Interference from the Irrelevant Domain in N-Back Tasks: An ERP Study

Yung-Nien Chen[1,2], Suvobrata Mitra[2], and Friederike Schlaghecken[2]

Abstract- Selective attention and interference from the irrelevant domain are frequently neglected factors in working memory experiments. Here identical stimuli were employed in n-back tasks under spatial and verbal task instructions to test whether information in the irrelevant domain was really irrelevant. The results reveal interference from the irrelevant domain in the replacement sub-process of the n-back task, and highlight the importance of taking cross-domain interference into account when drawing conclusions from neuropsychological experiments.

Key Words: Working memory, N-back task, Event-related potentials, Spatial, Verbal

Acta Neurol Taiwan 2007;16:125-135

INTRODUCTION

The term working memory (WM) refers to temporary maintenance as well as manipulation of information required for an ongoing cognitive task. In multi-component models of WM(1), a domain-general 'executive' subsystem retrieves, maintains and manipulates WM contents and controls various domain-specific 'slave' subsystems that maintain specific types of information. A commonly used task in electrophysiological and imaging studies on WM is the n-back task(2-4). In the n-back task, the participant is shown a series of items (e.g., letters, words or location markers) and is asked to decide, upon presentation of each item, whether a given property of the current item matches the same property of the item n presentations back. Figure 1 displays a schematic diagram of the 0-, 1- and 2-back tasks. If n=0, each new item is matched against the very first item in the series. If n=1, each new item is matched against the immediately preceding item, and if n=2, the new item is matched against the item presented just before the preceding item.

Researchers currently prefer n-back tasks in the study of WM because it taps into processes involving manipulation as well as maintenance of information in WM(5,6). According to logical analysis (Fig. 1), n-back tasks consist of three sub-processes: matching, replacement and shift. Replacement and shift can be shown by

From the [1]Department of Neurology, Chang Gung Memorial Hospital-Kaohsiung Medical Center, Chang Gung University College of Medicine, Kaohsiung, Taiwan; [2]Department of Psychology, University of Warwick, Coventry, UK.
Received September 8, 2006. Revised December 18, 2006. Accepted February 5, 2007.

Reprint requests and correspondence to: Yung-Nien Chen, MD. Department of Neurology, Chang Gung Memorial Hospital, No. 123, Ta-Pei Road, Niao-Song, Kaohsiung, Taiwan.
E-mail: ynchen@cgmh.org.tw

the differences between 1-back and 0-back and between 2-back and 1-back, respectively.

Cross-domain interference

A principle for experimental design is to reduce as many irrelevant factors as possible. The n-back task allows interface customization, and thus identical stimuli can be applied in different domains as different tasks to eliminate influences from the perceptual differences and "direct" comparison between tasks are allowed. However, a new factor - the cross-domain interference - is inevitably introduced. Participants presumably perform top-down control to process the relevant domain but ignore the irrelevant domain in sub-processes of n-back tasks. The key point is whether selective attention may exclude cross-domain influence from the beginning or it would let the influence sustain until the end of information processing.

Based on behavioural studies using letter and position n-back tasks, Meegan and Honsberger[7] concluded that irrespective of the actual stimulus materials or task demands, n-back task performance always involves both spatial and verbal processing. This conclusion is consistent with the neuroimaging results[2]. It is therefore reasonable to assume that the participants tend to process both domains at first but would then attempt to actively exclude the irrelevant domain. In contrast, early effects of selective attention have been demonstrated in a number of event-related potential (ERP) studies of WM[8-10]. Domain-specific distracter effects[11,12], where auditory distracters only affected verbal memory and visual-spatial distracters only affected spatial memory, were reported. However, the experimental design in such studies frequently aims to maximise the distinctiveness of spatial and verbal WM tasks, whereas under normal conditions, stimuli and events in the environment frequently belong to different domains simultaneously. When such multi-modal stimuli are employed, the effects tend to be somewhat less clear-cut[11], and cross-modal or supramodal distracter effects[13] may occur.

As yet, the mechanisms underlying such effects are unclear. The present study aims to close this gap by investigation of the time course of cross-domain interference with ERP, which has high temporal resolution. Words are presented at different screen locations, and participants must either respond to stimulus identity (verbal task) or stimulus position (spatial task). Consequently, stimulus features can match the features of the reference stimulus simultaneously in either the task-relevant or the task-irrelevant domain, or both. We hypothesized that stimuli with different match-attributes in different domains (for example, non-match in the task-relevant domain but match in the task-irrelevant domain) will cause cross-domain interference. The ERP pattern therefore are expected to be different from the pattern elicited by stimuli with the same match-attribute in different domains. This hypothesis can be confirmed by ERP patterns in replacement and shift sub-processes (represented by 1-back minus 0-back and 2-back minus 1-back difference waveforms) and in early to late latency windows.

METHODS

Participants

Twelve paid volunteers (seven female) ranging from nineteen to fifty (mean twenty-six) years of age participated in the study. All participants were Caucasians and English native-speakers. According to self-report, all had normal or corrected-to-normal vision, and half of the participants were right-handed.

Stimulus and apparatus

Stimulus presentation and data acquisition were managed by C-programs and running under MS-DOS. Behavioural and affect data were stored on the hard disc driver.

Stimuli were twenty English words with similar frequency and length. Words were presented in white on black on a 17" computer monitor, at one out of eight circularly arranged positions 4° from the screen centre. Words had a height of approximately 0.8° visual angle, and the width ranged from 3.2° to 6.4° (mean: 5°).

Procedure

Participants were seated in an armchair in front of a computer screen at a distance of approximately 60 cm. They were told to keep a comfortable posture, and to avoid eye movements or eye blinks during the experimental trials.

The experiment was splitted into two halves, separated by a break, during which participants were encouraged to leave the experimental room. Each half consisted of two 0-back blocks, two 1-back blocks, and two 2-back blocks in sequence. In the first half, each pair of blocks was preceded by a corresponding practice block to familiarise participants with the changing task requirements. In the second half, no practice blocks were administered. Experimental blocks consisted of sixty-four trials (thirty-two match trials and thirty-two non-match trials). Each trial began with the presentation of a fixation cross in the centre of a screen for 350 ms, followed by 350 ms of a blank screen. Then a stimulus word was shown for 500 ms at one of the eight predefined screen locations. This was followed by another blank screen for 1500 ms (Fig. 1). In all blocks, identity and location of each stimulus were determined pseudorandomly, to achieve an approximately even distribution of the target inI both identity and location. Practice blocks were constructed in the same way, but contained only twenty trials and additional feedback (the words "correct" or "wrong" presented in the centre of the screen) were provided immediately after the participant's response. Data from practice blocks was not saved.

In the 0-back task, participants indicated whether or not each stimulus matched the first one of the block. For the more demanding levels of the n-back task, participants had to match the current stimulus with the previous stimulus (1-back task) or the stimulus before the previous one (2-back task). Participants pressed a "yes" key for a match (match stimulus) and a "no" key for a mismatch (non-match stimulus). The " \ "and " / " keys of a

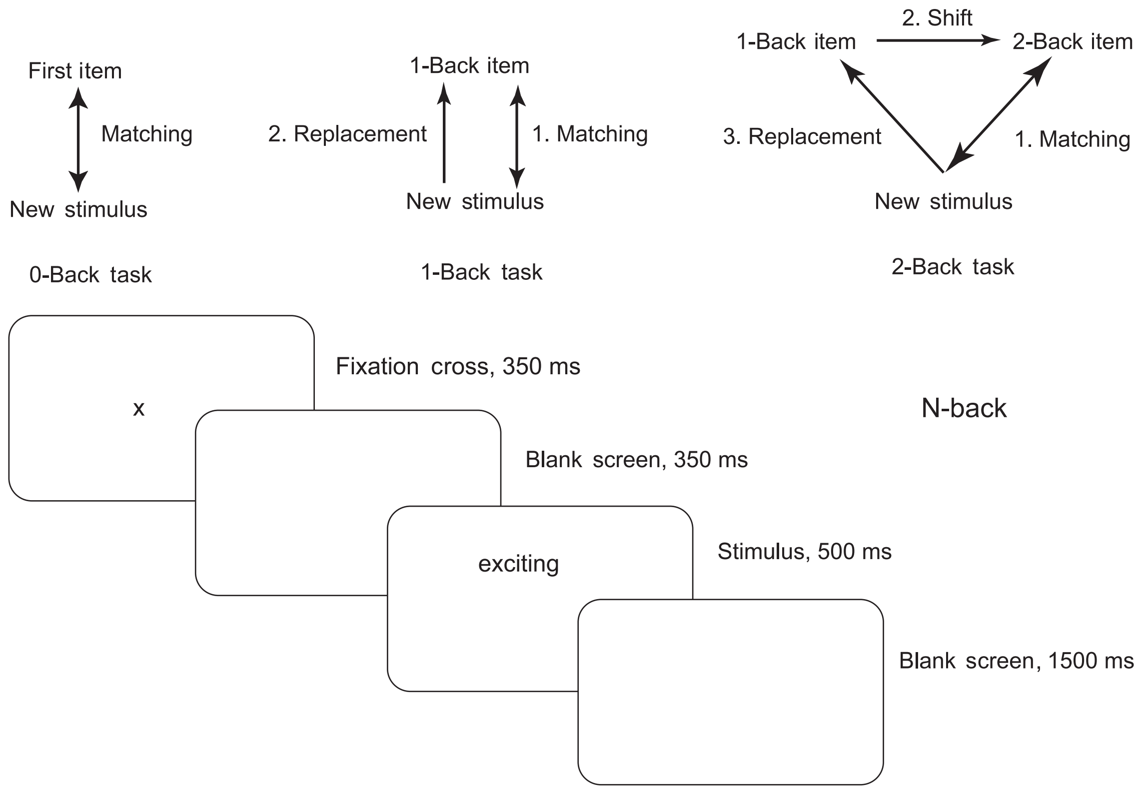

Figure 1. N-Back Tasks. The upper illustrates logical analyses of n-back tasks. The lower shows trial structure during testing.

computer keyboard were set to be the response keys, which had to be pressed with the left and right index finger, respectively. Participants were asked to respond as quickly and accurately as possible, and the assignment of keys to “yes” and “no” responses was counterbalanced across participants.

Two different versions of the n-back task were employed, and the participants were assigned randomly to either one. In the verbal version, the task-relevant feature (RF) of the stimulus words was their identity, whereas their location was irrelevant. In the spatial version, the location on the screen was task-relevant, whereas the identity was irrelevant. Note that verbal and spatial versions of the experiment differed only with respect to the instruction given to the participants, and were identical in all other respects. The frequency of match stimuli in either relevant or irrelevant domains was controlled to 50%. The task-irrelevant feature (IF) of the stimulus was compared with the relevant feature, and was marked as IF= Same (IS, same as the RF) and IF= Different (ID, different from the RF).

Acquisition

Continuous EEG recordings were obtained from 32 locations of the international 10-20 system (midline: FZ, CZ, PZ, OZ; left: Fp1, AF3, F7, F3, FC1, FC5, T7, C3, CP1, CP5, P7, P3b, PO3, O1; and corresponding right channels) with Ag / AgCl electrodes mounted on a nylon cap and a BioSemi Active-Two amplifier system. EEG signals were sampled at 256 Hz, off-line filtered using a 0.01 Hz high pass and a 30 Hz low pass filter, and re-referenced to the linked earlobes.

Pre-processing

Further analysis was conducted using EEGLAB 4.43[14] under the platform of MATLAB 6.1. EEGs were averaged off-line for epochs of 900 ms, each starting 100 ms prior to stimulus onset. Trials containing saccadic eye movement or eye blinks (indicated by an amplitude beyond 3 SD in single channel and 1.5 SD in all channels), and trials where participants gave an incorrect response, were excluded from analysis. EEGs on correct-response trials were averaged for each condition separately, relative to a 100-ms pre-stimulus baseline. Twelve ERP waveforms (RF (match / non-match)×IF (IS / ID)×N-Back (0 / 1 / 2)) were therefore constructed for each participant.

Behavioural data analysis

Behavioural data include response times (RT) on correct-response trials and error rate. The data were analysed using a repeated-measure analysis of variance (ANOVA) with the between-subject factor Task (spatial / verbal) and the within-subject factors RF, IF and N-Back.

Electrophysiological data analysis

Latency windows 200-400, 400-600 and 600-800 ms in replacement (1-back minus 0-back) and shift (2-back minus 1-back) processes were selected for analysis. ERP amplitude, which were defined as mean amplitude difference within each time window in each electrode, was analysed separately using *t*-tests for the difference between IS and ID for the distractedness effects. ERP amplitude was also tested separately using t-tests for the difference from zero baselines. t-significance probability mapping was then performed for presentation of pattern difference between IS and ID. Repeated-measure analyses of variance (ANOVA) were applied for the electrodes F7, AF3, CP5, CP1, P7, P3 and corresponding right channels with the between-subject factor Task (Spatial / Verbal) and the within-subject factors ACP (anterior / central / posterior), IF (IS / ID) and Hemisphere (Left / Right).

An α-level of .05 was set for all statistical analyses. Greenhouse-Geisser corrections were applied and corrected *p*-values were reported where appropriate.

RESULTS

Behaviour data

Fig. 2 shows all the behavioural data. Response time to match stimuli was shorter than that to non-match stimuli, $F(1,10)= 13.53$, $p= .004$ and the difference is increased with increasing memory load $F(1.3,12.8)= 23.79$, $p< .001$. The F values of all other RT effects were

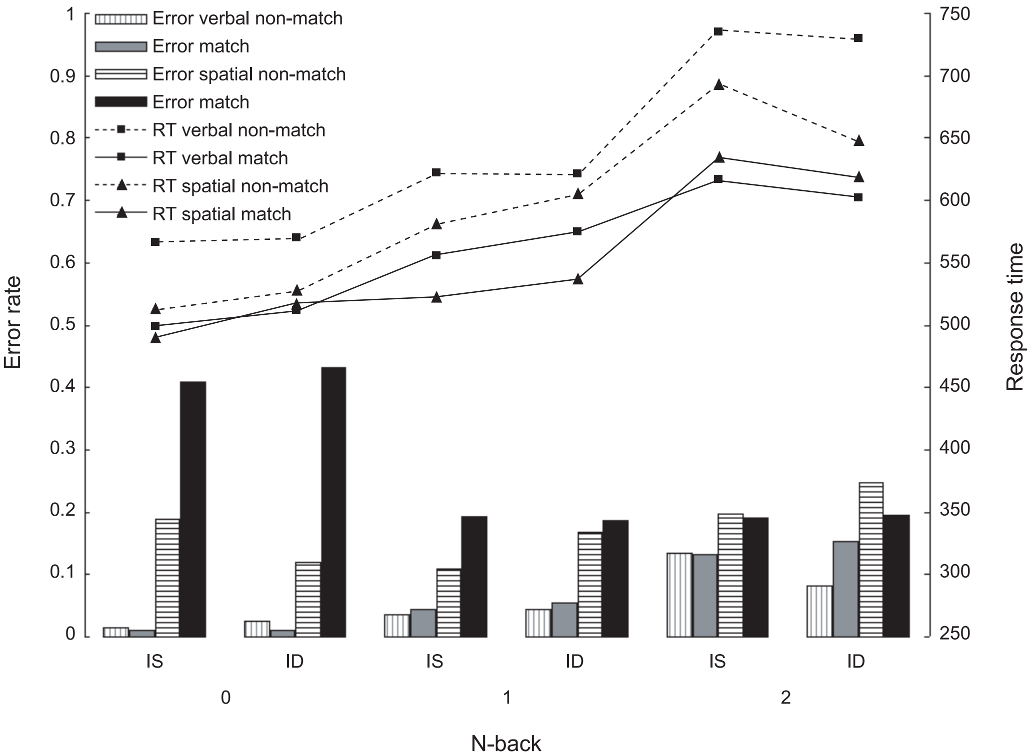

Figure 2. Response time (lines) and error rate (bars) in 0-, 1-, and 2-back conditions, separately for ID and IS conditions, for spatial and verbal tasks, and for match and non-match trials.

smaller than 3.58 with p values larger than .064. Error rate in spatial tasks were higher than in verbal tasks, $F(1,10)= 11.79$, $p= .006$. No other error rate-effects were statistically significant. The F values of all other error-rate effects were smaller than 3.59 with p values larger than .068.

Electrophysiological data

Fig. 3 shows t-statistical maps of replacement effects. Fig. 4 illustrates t-statistical maps of shift effects. Fig. 5 demonstrates grand mean amplitude of replacement (1-back minus 0-back difference) and shift (2-back minus 1-back difference) effects in every condition.

The t-statistical maps

The t-statistical maps provide intuitive patterns of information processing in replacement (Fig. 3). As shown in t-statistical maps, distractedness effects were obvious in spatial replacement. Interference began at around 200 ms after stimulus onset in posterior regions, at around 400 ms in frontal regions, and lasted until the end of the epoch (800 ms). In contrast, distractedness effects were not obvious in verbal replacement. In general, the amplitude in ID tended to be more positive-going especially in the posterior areas. This tendency could not be seen in verbal replacement. A possible interpretation is that patterns in ID were about the same (generally negative) in both spatial and verbal replacement, but patterns in IS were quite different. In spatial replacement, a generally negative-going pattern could be seen in IS, whereas a posterior positive-going pattern was seen in ID. No obvious pattern change was observed as time went in both spatial and verbal replacement.

In spatial replacement, the amplitude in IS was significantly negative-going in particular electrodes, and sustained around left frontal and right parietal regions. In

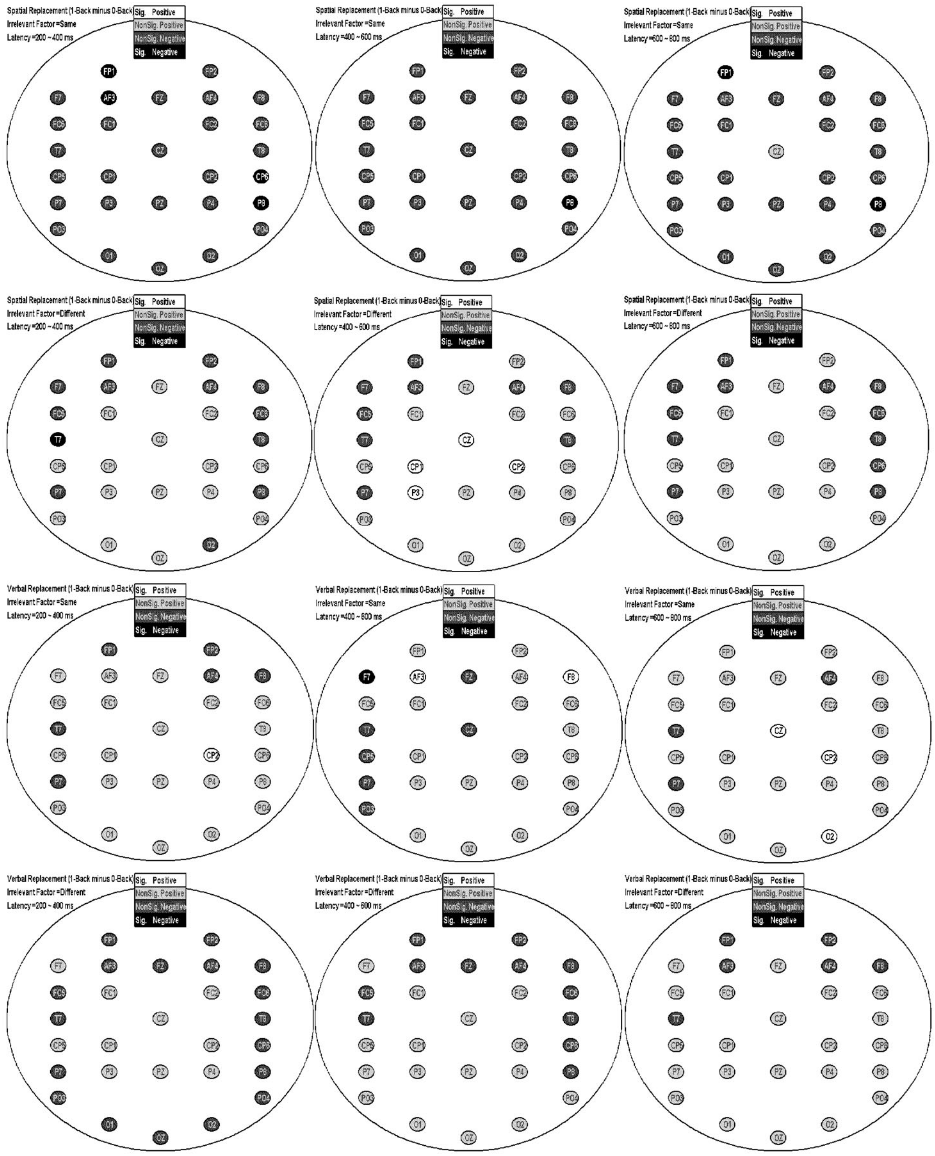

Figure 3. The *t*-statistical maps demonstrate effects of spatial replacement elicited in IS (Row 1) and ID (Row 2) conditions, and verbal replacement elicited in IS (Row 3) and ID (Row 4) conditions, in successive three time windows: 200-400 ms (Column 1), 400-600 ms (Column 2) and 600-800 ms (Column 3). The white, light grey, dark grey and black labels represent significant positive-going, non-significant positive-going, non-significant negative-going and significant negative-going amplitudes in these electrodes.

verbal replacement, in contrast, the amplitude in IS was significantly positive-going in particular electrodes. Interference began at around 200 and 400 ms after stimulus onset in posterior and in frontal regions, respectively, and returned to posterior regions toward the end of the epoch (800 ms). These significances were not seen in ID in verbal replacement. These results suggested that interference from the irrelevant domain 'blurred' ERP patterns in verbal replacement.

The pattern of shift effects (Fig. 4) was quite

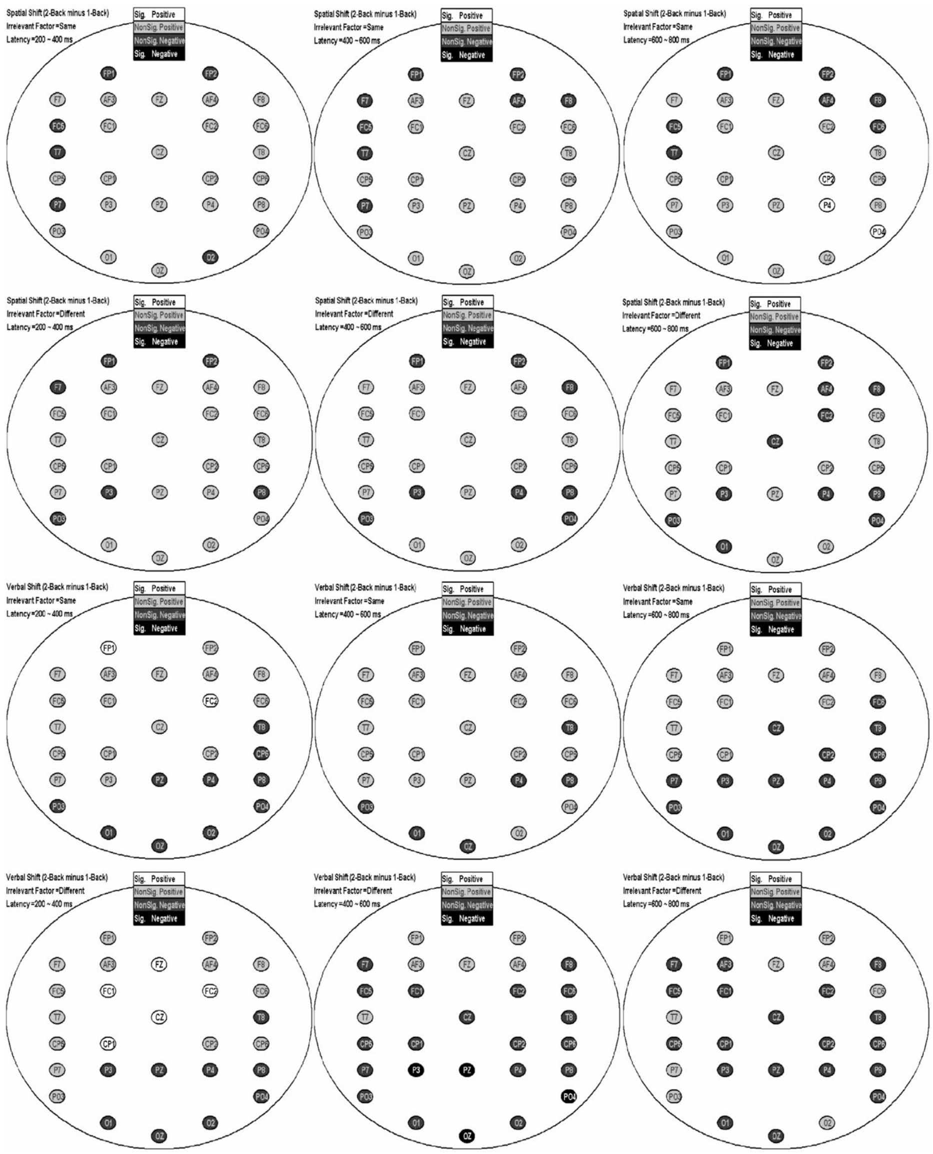

Figure 4. The *t*-statistical maps demonstrate effects of spatial shift elicited in IS (Row 1) and ID (Row 2) conditions, and verbal shift elicited in IS (Row 3) and ID (Row 4) conditions, in successive three time windows: 200-400 ms (Column 1), 400-600 ms (Column 2) and 600-800 ms (Column 3). The white, light grey, dark grey and black labels represent significant positive-going, non-significant positive-going, non-significant negative-going and significant negative-going amplitudes in these electrodes.

different from that of replacement effects (Fig. 3). Distractedness effects in spatial shift (Fig. 4) were obvious only in some electrodes. Numerically, distractedness effects extended from 200 to 800 ms in FC5 and P3 and from 400 to 800 ms in Cz. In contrast to spatial replacement (Fig. 3), distractedness effects in shift (Fig. 4) tended to be unsystematic. For example, they could be positive-going in P7 but negative-going in P3. Verbal shift also had no obvious distractedness effects.

Generally speaking, the amplitude in spatial shift

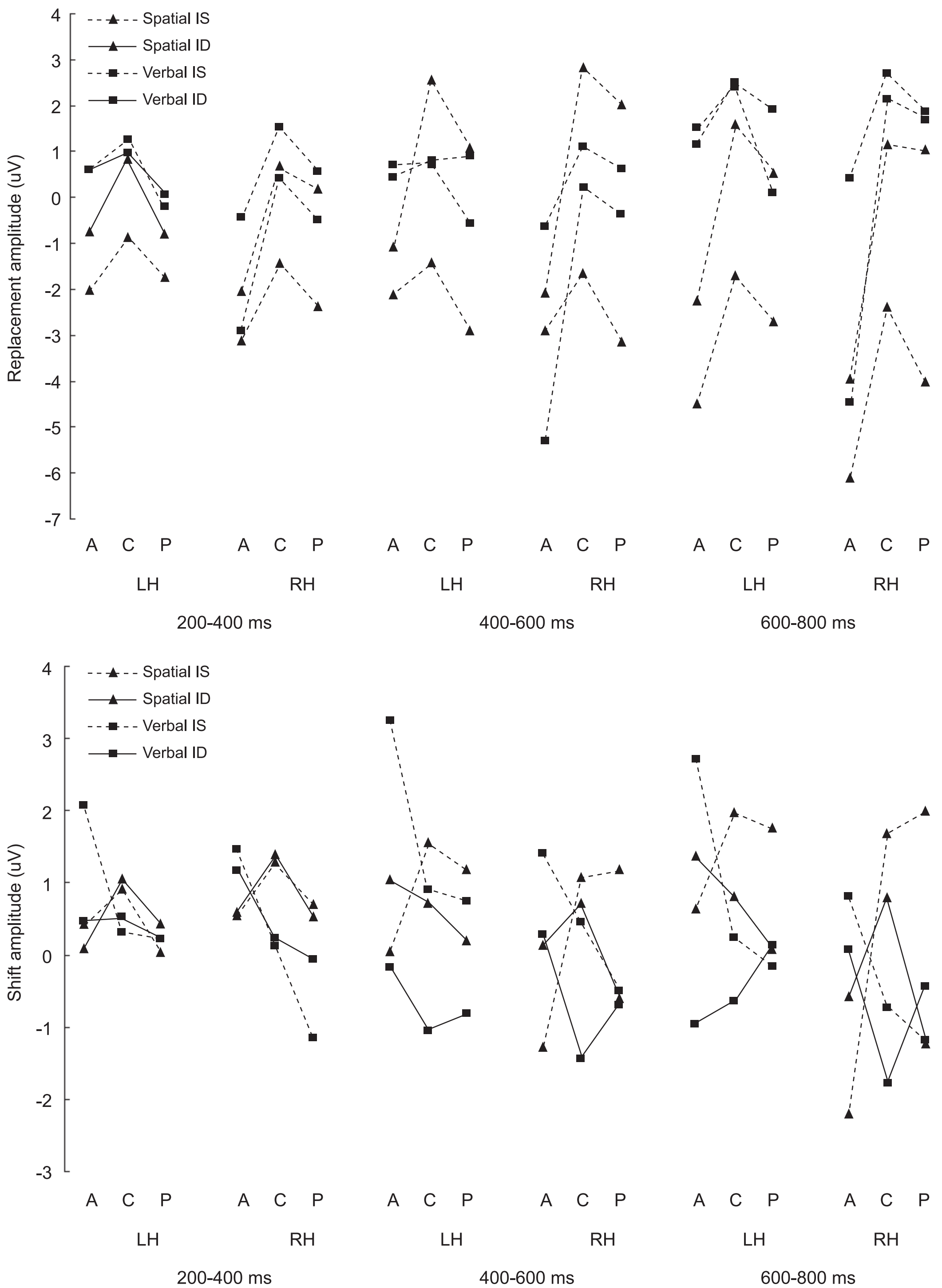

Figure 5. Replacement (upper) and shift (lower) amplitudes elicited during spatial (triangle) and verbal (square) tasks. Solid lines indicate ERPs elicited under ID condition. Dashed lines indicate ERPs elicited under IS condition. A: anterior; C: central; P: posterior; LH: left hemisphere; RH: right hemisphere.

was positive-going in both IS and ID, in contrast to that in spatial replacement (Fig. 3). Patterns in spatial shift (Fig. 4) did not change much as time went. On the other hand, amplitude in verbal shift was in general also positive-going in IS, but negative-going in ID. As time went, the amplitude tended to be negative-going especially in the posterior regions, but this tendency was not very obvious.

In spatial shift (Fig. 4), the amplitude in IS was significantly positive-going only at 600-800 ms in CP2, P4 and PO4 electrodes. In ID, no significant tendency was observed in any of the thirty-two electrodes. In verbal shift, the amplitude in IS was significantly positive-going only at 200-400 ms in FP1 and FC2 electrodes. However, in ID at 200-400 ms, the amplitude was significantly positive-going in five electrodes. On the other hand, at 400-600 ms, the amplitude was significantly negative-going in four electrodes. The electrodes showing significant tendency were dirtributed from frontal to occipital areas, and tended to change from positive-going to negative-going as time went.

ANOVA for replacement ERPs

A marginally significant Task effect (Fig. 5) was found in the time window of 200-400 ms, where the amplitude was more negative going under spatial instructions than those under verbal instructions, $F(1, 10)= 3.33$, $p= .098$. In the time window of 400-600 ms, the amplitude was more positive-going in ID than in IS under spatial instructions, whereas the amplitude was more positive-going in IS than in ID under verbal instructions, as evidenced by a marginally significant IF×Task interaction, $F(1, 10)= 4.39$, $p= .063$. Another marginally significant ACP effect showed that the amplitude was most positive-going in central electrodes and most negative-going in anterior electrodes, whereas those in posterior electrodes were amid them, $F(2, 20)= 3.81$, $p= .072$. The amplitude differences between ID and IS conditions increased from anterior to posterior electrodes, as evidenced by a significant IF×ACP interaction, $F(2, 20)= 13.22$, $p= .002$. Another significant IF×ACP interaction in the 600-800 ms time window revealed that the amplitude differences between ID and IS conditions increased from anterior to posterior electrodes, $F(2, 20)= 4.80$, $p= .042$. A marginally significant three-way IF×Hemisphere×Task interaction, $F(1, 10)= 4.17$, $p= .068$, revealed that the amplitude in ID were more negative-going than in IS in the left hemisphere but the ID amplitude was about the same as the IS amplitude under verbal instructions in the right hemisphere. Under spatial instructions, the ID amplitude wasere more positive-going than the IS amplitude. Other effects and interactions in replacement were not significant. The F values of all other replacement effects were smaller than 3.24 with p values larger than .101.

ANOVA for shift ERPs

Unlike replacement, all effects and interactions were not significant in ANOVA of 2-back minus 1-back amplitude difference (shift). The F values of all shift effects were smaller than 2.690 with p values larger than .131.

DISCUSSION

In replacement, significant or marginally significant interactions with irrelevant features were found at 400-600 ms, and significant interactions at 600-800 ms were also noted. These results indicate that cross-domain influence existed in replacement and lasted for at least 800 ms in latency. The assumption that a task with top-down control and cross-domain stimuli may provide a "pure" comparison between spatial and verbal information processing is thus challenged.

The first implication from these interactions is the possible effect of instruction. At 400-600 ms, the replacement-amplitude was more positive-going in ID than those in IS under spatial instructions, whereas the replacement-amplitude was more positive-going in IS than those in ID under verbal instructions. This pattern implicates that cross-domain interference did not depend on ID or IS, but on verbal or spatial instructions. If the irrelevant domain was verbal (i.e., under spatial instructions), the replacement-amplitude would be more positive-going at 400-600 ms, and vice versa. Together with the following findings that the amplitude at 200-400 ms was more negative-going under spatial instructions than that under verbal instructions, an interesting pattern emerges. The replacement-amplitude was more negative-going at 200-400 ms but more positive-going at 400-600 ms under spatial instructions, whereas the replacement-amplitude was less negative-going at 200-400 ms but less positive-going at 400-600 ms under spatial instructions. The conclusion is that the stimulus effects are stronger under verbal instructions than under spatial instructions.

The second implication is about functional anatomy. Amplitude differences between ID and IS conditions at 400-800 ms revealed that cross-domain influence was larger in posterior areas than in frontal areas. The frontal lobes are therefore "relatively distractedness-free" areas in replacement.

Effects and interactions from irrelevant domains were not significant in shifts. Together with the influences from the irrelevant domain shown in replacement, an interesting possibility is that such influence is originated from perceptual process per se because replacement manipulates external stimuli but shift manipulates already-encoded information. This would be inconsistent with the assumption that identical stimuli eliminate difference in perceptual processes and provide a pure comparison between spatial and verbal information processing. Further experiments are necessary to clarify this issue.

Response time was longer in spatial tasks than in verbal tasks. Error rate was also higher in spatial tasks than in verbal tasks. These behavioural results altogether suggest that spatial tasks are more difficult than verbal tasks. This conclusion provides reasonable explanation for the conclusion from ERP results, where verbal effects were stronger than spatial effects[15]. The prolongation of response time with memory loads also suggests a similar effect that 2-back task is more difficult than 1-back task, and 1-back task is more difficult than 0-back task.

From visual inspection of t-statistical maps, interference from the irrelevant domain 'blurred' ERP patterns in verbal replacement. In contrast to verbal replacement, ERP patterns seem to be 'sharper' for ID in verbal shift. A possible explanation is that shift manipulates already-encoded information and thus the irrelevant domain of a new stimulus has no direct influences in the shift process. The temporal changes in the spatial replacement implies an information flow of the posterior-anterior-posterior pattern, whereas the temporal changes in verbal shift implies unidirectional information flow from frontal to occipital areas. In comparison with the logical model of n-back tasks (Fig. 1), an interesting possibility is that replacement is related to posterior areas and shift is related to anterior areas (but information would flow to the posterior areas afterwards). Further experiments are necessary to examine and modify this interesting proposal.

CONCLUSION

Cross-domain interference from nominally irrelevant domains was observed in replacement. Thus, irrelevant domains are not really irrelevant. Consequently, even when identical stimulus displays are used to exclude perceptual effects, a 'pure' comparison of spatial and verbal information processing in WM tasks is still not general but process-specific. Thus, it is important to take the cross-domain interference into account while drawing conclusions from neuropsychological experiments.

REFERENCES

1. Baddeley AD, Hitch GJ. Developments in the concept of working memory. Neuropsychology 1994;8:485-93.
2. Smith EE, Jonides J. Working memory: a view from Neuroimaging. Cognit Psychol 1997;33:5-42.
3. Gevins A, Cutillo B. Spatiotemporal dynamics of component processes in human working memory. Electroencephalogr Clin Neurophysiol 1993;87:128-43.
4. Jansma JM, Ramsey NF, Coppola R, et al. Specific versus nonspecific brain activity in a parametric N-back task. Neuroimage 2000;12:688-97.
5. Ragland JD, Turetsky BI, Gur RC, et al. Working memory for complex figures: an fMRI comparison of letter and fractal n-back tasks. Neuropsychology 2002;16:370-9.
6. Meegan DV, Purc-Stephenson R, Honsberger MJ, et al.

Task analysis complements neuroimaging: an example from working memory research. Neuroimage 2004;21: 1026-36.
7. Meegan DV, Honsberger MJ. Spatial information is processed even when it is task-irrelevant: implications for neuroimaging task design. Neuroimage 2005;25:1043-55.
8. Wolach I, Pratt H. The mode of short-term memory encoding as indicated by event-related potentials in a memory scanning task with distractions. Clin Neurophysiol 2001; 112:186-97.
9. Awh E, Jonides J, Reuter-Lorenz PA. Rehearsal in spatial working memory. J Exp Psychol Hum Percept Perform 1998;24:780-90.
10. Berti S, Schröger E. A comparison of auditory and visual distraction effects: behavioral and event-related indices. Cogn Brain Res 2001;10:265-73.
11. Lange EB. Disruption of attention by irrelevant stimuli in serial recall. J Mem Lang 2005;53:513-31.
12. Lawrence BM, Myerson J, Abrams RA. Interference with spatial working memory: an eye movement is more than a shift of attention. Psychon Bull Rev 2004;11:488-94.
13. Logie RH, Zucco GM, Baddeley AD. Interference with visual short-term memory. Acta Psychol (Amst) 1990;75: 55-74.
14. Delorme A, Makeig S. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. J Neurosci Methods 2004; 134:9-21.
15. McEvoy LK, Smith ME, Gevins A. Dynamic cortical networks of verbal and spatial working memory: effects of memory load and task practice. Cereb Cortex 1998;8:563-74.