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Brain Research Bulletin 69 (2006) 214–221

BRAIN RESEARCH BULLETIN

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Backward inhibition in a task of switching attention within verbal working memory

Min Bao [a], Zhi-Hao Li [b], Xiang-Chuan Chen [a], Da-Ren Zhang [a,*]

[a] Hefei National Laboratory for Physical Science at Microscale, and School of Life Science, University of Science and Technology of China, Hefei, Anhui 230026, PR China

[b] Department of Biomedical Engineering, Emory University, Atlanta, GA 30322, United States

Received 11 July 2005; received in revised form 21 November 2005; accepted 7 December 2005
Available online 4 January 2006

Abstract

Three experiments were conducted to examine the backward inhibition effect in attention switching within verbal working memory. Experiment one showed significant backward inhibition effect in a "tri-count task". Experiment two suggested that the effect was not due to a perceptual inhibition on the previously presented figure. Experiment three excluded the sequential expectancy explanation for this inhibition effect. Our results suggest that attention switching between working memory items is accompanied by inhibition of the previously attended working memory item. The findings are discussed in respect to the account of the executive function.

Keywords: Working memory; Attention switching; Backward inhibition

1. Introduction

Attention allows people to selectively process the environment that is most relevant to their goals [9]. It was proposed long time ago that people could focus attention on just one "object" at a time [23,46]. This issue motivated a lot of investigation in different fields, including studies of switching attention between task sets [25,38,48] and studies of switching attention between working memory representations [12–14,26–29,52]. Task switching studies suggest that shifts between task sets are accompanied by inhibition of the previous task set [22,33,34], which is called "backward inhibition". The present study aims to investigate whether switching attention within working memory also coexists with concurrent inhibition of the previously attended working memory item.

One function of working memory is to maintain and manipulate information on line [2,3,15–18,49]. Cowan and many other working memory researchers currently assume a three-level functional architecture of memory according to the degree that the mental representations are activated. Within this framework, all passive memory representations belong to long-term memory (LTM); the currently activated subset of representations in LTM constitutes working memory; and the smaller set of representations that a person is aware of at any time comprises the focus of attention [1,5–8,32,36,42,50]. Recently, Oberauer [43] proposed the concentric model distinguishing three states of working memory representations: the activated LTM, the "region of direct access", and the "focus of attention". In fact, in the concentric model Oberauer distinguishes the "focus of attention" in Cowan's model into two levels: a capacity-limited "region of direct access" that holds a limited number of chunks available to be used in ongoing cognitive processes (this region corresponds most closely to what Cowan named the "focus of attention"), and a "focus of attention" to hold at any time the one chunk that is actually selected as the object of the next cognitive operation.

The classic Sternberg task demonstrates that people do not have simultaneous and immediate access to all items in working memory. Instead, a serial scan of memory items requires shifting attention across them [19,51]. With a serial "dual-count" task, Garavan [12] further measured the time cost of this attention switching and sought to elaborate the process underlying it. The "dual-count" task required participants to maintain two running

* Corresponding author. Tel.: +86 551 3601447; fax: +86 551 3601443.
E-mail address: drzhang@ustc.edu.cn (D.-R. Zhang).

0361-9230/$ – see front matter © 2005 Elsevier Inc. All rights reserved.
doi:10.1016/j.brainresbull.2005.12.007

counts of the number of times that one of two figures appeared, respectively. According to whether the successive stimuli were different or the same, two types of counting sequences were defined as "switch" (successive stimuli were different) and "nonswitch" (successive stimuli were same). "Nonswitch" reaction times were about 500 ms shorter than that of the "switch" condition. Garavan interpreted this difference as the cost for shifting the focus of attention from one counter to the other within working memory, and proposed that internal focus of attention is limited to just one item.

Noticeably, there are ERP and fMRI evidences showing that the internal attention switching is accompanied by the prefrontal–cingulate co-activation [13,14,26–29,52]. The cingulate and prefrontal co-activation was often found to be closely related to conflict monitoring and inhibitory control of the automatic or intrinsic attentional biases [4,31]. For the tri-count task, the automatic or intrinsic response is to repeatedly update the same count. It conflicts with a response requiring attentional switch and updating a different count in the "switch" condition. In addition, behavioral studies found an increasing shift cost with memory set size indicating the interference between memory items when one of them must be selected for processing [43–45]. Combining these behavioral and neuroimaging evidences, it is implicated that a successful "switch" may require the inhibition on the previously attended working memory item to reduce the interference between the previously and currently attended working memory item. If this is the case, we should be able to observe a backward inhibition phenomenon in the serial count tasks (e.g. the tri-count task).

Mayr and Keele [34] have provided evidence that selection of one task set is supported by inhibition of the previous task set. They found "backward inhibition" by comparing sequences of choice reactions in a paradigm where participants switched between three sets A, B, and C. In a sequence like ABA, task set A would be inhibited when switching to B. When a switch back to A follows immediately, A is still inhibited and reaction times will be particularly slow. Consistent with this idea, they found longer reaction times on the last reaction in sequences of lag-2-repetition ("inhibition" type) compared to lag-2-norepetition ("control" type). Using an altered methodological approach, Hübner et al. [22] confirms that backward inhibition counteracts perseverative tendencies when switching to a new task, with the evidence that backward inhibition selectively reduces interference exerted by the preceding task set.

The "tri-count" task was used in the present study in which the internal attention switched across three working memory items (A, B and C). Based on the similar logic as in Mayr's and Keele's study [34], we compared the reaction times on two kinds of counting sequences ("inhibition" type: ABA, CBC, BAB, BCB, CAC and CBC and "control" type: CBA, ABC, CAB, ACB, BAC and ABC) to see whether backward inhibition also exists in attention switching within working memory or not. If the answer is YES, we should observe longer reaction times on the last reaction of sequences of "inhibition" type compared to "control" type.

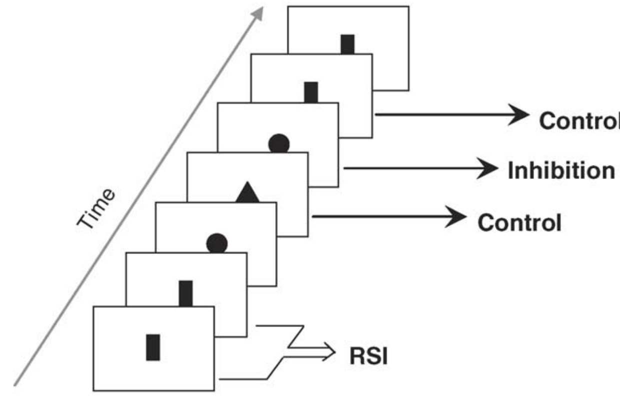

Fig. 1. Schematic diagram of the stimuli used in the tri-count task.

2. Experiment 1

2.1. Participants

The participants of all experiments of the present study are graduates or undergraduates of the University of Science and Technology of China (USTC). They gave consent to participate in the experiments and in return received course extra credit or monetary compensation.

2.2. Methods

Eighteen subjects (eight female, mean age 20.2 and age range 17–25) participated in experiment 1. We used the software "Presentation" (Neurobehavioral Systems Inc., http://nbs.neuro-bs.com/) to present the stimuli. The task included five pre-experiment warm-up blocks and 60 formal blocks that totally lasted about 1 h. The stimuli were random lists of three types of red geometric figures (rectangle, circle or triangle with equal covering area) displayed against a black background. Each subject's bar pressing would erase the current figure and call up a new one after a fixed 100 ms response stimulus interval (RSI) (Fig. 1). To proceed the task, participants were asked to press the spacebar at their own pace and to count the number of times that each kind of figure had appeared till the end of the block, at which time an instructing sentence was presented instructing subjects to report their counting results. After their oral report, they immediately received an oral feedback by the experimenter in the form of "right" or "wrong, the correct counts should be XXX". Subjects were asked to proceed through each block as accurately and quickly as possible. Both reaction time (RT) for each individual presentation (the time from a figure drawn on screen to subsequent key pressing) and the correctness of final counting result were recorded.

For the three figure types, there were six permutations of reporting order (R-C-T, R-T-C, C-R-T, C-T-R, T-R-C, and T-C-R). The 18 subjects were randomly divided into six groups with each group using one reporting order. RTs recorded in the 60 formal blocks were used in subsequent analysis which includes 226 responses of the "inhibition" type and 215 responses of the "control" type. We varied the number of figures within one block from 16 to 25 across blocks. This was necessary because if subjects knew how many figures were in a block, they would only need to count two of the figure types and derive the other count by simple subtraction. To avoid two-digit number counting, the occurrence of a figure in a block was no more than nine.

2.3. Results

The counting accuracy was computed as the percentage of the correctly reported blocks in the total of 60. Most errors were of the type that only the value of one digit was incorrect but off by only one. It is reasonable that the participants were diligent in updating their items in the blocks with this type of error. With or without considering this type of error, the counting accuracy was 87.8 ± 5.3% (absolute accuracy) and 95.0 ± 3.3% (relative accuracy), respectively. Our data showed that the RT for the "inhibition" type was significantly longer than that for the "control" type (paired t-test, $t = 6.68$, $p < 0.00001$; mean RT for "inhibition": 1899 ms; mean RT for "control": 1776 ms).

The result is consistent with the "backward inhibition" expectation. But one may ask whether the backward inhibition merely occurs on low level aspects. Namely, whether the backward inhibition is completely due to the perceptual inhibition on the previously presented figure? To answer this question, in experiment 2a subjects were required to perform an extra figure identification task besides the tri-count task. If we can still observe similar RT difference after subtracting RT of the figure identification task from that of the tri-count task, it is more likely that backward inhibition also exists in memory representation level.

3. Experiment 2

3.1. Experiment 2a

3.1.1. Methods

Another 12 participants (three female, mean age 21.1 and age range 18–23) completed 30 blocks of "figure identification" task and 30 blocks of "tri-count" task in experiment 2a. The order of the two sections was counter-balanced across participants. Before each section, the participants completed three corresponding warm-up blocks. The total experimental time was about 45 min. The parameters and procedure for the "tri-count" task is the same as in experiment one.

For the "figure identification" task, we used exactly the same stimuli presentation program as that in the "tri-count" task. However, without keeping an online count of each figure type, subjects just needed to identify each presented figure by pressing a pre-defined key (one of the "," "." and "/" key on the key board). For each individual subject, the figure-key mapping was consistent with his own reporting order in the "tri-count" task. For example, if one should report his counting result in the order of C-R-T, then in the "figure identification" task, he should press the "," key on identifying an circle, the "." key on identifying a rectangle, and "/" on a triangle. The RSI of both tasks were fixed 100 ms. Subjects made 120 responses of the "inhibition" type and 120 responses of the "control" type in both tasks.

3.1.2. Results

The relative accuracy for "tri-count" task of this group of subjects was 93.9 ± 8.1%. The absolute accuracy was 85.6 ± 12.3%. The accuracy for figure identification task was 95.1 ± 2.3%.

As we found in experiment one, in the "tri-count" task, the RT for the "inhibition" type was significantly longer than that for the "control" type by 122 ms (paired t-test, $t = 3.70$, $p = 0.004$; mean RT for "inhibition": 1693 ms; mean RT for "control": 1571 ms). In the figure identification task, the RT for the "inhibition" type was also significantly longer than that for the "control" type but by only 39 ms (paired t-test, $t = 3.30$, $p = 0.007$; mean RT for "inhibition": 670 ms; mean RT for "control": 631 ms). The result of the figure identification task showed that the low level contributions did exist in backward inhibition. But its contribution (39 ms) was no more than 1/3 of the "tri-count" inhibition-control RT difference (122 ms). We could subtract this small contribution from the backward inhibition cost (RT difference between the "inhibition" type and the "control" type) of the "tri-count" task without affecting the significance of the RT difference brought by a mental backward inhibition (paired t-test, $t = 2.53$, $p = 0.028$, see the third pair of bars in Fig. 2). So, it seemed that at least backward inhibition observed in the "tri-count" task was not completely brought by low level process such as figure identification.

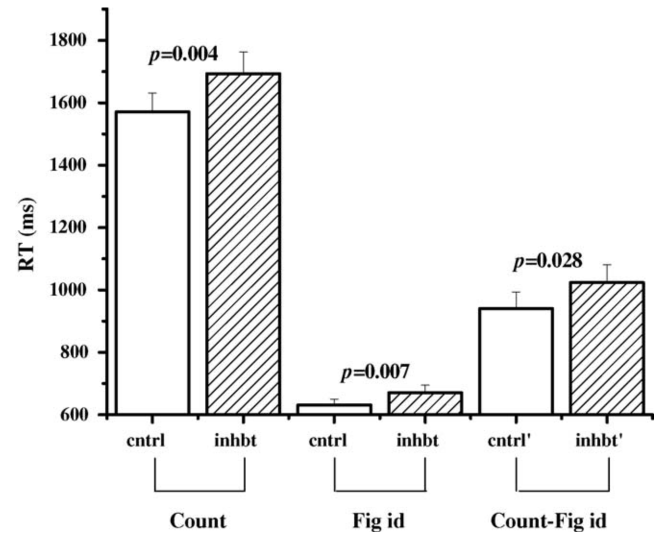

Fig. 2. Results of the experiment 2a. The left/middle bar pair (Count) shows RT comparison of the "control" (cntrl) and the "inhibition" (inhbt) condition in the tri-count/figure identification task; the right bar pair shows "cntrl" vs. "inhbt" RT comparison with the contribution of figure identification being subtracted out (cntrl' = cntrl of "Count"-cntrl of "Fig id", inhbt' = inhbt of "Count"-inhbt of "Fig id"). In the three comparison pairs, RTs of the "inhbt" conditions are all significantly longer than that of the corresponding "cntrl" conditions. The error bars stand for standard errors.

The experiment 2a was based on a "pure insertion or simple subtraction" premise. Although commonly used in many studies, this premise really involves some problems. Therefore, in the experiment 2b, we let two counts to relate to one figure each ("B" and "C"), and the third count was responsible for two different figures ("a" and "A"). If the backward inhibition only occurred due to a perceptual inhibition on the previously presented figure, it can be expected that there is no RT difference between a "CBA" sequence and an "aBA" sequence, and that an "ABA" sequence will be slower than an "aBA" sequence.

3.2. Experiment 2b

3.2.1. Methods

Another 12 participants (five female, mean age 21.5 and age range 18–27) completed 60 blocks of a modified "tri-count" task in experiment 2b, in which four geometric figures were recruited for the counting stimuli. The RSI was fixed 100 ms too.

In this task, the possibility of the four figures, rectangle, diamond, circle and triangle, was 16.7%, 16.7%, 33.3% and 33.3% (i.e. 1:1:2:2). The rehearsal order was counter-balanced across the subjects, and there were six kinds of rehearsal orders: PCT (parallelogram–circle–triangle), PTC, CPT, CTP, TCP and TPC.

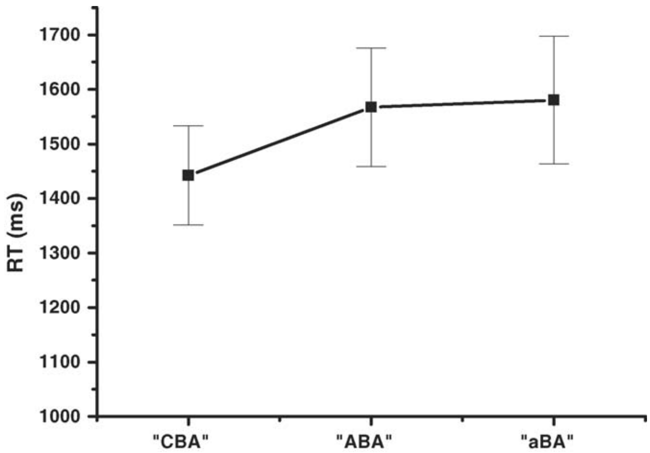

Fig. 3. Results of the experiment 2b. The error bars stand for standard errors. RTs of the “CBA” condition are significantly shorter than those of the other two conditions which have no significant difference in between.

Let’s use “B” for circle, “C” for triangle, “A” for rectangle and “a” for diamond. We specially concerned three kinds of triplets. The first type was called as the “CBA” type, which included CBA, CBa, BCA and BCa. The second type was called as the “ABA” type, which consisted of ABA, aBa, ACA and aCa. And the third type was called as the “aBA” type, comprising aBA, ABa, aCA and ACa. Totally, there were 40 responses for the “ABA” type and the “aBA” type each, 80 responses for the “CBA” type, 223 responses for the “control” type and 238 responses for the “inhibition” type.

3.2.2. Results

The relative accuracy of the subjects was 95.9 ± 3.7%. The absolute accuracy was 87.6 ± 10.6%.

The result of “control” versus “inhibition” comparison replicated the former experiments. Namely, participants responded faster in the “control” condition than in the “inhibition” condition ($t = 4.10$, $p = 0.002$). Importantly (see Fig. 3), the reaction time of the “CBA” (1442 ms) type was significantly shorter than that of the “ABA” (1567 ms) type ($t = 3.37$, $p = 0.006$), and that of the “aBA” (1581 ms) type ($t = 3.67$, $p = 0.003$). No significant difference between the “ABA” type and the “aBA” type was observed ($t = 0.34$, $p = 0.74$). The result of experiment 2b does not support the explanation that the backward inhibition only occurs on the perceptual level. Instead, it should occur on a higher level.

Backward inhibition was observed in all of the above experiments. However, there is still the sequential expectancy effect within our concern. This effect means that subjects prefer to perform the three tasks in turn within short runs [24]. In Mayr’s and Keele’s [34] experiments, an instruction cue was used between two successive tasks to exclude the sequential expectancy explanation, because this incorrect expectancy could be overwritten by subjects’ sufficiently long (e.g. 500 ms) preparation. In order to examine whether the observed backward inhibition could be due to this sequential expectancy effect, in the experiment 3a, cues were presented during the RSIs indicating which count participants should focus on for the next update. If the expected RT effect is not modulated through the manipulation of the cue-stimulus interval (CSI), the sequential expectancy explanation should be very unlikely.

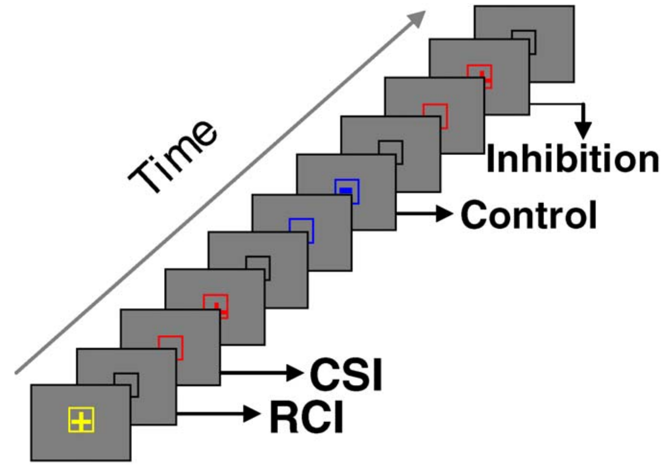

Fig. 4. Schematic diagram of the stimuli used in the experiment 3a.

4. Experiment 3

4.1. Experiment 3a

4.1.1. Methods

A new group of 24 participants (17 female, mean age 22.4, age range 17–27) were recruited for experiment 3a. They each completed one long preparatory section and one short preparatory section (the order of the sections was balanced across the subjects). Each section included 30 blocks. For each block, the initial three memory counts were all “5”. They each corresponded to one type of color (red, yellow and blue). The stimuli were plus or subtraction signs in one of the three colors (Fig. 4). Participants were told to add or subtract one to the corresponding count when seeing a plus or subtraction sign. Before the new stimulus came up, a frame in the same color as the upcoming stimulus appeared as an instruction cue telling the participants on which count they should focus for the next updating. The cue was always on the screen until a response was entered. The RCI (time between a response and the next cue) and the CSI (time between the cue and the next stimulus) could be varied. Two RCI/CSI combinations were implemented (600/50 ms and 50/600 ms, thus the RSI was always 650 ms) in two experiment sections, respectively. In this design, we have four experimental conditions: short preparatory “control”, short preparatory “inhibition”, long preparatory “control” and long preparatory “inhibition”.

This design was a little different from the original tri-count task because of the stimuli and two (instead of one) mathematical operations. These modifications were acceptable because the switch effect is stimuli independent; also, the increment and decrement operations equally affect RTs in different condition [12,14,43]. With such a paradigm, we could test whether the observed backward inhibition effect in the former experiments could merely be explained the sequential expectancy.

4.1.2. Results

The relative accuracies for the short and long preparatory condition were 89.2 ± 8.5% and 90.9 ± 8.1%. There was a numerical tendency toward higher relative accuracy for the long preparatory condition ($t = 1.23$, $p = 0.23$).

A 2 (switching condition: “inhibition” and “control”) * 2 (CSI: 50 and 600 ms) repeated measure ANOVA analysis yielded a significant main effects for the switching condition ($F(1, 23) = 15.7$, $p = 0.001$) and the CSI condition ($F(1, 23) = 5.26$, $p = 0.031$). But the interaction was not significant ($F(1, 23) = 1.40$, $p = 0.25$, see Fig. 5). Specifically, there was even a tendency toward the greater backward inhibition cost for the long preparatory interval. Paired t-test analysis revealed that

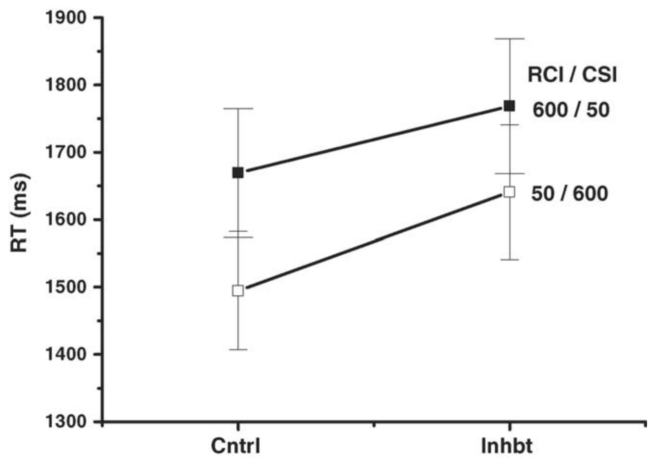

Fig. 5. Results of the experiment 3a. “Cntrl” stands for the switching condition of “control”; “Inhbt” stands for the switching condition of “inhibition”. The error bars stand for standard errors.

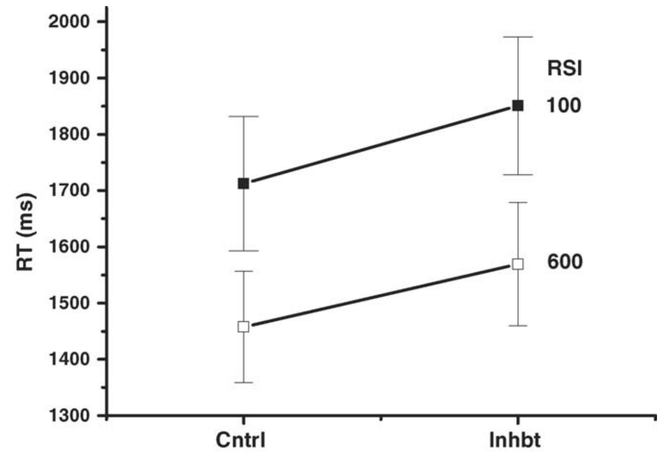

Fig. 6. Results of the experiment 3b. The error bars stand for standard errors.

the overall RTs decreased for the long preparatory interval suggesting that participants actually did use the advance information ($n = 20$, $t = 2.60$, $p = 0.018$, we failed to record the overall RTs of the first four participants. The comparison was only based on the data of the rest 20 participants. The ANOVA analysis of these 20 subjects showed significant main effects and non-significant interaction similar to that of all the 24 subjects).

This finding is similar to Mayr’s and Keele’s [34] results (the “second contrast”), suggesting that the backward inhibition effect observed in the present study should not be the result of the sequential expectancy explanation.

Another interesting trait of backward inhibition found by Mayr and Keele is its capability of persistence for a certain period of time. Therefore, in the following experiment, we compared the backward inhibition effect in short (100 ms) and long (600 ms) RSI conditions to see whether a similar phenomenon could be observed in the tri-count task.

4.2. Experiment 3b

4.2.1. Methods

Twelve new participants (five female, mean age 21.5 and age range 18–27) completed 60 blocks of tri-count task in experiment 3b. There were two sections, each including 30 blocks. The RSI of one section was fixed 100 ms and the other was 600 ms. The order of the two sections was counter-balanced across the subjects.

4.2.2. Results

A 2 (switching condition: “inhibition” and “control”) * 2 (RSI: 100 and 600 ms) repeated measure ANOVA analysis yielded a significant main effects for the switching condition, $F(1, 11) = 14.5, p = 0.003$, and the RSI condition, $F(1, 11) = 21.8$, $p = 0.001$. (The backward inhibition effect was significant in both RSI condition, paired t-test: RSI 100 ms, $t = 3.80$, $p = 0.003$; RSI 600 ms, $t = 3.13$, $p = 0.009$). But the interaction of the switching condition and the RSI factor was not significant ($F(1, 11) = 0.804$, $p = 0.39$, see Fig. 6).

The result showed that in tri-count tasks the backward inhibition effect really lasted for some time, and the backward inhibition cost did not significantly decrease at least in the RSI of 600 ms.

5. Discussion

Three behavioral experiments were performed to explore whether backward inhibition also existed in attention switching within verbal working memory. With a “tri-count” task design, there are only two types of possible twice switching sequence. After switched from one item to another, the attention can either switch back again to the first item (the “inhibition” type) or switch to a new item (the “control” type). If backward inhibition exists, we should observe longer reaction time on the last stimulus in trials of the “inhibition” type than of the “control” type. This is called the “mental backward inhibition” question. We are interested in this question because the answer could disclose an important characteristic of attention switching within working memory: whether internal attention switching coexists with inhibition on the previously attended item or not. In fact, in the first experiment, RTs for the “inhibition” type is significantly longer than that for the “control” type. This result supports our hypothesis that mental backward inhibition exists.

In spatial attention studies, people have found the “inhibition of return” phenomenon, that is, a slower “response” to a location from which exogenously cued attention had to be disengaged in the immediate past [47]. One popular explanation of the inhibition of return effect claims that attention is inhibited from moving to previously cued locations, thereby influencing perceptual processing at those locations. This interpretation is supported by neurophysiological evidence of smaller occipital P1 on valid-cue trials [35]. Posner and Cohen suggest that inhibition of return may reflect a mechanism that improves the efficiency of attentional searches by biasing attention toward novel locations and away from previously attended locations. On the other hand, Kübler et al. [26] identifies a supramodal switching process required for switching between working memory items, suggesting that switching between working memory items is a function of the “central executive” in Baddeley’s tripartite model [3]; Sylvester et al. [52] demonstrates a common cognitive mechanism involved in the allocation of attention, controlled by superior parietal cortex, in both the counter switching and response compatibility tasks; and some researchers also found extensively overlapping neural networks underlying orienting attention to locations in perceptual and mental representations [20,41]. These evidences indicate that the internal and external attention may have common neural substrates, perhaps both controlled by the attentional control system labeled as the "central executive". Combining the spatial and mental attention studies, a possible interpretation of mental backward inhibition would be that this inhibition effect may reflect a similar bias during internal attention switching that the attentional control system would avoid processing the working memory item from which the attention has just shifted away.

As Mayr and Keele [34] proposed, normal adults have the ability to finish off one task while resisting the tendency to jump to another one. This is called "goal stability". However, normal adults also can switch from one goal or action plan to another when necessary. This is called "goal flexibility". A paradox arises from the two opposing demands is that representations stable enough to resist incompatible action tendencies should also be difficult to abandon once a new goal needs to be established. Mayr and Keele [34] found that shifts between task sets are accompanied by inhibition on the previous task set. This inhibition was proposed to reflect that the utilization of inhibitory process on the once-activated task set can avoid perseverations efficiently, thereby resolving the "stability–flexibility" paradox. Hübner et al. [22] provides more direct evidence on this notion with the finding that backward inhibition selectively reduces interference exerted by the preceding task set. Similar "stability–flexibility" paradox also exists in the domain of switching attention within working memory. For example, on the one hand, in the "nonswitch" condition people can keep operating on one counter while resisting the tendency to add one to other counters. On the other hand, in the "switch" condition, people can switch to operate on a new correct counter successfully. The mental backward inhibition found here reveals an inhibitory process on the previously attended item during internal attention switching, thus provides a similar answer for the "stability–flexibility" paradox in memory domain.

To explore whether the backward inhibition merely comes from the perceptual level or not, we conducted experiment two which consisted of two sub-experiments. Based on the "pure insertion or simple subtraction" premise, experiment 2a compared the backward inhibition effect between a tri-count task and a figure identification task. Although we found backward inhibition in the figure identification task in which subjects had no memory demands, the RT cost was in the minority (less than 1/3) comparing to that brought by the counting task. Mayr and Keele [34] have proved that backward inhibition can be found in responses to the external features of stimuli (e.g. color, orientation, movement, etc.). So it is not surprising that we also found backward inhibition in our figure identification task. Particularly, in the figure identification task, subjects have to press three distinct keys. When a new geometric figure comes up subjects should change the responding finger. Since changing the finger meant a switch of motor control, the RT difference in the figure identification task could also come from the motor control level. Instead, in the "tri-count" task, subjects only press the spacebar, so attention switching on motor control is unnecessary. To say the least, even without considering the motor control effect, we still got significant RT difference brought by a mental backward inhibition after subtracting out the small contribution from the backward inhibition cost of the "figure identification" task. However, the "pure insertion or simple subtraction" premise is not necessarily the truth. For example, whether the figure identification and the counting proceed in strictly separable stages is unknown. In the experiment 2b, we used a modified tri-count task with two counts mapped to one figure each ("B" and "C") but the third count being responsible for two different figures ("a" and "A"). If the backward inhibition only occurs on the perceptual level, one cannot expect a RT difference between a "CBA" sequence and an "aBA" sequence. In addition, an "ABA" RT will be slower than an "aBA" RT. Our result does not support the perceptual explanation. In contrast, it is consistent with the interpretation that the backward inhibition observed in the "tri-count" task should also exist on the mental representation level.

However, the first two experiments could not exclude the sequential expectancy explanation [24]. Thereby in experiment 3a we used an instruction cue to forecast which count would be focused for next updating, and varied the RCI/CSI combination in different experimental sections. The result that backward inhibition is not modulated through the temporal manipulation of CSI contradicts with the sequential expectancy explanation. Moreover, in experiment 3b, the finding that the backward inhibition cost did not significantly decrease in the long RSI condition suggests that when attention is switched from one working memory item to the other, the previous attended item is also inhibited for a certain period of time.

It is noteworthy that the lag analysis of the first experiment in Oberauer's 2003 paper show that with larger set sizes the item selected just before the one presently focused could still be retrieved slightly faster than other items that were focused longer ago [44]. This RT pattern is contrary to ours. The reverse RT patterns may result from different experimental method between the two studies. In an earlier paper [43], Oberauer found switching cost increased with active (with updating requirement) setsize but not with passive (without updating requirement) setsize, which demonstrated different memory status of digits between active and passive set. Noticeably, Oberauer [43] also found when active setsize increased, the recall accuracy of passive digits kept uninfluenced in the first experiment but significantly descended in the second experiment. This fact indicates that in Oberauer's 2002 paper [43], the "active set" in the first experiment is credibly independent of the passive set, while the "active set" in his second experiment not. In the present study, our three counters were updated frequently. The digits in Oberauer's experiment one of the 2003 paper [44], instead, were never updated throughout a trial. Comparing to Oberauer's digits [44], our three counters are more close to the "active set" of the first experiment in Oberauer's 2002 paper. However, Oberauer's digits [44] are very close to the "active set" of the second experiment in that paper. Therefore, it is possible that the different working memory status between Oberauer's digits [44] and our counters leads to contrary finding of the two studies. To say it in detail, following the concentric model [43] our on-line updating counters are held in the "region of direct access", and competitive with each other. But Oberauer's [44] digits may be held within the "activated part of long-term memory", and do not contribute to crosstalk. Thus to avoid competition between updating counters, inhibitory process on the previous attended counter may be necessary. Instead, no inhibition on Oberauer's digits is needed.

The present paradigm might be used to assess the inhibitory function in special populations. In fact, some researchers have examined the task switching function in obsessive-compulsive disorder (OCD) patients [39] for OCD patients often have deficits in attentional inhibition. But inconsistent with their expectation, they did not find significant group difference on backward inhibition. This might be ascribed to the complexity of the inhibitory deficits in OCD. For instance, it was demonstrated that one of the inhibitory deficits, the negative priming deficits in OCD was strongest at relatively rapid presentation rates (100 ms), reflecting the modulation of psychophysical parameters on behavior of inhibitory deficits [10]. In addition, deficits in negative priming tended to be more apparent among OCD checkers as opposed to OCD non-checkers, suggesting that this particular cognitive deficit in OCD may vary across subtypes [40]. Given that obsessional doubt has been seen as a key clinical feature of OCD, a number of studies on memory showed OCD patients exhibited deficits in "memory confidence" [11,21,30,37,53]. So, if OCD patients were asked to fulfill the "tri-count" task, when attention is switched within working memory, the deficits in memory confidence could appear as lacking inhibition and excessive concern on previous attended item. Thereby perhaps the disappearance or reverse of backward inhibition would be observed. This can be an open question for our future research.

6. Conclusion

In the present study, we observed backward inhibition when attention switching across different verbal working memory items. The finding that backward inhibition occurs not only in task switch but also in working memory attention switch implies that it could be a particular instance of a general mechanism that serves to reduce interference from all potentially competing cognitive objects.

Acknowledgements

We thank all of the volunteers who participated in our experiments. This research is supported by the National Nature Science Foundation of China (30370478 and 30470572), and the Ministry of Science and Technology of China (2006CB500705).

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