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The current study compared the processes of updating verbal and visuospatial working memory (WM) and examined the roles of central executive and slave systems in working memory updating tasks, by changing the number of items updated simultaneously to manipulate the load on central executive. Experiment 1 used the verbal WM updating task, and the results validated the efficiency of the paradigm to manipulate the load on central executive. Experiment 2 employed the val WM updatingtva-1(s-)6(k1(f-8(al)- t)-7a63(v)-13t

have to keep on changing the contents of working memory according to the newer information in the updating operation.

Updating has been testified as one of the important executive functions[4–6]. Many brain imaging researches have found that activities in right mid-dorsal prefrontal cortex (PFC), left middle frontal regions, and right frontal pole (Broadman areas, BA9, BA46/10) are associated with updating function[7,8]. Moreover, the event-related potential (ERP) studies indicated that the activation of the prefrontal brain areas underlay the executive activities[9,10]. This function is to refresh continuously the

that executive control was required at the period of encoding but not during maintenance rehearsal. Therefore, the secondary task that placed a load on the cen

and slavery systems, it is important to select a better method for manipulating the load in the tasks. In Experiment 1, we controlled the numbers of items updated at the same time to vary the load on CE. This method could be demonstrated to be effective if updating times had cumulate effect on performance decrements with an increase in updating item number.

1.1 Method

(i) Participants. Twenty undergraduate and graduate students (7 males, 13 females, 20—30 years of age, mean 24.6) from the Northeast Normal University took part in the study. All the participants were right-handed, and had normal or corrected-to-normal vision. They were paid for their participation.

(ii) Apparatus and Materials. Stimuli were presented in the center of a PIII 15' computer monitor. We used capital consonants with a height of 3 cm (2.9° of visual

ated the two tasks at the same time. The order of presentation of the two conditions (no vs. add secondary task) was counterbalanced across participants. Practice trials were completed prior to the main experiment blocks. The participants were given the opportunity to take a break after the completion of the first block of trials.

Thus, the experiment involved a 3×4×2×4 within-participants design with the factors of updating number (updating character number: 1, 2, and 3), updating times (0, 1, 2, and 3), secondary task (no vs. add secondary task) and serial location (serial location of four recent items in a sequence: 1, 2, 3, and 4).

2.2 Results

Table 2 shows the responses for each condition scored as

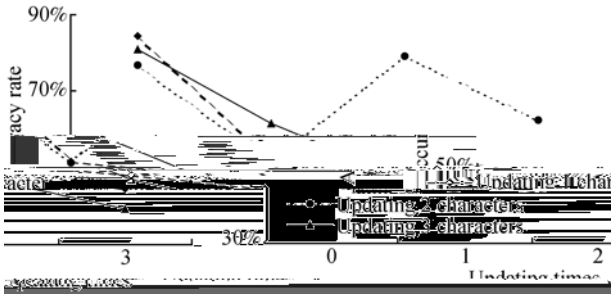

Figure 4 Performance in different updating number and updating times conditions of Experiment 2. The data show cumulate effect of updating more items at one time.

Furthermore, we got a similar result pattern as that in Morris and Jones' study[11], that is, the main effects of both updating number and secondary tasks were significant whereas no interaction between them occurred. It suggested that memory updating required central executive resources but not the articulatory loop, and the serial recall aspect of the task required the articulatory loop but not the central executive. Thus, our data suggested, in agreement with the study by Morris and Jones[11], that

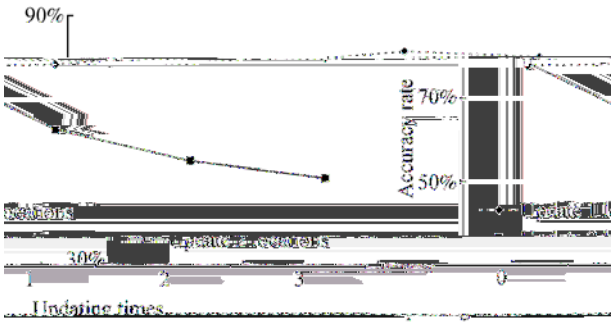

Figure 6 Performance in different updating number and updating times conditions of Experiment 3. The data show cumulate effect of updating more items at one time.

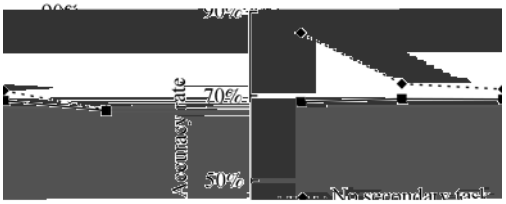

Figure 8 Performance influenced by updating times and secondary task in Experiment 3. The data shows the interaction between the effect of updating times and the effect of secondary task.

Finally, both the updating number×secondary task and the updating times×secondary task interactions were significant ((1,13) = 9.1, 0.05, and (3,39) = 4.3, < 0.05). Follow-up ANOVAs revealed that when updating one location, the performance decreased significantly with the secondary task ((1,13) = 9.9, < 0.01); When updating two locations, the performance did not change significantly, whether the participants performed the secondary task or not (Figure 7). Similarly, when there was no updating, the performance decreased significantly with the secondary task ((1,13) = 22.7, < 0.001); when updating times increased, the performance did not change significantly, whether the participants performed the secondary task or not (Figure 8).

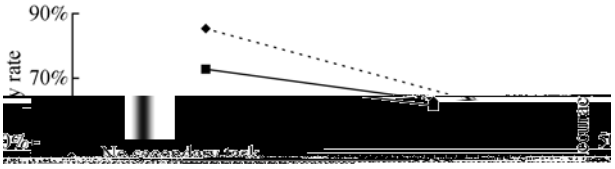

Figure 7 Performance influenced by the updating number and secondary task in Experiment 3. The data show the interaction between the effect of updating item number and the effect of the secondary task.

3.3 Discussion

As in Experiments 1 and 2, updating times had cumulate effect on performance with an increase in updating item number. Therefore, these results indicated that the method of controlling the load on CE is effective, and demonstrated that updating needs the control processing of CE. With the increase of load on CE, the performance was impaired, no matter whether there was a secondary task or not (Figures 7 and 8). However, the degree of decrement was substantially different. If there was no secondary task, the slope of performance went down more sharply than that with the secondary task. It suggested that the performance was less accurate when the load on CE was high, and the performance would not decrease much when adding the secondary task.

Moreover, both the updating number and updating

charge of the updating component, while the phonological loop was responsible for the serial recall component. In the visuospatial working memory updating task, central executive and visuospatial sketchpad dealt with the updating component together, while the visuospatial sketchpad was responsible for the serial recall component by itself. Furthermore, the similar pattern of results in the three experiments demonstrated that the method of changing the number of updating items was effective in controlling the load on CE. Manipulating the CE function directly, such a method can also avoid a response selection bottleneck and a strategy trade-off between primary and secondary tasks in the dual-task methodology[28].

Morris and Jones found that the number of updates did not affect performance[11]. They inferred that the executive could either perform several updates in rapid sequence without overloading its capacity or could have a very rapid 'recovery' rate when performing such operations. However, we did find that the updating times had cumulate effect on performance decrements with the increasing number of updates to change the load on CE, which was not found in their experiment. Kusak et al. attributed this to the variance in the memory load[10]. This explanation may not be appropriate, since we merely required the participant to recall the three or four recent items (which was the same as that in Morris and

6 Miyake A, Friedman N P, Emerson M T, et al. The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. Cogn Psychol, 2000, 41: 49—100
7 Salmon E, van der Linden M, Collette F, et al. Regional brain activity during working memory task. Brain, 1996, 119: 1617—1625
8 van der Linden M, Collette F, Salmon E, et al. The neural correlates of updating information in verbal working memory. Memory, 1999, 7: 549—561