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Research report

Modality specificity in the cerebro-cerebellar neurocircuitry during working memory

H.B. Tommy Ng[a], K.-L. Cathy Kao[a], Y.C. Chan[b,c], Effie Chew[b,c], K.H. Chuang[d], S.H. Annabel Chen[a,e,*]

[a] Division of Psychology, School of Humanities and Social Sciences, Nanyang Technological University, 637332, Singapore
[b] Division of Neurology, University Medicine Cluster, National University Health System, Singapore
[c] Department of Medicine, Yong Loo Lin School of Medicine, National University of Singapore, Singapore
[d] The Queensland Brain Institute, The University of Queensland, Brisbane, Queensland, Australia
[e] Centre for Research and Development in Learning (CRADLE), Nanyang Technological University, 637459, Singapore

HIGHLIGHTS

- We examined hemispheric lateralization patterns in working memory.
- Left lateralized IFG and IPL were activated during verbal working memory.
- Right lateralized cerebellar lobular VI and VIII were also activated in verbal working memory.
- A left-cortical right-cerebellar network underlies verbal working memory.
- No evidence for a right-cortical left-cerebellar network in visual working memory.

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ABSTRACT

Previous studies have suggested cerebro-cerebellar circuitry in working memory. The present fMRI study aims to distinguish differential cerebro-cerebellar activation patterns in verbal and visual working memory, and employs a quantitative analysis to deterimine lateralization of the activation patterns observed. Consistent with Chen and Desmond (2005a,b) predictions, verbal working memory activated a cerebro-cerebellar circuitry that comprised left-lateralized language-related brain regions including the inferior frontal and posterior parietal areas, and subcortically, right-lateralized superior (lobule VI) and inferior cerebellar (lobule VIIIA/VIIB) areas. In contrast, a distributed network of bilateral inferior frontal and inferior temporal areas, and bilateral superior (lobule VI) and inferior (lobule VIIB) cerebellar areas, was recruited during visual working memory. Results of the study verified that a distinct cross cerebro-cerebellar circuitry underlies verbal working memory. However, a neural circuitry involving specialized brain areas in bilateral neocortical and bilateral cerebellar hemispheres subserving visual working memory is observed. Findings are discussed in the light of current models of working memory and data from related neuroimaging studies.

1. Introduction

Working memory may be conceptualized as a neural system that temporarily maintains, stores, and manipulates information for complex cognitive tasks such as reasoning, learning, and language comprehension [7]. Within the theoretical framework, mechanisms of the phonological loop and visuo-spatial sketchpad are thought to support verbal and visual working memory, respectively.

Data from neuroimaging studies have consistently demonstrated the involvement of left inferior frontal and left inferior parietal regions in verbal working memory, areas of the brain that have been linked to phonological rehearsal and storage, respectively [20,21,3,36,11,35,116,55]. Although cerebellar activations were also observed in early neuroimaging studies [96,99,56], their

* Corresponding author at: Division of Psychology, School of Humanities and Social Sciences, HSS-04-19, 14 Nanyang Drive, Nanyang Technological University, 637332, Singapore.
E-mail addresses: annabelchen@ntu.edu.sg, tommymr25@yahoo.co.uk, ENGZ0001@e.ntu.edu.sg (S.H.A. Chen).

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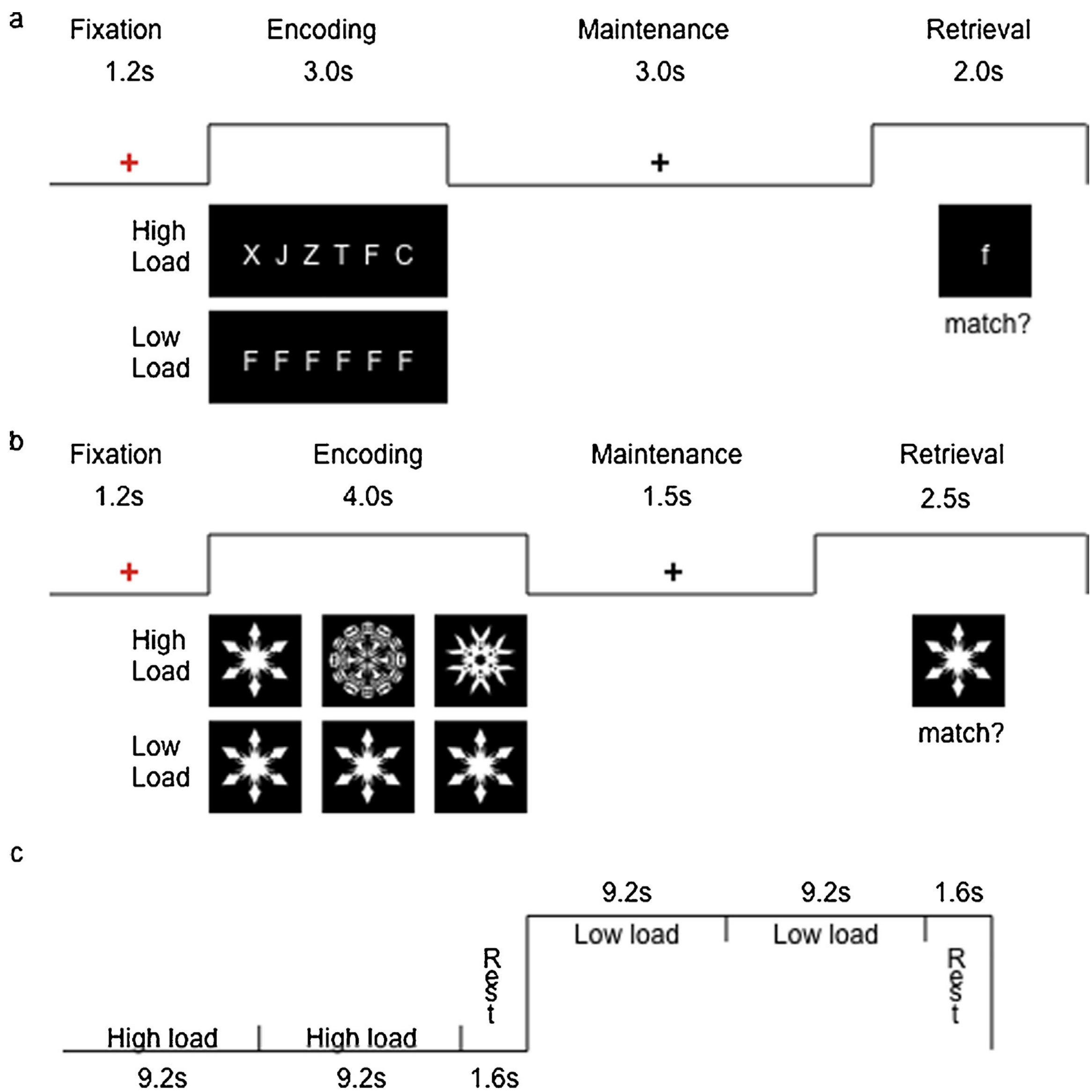

Fig. 1. Event timing of a single trial of the Sternberg working memory tasks. Stimuli presented during high-load and low-load condition of (a) verbal working memory and (b) visual working memory tasks. (c) Timing of one cycle of high-load and low-load trials interleaved by a 1.6 s rest interval.

exact function in verbal working memory was not well understood (see [56]).

In a previous fMRI study, Desmond et al. [28] identified two cerebellar regions that were differentially activated during verbal working memory: one located bilaterally in the superior hemisphere (lobule VI/Crus I), and another in the inferior aspect (lobule VIIB) of the right hemisphere. Based on the canonical cortico-ponto-cerebellar network [81,59] that forms a closed loop circuitry via the thalamus [123,2,79]; for review see [102], the authors proposed a cerebro-cerebellar model of verbal working memory to account for superior cerebellar contribution to phonological rehearsal and encoding and inferior cerebellar contribution to phonological storage processes. In a later event- related fMRI study, Chen and Desmond [17] found concomitant activation of the superior cerebellum and left frontal regions during encoding, and concomitant activation of the right inferior cerebellum and left parietal regions during maintenance, supporting earlier speculations that a lateralized left cortical-right cerebellar neurocircuitry supports verbal working memory.

Although the laterality effect was observed in a number of subsequent studies [18,60,61,73], a caveat was that hemispheric lateralization was assessed via visual comparison of the number of activated voxels and activation intensity (as indicated by the normalized Z value) in homologous brain regions, without the rigour of statistical testing. To address this, one of the objectives of the present study was to evaluate the laterality effect of verbal working memory by means of a laterality index measurement [10,26,29,40], which statistically evaluates voxel *beta*-values of homologous regions of interest. Specifically, an unbiased threshold-free computation of voxel *t*-values within regions of interest was used to calculate the laterality index. This approach has been shown to minimize computational biases that are associated with statistical thresholding [75]; for review see [113].

Another objective of the present study was to verify the laterality effects of working memory processes in the visual system. In the animal literature, an abundance of neurophysiological evidence converged on the involvement of ventral prefrontal and occipitotemporal brain areas in pattern, object, and face recognition and recall [135,83,82,101,109,106]. These results are in good concor-