Age-related and individual differences in the neural correlates of spatial and temporal information in working memory

Ya-Ping Chen[1,2], Ya-Wen Fang[1], Ching-Po Lin[3], Ovid Jyh-Lang Tzeng[1,2,3,5], Hsu-Wen Huang[1,4], Chih-Mao Huang[1,4,5]

1.Laboratory for Cognitive Neuroscience, Institute of Linguistics, Academia Sinica, 2.College of Humanities and Social Sciences, Taipei Medical University, 3.Institute of Neuroscience, National Yang-Ming University, Taipei, Taiwan, 4.Department of Biological Science and Technology, 5.Institute of Molecular Medicine and Bioengineering, National Chiao-Tung University, Hsinchu, Taiwan

INTRODUCTION

Working memory (WM), the executive processes responsible for online manipulation of various domains of information to guide goal-directed behavior, appears to be declined with age. However, the neural pattern of age-related cortical over-recruitment has been reported during working memory and is typically interpreted as being compensatory (Huang et al., 2012). There is evidence that such neural responses may reflect age-related differences in modulation of neural activity in response to task demands (i.e., Compensation-Related Utilization of Neural Circuits Hypothesis, CRUNCH) (Reuter-Lorenz & Cappell, 2008). In the present study, we employed functional magnetic resonance imaging (fMRI) to examine CRUNCH model and to investigate age-related and individual differences in the neural correlates of working memory. Specifically, we explored age-related differences in neural activity across three levels of task demands (low load, medium load, and high load) of working memory for temporal and spatial information with event-related design.

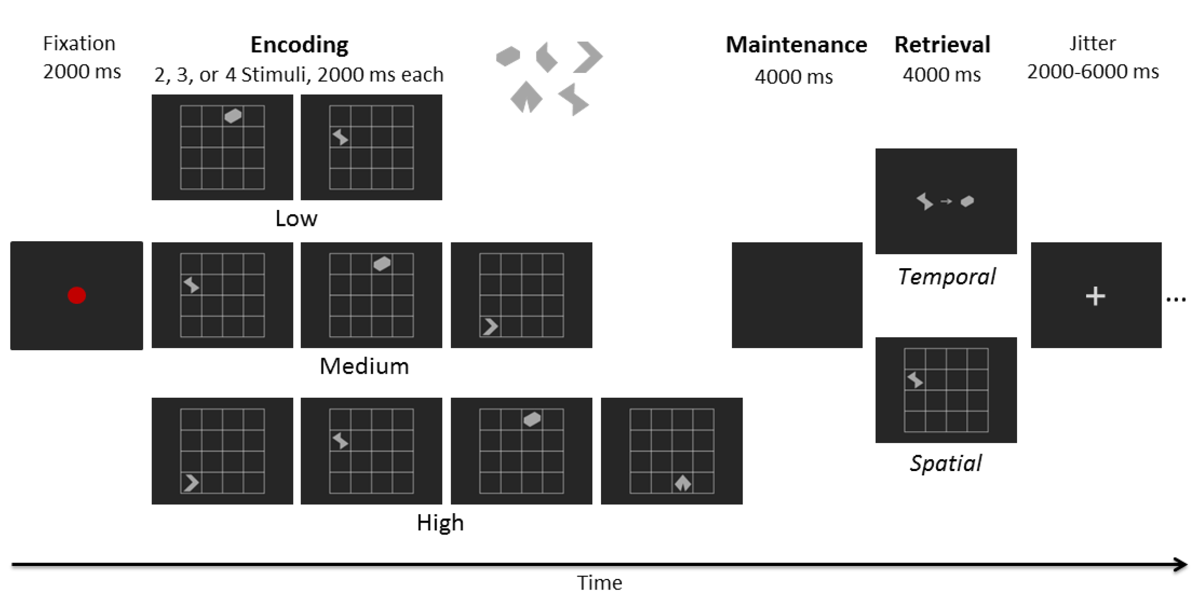
METHODS

Participants

Seventeen healthy young adults (7 males; mean age 22.9 ± 1.8 years, age range 20-25 years, mean school education 16.1 ± 1.4 years) and 17 healthy older adults (3 males; mean age 65.0 ± 4.4 years, age range 60-74 years, mean school education 14.4 ± 2.6 years) participated in this study. They are all right-handed native speakers.

Experimental procedure

Each trial began with a red point for 2 s and followed by an encoding phase. During encoding, different levels of task with set sizes two through four were manipulated. The stimuli consisted of one of five abstract objects and a 4-by-4 square grid.



In each trial, two (low load), three (medium load), or four (high load) of five abstract objects (Parra et. al., 2009) were randomly chose. Participants were instructed to memorize the temporal order of those abstract objects for the temporal working memory task and to remember the location for the spatial task. The encoding phase was followed by 4-second blank as a maintenance phase in which participants were asked to maintain the order or the location of the just presented abstract objects. During retrieval phase in the temporal condition, the two abstract objects were presented with a right arrow between which indicated the present order of those two objects. Participants were instructed to indicate if the temporal order is correct by pressing one of two buttons by index or middle finger of right hand once the probe was presented. In the spatial condition, one object in the encoding phase was presented randomly in the grid. Participants should judge the location of the item is correct or not. Trials were separated by a jittered interval of 2, 4, or 6 s. There were 3 sessions for each condition, each consisting of 21 trials, 7 trials for each level.

Imaging Protocol and Data Analysis

A 3T MRI scanner equipped with a high-resolution 12-channel head array coil (Magnetom Trio, Siemens, Erlangen, Germany) was used to acquire functional magnetic resonance images. Functional images were acquired using a gradient-echo EPI sequence with following parameters: TR = 2000 ms, TE = 27 ms, FOV = 220 mm, 33 axial interleaved slices, voxel size = 3.4 x 3.4 x 4 mm^3.

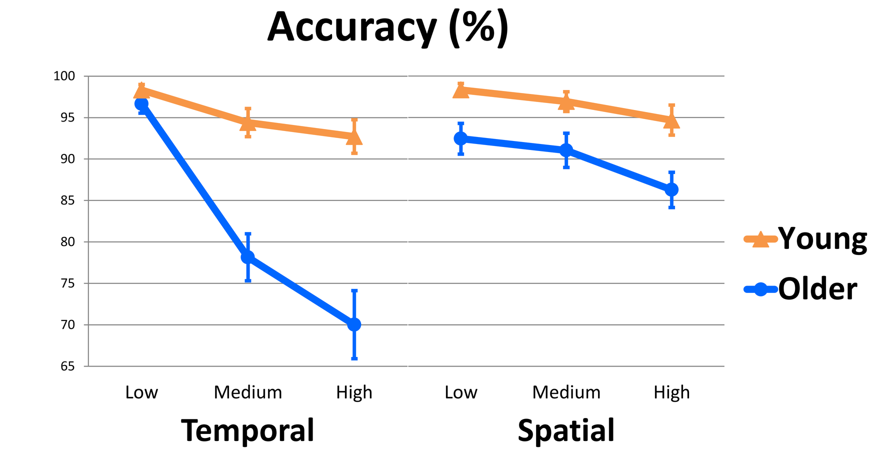
Functional images were pre-processed and analyzed using SPM8. Images were slice-time corrected, realigned, spatially normalized, smoothed with 6 mm FWHM. Event-related BOLD response was modeled by convolving with the canonical hemodynamic response function. Significant regions of activation were identified with threshold uncorrected p< 0.001 and cluster size>10.

RESULT & DISSCUSSION

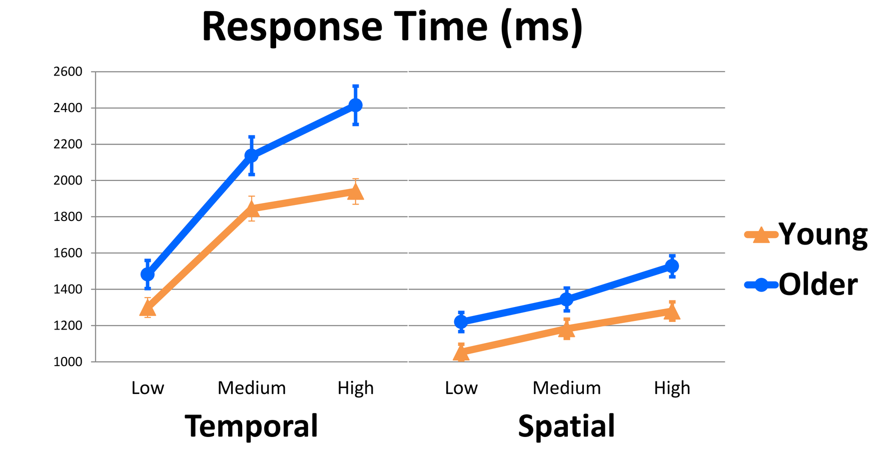
Behavioral results

The effect of working memory load was observed both on accuracy and reaction times in the two conditions. Participants showed less accurately and more slowly in the temporal condition than in the spatial condition. Older adults showed a decline in performance (both accuracy and reaction times) with increasing working memory demands in temporal WM, consistent with CRUNCH model.

Accuracy (%)



Response Time (ms)

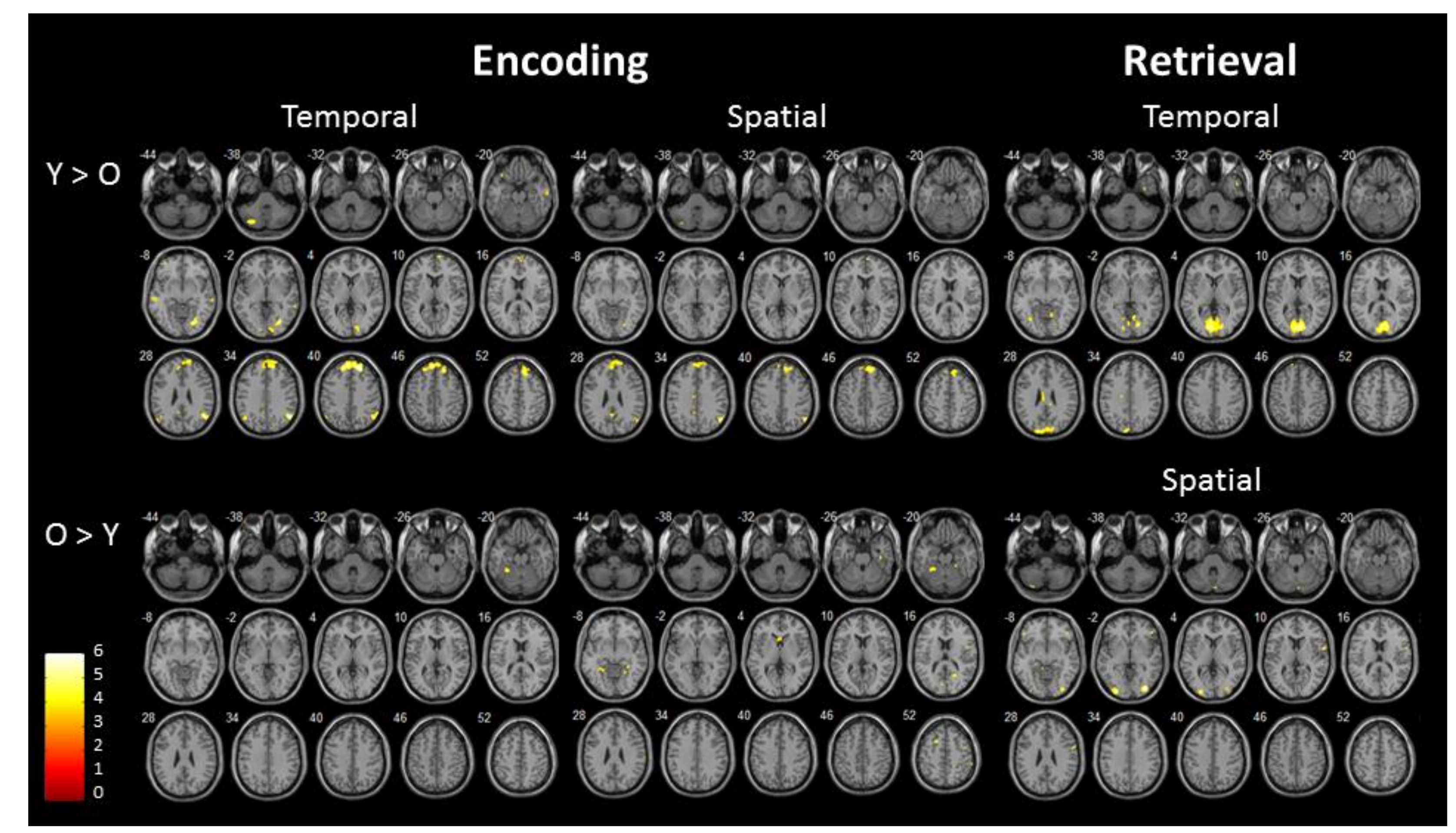


fMRI results

Whole brain analysis

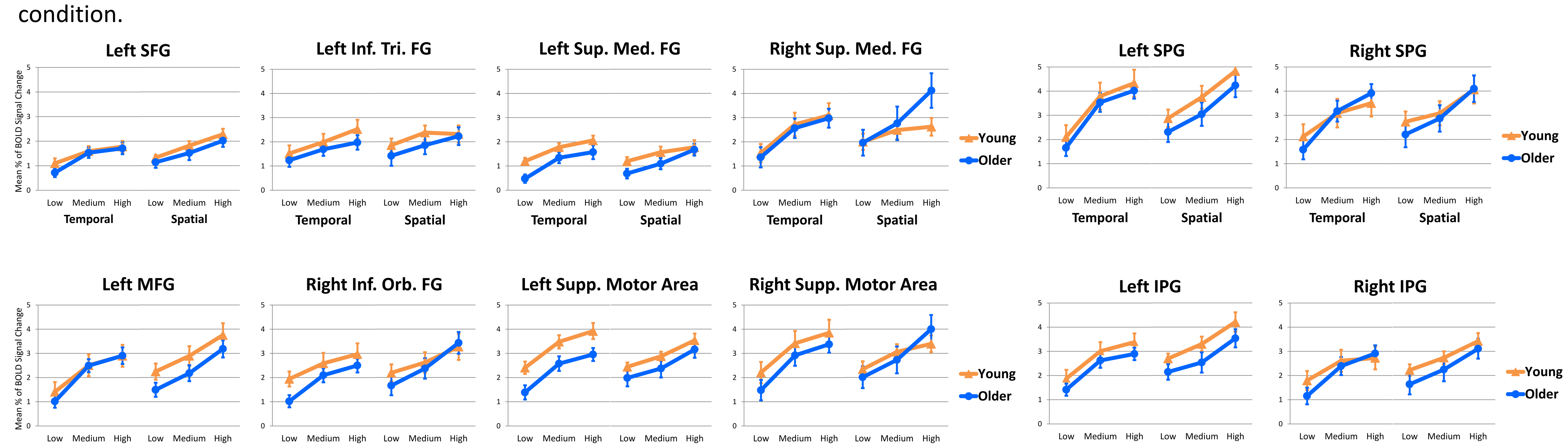
In the encoding phase, young adults showed more activation in the superior medial frontal gyrus, bilateral angular gyrus, and left cerebellum than older adults both in temporal and spatial conditions. Older participants revealed higher activation in the left superior frontal gyrus and the left superior parietal gyrus, which provides additional evidence for hemispheric asymmetry reduction in older adults.

In the retrieval phase, young adults had more activation in the midline of posterior parietal cortex in the temporal condition, whereas older individuals showed higher bilateral occipital cortex activation compared to the young performers.



ROI analysis

The ROI analysis showed age-related differences in neural recruitment in response to different conditions and load effects in the retrieval phase. Young adults showed more activation in the medial prefrontal cortex and supplementary motor area, which have been mentioned dealing with temporal information in previous studies, but this pattern does not found in older individuals. Young participants revealed increased parietal activation with increasing task demands especially in spatial condition, while older group revealed similar parietal activation in temporal and spatial condition.



CONLUSION

These findings provide evidence for CRUNCH model, and also suggest that the midline of prefrontal cortex play an important role in manipulating temporal information.

REFERENCES & ACKNOWLEDGEMENT

Huang CM, Polk TA, Goh Jo, Park DC (2012) Neuropsychologia 50(1): 55-66. Reuter-Lorenz PA, Cappell KA (2008) Curr Dir Psychol Sci 17(3): 177-182. Parra MA, Abrahams S, Fabi K, Logie R, Luzzi S, Della Sala S (2009) Brain 132:1057-1066. This work was supported in part by UST-UCSD International Center of Excellence in Advanced Bioengineering sponsored by the Ministry of Science and Technology I-RiCE Program under Grant Number: MOST 103-2911-I-009-101 and by Academia Sinica Grant AS-103-TP-C04.
E-mail: yapingchen21@gmail.com, cmhuang@nctu.edu.tw