditional models.[5] This correlational study aims to unveil similarities and differences between these models. The moderate to high correlation observed between recall error and precision, particularly noticeable in the third bar (the least challenging to memorize due to the shortest delay interval), highlights that when the memory load is lower in the sequential task, the results are more correlated to the less challenging task (i.e., DMS). This is complementary to a study by Zokaei et al., which compared digit span measures with a precision task and found significant correlations between performance in backward digit span (the more difficult condition in a slot model task) and precision in a resource model task.[6] In addition, our study had the benefit of showing the correlation pattern between these two tasks with higher temporal resolutions in DMS (from 0.5 to 8s) and sequential tasks (1 to 3 bars). These analyses showed that no significant correlation was observed in the 2s and 4s delay periods (Fig. S1 1), which shows the importance of considering full range of delay interval.

The absence of a significant correlation between uniform error and performance in the DMS task suggests that slot models tasks (e.g., DMS) cannot be used to study uniform error. It is worth noting that the Mixture Model, introduced earlier by Bays et al., categorizes error patterns into three types: target, non-target, and uniform error. However, with the incorporation of the neural resource model (Stochastic sampling), the uniform error seems to be less relevant.[7, 8]

In our study, our inclusion criteria were limited to individuals younger than 40 years old to avoid any potential confound.[9, 10] However, this study had limitations and could be improved by conducting future EEG and functional MRI studies, along with behavioral paradigms, to distinguish between different models and pathways involved.

In conclusion, our study revealed a significant correlation between the resource and slot models, determining that the slot model isn’t necessarily outdated. This can serve as a confirmatory approach for when dealing with larger sample sizes and limited time, allowing reliance on classical models. However, when addressing sources of errors and their underlying features, classical slot models exhibit a weaker association with memory function.

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Declaration of interests

The authors declare no competing interests.

Author contributions

Conceptualization: F.H, A.M, I.A, M.S. Paradigms development: A.M, M.S. Data acquisition: A.M, A.A. Statistical analysis: F.H, A.M, M.S. Data interpretation: F.H, A.M, I.A, M.S. Drafting original manuscript: F.H. Revising the manuscript: All authors. Funding acquisition: I.A. All the authors have read and approved the final version for publication.

Ethics

This study followed the latest update of the Declaration of Helsinki and was approved by the Iranian National Committee of Ethics in Biomedical Research (Approval ID: IR.MUI.MED.REC.1400.441).

Data availability

Anonymized data will be available upon request from corresponding authors. The corresponding author will consider the request against the data-sharing policy in the protocol and ethical approval of the study.

Code availability

The source codes for the analog report MATLAB toolbox are available at

https://www.paulbays.com/toolbox/.

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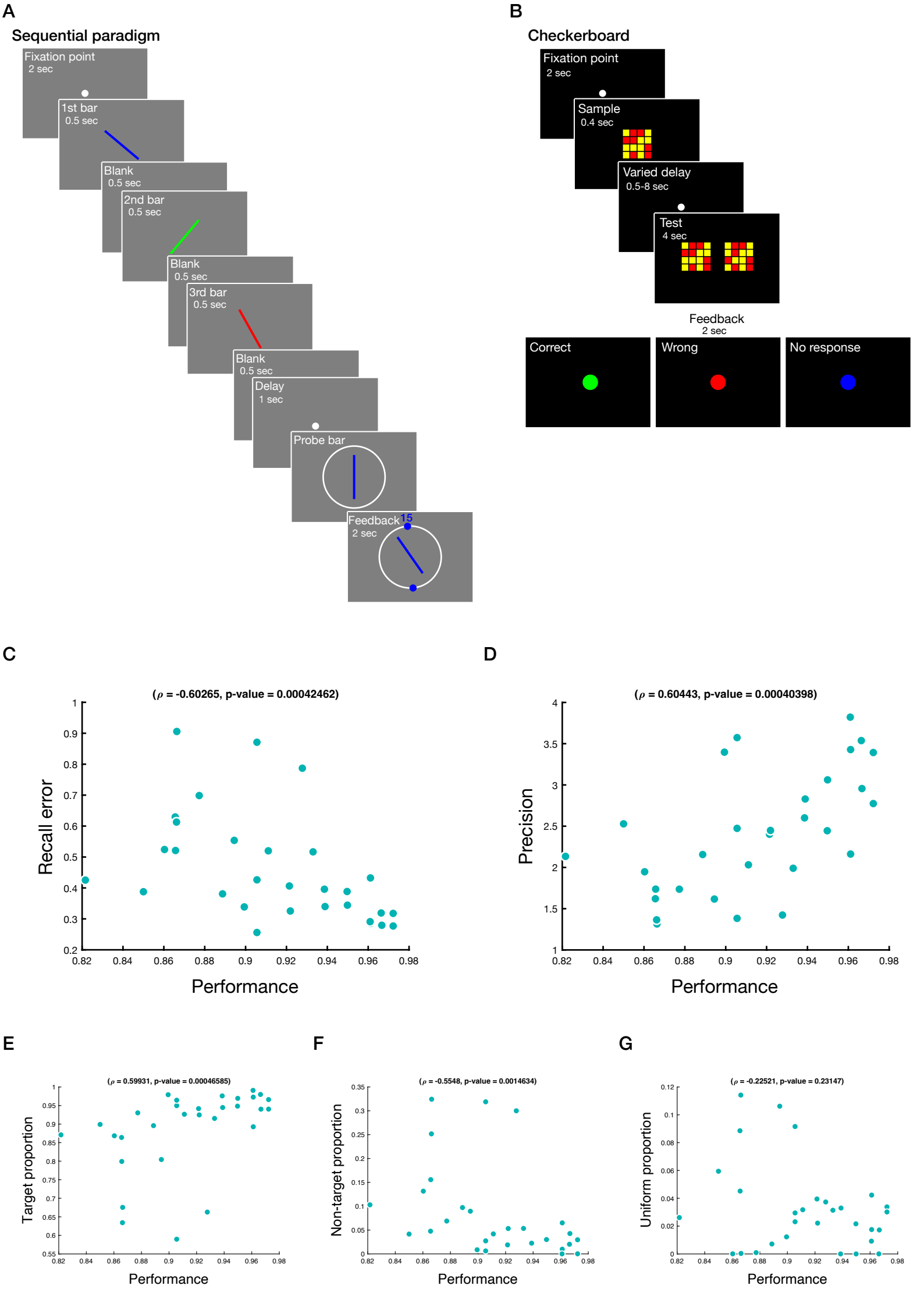
Figure 1: Schematic design and correlations between performance of DMS with errors in sequential tasks. Delayed match-to-sample task (A). Analog recall paradigm with sequential bar presentation (B). Correlation between recall error (D), precision (D), target (E), non-target (F), and uniform proportions (G) with DMS performance.


A
Sequential paradigm
Fixation point
2 sec
1st bar
0.5 sec
Blank
0.5 sec
2nd bar
0.5 sec
Blank
0.5 sec
3rd bar
0.5 sec
Blank
0.5 sec
Delay
1 sec
Probe bar
Feedback
2 sec
15
B
Checkerboard
Fixation point
2 sec
Sample
0.4 sec
Varied delay
0.5-8 sec
Test
4 sec
Feedback
2 sec
Correct
Wrong
No response
C
(ρ = -0.60265, p-value = 0.00042462)
Recall error
Performance
D
(ρ = 0.60443, p-value = 0.00040398)
Precision
Performance
E
(ρ = 0.59931, p-value = 0.00046585)
Target proportion
Performance
F
(ρ = -0.5548, p-value = 0.0014634)
Non-target proportion
Performance
G
(ρ = -0.22521, p-value = 0.23147)
Uniform proportion
Performance