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Memory Asymmetry of Forward and Backward Associations in Recognition Tasks

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Abstract

There is an intensive debate on whether memory for serial order is symmetric. The objective of this study was to explore whether associative asymmetry is modulated by memory task (recognition vs. cued recall). Participants were asked to memorize word triples (Experiment 1–2) or pairs (Experiment 3–6) during the study phase. They then recalled the word by a cue during a cued recall task (Experiment 1–4), and judged whether the presented two words were in the same or in a different order compared to the study phase during a recognition task (Experiment 1–6). To control for perceptual matching between the study and test phase, participants were presented with vertical test pairs when they made directional judgment in Experiment 5. In Experiment 6, participants also made associative recognition judgments for word pairs presented at the same or the reversed position. The results showed that forward associations were recalled at similar levels as backward associations, and that the correlations between forward and backward associations were high in the cued recall tasks. On the other hand, the direction of forward associations was recognized more accurately (and more quickly) than backward associations, and their correlations were comparable to the control condition in the recognition tasks. This forward advantage was also obtained for the associative recognition task. Diminishing positional information did not change the pattern of associative asymmetry. These results suggest that associative asymmetry is modulated by cued recall and recognition manipulations, and that direction as a constituent part of a memory trace can facilitate associative memory.

Keywords

memory; association; sequence; recognition; cued recall

Episodic experience is featured by its serial order or sequence of events. People tend to remember events that are interconnected by time or by their order; e.g., thunder always

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follows lightening, and a phone number is composed of a series of digits. Based on the list length, memory for serial order could be divided into memory for more than two items in sequence (e.g., triples, lists) and memory for associative pairs. Sequence memory is usually tested by serial recall, transitive inference, and recency judgment tasks (e.g., Fortin, Agster, & Eichenbaum, 2002; Heckers, Zalesak, Weiss, Ditman, & Titone, 2004; Lehn et al., 2009), whereas memory for associative pairs is tested by recall and associative recognition tasks. The association of serial events could be retrieved by their initial direction (forward association), or by opposite direction (backward association). Backward memory is a sensitive measure for brain lesioned patients and for old age (Sun et al., 2005; Thomas, Milner, & Haberlandt, 2003). Elderly people are impaired in both forward and backward digit span tasks (e.g., Gregoire & VanderLinden, 1997; Hester, Kinsella, & Ong, 2004). AD patients are selectively impaired in the backward reproduction of verbal and spatial span sequences (e.g., Carlesimo et al., 1998) and rats with hippocampus lesions can not form normal backward associations, while the formation of forward associations is preserved (Bunsey & Eichenbaum, 1996).

For a couple of decades it has been intensively debated whether memory for serial order is symmetric. The independent association hypothesis (IAH) proposes that direction is a general feature of memory for sequential associations (Kahana, 2002). Forward associations (A-B) are formed along with, but are better remembered than, backward associations (B-A). In contrast, based on the Gestalt theory, the associative symmetry hypothesis (ASH) proposes that item A and B are encoded as a single unit, and the association has the same strength, irrespective of whether it is cued forwardly or backwardly (Asch & Ebenholtz, 1962; Kahana, 2002; Kahana & Caplan, 2002).

Many distributed memory models are based on explicit but contrary assumptions regarding the symmetry of associations (Rizzuto and Kahana, 2001; Sommer, Schoell, & Buchel, 2008). Some models are built on the assumption that forward and backward associations have the same strength, such as the theory of distributed associative memory (TODAM, or convolution-correlational model. Murdock, 1982) and auto-associative matrix model (Rizzuto & Kahana, 2001). Other models assume separate forward and backward associations, and a forward advantage, such as retrieving effectively from memory model (REM, Shiffrin & Steyvers, 1997) and the search of associative memory model (SAM, Gillund & Shiffrin, 1984). Understanding what factors modulate associative asymmetry is therefore important for establishing theories of associative memory (Kahana, 2002; Sommer, Rose, & Buchel, 2007).

We first review recent findings favoring both, the IAH and the ASH. Then we point out that most studies using cued recall tasks report memory symmetry; whereas studies using recognition tasks report better memory for forward than backward associations, suggesting that associative asymmetry differs as a function of memory task. Finally we outline how we pursued experiments to address the issues on associative asymmetry in the present study

Brief review on studies related to IAH and ASH

Both, the IAH and the ASH are supported by experimental findings. In support of the IAH, Ebbinghaus (1885/1913) found that both forward associations (e.g., a-b, a-c) and backward associations (e.g., b-a and c-a) were formed when he used lists of meaningless syllables (e.g., a-b-c-d-e) to explore memory for serial order. In addition, associative memory was asymmetric, because a syllable was more strongly associated with the latter syllable, than with the previous one. Using a cued recall task, Kahana and Caplan (2002) sequentially presented two 19-word lists either once or four times. Recall performance with a forward probe (A-?) was better than that with a backward probe (?-B). Similarly, Thomas et al.

(2003) found that when participants recalled 4–6 word lists, their response times were faster for forward than for backward directions (c.f., Madigan, 1971). They thus assumed that participants use a forward search strategy in backward recall in order to recover the reversed order. In addition to word lists, when word triples were used, forward subpairs were also recalled better than backward subpairs (Kahana & Caplan, 2002). The asymmetry between forward and backward associations is enhanced when word lists (vs. pairs) are used (Murdock, 1966; Thomas et al., 2003), when pairs are composed of different word types (e.g., abstract vs. concrete), from different modalities (Murdock, 1965), and when double-cues are used (Kahana, 1993; Kahana & Caplan, 2002).

In addition to cued recall tasks, associative asymmetry was also found in studies of free recall and recognition tasks. Participants were twice as likely to recall the subsequent item as the prior one in a free recall task (Kahana, 1996). But associative interference and retrieval strategies are factors that are hard to control for in free recall tasks. As for recognition tasks, studies have found forward advantage using different paradigms. By using old/new recognition judgments, old and recombined pairs are presented, with the same-order and reversed-order formats included in old pairs. Forward pairs are recognized faster and more accurately than backward pairs when participants encode pairs under the unitization condition (Haskins, Yonelinas, Quamme, & Ranganath, 2008; Wiegand, Bader, & Mecklinger, 2010), under sentence encoding (Giovanello, Schnyer, & Verfaellie, 2009; but see Haskins et al., 2008), and under passive viewing conditions (Kahana, 1993). However, because participants are not asked to make judgment on direction, it is unclear whether directional information is retrieved and used for the old/new judgment. Compared with associative recognition, the directional judgment straightly tests whether participants remember the order information. Using this task, the results showed that the direction of forward pairs is more accurately judged than that of backward pairs (Greene & Tussing, 2001; Kounios et al., 2003).

On the other hand, in support of the ASH, some studies have found comparable memory performance for forward and backward directions, mostly in cued-recall tasks (e.g., Caplan, Glaholt, & McIntosh, 2006; Murdock, 1962, 1966), and high correlations between forward and backward recall in a test-retest procedure (e.g., Kahana, 2002; Caplan, 2005; Caplan et al., 2006; Madan, Glaholt, & Caplan, 2010; Sommer et al., 2007). In this procedure, participants are asked to recall a specific association twice (e.g., A—B pair was tested by A-? in Test 1 and ?-B in Test 2), during which half of the pairs are tested in the same direction (i.e., forward – forward and backward - backward, congruent condition), and the other half are tested in the opposite direction (i.e., forward-backward and backward – forward, incongruent condition). Using contingency analysis, the correlation between the congruent and incongruent conditions is calculated with Yule's Q as an index of dependence (Kahana, 2002; Hayman & Tulving, 1989). Because the performance of Test 2 is usually better than that of Test 1, the comparison of different correlation (e.g., congruent vs. incongruent) seems a better choice to determine whether forward and backward associations are significantly correlated. The ASH predicts that if the association is recalled in forward order, it could also be recalled in backward order, making the correlation under the incongruent condition high and comparable to that under the congruent condition (Kahana, 2002; Rizzuto & Kahana, 2000). Conversely, if forward and backward associations are modulated independently, the correlation under the incongruent condition could be low and different from that under the congruent condition. Kahana (2002) and Rizzuto & Kahana (2001) showed that there was a high correlation between forward and backward associations when word pairs were recalled (.99 vs .93 for congruent and incongruent conditions) (Caplan, 2005). Although the congruent Q is usually significantly higher than the incongruent Q , these values are near ceiling, thus their variances may be low (Caplan, 2005), and generally support the ASH (Madan et al., 2010). Similar findings have also

obtained when triples (Caplan et al., 2006), pairs (Madan et al., 2010; Rizzuto & Kahana, 2000, 2001); and object – location pairs (Sommer et al., 2007) are used.

Variables to influence memory asymmetry for triples and pairs

As introduced above, there are relatively consistent findings on associative asymmetry for sequence memory when the items are more than three (e.g., Caplan, 2005; Kahana & Caplan, 2002; Thomas et al., 2003), but whether forward and backward memory differs when word pairs and triples are used is still unclear. There are several potential variables that could influence memory asymmetry for pairs and triples. First, while the ASH is mainly supported by studies that adopted cued recall tests (for reviews, see Kahana, 2002, Sommer et al., 2007), the IAH is supported by studies that adopted free recall and recognition tests (e.g., Giovanello et al., 2009; Greene & Tussing, 2001; Kahana, 1996). This raises the possibility that associative asymmetry is modulated by memory task or retrieval requirement. Recognition memory tasks differ from cued recall task in various ways (Staresina & Davachi, 2006). Participants can make recognition judgment when the two words are presented (Giovanello et al., 2009; Kahana, 1993), but have to retrieve target responses, and exclude other inappropriate interference in the cued recall task. Some researchers propose that recalling an item from memory primarily depends on recollection process, whereas recognizing depends on both, recollection and familiarity (for reviews, see Eichenbaum, Yonelinas, & Ranganath, 2007; Rugg & Yonelinas, 2003; Yonelinas, 2001; but see Dunn, 2008; Squire, Wixted, & Clark, 2007). Others propose that recalling an item includes sequential sampling and a recovery attempt (SAM model, Raaijmakers & Shiffrin, 1992; Tomlinson, Huber, Rieth, & Davelaar, 2009), during which interference may occur. Recognition does not necessarily involve sequential sampling (Raaijmakers & Shiffrin, 1992). In recognition tasks, forward associations are more familiar by associative sequence and positional information than backward associations, thus forward advantage is obtained. In contrast, recalling from a probe could involve other processes that obscure associative asymmetry. To what extent task requirements modulate associative asymmetry needs systematic investigation.

Second, although associative asymmetry for pairs exists in recognition studies, the results are not consistent with respect to whether forward advantage is related to different types of word pairs. Word pairs can be divided into unitized (or fused, Kounios et al., 2003), semantically related and semantically unrelated pairs (see Achim, Bertrand, Montoya, Malla, & Lepage, 2007). There is evidence for a significant forward advantage when two words are unitized, but the results on unrelated pairs are inconsistent. For example, Haskins et al. (2008) found that forward and backward unrelated pairs were recognized at similar levels when both words were encoded as part of a sentence, but Giovanello et al. (2009) found that under both, item and relational encoding conditions participants recognized unrelated forward pairs better and more quickly than backward pairs. Also note that previous studies mostly used semantically *unrelated* word pairs. Only a few studies employed semantically *related* pairs and found that semantic relatedness enhances the recall, but impairs associative recognition in some situations (Greene & Tussing, 2001).

Third, previous studies have suggested that presentation mode and material length influence associative asymmetry. Some researchers proposed that simultaneous presentation is important for associative symmetry (Wickelgren, 1977) because of bidirectional encoding (McCormack & Haltrecht, 1965). Sommer et al. (2007) found sequential presentation lead to smaller *Q* values between forward and backward associations, although the general pattern did not change. For material length, memory symmetry is usually obtained when associations between two items are recalled (e.g., Kahana, 2002; Caplan et al., 2006; Sommer et al., 2007), but there are inconsistent findings on memory asymmetry when

triples are used (e.g., Kahana & Caplan, 2002; Thomas et al., 2003). Some propose that memory for more than two items in sequence (e.g., triples, lists) and memory for associative pairs rely on different mechanisms. However, Caplan et al. (2006) found comparable mean performance between forward and backward recall for both pairs and triples. The correlations between forward and backward were also rather high ($> .90$), which suggests that there is also associative symmetry in triples.

Overview of the current study

The main goal of the present study was to investigate whether associative asymmetry was modulated by memory test (recognition vs. cued recall). To determine to what extent other factors contributed to associative asymmetry, the factors semantic relatedness, presentation mode, material length and test mode were also included. In a series of six experiments, we first compared memory for forward and backward associations in cued recall and recognition tasks (Experiment 1–4). Next we investigated the mechanisms underlying forward advantage (Experiment 5 and 6). Directional judgment tasks straightly tested whether participants remembered order information and allowed a good comparison between recalling and recognizing order information. In Experiment 1–4, after participants memorized associations between words during encoding, they had to retrieve the words by a forward (A→?) or a backward (?→B) cue during the cued recall test, and had to make a forward/backward recognition judgment (e.g., A—B, D—C) during the recognition test. The word triples and word pairs were presented simultaneously (Experiment 1 and 3) or sequentially (Experiment 2 and 4). An analysis of memory accuracy and correlation analyses were included in Experiment 2 and 4.

In the recognition task, participants may make directional judgment simply by matching the perceptual position to that during encoding. To avoid this possibility, in Experiment 5 we presented the words pairs vertically, instead of horizontally, and asked participants to make directional judgments. In addition, previous studies have reported inconsistent findings regarding forward advantage in associative judgments. Different from directional judgment tasks that emphasize retrieving the directional/order information (Greene & Tussing, 2001), old/new associative judgments emphasize retrieving relational information between words, rather than order information only. We therefore adopted an associative recognition memory task in Experiment 6 to explore whether the forward advantage can also be found during associative recognition judgments. Participants had to discriminate between old and recombined pairs irrespective of their direction (same-order/position or reversed-order/position), or to make the directional judgment irrespective of their pair type during retrieval.

Experiment 1

Method

Participants—Twenty-one young (21.95 ± 1.66 years old, 11 males) right-handed students from Peking University participated in the experiment. All participants were native Chinese speakers. They had normal or corrected-to-normal vision, without any history of neurological or psychiatric disorders. All participants were paid for their participation and gave informed consent in accordance with procedures and protocols approved by the institutional Review Board of the Department of Psychology, Peking University.

Materials—Three within-subject factors were included, i.e., direction (forward, backward), relation type (related, unrelated), and task (cued recall, recognition). A total of 432 two-character Chinese words were selected to form 144 word triples (A—B—C). The words in half of the triples were semantically related to each other (e.g., 羚羊—狐狸—猎犬 antelope-fox-hound), and those in the other half were unrelated (e.g., 面包—阴谋—职责 bread-conspiracy-

responsibility). Because word type influences associative asymmetry (Lockhart, 1969), all words were selected to be nouns. Each word was composed of two Chinese characters that correspond to two spoken syllables. To avoid interference between words, less than 1% of the characters were repeated. To control for word familiarity and complexity, all words had medium frequencies (20.44 ± 38.55 per million) and medium number of strokes (18.33 ± 5.07). There was no significant difference in word frequency and number of strokes among three positions (all $p > .30$). A separate group of six participants rated the relatedness (1 most related, 6 most unrelated) for all the triples, and confirmed that the manipulation of association type was successful (related: 1.30 ± 0.37 , unrelated 4.31 ± 0.47 , $t(143) = 43.25$, $p < .001$).

Word triples were first pseudorandomly divided into three study-test blocks, with equal numbers of related and unrelated triples in each block. Then triples in each block were randomly divided into four sets, each composed of 12 triples that were used for different conditions, respectively (i.e., forward/backward associations, and cued recall/recognition tests). The arrangement of the three study-test blocks and four sets was counterbalanced across participants so that each word triple had an equal chance to be in different conditions.

Procedure—Participants performed three study-test blocks in a random order. During each block, participants first learned each of the 48 word triples for 6 s; then after a short distraction to avoid rehearsal, they performed a cued recall and a recognition task. During study, the three words in a triple were presented simultaneously (in a row) at the center of screen (see Figure 1a). Participants were encouraged to associate the three words and memorize them. During the cued recall test, a probe indicating the direction to recall (e.g., B--?) was presented for 5.5 s, and participants were asked to respond as quickly and accurately as possible (see Figure 2a). Each triple was tested once by either a forward (e.g., B--?) or a backward probe (e.g., ?--B). To control for probe position, only the middle word was used as the probe. As a total of 48 triples were used in a study-test block, there should have been proactive interference from the prior triple and, in turn, any potential recency effects within triple would be attenuated. During the recognition test, a subpair of a studied triple was presented for 5 s, and participants were asked to judge whether the subpair was presented forwardly or backwardly at study by button press as quickly and accurately as possible (see Figure 2b). Each triple was tested once, with the middle word being paired with another word to compose either a forward (e.g., A—B) or a backward subpair (e.g., C—B).

The two tasks were performed separately in each block, with the order of tasks and button presses being counterbalanced across blocks. The forward and backward subpairs were pseudorandomly presented during the two tasks and not more than three subpairs in the same direction were contiguously presented. To control for serial position effects, the first and last two triples during encoding were filler items, and were not tested in the following memory tasks. All participants took part in a practice block to familiarize themselves with both the study and test procedures before the first block.

Data analysis—The reaction times (RTs) in the cued-recall task were recorded with a microphone, which was connected to the sound card of the computer. The RTs were analyzed using the Presentation software. The experimenters scored the accuracy by replaying the responses afterwards. The responses and RTs in the recognition task were recorded by button press. Correct responses in the cued recall task were words that were recalled as being in the right direction, and the correct responses in the recognition task were the subpairs that were judged as being in the same direction (forward/backward) as what they were presented at study. The d' and β values were calculated on the basis of signal detection theory (Macmillan & Creelman, 2005), assuming forward associations (i.e.,

subpairs presented in the right order) as signal and backward (i.e., subpairs presented in the reversed order) as noise. Hits were defined as forward subpairs being judged as forward, and false alarms were defined as backward subpairs being judged as forward. The d' value thus indicates the participants' capability to discriminate between forward and backward subpairs and is independent of response bias. The β value indicates the response criterion that participants adopt. A neutral response bias is indicated by $\beta = 1$. A liberal (conservative) criterion is reflected by β values lower (larger) than 1 (Snodgrass & Corwin, 1988, p.36).

Four subjects' RT data were excluded because RTs were not recorded for both tasks. Repeated measures ANOVAs were performed for accuracy and RTs with direction and relation type as factors for each task. Post-hoc pairwise comparisons were Bonferroni-corrected. The G*Power 3 software (Faul, Erdfelder, Lang, & Buchner, 2007) was used to estimate the power of the statistical tests we used. The power test for accepting the null hypothesis is to give an estimate of the Type II error (β , falsely accepting the null hypothesis). The larger the power ($1-\beta$), the lower the probability of the Type II error would be.

Results

Cued recall task—For response accuracy (see Figure 3, upper left), there was no significant effect of direction, $F(1, 20) = 2.26, p = .148$, partial $\eta^2 = .10$, $power = .99$, and no interaction between direction and relation type, $F(1, 20) = .54, p = .472$, partial $\eta^2 = .02$, $power = .73$. The main effect of relation type was significant, with the related triples being better recalled than unrelated ones, $F(1, 20) = 144.29, p < .001$, partial $\eta^2 = .88$, $power = .99$. Similarly for RTs (see Table 1), there was also a main effect of relation type, as the related triples were recalled faster, $F(1, 16) = 9.25, p = .008$, partial $\eta^2 = .37$, $power = .99$. There were no significant effects of direction, $F(1, 16) = 1.10, p = .318$, partial $\eta^2 = .07$, $power = .72$, and the interaction, $F(1, 16) = .78, p = .390$, partial $\eta^2 = .05$, $power = .74$. These data suggest that participants recall the related triples better than the unrelated triples, irrespective of the probed direction.

Recognition memory task—For response accuracy (see Figure 3, lower left), similar to the results in cued recall, the direction of the related subpairs were judged more accurately than that of the unrelated subpairs, $F(1, 20) = 16.61, p < .001$, partial $\eta^2 = .45$, $power = .99$. Different from the cued recall task, forward subpairs (i.e., subpairs presented in the same order as during encoding) were more often judged to be in the right direction than backward subpairs, $F(1, 20) = 27.23, p < .001$, partial $\eta^2 = .58$, $power = .99$, with no significant interaction between relation type and direction, $F(1, 20) = 0.78, p = .525$, partial $\eta^2 = .02$, $power = .68$. For RTs (see Table 1), there were no significant main effects of relation type and direction ($F_s < .1, p > .60$). Although the interaction was significant, $F(1, 20) = 4.30, p = .050$, partial $\eta^2 = .18$, none of the simple contrasts reached significance ($ps > .10$). The d' for the related subpairs was significantly higher than that for the unrelated subpairs (2.64 vs. 1.79), $t(20) = 4.39, p < .001$. Both d' scores were significantly higher than chance level ($t(20) = 12.92, t(20) = 9.34, ps < .001$), suggesting that participants are capable of discriminating the direction of forward and backward subpairs. The β values were comparable to the neutral β value (1.49 and 1.16 for related and unrelated subpairs, $t(20) = 1.32, t(20) = .58, ps > .20$, suggesting that participants adopted a neutral response criterion for both types of subpairs.

Discussion of Experiment 1

In Experiment 1, we found a dissociation of the cued recall and recognition tasks in associative asymmetry. The results showed that memory accuracy for forward and backward

associations was not significantly different in the cued recall task, but was significantly higher for forward than backward associations in the directional recognition task.

There are inconsistent findings on memory for triples in the cued recall task. Some studies showed forward advantage in recall accuracy (Kahana & Caplan, 2002), whereas others showed comparable performance in either accuracy or correlational analysis (Caplan et al., 2006). Kahana and Caplan (2002) used sequential presentation for multiple times during study, and used both double (e.g., AB?, ?BC) and single cues. These manipulations have been identified to enhance associative asymmetry (Kahana, 1993; 2002). When words were presented simultaneously, participants were likely to encode their associations but diminish their order information, because participants could process the words bidirectionally (McCormack & Haltrecht, 1965). When the words were presented sequentially, participants could associate them and encode their order to form a memory for the sequence. The objective of Experiment 2 was to explore whether the dissociation between cued recall and recognition existed when sequential presentation was used. To ensure that participants processed the words in their presentation order, and to diminish the possibility that they encoded them bi-directionally (McCormack & Haltrecht, 1965), each word was presented at the center of the screen. In addition, participants were instructed to attend to each word and try to remember the pairs by presentation order. Both mean performance and correlation analyses were employed in Experiment 2.

Experiment 2

Method

Participants—Thirty-two right-handed students (22.69 ± 2.05 years old, 16 males) from Peking University participated in the experiment. All participants were native Chinese speakers. They had normal or corrected-to-normal vision, without any history of neurological or psychiatric disorders. All participants were paid for their participation and gave informed consent in accordance with procedures and protocols approved by the institutional Review Board of the Department of Psychology, Peking University.

Materials and Procedure—The materials and procedure were the same as in Experiment 1, except the following. (1) Each word in a triple was sequentially presented at the center of the screen for 1750 ms and an interval of 250 ms with a blank screen. The fixation duration was also limited to 3000 ms (see Figure 1b). (2) Participants were asked to read each word when it appeared, and to try to remember them by order. (3) To obtain the correlation coefficient scores, each participant performed each of the tasks (i.e., cued-recall and recognition) twice (Test 1 and Test 2). (4) To match the duration with that of the word pairs in the recognition task, the subpairs were tested for 2000 ms. The fixation duration was also limited to 1000 ms.

To compare with the results of Experiment 1 and to control for serial position confound, the cues for Test 1 were the middle words (B-?, ?-B), and those for Test 2 included the first (A-?) and third (?-C) words. All subpairs were presented in random order (Test 1) and then presented again in a newly randomized order (Test 2) without delay. Half of the words were tested in the same direction in both tests, and the other half were tested in the opposite direction, yielding the following four conditions: forward-forward, forward-backward, backward-forward, and backward-backward. Each triple was tested for the same subpair on Test 1 and Test 2 (i.e., if a triple was tested for its AB subpair on Test 1, it would always be tested for the AB subpair on Test 2). There were equal numbers of triples as AB and BC subpairs. The arrangement of the materials was counterbalanced across participants so that each subpair had an equal chance to be presented in different conditions.

Data analysis—Accuracy and RTs were analyzed by the same approach as in Experiment 1. In addition, the correlation coefficient of the accuracy data was measured in terms of Yule's Q for each participant. The Yule's Q is defined as $Q = (ad-bc)/(ad+bc)$ (Kahana, 2002). For each 2*2 table, a is the number of responses that were correct in both tests (+/+), b is that correct in test 1 but incorrect in test 2, c is that incorrect in test 1 but correct in test 2, and d is that incorrect in both tests. We first calculated the Q s for each participant and corrected them by adding 0.5 for each cell (Kahana, 2002; Madan et al., 2010; Rizzuto & Kahana, 2001). The control Q was calculated for each participant to estimate the correlation due to list-to-list variability. It was the correlation between Test 1 randomly taken from one subpair, and Test 2 randomly taken from a different subpair from the same list (Caplan et al., 2006, Madan et al., 2010). Because the related and unrelated subpairs were mixed together for each task, the control Q was not separated by relation type. Thus the congruent Q and incongruent Q for related and unrelated triples were also combined to compare them with the control Q for each task. Next we calculated the z score of each Q for each participant by doing the log-odds ratio transformation (Hayman & Tulving, 1989, Kahana, 2002, Madan et al., 2010, Rizzuto and Kahana, 2001), and conducted the ANOVA to find the differences in z scores. Finally, we calculated the combined contingency tables for each condition, and conducted the chi-square tests using the log-linear model (Hayman & Tulving, 1989). Values more than 3.84 will be taken as the evidence that the levels of association in two 2*2 tables are sampled from different distribution.

Results

Cued recall task—For memory accuracy, similar to Experiment 1, neither Test 1 nor Test 2 showed significant effects of direction, $F(1, 31) = 0.52$ and $F(1, 31) = 2.51$, both $p > .20$, partial $\eta^2 = .02$, both $power > .96$ (see Figure 3, upper right). But there was a significant interaction of relation and direction in Test 2, $F(1, 31) = 8.26$, $p = .007$; partial $\eta^2 = .21$, $power = .99$, showing that related pairs were recalled more accurately by forward than by backward cues. For RTs (see Table 1), there were no significant effects of direction, either by separate test or by collapsing data ($ps > .20$). These data confirmed the results of Experiment 1 and suggest that sequential presentation does not influence the symmetry pattern. In addition, to exclude the possibility of serial position confound within triples, we compared the triples that were cued by the first and third words (i.e., the middle words as targets), and the results showed similar memory accuracy (.39 vs. .43, $t(31) = 1.12$, $p = .267$) and RTs (2195 ms vs. 2359 ms, $t(31) = .78$, $p = .441$) between them.

For the correlational analysis (see Table 2), the ANOVA revealed a significant effect of congruency, $F(1, 31) = 100.9$, $p < .001$, partial $\eta^2 = .77$. The interaction between congruency and relation type was also significant, $F(1, 31) = 6.41$, $p = .017$, partial $\eta^2 = .17$, showing that the z difference between the congruent and incongruent conditions was larger for related than for unrelated subpairs. For comparison with the control condition, we calculated the z scores by averaging the log-odds ratio of Q for related and unrelated conditions. An ANOVA with the factor congruency (congruent, incongruent, control) showed a significant effect, $F(2, 62) = 215.13$, $p < .001$, partial $\eta^2 = .87$. Furthermore, the z scores in the congruent and incongruent conditions were significantly higher than in the control condition (both $p < .001$) (see Figure 4). We then calculated the combined contingency tables, and obtained Q values of .99 in the congruent condition, of .86 in the incongruent condition, and of .25 for the control condition. The chi-square tests showed that both congruent Q and incongruent Q were significantly higher than the control Q , $\chi^2 = 58.09$ and 9.84 , both $p < .001$. There was also a significant difference between the congruent Q and the incongruent Q , $\chi^2 = 18.24$, $p < .001$. Note that the incongruent Q was closer to the congruent Q than to the control Q , thus support the associative symmetry in the cued recall task.

Recognition task—For memory accuracy, the direction of forward subpairs was judged more correctly than that of backward subpairs in both tests, $F(1, 31) = 39.90$ and 17.80 , both $p < .001$, partial $\eta^2 = .56$ and $.36$, $power = .99$. The direction of related subpairs was recognized better than that of unrelated subpairs, $F(1, 31) = 8.97$ and 10.09 , both $p < .003$, partial $\eta^2 = .22$ and $.25$, with no significant interaction between relation type and direction ($F_s < .2$, $p > .70$) (see Figure 3, lower right). There were no significant effects for RTs in Test 1, but in Test 2, the direction of forward subpairs were judged more quickly than that of the backward subpairs, $F(1, 31) = 9.67$, both $p < .004$, partial $\eta^2 = .24$. The d' in both tests was significantly higher than 0 (all $t > 4.70$, $p < .001$), and the β values were comparable to the neutral β value (all $t < 1.10$, $p > .05$) for related and unrelated subpairs. The related d' was higher than the unrelated d' (1.35 vs. $.91$, $t(31) = 3.25$, $p < .001$). These data suggest that the direction of forward subpairs is recognized better than that of backward subpairs independent of response criterion.

For the correlational analysis (see Table 2), the ANOVA of relation by congruency showed a significant effect of congruency, $F(1, 31) = 12.93$, $p < .001$, partial $\eta^2 = .30$ for both related and unrelated pairs. An ANOVA with the factor congruency (congruent, incongruent, control) showed a significant effect, $F(2, 62) = 17.75$, $p < .001$, partial $\eta^2 = .40$ (see Figure 4). The congruent z score was significantly higher than the control z score ($p < .001$), but different from that in the cued recall task, the incongruent z was comparable to the control z ($p = .062$). In the combined contingency tables, the chi-square tests showed that the congruent Q was significantly different from the control Q (.65 vs. .13), $\chi^2 = 7.77$, $p = .020$, but the incongruent Q was comparable to the control Q (.33 vs. .13), $\chi^2 = .83$, $p = .90$. There was also marginal significant difference between congruent and incongruent condition ($\chi^2 = 3.19$). Note that the congruent Q was closer to the control Q rather than to the incongruent Q . These data suggest that the control and incongruent condition are statistically comparable and by this support the associative asymmetry in the recognition task.

Comparison between Experiment 1 and 2 (simultaneous vs. sequential)—

Sequential presentation lowered memory accuracy in both, recall and recognition of triples, $F(1, 51) = 5.23$ and 31.86 , $p = .026$ and $p < .001$, partial $\eta^2 = .09$ and $.39$. When the performance for forward and backward triples was compared (i.e., forward bias), the forward bias in sequential presentation was not significantly different from that in simultaneous presentation for the recognition task, $F(1, 51) = 2.71$, $p = .106$, partial $\eta^2 = .05$.

Discussion of Experiment 2

In this experiment, the sequential presentation for each triple and instruction of directional encoding ensured that participants encoded the triples as a sequence. The central presentation of each word during encoding also diminished the possibility that participants made recognition judgment by the position of words. The results replicated the dissociation of recognition and cued recall tasks in associative asymmetry in Experiment 1. Thus although sequential presentation lowered memory performance, the performance pattern did not change.

The results of the correlational analysis also supported the dissociation of the cued recall and recognition tasks in associative asymmetry. In the cued recall task, the correlation between forward and backward associations (i.e., incongruent Q) were high for related and unrelated triples, and congruent Q and incongruent Q were significantly higher than the control Q . Conversely, in the recognition task, the incongruent Q was comparable to the control Q , and the two Q value ranges overlapped. This suggests that the correlation between forward and backward associations is low in the recognition task, and they can be assumed to be statistically independent.

When the middle words were used as cues, there may have been a target ambiguity problem (Kahana & Caplan, 2002), because B was associated with both A and C. But Kahana and Caplan (2002) found comparable performance between A? and B?, ?B and ?C, suggesting that using middle words as cues could not influence the performance pattern. In addition, we found comparable performance when triples were cued by the first and third words (i.e., the middle words as targets), which excluded the possibility of the serial position confound within triples.

Some studies have suggested that material length influences memory asymmetry. Associative asymmetry is often reported for triples and word lists (e.g., Kahana & Caplan, 2002; Thomas et al., 2003, but see Caplan et al., 2006), but associative symmetry is usually reported for word pairs (e.g., Kahana, 2002; Rizzuto & Kahana, 2001). To what extent the material length influences associative asymmetry is unclear. In Experiment 3 and 4, we investigated whether dissociations between cued recall and recognition in associative symmetry also exist when word pairs rather than word triplets were learned.

Experiment 3

Method

Participants—Twenty young (21.80 ± 1.74 years old, 8 males) right-handed students from Peking University participated in the experiment. All participants were native Chinese speakers. They had normal or corrected-to-normal vision, without any history of neurological or psychiatric disorders. All participants were paid for their participation and gave informed consent in accordance with procedures and protocols approved by the institutional Review Board of the Department of Psychology, Peking University.

Materials—The materials were the same as Experiment 1. Three within-subject factors were included in Experiment 3, i.e., direction (forward, backward), relation type (related, unrelated), and task (cued recall, recognition). The first and third words in the triples in Experiment 1 were selected to compose 144 word pairs (e.g., 羚羊—狐狸—猎犬, antelope- hound, 面包—阴谋—职责, bread- responsibility). Less than 1% of the characters were repeated across words. There was no significant difference between positions of the two words in a pair (left or right) in word frequency and number of strokes ($ps > .3$).

Procedure—The procedure was the same as that in Experiment 1, except that (1) during encoding, each pair was presented for 4 s to equate the presentation time for each word as was done in Experiment 1. The fixation duration was limited to 3000 ms. (2) During the cued recall test, each word had equal chance to be a probe (i.e., A --? for forward recall, and ?--B for backward recall). During the recognition test, the position of the two words in a pair remained the same (A–B) or was reversed to become a backward pair (B–A).

Data analysis—Two participants' data were excluded from analysis due to their biased performance (i.e., they responded to nearly all trials as forward or backward in the recognition task). One more subject's RT data was excluded because RTs were not recorded for both tasks. Same as Experiment 1, repeated measure ANOVAs were performed separately for accuracy and RTs in both tasks, with direction and relation type as factors.

Results

Cued recall task—For memory accuracy (see Figure 5, upper left), similar to Experiment 1, there was neither a significant effect of direction, $F(1, 17) = 1.62$, $p = .220$, partial $\eta^2 = .09$; $power = .99$ nor an interaction between direction and relation type, $F(1, 17) = .28$, $p = .603$, partial $\eta^2 = .02$; $power = .81$. But the related pairs were better recalled than the

unrelated ones, $F(1,17) = 81.27, p < .001$, partial $\eta^2 = .67$, $power = .99$. For RTs (see Table 1), there was also a main effect of relation type, showing that the related pairs were more quickly recalled, $F(1, 16) = 32.28, p < .001$, partial $\eta^2 = .67$, with no significant effect of direction, $F(1, 16) = 0.62, p = .443$, partial $\eta^2 = .04$; $power = .87$, and interaction between direction and relation type, $F(1, 16) = 1.67, p = .215$, partial $\eta^2 = .09$; $power = .99$. These data suggest that participants recall the related pairs better than the unrelated pairs, but equally well regardless of probed direction.

Recognition task—For memory accuracy, different from that in the cued recall task, the directions of the forward pairs were better recognized than that of the backward pairs, $F(1, 17) = 33.53, p < .001$, partial $\eta^2 = .51$, $power = .99$. The directions of the related pairs were recognized at a similar level to that of the unrelated pairs, $F(1, 17) = 2.60, p = .126$, partial $\eta^2 = .13$, $power = .99$, with no significant interaction between relation type and direction, $F(1, 17) = 0.05, p = .831$ (see Figure 5, lower left). For RTs, only a main effect of direction was significant, $F(1, 17) = 16.63, p < .001$, partial $\eta^2 = .29$. The effect of relation type and the interaction were not significant ($F_s < 2, p > .30$) (see Table 1). The d' for the related pairs was significantly lower than that for the unrelated pairs (1.95 vs. 2.27, $t(17) = 2.53, p = .022$), and both d' scores were significantly higher than 0 ($t(17) = 8.24$ and $10.40, ps < .001$). The β values were comparable to the neutral β values (.75 and .80 for related and unrelated pairs, $t(17) = 1.94$ and $1.50, ps > .05$). These data suggest that the directions of forward pairs were better recognized than that of backward pairs independent of response criterion.

Comparison between Experiment 1 and 3 (triples vs. pairs)—Pairs had higher accuracy than triples in the recall task, $F(1, 37) = 4.32, p = .045$, partial $\eta^2 = .10$, especially for the unrelated items. Although forward and backward associations were comparable in accuracy, triples showed a higher forward bias than pairs in the recall task, $F(1, 37) = 4.40, p = .043$, partial $\eta^2 = .10$, suggesting that material length may influence associative symmetry.

Discussion of Experiment 3

Experiment 3 showed that memory symmetry occurred as a function of memory retrieval task when word pairs were used. Similar to Experiment 1, accuracy and RT for recalling forward pairs were not significantly different from recalling backward pairs, but in the recognition task, the direction of forward pairs was recognized more accurately and more quickly than of backward pairs. Thus at least when sequential order is limited to three words, memory performance for forward and backward associations was modulated by task requirement.

Participants recalled more related pairs than unrelated pairs in the cued recall test, but they recognized them at similar level in the recognition task. Unexpectedly, in the recognition task d' was higher for the unrelated pairs than for the related pairs. It is possible that participants benefited from relational structure in the more difficult retrieval (cued recall) situation, whereas this was not the case in the easier (recognition) situation, because the relations between the words interfered with the participants' recognition judgment. Greene and Tussing (2001) also found that related pairs had lower $d\beta$ than unrelated pairs when old/recombined judgments and forward/backward judgment were required, suggesting that semantic relatedness may impair retrieving sequence memory for pairs.

We continued to present the pairs sequentially in Experiment 4 to explore whether the presentation mode influences associative asymmetry. Similar to Experiment 2, we instructed participants to attend to each word, and to remember them by order. Both mean performance and correlation analyses were employed in Experiment 4.

Experiment 4

Method

Participants—Twenty-three right-handed students (22.25 ± 2.45 years old, 10 males) from Peking University participated in the experiment. All participants were native Chinese speakers. They had normal or corrected-to-normal vision, without any history of neurological or psychiatric disorders. All participants were paid for their participation and gave informed consent in accordance with procedures and protocols approved by the institutional Review Board of the Department of Psychology, Peking University.

Materials and Data analysis—The materials and procedure were the same as in Experiment 2, except that (1) each word pair (instead of triples) was presented sequentially at the center of the screen and (2) both words had equal chance to be used as cues in the cued recall task. The arrangement of the materials was counterbalanced across participants so that each word pair had an equal chance to be in different conditions. Data analysis was the same as Experiment 2.

Results

Cued recall task—For memory accuracy, similar to Experiment 3, neither Test 1 nor Test 2 revealed significant effects of direction, $F(1, 22) = 0.38$ and $F(1, 22) = 0.01$, both $p > .50$, partial $\eta^2 = .02$, both $power > .96$ (see Figure 5, upper right). Related pairs were recalled better than the unrelated pairs in both tests, $F(1, 22) = 54.80$ and $F(1, 22) = 29.53$, both $p < .001$, partial $\eta^2 = .71$ and $.57$. There was no significant RT bias to forward pairs ($F(1, 22) = 1.15$, $p = .704$). These data confirm the results of Experiment 3 and suggest that sequential presentation does not influence the symmetry pattern.

For the correlational analysis (see Table 2), the ANOVA of with factors relation and congruency showed a significant congruency effect, $F(1, 22) = 51.15$, $p < .001$, partial $\eta^2 = .70$, for both related and unrelated subpairs, and the interaction was not significant, $F(1, 22) = 2.42$, $p = .134$, partial $\eta^2 = .10$. An ANOVA with factor congruency (congruent, incongruent, control) showed a significant effect, $F(2, 44) = 130.14$, $p < .001$, partial $\eta^2 = .86$. The z scores of the congruent and incongruent conditions were significantly higher than the control z score (both $p < .001$) (see Figure 4). The results for the combined contingency tables showed that the congruent Q values were significantly higher than the incongruent Q values (.99 vs. .83), $\chi^2 = 13.50$, $p < .001$, and both of them were significantly higher than the control Q values (.25), $\chi^2 = 41.86$ and 6.91 , both $p < .001$. The incongruent Q was closer to the congruent Q than to the control Q , suggesting that the congruent and incongruent conditions are comparable, which supported the associative symmetry in the cued recall task.

Recognition task—For memory accuracy, the direction of forward pairs was better recognized than that of backward pairs in both tests, $F(1, 22) = 78.37$ and 25.70 , both $p < .001$, partial $\eta^2 = .56$ and $.36$, $power = .99$. The direction of forward pairs was also recognized more quickly than the direction of backward pairs, $F(1, 22) = 3.46$ and 22.19 , $p = .076$ and $p < .001$, partial $\eta^2 = .14$ and $.50$ (see Figure 5, lower right). The related pairs were recognized at comparable level to the unrelated pairs in direction, with no significant interaction between relation type and direction ($ps > .20$). The d' in both tests was significantly higher than 0 (all $t(22) > 6.0$, $p < .001$), and the β values were comparable to the neutral β value (all $t(22) < 2.0$, $p > .05$, except for related pairs in Test 1) for related and unrelated pairs. Different from that in the simultaneous presentation, the d' was comparable for related and unrelated ($t(22) = .44$, $p = .668$).

For the correlational analysis (see Table 2), the ANOVA with factors relation and congruency revealed a significant congruency effect, $F(1, 22) = 10.06$, $p = .004$, partial $\eta^2 = .32$ for both related and unrelated pairs (interaction $F(1, 22) = .24$, $p = .630$, partial $\eta^2 = .01$). The ANOVA with factor congruency (congruent, incongruent, control) showed a significant congruency effect, $F(2, 44) = 23.51$, $p < .001$, partial $\eta^2 = .57$, with the congruent z and incongruent z scores being significantly higher than the control z (both $p < .01$). In the combined contingency table, the congruent Q was significantly higher than the control Q (.86 vs. .22), $\chi^2 = 11.97$, $p < .001$, but the incongruent Q was comparable to the control Q (.59 vs. .22), $\chi^2 = 2.34$, $p > .05$. The congruent Q was also higher than the incongruent Q ($\chi^2 = 3.74$). These data show a low correlation between forward and backward associations and support the associative asymmetry in the recognition task.

Comparison between Experiment 3 and 4 (simultaneous vs. sequential)—The different presentation modes did not significantly change the performance of pair accuracy and RT in the recall task, but in the recognition task the RT bias for the simultaneous presentation was significantly larger than that for the sequential presentation, $F(1, 41) = 5.78$, $p = .020$, partial $\eta^2 = .14$.

Comparison between Experiment 2 and 4 (Triples vs. pairs)—When stimuli were presented sequentially, accuracy was higher for pairs than word triples in the cued recall task, $F(1, 53) = 23.88$, $p < .001$, partial $\eta^2 = .31$, but not in the recognition task, $F(1, 53) = 2.45$, $p = .123$, partial $\eta^2 = .04$. The forward bias did not differ between the two stimulus types in both tasks. There was only a trend towards a larger forward bias for pairs than for triples in the recognition task, $F(1, 53) = 2.72$, $p = .105$, partial $\eta^2 = .05$. The control Q values were not significantly different between triples and pairs ($ps > .40$), but the congruent Q value was significantly higher for pairs than for triples in the recognition task ($p = .020$). The congruency effect did not differ between triples and pairs in both tasks ($Fs < 1.0$, $p > .70$).

Discussion of Experiment 4

In Experiment 4, the words pairs were presented sequentially during encoding. The results of the accuracy and correlational analysis confirmed the dissociation of memory asymmetry in cued recall and recognition tasks for word pairs. This suggests that even when the triples or pairs are simultaneously presented, they are intrinsically encoded as a sequence. In addition, the similar pattern of results between triples and pairs suggests that the dissociation between cued recall and recognition is not affected by material length. Caplan et al. (2006) also found that for both pairs and triples, there was no significant difference between forward and backward recall for both mean and correlation analysis (cf. Kahana & Caplan, 2002).

In the recognition task, some of the words pairs were in the same order as those during encoding and others were in reversed order. As the position of each word is probably automatically encoded (Ellis, 1990), the pairs may be more familiar and easier to be recognized when they were presented as the forward pairs. Thus a copy-cue/perceptual matching mechanism might have selectively contributed to forward advantage in recognition tasks (Giovanello et al., 2009; Kahana & Caplan, 2002). Compared to the simultaneous presentation, the sequential presentation of words at the center of the screen prevented the possibility that participants made directional judgment simply by their perceptual position (i.e., left, right). One further issue was to investigate (as in Experiment 1 and 3), to what extent the forward advantage in the recognition task was due to perceptual matching when the words are presented simultaneously. To address this issue, participants in Experiment 5 were asked to encode the simultaneously presented word pairs, and made the directional

recognition when the two words were vertically presented. This manipulation would avoid the repetition of the perceptual position information. Both mean performance and correlational analyses were employed in Experiment 5.

Experiment 5

Method

Participants—Twenty-two right-handed students (21.33 ± 1.88 years old, 10 males) from Peking University participated in the experiment. All participants were native Chinese speakers. They had normal or corrected-to-normal vision, without any history of neurological or psychiatric disorders. All participants were paid for their participation and gave informed consent in accordance with procedures and protocols approved by the institutional Review Board of the Department of Psychology, Peking University.

Materials and Data analysis—Only 72 word pairs from Experiment 4 were used in Experiment 5. During encoding, the words of a pair were presented simultaneously for 4 s as in Experiment 3. During retrieval, the two words were presented vertically, instead of horizontally, for 2 s at the center of the screen. The forward pairs were those that the first word was in the upper line and the second word was in the lower line, connected with a dash, and the backward pairs were those presented in opposite direction (see Figure 2c). In order to obtain correlational scores, participants were asked to make the directional recognition task twice as that in Experiment 2 and 4. The arrangement of the materials was counterbalanced across participants so that each word pair had an equal chance to be in different conditions. Data analysis was the same as that in Experiment 4.

Results

Recognition task—For memory accuracy, the direction of forward pairs was better recognized than that of backward pairs in Test 1 (.87 vs. .70), $F(1, 21) = 20.68$, $p < .001$, partial $\eta^2 = .50$, $power = .99$ (see Figure 6, left), but not in Test 2 (.82 vs. .81), $F(1, 21) = .80$, $p = .381$, partial $\eta^2 = .04$. The direction of forward pairs was also recognized more quickly than the backward pairs in both tests (1052 ms vs. 1175 ms in Test 1, and 1018 ms vs. 1087 ms in Test 2), $F(1, 21) = 27.46$ and 13.01 , $ps < .002$, partial $\eta^2 = .57$ and $.38$. The direction of the related pairs was recognized at a comparable level to that of the unrelated pairs, with no significant interactions between relation type and direction for both accuracy and RTs ($ps > .20$). The d' in both tests was significantly higher than 0 ($ps < .001$), and the β values were comparable to the neutral β value ($ps > .05$).

For the correlational analysis (see Table 2), the ANOVA with factors relation and congruency showed a significant congruency effect, $F(1, 21) = 16.09$, $p < .001$, partial $\eta^2 = .43$ for related and unrelated subpairs (interaction $F(1, 22) = .04$, $p = .844$, partial $\eta^2 = .01$). The ANOVA showed a significant congruency effect, ($F(2, 42) = 16.00$, $p < .001$, partial $\eta^2 = .43$). Further analysis showed that the congruent z score was significantly higher than the control z score ($p < .001$), but the incongruent z score was comparable to the control z ($p = .951$) (see Figure 4). Similarly, in the combined contingency tables, the congruent Q was significantly higher than the control Q (.81 vs. .26), $\chi^2 = 5.84$, $p < .05$, but the incongruent Q was comparable to the control Q (.27 vs. .26), $\chi^2 = .01$, $p > .90$. There was also a significant difference between congruent Q and incongruent Q ($\chi^2 = 6.59$, $p < .01$). These data suggest that the incongruent condition is more similar to the control condition, and the forward and backward associations are independent.

Comparison between Experiment 4 and 5 (horizontal vs. vertical tests)—

Vertical test lowered the Q values in Experiment 5 as compared to Experiment 4, $F(2, 86) =$

3.25, $p = .044$, partial $\eta^2 = .07$, showing that there was no significant difference in control z scores ($p = .678$), but both congruent and incongruent z scores were lower for vertical than for horizontal presentation (both $p < .03$). The Q difference did not change significantly, $F(1, 43) = .66$, $p = .421$, partial $\eta^2 = .02$.

Comparison between Experiment 3 and 5 (horizontal vs. vertical tests)—The accuracy performance did not significantly change between horizontal and vertical tests, $F(1, 38) = .01$, $p = .99$, partial $\eta^2 = .001$. The d' scores were not significantly different for horizontal and vertical presentations, $t(38) = .57$ and 1.12 for related and unrelated pairs, both $p > .20$.

Discussion of Experiment 5

The results of Experiment 5 showed that when the two words were presented vertically, instead of horizontally, the direction of forward pairs was judged more accurately and more quickly than that of backward pairs. In addition, the incongruent Q was comparable to the control Q , suggesting that the correlation between forward and backward associations was small. These results indicate that the associative asymmetry in the recognition task cannot be attributed to a copy-cue/perceptual matching mechanism.

The recognition of direction was different from typical associative recognition because it emphasizes retrieving order information and not associative information. It is unclear whether retrieving the two types of information is related. In addition, a forward advantage is not consistently found when associative recognition tasks are used in previous studies (Giovanello et al., 2009; Haskins et al., 2008). Therefore, Experiment 6 was designed to explore whether the forward advantage found for the recognition of directions extends to associative recognition judgments. Old and recombined pairs (i.e., two words that were not presented together but with the same left/right position as in study) with the same order/position and reversed order/position formats were included. In the directional judgment task, participants were asked to make a decision whether the two words were in the same position as at study, regardless of whether they were presented together (i.e., old pairs) or not (recombined pairs). In the associative judgment task, they had to make a decision whether the two words were presented together during study, regardless of whether they were presented in the same-position or in a reversed-position.

Experiment 6

Method

Participants—Twenty-two right-handed students (22.59 ± 2.52 years old, 10 males) from Peking University participated in the experiment. All participants were native Chinese speakers. They had normal or corrected-to-normal vision, without any history of neurological or psychiatric disorders. All participants were paid for their participation and gave informed consent in accordance with procedures and protocols approved by the institutional Review Board of the Department of Psychology, Peking University.

Materials—Three within-subject factors were included in Experiment 6, i.e., task (directional, associative), order/position (same, reversed), and pair type (old, recombined). A total of 240 unrelated word pairs were selected and divided into ten sets, with word frequency and number of strokes matched across groups, and between left and right positions ($F_s < 1$, $p > .40$). To exclude that participants recognized the words by only the left or the right word, two sets were used to make up filler pairs (i.e., left word – another left word; right word – another right word) for the associative judgment task. Among the remaining eight sets, half of the sets were used for the directional judgment task, and the

other half were used for the associative judgment task. For each set, the 96 pairs were further divided into four subsets, i.e., old pairs with the same-position, old pairs with the reversed-position, recombined pairs with the same-position, and recombined pairs with the reversed-position. Altogether, there were 96 pairs for the directional judgment task (48 old, 48 recombined pairs) and 144 pairs for the associative judgment task (48 old, 48 recombined with the same or reversed-order, 48 fillers with words in left-left or right-right combinations). Less than 1% characters were repeated among words. The sets and subsets were counterbalanced so that each pair had equal opportunity to be used in different conditions.

Procedure—During study, each of the 240 pairs was presented at the center of the screen for 3 s, and participants were asked to read the two words, and made a sentence between the two words by their order. After three minutes distraction of calculating 1000 minus 7, different types of pairs were randomly presented for 1.5 s, and participants performed the directional judgment task and associative judgment task, separately. During the directional judgment, participants judged whether the two words in a pair were in the same position as during study, irrespective of their associative combination. During the associative judgment, participants judged whether the two words in a pair were in the same combination as during study, irrespective of their position. The two tasks were tested in blocks, and each pair was tested only once. The order of the tasks and the button press were counterbalanced across participants.

Data analysis—The data from one participant were not recorded for the directional judgment, and the other not for the associative judgment, both due to technical problems. Repeated ANOVA was performed, with direction and pair type as factors for each task.

Results

For the associative judgments accuracy was higher, $t(19) = 4.04$, $p < .001$, and reaction times slower, $t(19) = 2.03$, $p = .057$, than for the directional judgments. Both tasks had above chance d' values (0.45 and 1.23), $t(20) = 3.62$, and $t(20) = 4.93$, both $p < .03$, suggesting that participants are capable of discriminating pairs in the same-position and in the reversed-position, as well as between old and recombined pairs. The β values were not significantly different from the neutral response in the directional judgment (1.11), $t(20) = .68$, $p = .499$. As fillers were included in the associative recognition task, participants adopted a conservative criterion (vs. neutral criterion) to make old judgments (1.84), $t(20) = 3.22$, $p = .004$.

Directional judgment task—The ANOVA showed significant effect of direction, because the pairs in the same-position were recognized more quickly, $F(1, 20) = 10.10$, $p = .005$, partial $\eta^2 = .35$ than those in the reversed-position. The pairs in the same-position tended to be recognized more accurately, $F(1, 20) = 3.54$, $p = .074$, partial $\eta^2 = .15$ (see Figure 6, right). These data suggest that forward advantage can occur for both, old and recombined pairs. Nevertheless, note that the interaction of direction and pair type for accuracy was $p = .105$, $F(1, 20) = 2.88$, partial $\eta^2 = .13$. Further analysis revealed that only old pairs ($p < .02$), but not the recombined pairs ($p > .30$, power = .57), showed a forward advantage in accuracy (.60 vs. .54). This suggests that the contribution of association direction is more pronounced for forward advantage.

Associative judgment task—The interaction of direction and pair type was significant for accuracy, $F(1, 20) = 4.24$, $p = .050$, partial $\eta^2 = .18$ and marginal significant for RTs, $F(1, 20) = 3.62$, $p = .072$, partial $\eta^2 = .15$, showing that for old pairs, but not for recombined pairs, pairs in the same-position were recognized better and more quickly than those in the

reversed-position (both $p < .05$) (see Figure 6, right). Recombined pairs were judged more accurately than old pairs, $F(1, 20) = 11.49$, $p < .001$, partial $\eta^2 = .37$. Other main effects of direction and pair type in accuracy and RTs were not significant ($F_s < 3$, $p > .10$). Two types of filler pairs did not show significant difference (.76 vs. .77 for accuracy, 1048 ms vs. 1044 ms for RTs), $t(20) = .46$ and .05, $p_s > .70$. These data suggest that directional information facilitates the associative judgment for old pairs.

Discussion of Experiment 6

Experiment 6 confirms the results of our previous experiments in that accuracy was higher for (old) pairs in the same-position than those in the reversed-position in the directional judgment. Different from Experiment 5, we included recombined pairs in the directional judgment task. As the two words were not associated during encoding, participants could only rely on positional information for the recombined pairs to make the directional decisions. The results showed that the forward advantage was only significant for old pairs, but not for the recombined pairs, suggesting that associative integrity is important for forward advantage in the directional judgment.

Notably, a forward advantage was also found only for the old pairs for the associative judgments. Thus direction as a detailed information could enhance associative retrieval. Altogether our results support previous studies (Giovanello et al., 2009; Kahana, 1993) and suggest that forward advantage occurs in the recognition task, irrespective of whether participants were asked to judge direction or association. In addition, consistent with other results, the present data suggest that when associations between words are formed, order/serial information is a constituent part of this association.

General discussion

The main goal of this study was to explore the extent to which associative symmetry is modulated by memory test (cued recall vs. recognition). The results showed that for the cued recall task, both triples and pairs revealed associative symmetry, but for the recognition task, forward associations were better recognized than backward associations, irrespective of whether they were presented simultaneously or sequentially, and whether they were tested in a directional or associative recognition tasks. In addition, pairs in the same-order enhanced associative judgment. These data suggest that associative asymmetry is modulated by cued recall and recognition tasks, and directional order as a part of the memory representation can facilitate associative recognition memory.

Associative symmetry in the cued recall task

Consistent with previous findings on associative symmetry, forward associations were recalled at similar levels as backward associations, irrespective of relation type, presentation mode and material length. The high powers in Experiment 1–4 suggest that the absence of associative asymmetry in the cued recall is not a power problem. Many previous studies that use cued recall tasks have found relatively consistent findings on associative symmetry for word pairs (e.g., Caplan et al., 2006; Kahana, 2002; Murdock, 1966), triples (Caplan et al., 2006) and object-location associations (Sommer et al., 2007). Few studies found forward advantage in cued recall tasks (e.g., Kahana & Caplan, 2002). Our Experiment 2 used similar procedures as Kahana and Caplan (2002), with the exception that participants studied Chinese word triples once and cued by single words. We only found significant forward advantage for related triples in Test 2. It was possible that some experimental procedures, such as double-item cues (Kahana, 1993; Kahana & Caplan, 2002) are important factors to produce associative asymmetry.

In addition to memory performance, correlation analysis is a valid way to determine whether forward and backward associations are independent (Kahana, 2002). We obtained correlation scores between forward and backward association around .75 for both triples and pairs. Similar to previous findings, these incongruent Q values were significantly higher than the control Q s (e.g., .90 for pairs in Madan et al., 2010; .80 for triples in Caplan et al., 2006; .83 study for pairs once in Kahana, 2002). As stated by Madan et al. (2010), a close approximation of ASH could be supported by the high correlation between forward and backward associations. Therefore, the high incongruent Q rejected the possibility that forward and backward associations are fully independent in the cued recall task.

On the other hand, the incongruent Q s were significantly lower than the congruent Q s. We assume that the correlation is influenced by various factors. First, the congruent Q was close to 1 because participants made the same responses twice, irrespective of whether the responses were correct or not. This effect of earlier test could artificially inflate the congruent Q especially in the cued recall task. Second, the lower incongruent Q values may be related to sequential presentation and material features. Sequential presentation could make the Q values lower (e.g., in Sommer et al. (2007) study was .67 vs. .63 for simultaneous presentation, and .67 vs. .57 for sequential presentation). In addition, instead of using alphabetic words, we obtained associative symmetry with Chinese word triples and pairs. Each Chinese word is composed of two characters, with each character having its specific meaning and phonological features. Different from alphabetic words, each Chinese character within a target word could compose different words with similar meanings. For example, if participants had to retrieve lamp (台灯), they may respond as 台灯, 电灯, 灯光, all of which share the same character within the target words (灯), but only one is regarded as correct response (台灯). The phenomenon of inconsistent responses was shown especially under the incongruent condition as different cues were used to retrieve the same triple or pair in Test 1 and Test 2, making the incongruent Q lower. Because both words were presented in the recognition task, the interference from other responses was less frequent than that in cued recall.

Associative asymmetry in the recognition task

The novel finding of our study was the behavioral dissociation between cued recall and recognition tasks in associative asymmetry. Across six experiments, we consistently found forward advantage in the recognition tasks. When participants were asked to make directional judgment, forward triples/pairs were more accurately (and more quickly) judged than backward associations. The results of forward advantage were consistent with prior studies using associative recognition tasks (e.g., Haskins et al., 2008; Giovanello et al., 2009; Kahana, 1993; Wiegand et al., 2010) and directional tasks (e.g., Greene & Tussing, 2001; Kounios et al., 2003).

In addition, different from the cued recall tasks, there were comparable correlations between the control and the incongruent conditions in Experiment 2 and 4. The Q values were generally lower in recognition tasks (vs. cued recall). Previous findings also found that the Q value in the recognition task is in the range of .4-.7 (e.g., Hayman & Tulving, 1989). Across the experiments, because there were comparable control Q values in the cued recall and recognition tasks, the main difference between cued recall and recognition was that the incongruent Q values were lower in the recognition task. These results suggest that forward and backward associations are independently modulated, and lend strong support to the IAH.

One objection against the associative asymmetry in the recognition task could be that the pairs were presented at the same position for forward pairs, but not for backward pairs. As the position of each word is probably automatically encoded (Ellis, 1990), participants could

make judgment partly based on perceptual familiarity from positional information (Giovanello et al., 2009; Kahana & Caplan, 2002). If the order is reversed, neither the directional and positional familiarity could be relied on. Indeed we found that simultaneously presentation had higher accuracy than sequential presentation, and in Experiment 6, the recombined pairs had a forward bias trend. To diminish this possibility, in Experiment 2 and 4, the words in a triple or a pair were presented at the center of the screen, thus making the study-test position of the words not matched. In addition, the positional information was changed in Experiment 5 by presenting the test pairs vertically. Although the Q values were lower for vertical test than horizontal test, the results showed forward advantage in memory performance and low correlations between forward and backward pairs. The incongruent Q values were comparable to the control Q values. These data suggest that forward advantage occurs not because participants remember specific position of each word and rely on perceptual matching between study and test word pairs, but because they remember the associative direction between words.

Moreover, across all experiments, the d' scores were significantly higher than 0, and the response bias scores were around 1, which indicates that participants adopt a neutral response rather than a liberal response bias (i.e., a higher tendency to respond “forward”) to discriminate the direction of forward and backward associations. The results of Experiment 6 reveal that only old pairs showed significant forward advantage when the direction was judged, suggesting that associative integrity is important for directional judgment.

The reason why associative asymmetry can be observed in recognition, but not in cued recall tasks could be understood by considering the different processes involved in both tasks and also the type of memory they assess. Recalling an item from memory primarily depends on recollection processes that are reliant on MTL and prefrontal cortex (PFC) structures and their interaction, whereas recognition memory depends on recollection and familiarity processes and the integrity of MTL structures (for reviews, see Eichenbaum et al., 2007; Yonelinas, 2001; but see Dunn, 2008; Squire et al., 2007). In the recognition task, both words in a pair are presented and forward association is more familiar in associative sequence than backward association, thus associative asymmetry is obtained. In contrast, for cued recall task, there is no familiarity for order information. Rather, the forward advantage disappears presumably because there is more interference from similar associations (Cohn, Moscovitch, & Emrich, 2008; Tomlinson et al., 2009), more recollection process and more working memory load involved in the cued recall task. It is possible that episodic memory is directional in nature, but for pairs and triples, when associative information is recalled, more recollective processing is involved for backward associations, hence the directional advantage disappears.

Other factors to modulate associative asymmetry

In addition to task requirements, we included other factors, such as presentation mode, relation type, material length, and test mode, to determine whether they modulate associative asymmetry. The results showed that these factors play some role in it. For presentation mode, previous studies suggest that sequential presentation is related to associative asymmetry (e.g., Sommer et al., 2007). Sequential presentation generally lowered the accuracy and incongruent Q values (e.g., Sommer et al., 2007). In our study, there was a trend of larger forward bias for sequential presentation in triple recognition, although this effect did not reach significance. In addition, associative asymmetry was larger for simultaneous presentation (vs. sequential) in RT of pair recognition, presumably due to additional perceptual matching mechanisms. For relation type, the forward advantage is more likely to occur for unitized pairs (Haskins et al., 2008; Kounios et al., 2003). In our study, there were no significant interactions between relation type and direction in mean performance. But the associative asymmetry (Test 2) and Q difference was larger for related

than unrelated triples for recalling triples (Exp. 2). For material length, pairs had higher accuracy than triples in the cued recall task and higher Q values in the recognition task, and triples were more possible to have higher forward bias in the cued recall task. Finally, vertical test lowered the Q values but the Q difference did not change.

More importantly, we should emphasize that the dissociation of cued recall and recognition tasks in associative asymmetry was generalized to both semantically related and unrelated triples/pairs, whether they were presented sequentially or simultaneously, and independent of the type of recognition tasks. One common feature across these experiments is that we asked participants to associate the words as a pair or triple during encoding. Experiment 6 showed that asymmetry also emerged in an associative recognition task, suggesting that episodic experience is featured by its serial order or sequence of events. It is possible that when the pairs or triples are presented, the words are intrinsically associated by their semantic and sequential information, making the effects of other factors of presentation mode, relation type and material length small. Vertical test cues significantly diminish the contribution of positional information, leaving the associative information intact for associative asymmetry.

IAH vs. ASH, and associative memory

Both mean performance and correlation analysis were adopted and the result pattern was consistent, thus both of them are valid in assessing associative asymmetry. However, both approaches have some limitations. On the one hand, the IAH and ASH could not be distinguished by only analyzing mean memory performance (Madan et al., 2010). When forward advantage is obtained, one could not reject the ASH (Rizzuto & Kahana, 2001), because asymmetry could be obtained if pre-existing associations of items are not controlled for (Kahana, 2002) (e.g., two items from different classes). When forward and backward performance is comparable, one could not reject the IAH, because forward and backward associations could have equal strength but still independent (Kahana, 2002). From this point of view, the correlation analysis is a better approach than mean performance to distinguish associative asymmetry and symmetry (Kahana, 2002). Within the range of congruent Q and control Q , associative asymmetry could be obtained if incongruent Q is more close to control Q rather than to congruent Q , whereas associative symmetry could be obtained if incongruent Q is more close to congruent Q rather than to control Q . On the other hand, Yule's Q value is also influenced by memory test (e.g., recognition, recall), earlier test and its outcome (output encoding), item variability (Kahana, 2002), overall mean performance and presentation mode. For example, the Q values were usually higher for cued recall than for recognition, reflecting the influence of Test 1. In addition, the Yule's Q is a ratio and is extremely sensitive to cells having values of zero or near zero (Rizzuto & Kahana, 2001). Therefore, when assessing associative symmetry and asymmetry, results of both mean performance and correlation analysis should be taken into consideration.

In addition, various factors that enhance associative asymmetry reported in the literature should be controlled (e.g., Kahana, 2002; Sommer et al., 2007). For example, in the present study, all words in triples or pairs were presented only once. Each triple and pair had equal chance to be used as forward and backward associations to diminish the influence of anticipation learning (Kahana, 2002; Sommer et al., 2007). Cued recall and recognition tasks were manipulated as within-subject factors and tested separately, thus individual variability was diminished.

The dissociation of associative symmetry between cued recall and recognition tasks reconciles the debates of IAH and ASH in that associative asymmetry is modulated by task requirement, at least when material length is limited to three words. By using the directional recognition task, we straightly verified that participants remembered the order information

and forward and backward associations were independent. Also as suggested by the results of Experiment 6, the directional information is a constituent part of association between words. When participants remember the relations between words, the semantic and directional/order relations are processed, which leads to better recognition for forward associations than backward associations. Thus associations may be inherently asymmetric but that symmetry in pairs may arise from some other processes (Kahana & Caplan, 2002). For example, although directional information is required for the cued recall task, due to that there are more complex processes involved in, especially for backward associations, such as higher demands on retrieval cue processing and a correspondingly higher working memory load, the forward advantage is attenuated and disappears. Therefore, the IAH is more appropriate to account for associative memory. Because many memory models differ in their weighing of forward and backward associations (Kahana, 2002; Sommer et al., 2007), our study has the implication that task requirements are an important factor to be taken into account when memory models are established.

For list memory more than triples, studies have found a relatively consistent forward advantage in cued recall task (Thomas et al., 2003; for review, Kahana & Caplan, 2002). Caplan (2005) further found that the incongruent Q was lower than congruent Q for the word list (.85 vs. .58). With more words in a list, there would be more interference among the items, which lead to more enhanced forward advantage. Further studies are needed to investigate what factors (e.g., more interference when the sequence is longer) play roles in the associative asymmetry for word lists.

In sum, our study found that memory task modulates associative symmetry in that there was forward advantage in recognition task, but associative symmetry in the cued recall task. Pairs in the same-order enhanced associative recognition judgment. These data suggest that direction is a basic feature of associative memory, and recovery of temporal information is a fundamental process central to episodic memory.

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Figure 1.
Encoding phases in Experiment 1 and 2.

Figure 2.
Retrieval phases in Experiment 1 and 5.

Figure 3.

Mean performance of Experiment 1 and 2. After the word triples were presented simultaneously (Exp.1) and sequentially (Exp.2), participants correctly recalled more forward subpairs than backward ones, and correctly recognized the direction of forward subpairs than backward ones. Error bars represent standard errors of the mean.

Figure 4.

Correlation results of Experiment 1–5. The incongruent Q was closer to congruent Q in the cued recall tasks, but closer to the control Q in the recognition tasks. Error bars represent standard errors of the mean.

Figure 5.

Mean performance of Experiment 3 and 4. Similar to that in Experiment 1 and 2, the forward advantage was found in the directional recognition task, but not in the cued recall task after the word pairs were studied simultaneously (Exp.3) and sequentially (Exp.4). Error bars represent standard errors of the mean.

Figure 6.

Results of Experiment 5 and 6. The forward advantage existed when the pairs were tested vertically. In both directional and associative judgment tasks, the old pairs in the same-position were recognized more accurately than those in the reversed-position. The F/B task refers to the directional judgment task, and the O/R task refers to the associative judgment task. Error bars represent standard errors of the mean.

Table 1

RT results of Experiment 1–5 (ms)

		Related Forward				Unrelated Forward			
		Backward	Mean	SD	Backward	Mean	SD	Backward	Mean
Cue recall	Triple	Exp.1	Simultaneously	2644	2672	3159	2877		
			<i>SD</i>	374	450	891	802		
	Exp.2	Sequentially	2422	2403	2740	2185			
			<i>SD</i>	672	564	1012	835		
Pair	Exp.3	Simultaneously	1800	1993	2335	2261			
			<i>SD</i>	372	372	584	377		
	Exp.4	Sequentially	1904	1872	1999	2107			
			<i>SD</i>	303	305	459	542		
Recognition									
Triple	Exp.1	Simultaneously	2329	2273	2269	2376			
			<i>SD</i>	512	399	592	503		
	Exp.2	Sequentially	1271	1310	1273	1312			
			<i>SD</i>	166	140	158	181		
Pair	Exp.3	Simultaneously	1407	1655	1481	1651			
			<i>SD</i>	495	429	463	410		
	Exp.4	Sequentially	1182	1194	1149	1241			
			<i>SD</i>	153	184	141	165		
Exp.5	Vertical		1052	1190	1036	1174			
			<i>SD</i>	187	188	154	166		

Table 2Estimation of Yule's Q in Experiment 2, 4 and 5 (after correction)

		Related Congruent	Incongruent	Unrelated Congruent	Incongruent
Cue recall					
Triple	Exp.2	<i>Mean</i>	0.95	0.54	0.96
		<i>SD</i>	0.05	0.44	0.06
Pair	Exp.4	<i>Mean</i>	0.94	0.55	0.96
		<i>SD</i>	0.07	0.36	0.06
Recognition					
Triple	Exp.2	<i>Mean</i>	0.55	0.22	0.43
		<i>SD</i>	0.36	0.47	0.39
Pair	Exp.4	<i>Mean</i>	0.66	0.48	0.74
		<i>SD</i>	0.40	0.35	0.26
Exp.5		<i>Mean</i>	0.68	0.23	0.63
		<i>SD</i>	0.34	0.55	0.39
					0.40