Associative Symmetry vs. Independent Associations in the Memory for Object-Location Associations

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Abstract

The formation of associations between objects and locations is a vital aspect of episodic memory. More specifically, remembering the location where we experienced an object and, vice versa, the object we encountered at a location, are both important elements for the memory of an event. If episodic associations are holistic representations of individual components or if there are unidirectional, separately modifiable connections between them has been investigated nearly exclusively using verbal stimuli. A preliminary conclusion from this controversy is that associations are at least not independent (Kahana, 2002). We used variations of a novel object-location learning paradigm to complement the accumulated evidence and to develop it into another important class of paired-associates.

keywords: associative memory, object-location associations, associative symmetry, independent associations, episodic memory
**Introduction**

The formation of associations between previously unrelated stimuli is a vital aspect of memory function. Two major theories concerning the nature of episodic associations have been advanced in the verbal memory literature: the independent association and the associative symmetry hypotheses (Kahana, 2002). These differ fundamentally in their perspective on associations; whereas the former hypothesizes associations to be unidirectional and separately modifiable links between the mental representation of stimuli, the latter postulates a holistic representation of the constituent elements.

We begin this article with a short overview of the empirical data that support these opposing theories. Such a summary is of particular interest because much of the incompatibility in the experimental findings might be attributable to differences in the employed paradigms. Subsequently, we will evaluate the two commonly used analytical approaches, which exhibit interpretational ambiguity on the one hand and design inherent confounds on the other (Kahana, 2002; Kahana, Rizzuto, & Schneider, in press). Based on this critical review of the findings and methods, we will then argue for object-location associations as stimuli ideally suited to complement the evidence that was derived nearly exclusively from studies using verbal material.

After outlining the motivation behind the current study, we will systematically vary the encoding and retrieval conditions of the novel object-location learning paradigm in a series of four experiments to shed new light on the nature of associative memory traces.
Part 1: Literature Overview

Independent association hypothesis

The independent association hypothesis (IAH) proposes that associations are unidirectional pointers connecting different mental representations (Wolford, 1971; Wollen, Allison, & Lowry, 1969). Consider, for example, the occurrence of a book on a table. According to the IAH, the mental representations of book and table are connected by two distinct unidirectional associations, one pointer from book to table and a separate one from table to book. These forward and backward associations are separately modifiable and statistically independent (Wolford, 1971).

In the beginning, this perspective was based on a research tradition which considered the formation of verbal associations as analogous to the learning of a classically conditioned associations and assumed similar directionality in both processes (Goss, Morgan, & Golin, 1959). The anticipation method of paired-associates learning was the standard paradigm to test the predictions of the IAH. In this paradigm, a stimulus A is presented to the subject that is asked to produce the associated stimulus B from memory. Independent of the response, B is shown after a short delay as ‘reinforcement’ and this sequence is repeated for the whole list of stimuli until a certain learning criterion is reached, e.g. in terms of percent correctly anticipated responses B. The most common finding across studies using this method was a superiority of the forward (i.e. A → B) over the backward (i.e. B → A) performance after reaching the criterion (Ekstrand, 1966). This was taken as evidence that the strength of associations is sensitive to the temporal order of encoding, where the forward association was supposed to be stronger. After the identification of confounds in the anticipation methods that biased the results (Asch & Ebenholtz, 1962; Battig, 1965), various approaches to overcome these shortcomings were...
proposed. These refined paradigms still lead in some instances to asymmetries in retrieval performance, which will be discussed below.

**Associative symmetry hypothesis**

The opposing view was first raised by Gestalt psychologists and states that associations between distinct items are established simultaneously and with equal strength (principle of associative symmetry, Asch & Ebenholtz, 1962). According to the associative symmetry hypothesis (ASH), direction and association have different sources; in other words, direction is not a part of the associative process. In its strongest formulation, the ASH claims that paired-associates can be encoded as composite units resulting in holistic representations of the association in memory (Mandler, Rabinowitz, & Simon, 1981). Asch and colleagues (1960, 1962) initially observed associative symmetry by using stimuli that were global forms made out of small figures. They further emphasized that the paired associates in the anticipation method are produced from memory with differing frequency, which leads to differential availability of the items and crucially confounds the results in favor of the IAH. Thereafter, the ASH was further confirmed by verbal material after ensuring equal availability of the items (Asch & Ebenholtz, 1962; Asch & Lindner, 1963) and by a dichotic auditory presentation of the paired-associates (Murdock, 1965, 1966). Using unlearning paradigms, even with the traditional anticipation method, equal interference effects were discovered for forward and backward associations which, was taken as additional evidence for the ASH (Birnbaum, 1966; Keppel & Underwood, 1962; Murdock, 1956).

**Summary of the empirical findings**

The apparent contradictory findings supporting the opposing theories can be ascribed in part to major differences in experimental procedures and stimulus material (Kahana, 2002).
Asymmetries in retrieval are usually produced when the constituent elements of the paired-associates are drawn from different stimulus classes, as has been shown for adjective-noun and concrete-noun-abstract-noun pairs (Lockhart, 1969), digit-letter pairs (Bartling & Thompson, 1977; Levy & Nevill, 1974), or if item availability was experimentally altered between both items (Asch & Ebenholtz, 1962; Horwitz, Norman, & Day, 1966). These findings of asymmetry are not a function of the encoding direction, but of the employed stimulus material, which differs with respect to the amount of its pre-experimental associates (Kahana, 2002). Furthermore, a nominal-functional stimulus-discrepancy as described for meaningless items can cause asymmetrical retrieval (Houston, 1964; Underwood, Ham, & Ekstrand, 1962).

Other findings of asymmetrical retrieval could not be explained by these variables because common nouns and numbers were used as stimuli (e.g. Battig & Koppenaal, 1965; Giurintano, 1972; Newman, 1972; Wollen, 1968), where it seems noteworthy to mention that the observed asymmetries are in general not substantial (<10%, Kahana, 2002). An analysis of this literature led Wickelgren (p. 248, 1977) to conclude that backward associations are in general weaker when the order of encoding is controlled; an explanation which also fails to account for all the empirical data (e.g., Wollen & Lowry, 1971). We will discuss the suggested impact of order on the resulting memory in depth in the context of Experiment 4, which was designed to test that hypothesis.

In summary, there remained empirical inconsistencies in the ASH versus IAH debate, which unfortunately faded from the literature before any compelling conclusion, able to integrate all empirical findings, was disclosed. Also, the emergence of mathematical memory models (Pike, 1984) did not lead to an imperative judgment in favor of one theory: models that assume independent forward and backward associations can mimic associative symmetry and models with symmetrical associative mechanisms can produce asymmetric retrieval under certain
conditions (Kahana, 2002). As a way out of this impasse, Kahana (2002) introduced a sophisticated experimental approach which promised more satisfying empirical and theoretical conclusions. This approach and its results will be the topic of the following section.

**Part 2: Methodological Issues**

*Average performances vs. correlational measurements*

The vast majority of paired-associates learning studies interpreted higher performance in forward than backward retrieval as evidence for the IAH and equal performance in both retrieval directions as favoring the ASH. However, the average performance in forward and backward retrieval is not the best criterion to choose between the IAH and ASH (Horwitz, Day, Light, & White, 1968; Kahana, 2002; Wollen et al., 1969). Equal average performance is only a necessary, but not sufficient prerequisite for the symmetry of the level of individual associations. The crucial question is, if each association is equally forward and backward retrievable. This would imply that at least the pointers between both mental representations are equipotent, and would open the possibility that those associations are represented holistically.

Only a handful of studies tested the individual paired-associates in both retrieval directions and three of them did not take statistical advantage of this design by correlating the performance across items, but rather compared average performances that were symmetric (Asch et al., 1960; Asch & Ebenholtz, 1962; Horwitz et al., 1968).

Wollen and colleagues (Wollen et al., 1969) averaged recall performance over 4 tests in each direction and used a regression analysis on the individual item level. They interpreted the observed correlation coefficients between .28 and .47 as a significant enough departure from 1 to reject the ASH. But because they did not relativize the magnitude of the coefficients with respect
to the correlation of responses in one direction, it cannot be definitely decided if the observed correlations are in fact incompatible with the ASH.

Therefore, Kahana (2002) introduced a novel experimental design to test for symmetry vs. asymmetry on the level of individual items: each of the studied wordpairs was tested twice, half of the wordpairs twice in the same direction (forward or backward, congruent retrieval condition) and the other half of them in both directions (forward and backward, incongruent retrieval condition). This allowed, the correlation in the congruent retrieval condition to serve as a baseline in the particular experimental setting and controls for confounds which contribute to the observed correlation. The results provided strong support for the ASH: congruent and incongruent correlations were statistically indistinguishable, which is compatible with the existence of two highly correlated associations as well as with a holistic representation (Kahana, 2002).

Confounds of successive memory tests

Methods employing successive testing are not undisputed (Kahana, 2000). Several factors, apart from the nature of the underlying memory trace, were identified that influence the magnitude of the correlation between successive tests (Kahana et al., in press). Although these sources of dependency are not the primary theoretical interest themselves, they could lead to substantial effects on the observed correlations (Flexser, 1981). Two phenomena can potentially lead to an artificial increase in the measured correlation: variability in the goodness of encoding and output encoding. The former refers to the situation, when due to fluctuations in attention, or differences in difficulty for some paired-associates, both constituent items (e.g. object and location) are encoded very efficiently, whereas other paired-associates are processed only shallow. Output encoding describes the finding that successful retrieval of an item during the first memory test
boosts performance for this item in subsequent memory tests (Humphreys & Bowyer, 1980; Richardson & Gropper, 1964). On the other hand, unsystematic variability in processes during retrieval induces performance variance between successive tests and thus leads to a reduction in the observed correlation between tests. In particular, fluctuations in factors like response criteria, depth of encoding the retrieval cue, or the willingness to finish memory searches across the two tests of a paired-associate lead to a decline in the correlation.

Part 3: The current study

General goal of the study

As outlined above, the controversy regarding the nature of associative memory did not lead to a comprehensive conclusion because i) it seemed impossible to integrate all of the partly incompatible findings, and ii) the general approach of comparing average performances for theoretical reasons can only lead to ambiguous results. As a consequence of that dilemma, the debate receded into silence for several years. It was recently revitalized by the invention of a sophisticated method of successive testing by Kahana (2002), which can prevail against the prior interpretational ambiguities. The application of this experimental procedure to simultaneously presented meaningful words as paired associates resulted in strong empirical support for the ASH (Kahana, 2002).

The goal of the current study was therefore to further investigate the nature of episodic associations by taking advantage of this experimental design as well as object-location associations as stimuli. This type of paired associates is essential in episodic memory and its introduction to the study of associative symmetry itself represents, in our view, an important complement to the existing literature, as we will outline in detail below. Furthermore, the intention behind systematically altering encoding and retrieval conditions was i) to provoke
differential, suggestive changes in the critical behavioral parameters (average as well as
correlational measurements), and ii) to estimate the magnitude of confounding factors in the
employed method of successive testing.

Object-location associations as stimuli

The crucial influence of the perceptual condition on the formation of associations was shown
early by Gestalt Psychologists (Köhler, 1941; Prentice & Asch, 1958), but except for the work by
Asch and colleagues (Asch et al., 1960; Asch & Ebenholtz, 1962), studies on the IAH-ASH
controversy exclusively employed verbal paired-associates. These were presented successively
or simultaneously on the left and right side of a display and are encoded as heterogeneous units
by verbal processes. This standard procedure singles out specific types of stimuli, as well as
relationships between them that are frequent in experience and important for theory, but are
neither the representative nor the sole cases (Asch et al., 1960).

Object-location associations are another naturalistic modality of daily-life associations,
especially in episodic memory (e.g. the memory for a book on a table, or for the parking spot of a
car). Both elements of these paired-associates are usually presented in temporal and spatial
coincidence, similar to the stimuli used by Gestalt psychologists. Moreover, object-location
associations offer the possibility of separating the constituent elements – object and location –
during encoding, similar to verbal paired-associates and thus to investigate directly the influence
of the presentation mode on retrieval performance.

Another aspect of empirical and theoretical interest in using object-location associations as
stimuli concerns particular characteristics of this type of information. Whereas verbal paired
associates are encoded based on effortful, verbal processes, empirical evidence suggests that the
encoding of object-location associations occurs partly automatically. More specifically, since
the controversy stimulated by the seminal article from Hasher and Zacks (1979) on automatic and effortful mnemonic processes, two findings have emerged from studying the memory for locations: i) the distinction between automatic and effortful processes is continuous rather than binary and ii) the encoding of the location of an object can occur automatically, but is often supported by task dependent effortful processes (Ellis, 1990, 1991; Kohler, Moscovitch, & Melo, 2001; Naveh-Benjamin, 1988). The opposite process, namely the binding of an object to a particular location, was to our knowledge never explicitly investigated with respect to the contribution of automatic and effortful processes. Only one study (Postma & De Haan, 1996) suggests that verbal, effortful processes might be involved in the assignment of an object to a location, at least to a certain extent.

In summary, two characteristics of object-location associations distinguish them from the commonly used verbal paired associates: i) the spatial and temporal coincidence and ii) the at least partly automatic encoding. These make them ideal stimuli to attain the goal of our study, namely to deepen and complement the understanding of the nature of episodic associations.

*The paradigm*

In all 4 experiments, we used variations of a previously established single-trial learning paradigm with object-location association as stimuli (Figure 1, Sommer, Rose, Gläscher, Wolbers, & Büchel, 2005; Sommer, Rose, Weiller, & Büchel, 2005). In each of 10 sessions, subjects encoded 16 unique object-location associations. The memory for each paired-associate was tested subsequently in two retrieval conditions. i) The object served as the retrieval cue and subjects had to recognize the location associated with that object. ii) The location served as the retrieval cue and subjects had to recognize the object associated with that location. Associative memory differs in its specificity, e.g. one might remember the exact parking slot of one’s car or
just the side of the street (Dodson, Holland, & Shimamura, 1998). This variability was operationalized by assessing the specificity of memory parametrically in both retrieval directions. It was specifically emphasized to the subjects not to guess the associated item, but to select as many items as necessary to be confident or to indicate the absence of confident retrieval.

Overview over the 4 experiments

In the first experiment, we adapted the technique developed by Kahana (2002) as well as possible to the described paradigm. Thus, we aimed to investigate if object-location associations are retrieved symmetrically, as has been shown for verbal paired-associates. Moreover, through an additional analysis, we aimed to estimate the effect size of variability in the goodness of encoding. In experiments 2 and 3, we systematically varied the retrieval conditions with the aim i) to challenge the result of experiment 1 by exploring the provoked performance changes, and ii) to study the extent of other confounding factors on the magnitude of the correlational measurements. In particular, the effect of output encoding and of variability in retrieval processes between tests were explored. In experiment 4, we distorted the spatial and temporal coincidence of object-location associations during encoding and presented them successively at different positions.

In all experiments, half of the paired-associates were queried at both successive tests with the same retrieval cue (object or location, congruent condition), whereas the other half were queried subsequently by both retrieval cues (incongruent condition). The correlation of performance in the congruent condition serves in each case as an experimental baseline that is crucial for the interpretation of the magnitude of the incongruent correlation.
Experiment 1

The first experiment was designed as a close analogue to the study by Kahana (2002) to test if the reported symmetry in the memory for verbal paired associates can also be found for object-location association.

Methods

Participants. Thirty volunteers participated in the experiment for payment (9 female; age range, 21-32 years; mean age, 25.6 years; recruited by advertisement).

Procedure. Each of 10 sessions (+ two practice sessions) consisted of 4 phases termed: 1) familiarization, 2) encoding, 3) distraction, and 4) retrieval. In each session, a new subset of 16 pictures of common objects (Snodgrass & Vanderwart, 1980) were used, including 8 natural and 8 artificial objects. The order of subsets was randomized over subjects. The pictures from each session belong to two categories or semantic fields like "African animals" and "musical instruments", "body parts" and "vehicles" etc. At the beginning of each phase in each session, the instructions appeared on the screen to cue subjects to the task. The background was grey in all four phases, instructions were presented in white. Picture stimuli were presented controlled by a PC using the software "Presentations" (http://www.neurobehavioralsystems.com). Participants entered the responses by pressing buttons on a computer mouse.

The familiarization phase was introduced after pilot studies showed that the pictures used were not equally familiar and verbalizable for German volunteers (Genzel, Kerkhoff, & Scheffter, 1995). Thus, the familiarization phase ensured that all subjects recognized all pictures in a comparable time frame during the encoding phase. During the familiarization phase, the pictures of the particular session were shown in the center of the screen for 2.5 sec in randomized order.
The common German name for the object was presented beneath the picture. The subjects were instructed to press the response button as soon as they recognized the picture and read the name.

In the encoding phase (Fig. 1), the subjects were shown an irregular array of 16 black boxes with the pictures of the particular subset hidden. Each picture was shown for 2 sec sequentially in a randomized order while the subject had to make a natural/artificial judgment by pressing one of two response buttons. We indicated the location of the next picture in advance (after presenting the last picture) by changing the color of the frame of the relevant box from gray to white for 500 ms. This was undertaken to avoid orienting reactions when presenting the objects, which may otherwise interfere with encoding and to shorten the time for elaborate encoding strategies. The ISI was jittered between 1.5 and 2.5 sec from the indication of the next location by the color change of the frame until the appearance of the particular picture. It was emphasized in the instructions that subjects should not use elaborate strategies to encode the location associated with an object.

In the immediately following distraction phase, subjects were instructed to count aloud backwards in steps of three from a random number between 80 and 100 displayed on the screen to minimize recency effects from the subsequent retrieval phase.

In the retrieval phase, each of the previously encoded object-location-associations were probed twice in randomly intermixed order. In the first half of the retrieval phase, 8 of the encoded 16 associations were probed by the object serving as the retrieval cue and the remaining 8 associations by the location serving as the retrieval cue. In the second half of the retrieval phase, 8 associations were probed again by the same retrieval cue as before (4 by the object- and 4 by the location-cue, congruent retrieval condition) and the remaining 8 were probed by the opposite cue as before (incongruent retrieval condition).
In object retrieval cue trials, one picture was presented in the center of the screen for 3 sec followed by the empty array of 16 boxes. Subjects were instructed to select the remembered location of the picture in the study phase by moving the mouse cursor to that box and clicking with the mouse button. It was specifically emphasized to the subjects that they should not guess the location, but select as many boxes as necessary in case of doubt or indicate that they forgot the location. In trials with the location as the retrieval cue, the empty array of 16 boxes were presented for 3 sec where one box was marked as the retrieval cue by a white question mark. This cue was followed by all 16, slightly downsized pictures of the particular subset randomly arranged in two rows in the center of the screen (Fig.1). Subjects were instructed to select the object which was presented before at that location by moving the mouse cursor to that picture and clicking with the mouse button. Again, it was emphasized to the subjects that they should not guess the picture but select as many as necessary in case of doubt or indicate that they forgot the picture.

During the two practice sessions, subjects received feedback after each response if the correct location/object was among the selected ones. This feedback was introduced to allow an adjust for individual response criterion in order to minimize false responses by guessing and indicating a forgotten location/object in case of low confidence. At the end of all sessions, a feedback for the overall memory performance for the session was given (total number of correct and “forgotten” responses in location- and object-retrieval-cue trials in that session).

**Results**

Response accuracy during the encoding phase was high (94.9 %, SD 2.75), and only objects which were categorized correctly by the subject were analyzed further. 99.8 % (SD .4%) of the responses in the object cue, and 98.9 % (SD 2.6%) in the location cue conditions of the retrieval
phase fell into the five response categories 1 to 4 indicating the number of selected locations/objects and the fifth category indicative of a forgotten location/object. We will refer to the graded ranks of response specificity from here on as RC 1 to RC4 (1 to 4 selected objects/locations) and RC 5 (indicative of a forgotten object/location). To simplify further analyses, only these 5 ranks of response accuracy were included. A Greenhouse-Geiser adjustment for degrees of freedom was applied in all analyses to guard against violation of the sphericity assumption. Only significant (p<.05) results are reported.

Accuracy

We begin the analysis of the memory performance with the “traditional” comparison of forward- and backward-retrieval. Due to the fact, that it cannot be conclusively decided what subjects encode first, we will not use these terms but refer to the retrieval conditions as object-cue and location-cue condition. Differences in the memory performance are expressed in our design as differences in the frequency distribution of the 5 RCs between retrieval cue conditions which is indicated in percent of all responses in that retrieval cue condition (equivalent to probability).

In the first analysis, the frequency of RCs in both retrieval cue conditions were therefore compared in a cue-type × RC ANOVA which revealed a significant main effect of RC (F(2.5,72.7)=41, MSe=391, p<.00), a significant interaction (F(3.1,89.6)=3.2, MSe=23.3, p<.05), and an effect of cue type (F(1,29)=4.4, MSe=.5, p=.05). The latter effect reflects the fact that in the object cue condition, more responses fell into the 5 RCs which were entered in the analysis. A closer post-hoc inspection of the interaction revealed that in both conditions, RC1 was more frequent (Tukey HSD tests p<.00). In addition, in the object cue condition, RC5 was less frequent than the other, and in the location cue condition, RC 5 was less frequent than RC2 and RC 3 (Tukey HSD tests p<.05). The comparison of the frequency of individual RCs between
retrieval cue conditions was the crucial aspect of this analysis. We found no significant difference within one RC dependent on the retrieval cue condition.

Also, the hit rate did not differ between both retrieval cue conditions as revealed by a cue-type × RC ANOVA, but is greatest for RC1 independent of the retrieval condition (F(1.9,51.9)=50, MSe=192, p<.00; post hoc Tukey HSD p<.00 for RC 1 vs 2, 3, and 4 and p<.05 for RC 2 vs 3, and 4).

Although subjects were instructed not to guess, they sometimes indicated with high confidence an incorrect location or object. This implies that subjects selected to a certain extent the correct location/object alone by chance and not as a result of a strong memory trace. The likelihood for such a lucky guess depends on the number of selected locations/objects. Therefore, the hit rates have to be corrected for lucky guesses to test if they are above chance in all RCs. Furthermore, this more valid estimation of memory trace strength also has to be compared between both retrieval conditions.

Assuming that the misses provide a rough estimate of the guessing rate for hits in our paradigm (Snodgrass & Corwin, 1988), we adopted the following as a way to correct for guessing (Rugg, Schloerscheidt, & Mark, 1998) in for our m-alternative recognition task. For 1 selected location, the probability for a lucky guess is 1/16. Therefore, the miss rates represents 15/16 of the merely guessed responses, 1/16 of lucky guess are hidden in the hit rate. In other words, 1/15 of the miss rate is just by chance correct and the hit rate has to be corrected by this value to get a more valid behavioral measure of the accuracy. Following this rational, the hit rates in the four categories were corrected for guessing. Importantly, the corrected hit rate in all categories significantly exceeded the particular chance level (p<.00 for all RCs) and again, there was no difference in frequency between both retrieval cue conditions; only RC1 was more frequent (F(2.3,66.0)=31.9, MSe=273, p<.00).
We use the “lucky guess” corrected frequency distributions of the various RCs as the dependent variable as this is the more valid parameter of the strength of the underlying memory trace. In addition, to control for potential differences in the amount of incorrect responses, the sum of incorrect responses across categories served as a dependent variable.

Each association was tested twice and could be queried by a location or an object cue. The second test encompasses two conditions: congruent and incongruent. In the congruent condition, the association is tested again with the same cue, in the incongruent condition with the other cue. For both retrieval cue conditions, there are three sub-conditions: first retrieval, second retrieval congruent, and second retrieval incongruent. To test, if there are differences in the frequency of the RCs between these sub-conditions, we computed a cue-type × sub-condition ANOVA for each RC: Only the frequency of RC2 in the first and second congruent condition cued by the object is more frequent than in the second incongruent condition and the location cue conditions (main effect condition (F(1.9,55.8)=3.9; MSe=27.9; interaction (1.9,54.4)=3.6;MSe=10.2, p<.05, Tukey HSD p<.05). The incorrect responses over all RCs were summed and similarly analyzed with no significant effect.

Response Latency

Response latencies (RL) were measured as the time from the occurrence of the retrieval cue until the selection of the first object/location, or indication of a forgotten object/location. For each subject, the median RL for each RC was calculated. In a first analysis, the RLs of hits in RC 1-4 and RC 5 (forgotten associates) were compared. Subjects were faster in responding to an object cue (cue-type × RC ANOVA, main effect of cue-type F(1,12)=98, MSe=2.5*10^6, p<.00) and faster responding with high specificity (RC1 and RC2) than with lower specificity (main effect RC F(2,28.9)=5.9, MSE=2.7*10^6, p<.00; post hoc Tukey HSD p<.05). Also, the interaction
reached significance (F(2.5,30.5)=7.8, MSe=1.2*10^6, p<.00) indicating a steeper slope for the location retrieval cue condition. In a subsequent analysis, correct and incorrect responses were compared (cue type × accuracy × RC ANOVA) and revealed that incorrect responses were significantly slower than correct ones (F(1,15)=37, MSe=1.4*10^6, p<.000) and that this effect was greater for the location retrieval cue condition (F(1,15)=7.4, MSe=, p<.05). In addition, the main effects of cue-type (F(1,15)=124.6, MSe=3.1*10^6) and RC (F(2.2,33.6)=8.4, MSe=2.9*10^6) were again significant. The RLS of incorrect responses in the various RCs were compared in a third ANOVA (cue type × RC) and did not show an effect of RC, but rather of cue-type (F(1,16)=91, MSe=3.3*10^6, p<.00).

Correlation

These analyses of the RLS suggest that one cannot unambiguously to the strength of the underlying memory trace infer from the number of incorrect responses. It is probably a quite heterogeneous category of events. Incorrect source attribution can be caused by a variety of reasons, as has been extensively studied within the source memory framework (Johnson, Hashtroudi, & Lindsay, 1993). For the correlation analysis, we excluded the incorrect responses. All correlation coefficients are therefore calculated only over the hits in RC 1 to RC 5.

The ranking of responses according to the number of selected locations/objects into RCs from 1 to 5 provides ordinal distributed performance measures with many tied ranks. We therefore decided to calculate the correlations of performance between the successive testing as Kendall’s τ (tau) which controls for tied ranks. The distribution of Kendall’s τ has slightly better statistical properties than the alternative rank correlation coefficient Spearman’s ρ and thereby allows the adoption of parametric statistical procedures (Conover, 1998).
The correlation in the congruent retrieval condition was $\tau_{\text{congruent}}=.67$ (SD=.15) and in the incongruent retrieval condition $\tau_{\text{incongruent}}=.63$ (SD=.1), where the difference is not significant ($t(29)=1.46$, $p=.15$). Then the coefficients were calculated for the two congruent sub-conditions (two times object-cue, two times location-cue respectively) and the two incongruent sub-conditions (first retrieval object-, second retrieval location-cue, and vice versa) separately. A symmetry $\times$ first cue ANOVA revealed no effect of retrieval sub-condition.

The only study with a comparable design used words as study material and assessed memory performance as dichotomized, where misses and incorrect responses are pooled together (Kahana, 2002). They calculated Yule’s Q from 2x 2 contingency tables. To be able to more directly compare our results with their findings we also dichotomized the behavioral performance post hoc by pooling RC1 to 4 and RC5 and incorrect responses. The resulting Qs did not differ $Q_{\text{congruent}}=.96$ (SD .04) and $Q_{\text{incongruent}}=.95$ (SD .04) ($t(29)=.5$).

The RLs during retrieval were also correlated using Kendall's $\tau$ to prevent an effect of outliers, a common occurrence in reaction time data. Due to the fact that the RLs in both retrieval cue conditions differed significantly, the calculation of the correlation for all congruent retrieved paired-associates would lead to an artificial increase in the coefficient. Therefore, we computed the correlation separately for the four sub-condition: two times cued by an object $r=.17$, two times cued by a location $r=.19$, first cued by an object second by a location $r=.14$ and vice versa $r=.13$. The correlations in these four sub-condition did not significantly differ (symmetry $\times$ first cue ANOVA) and all were significantly greater than 0 ($t(29)=5.8$, 7.6, 5.1, 3).

The reaction time of the encoding task had no influence on subsequent memory performance (cue-type $\times$ RC ANOVA $F(1.2,19.9)= .95$, MSe= $5.7*10^5$).
Given that in all 10 sessions the same locations were used in association with different pictures, the locations became more familiar over sessions whereas the pictures were, despite the familiarization phase, relatively novel. In addition, a practice effect which led to an increase in performance has been reported for learning object-location associations (Naveh-Benjamin, 1987, 1988). To test the possibilities that i) this disparity led to differences in the processing of both cue types over time, ii) subjects became increasingly confused by the multiple former associated pictures, and iii) practice resulted in an improvement of performance, a time × cue-type ANOVA for all 5 RCs and the incorrect responses was conducted. No significant interaction between cue type and time was observed in any of these analyses. The frequency of RC1 increased over sessions independent of cue-type (main effect session F(6.4,173.1)=8.3; MSe=438), where HSD test indicated an increase over the first three sessions (p< .05). The frequency of incorrect responses was higher in session 1 than later in the experiment (F(5.2,140.6)=5.8, MSe=244.9; HSD p<.05).

Discussion Experiment 1

Accuracy: average and correlational measurements

The traditional criterion to judge from the results of a given experiment in favor for the ASH or IAH is the comparison between the performance measured in accuracy in the forward and backward retrieval condition. The equivalent comparison in our study between behavioral performance in response to the object and the location retrieval cue revealed no substantial difference (Figure 2). This result holds for the overall frequency of each RC, the hit rate as well as the lucky guess corrected frequency of the RCs (Table 1). Also, the more detailed analysis of the effect of the three sub-conditions, i.e. tested the first time, tested the second time by the same
cue (congruent) or the second time by the other cue (incongruent condition) resulted only in a small advantage of RC2 responses in the object cue condition (Figure 3).

As outlined in the introduction, this is only a necessary but not sufficient prerequisite for the acceptance of the ASH. More precisely, the equal accuracy in the object and location retrieval cue condition means that, on average, object-location associations are equally available in both directions. This constraint was called the “Revised Symmetry Hypothesis” by Wollen (1969) and already the “principle of associative symmetry” postulated that the relation of symmetry holds for individual associations, not only for populations of instances (Asch & Ebenholtz, 1962). Thus, the critical point is if a particular association between an object and a location is of equal strength in both directions. Due to the discussed confounds on successive memory tests, we used the congruent correlation as an internal control condition. In our paradigm, the congruent and incongruent correlation do not differ (Table 2) and are – expressed in Yule’s Q – comparable to the ones obtained using simultaneously presented word pairs (Kahana, 2002).

In all, the equal response performance for both retrieval cue types and the similar correlation in the congruent and incongruent condition argue in favor of highly correlated associations or a holistic representation of object-location associations in memory.

**Response Latencies: average and correlational measurements**

The response latencies in experiment 1 differed substantially between both retrieval cue conditions, yet were equally high, even though relatively low correlated in the incongruent and congruent condition.

The few studies in the context of the ASH-IAH controversy which employed RLs as dependent variables reported inconsistent findings. Whereas some found equal median RLs corresponding to equal performance in forward and backward recall (Birnbaum, 1966; Horwitz et al., 1966),
others found the same forward advantage in RLs as in accuracy (Wollen & Allison, 1968). These studies agree insofar as they observed the same trend in both performance measures –accuracy and RL.

Only one study reported a difference between both dependent variables similar to our results (Waugh, 1970). The accuracy for forward as well as backward retrieval was close to perfect due to overlearning of the paired-associates. On the contrary, when the retrieval direction was changed for half of the subjects, the RLs were relatively slower for backward retrieval in the beginning. This difference in RL for the retrieval directions was interpreted as the consequence of automatization due to the extensively practiced response direction. The discrepancy between accuracy and RLs led to a postulated differentiation of the observed retrieval performance in a performance component and memory where the latter one is symmetric and the former one is due to the repeated learning asymmetric (Waugh, 1970).

This discussion is of particular importance for the interpretation of our results. The individual object-location associations were retrieved symmetrically, as indicated by the accuracy measurements (average performance and correlation). The correlation of RLs is low, but significantly greater than 0 and equal in all retrieval conditions. The only behavioral variable that differs between the object and the location retrieval condition are thus the average RLs. The substantially shorter RLs in the object retrieval cue condition could be caused by the following reasons. To begin with, in the location retrieval cue condition, all 16 objects were rearranged for each trial and the subjects had to encode them in order to select the ones they associated with the cue. This time-consuming visual search process in only one of the two retrieval conditions is an experimental byproduct and not related to differences in the mnemonic processes. The two other potential causes for the prolonged RLs in the location retrieval cue condition concern cognitive processes directly related to memory. First, associative memory traces might be slightly stronger
from an object to its location as expressed in shorter RLs. Yet, it seems unlikely that slightly stronger memory traces would only be reflected in substantial shorter RLs and not also in differences in accuracy. Secondly, the retrieval of a location may potentially rely more on faster, automatic processes than the retrieval of an object. If and to what extent differences in automaticity in the two retrieval conditions - analogous to the results from Waugh et al. (1970) – caused the differences in RLs cannot be decided due to the described visual search processes. But, even if the differential contribution of these two processes (visual search and effortful processes) to the RLs cannot be disentangled, we would argue that the differences in RLs concern the performance component rather than memory strength itself (Waugh, 1970). Altogether, differences in RLs are only interpretable within a retrieval condition, but not comparable between both conditions. Within the two retrieval conditions, the RLs increased over the RCs. This correlation between RLs and memory specificity is, besides the over RCs decreasing hit rate, another consistency between our parametric assessment of associative memory and confidence ratings as used in familiarity tests (Hockley & Murdock, 1987; Yonelinas, 2001).

Potential influence of intentionality on performance

In the employed learning paradigm, subjects were clearly aware the memory test would follow each session. This topic is addressed because some authors claimed that only incidental learning settings are suited to test the predictions of the ASH and IAH (Ekstrand, 1966). A significant influence of intentional vs. incidental learning on the relative performance of forward and backward retrieval was explicitly negated by two studies (Epstein, Szymanski, & Daggett, 1977; Newman & Campbell, 1971). One found support for the ASH and observed overall higher performance under intentional conditions (Epstein et al., 1977). The results of the other one
(Newman & Campbell, 1971) are especially convincing in the following context. They varied the order of pronunciation of the paired-associates (first the left vs. first the right word) and the direction of the expected retrieval (left word vs. right word as retrieval cue) in a 2 x 2 factorial design. The instructions with respect to the expected retrieval order had no impact on forward and backward performance but rather the order of pronunciation, where the later processed word was more easily retrieved and thereby led to the observed asymmetry. Furthermore, led an intentional learning situation not in every case to symmetrical associations (Wollen & Allison, 1968). Intentional learning in recognition tests usually leads to the same performance as an incidental setting (Estes & Da Polito, 1967). Apart from the presented empirical evidence that intentionality has no clear effect, the “principle of associative symmetry” postulates that the symmetry of associations is supposed to be independent of intention and effort of the learner (Asch & Ebenholtz, 1962). The fact that we did not observe a correlation between encoding time and memory performance casts doubt that subjects employed elaborative strategies to support associative processes.
Additional Analysis: Variability in the Goodness of Encoding

Variability in the goodness of encoding refers to the fact that due to fluctuations in attention, to changes in the employed strategy, or to item difficulty some object-location associations might be encoded very deeply and efficiently whereas others are processed rather hastily and shallow. The probability of retrieving the elements of deeply encoded associations on both successive tests is relatively high, whereas for the less attended associations, probably neither the object nor the location can be retrieved. This variability introduces a common source of variance to both successive tests and could lead to correlations after collapsing across items that were not present in the pre-collapsed data (Simpson's Paradox, Flexser, 1981; Hintzman & Hartry, 1990; Kahana, 2000; Kahana et al., in press). Variability in the goodness of encoding is experimentally difficult to control, and its influence on the observed correlation between successive tests cannot be definitely specified.

To obtain at least an estimation of the magnitude of its influence in our paradigm, we took advantage of two inherent characteristics of the design: the serial and the spatial position effect. In previous studies using variations of the task, we consistently observed a primacy effect, presumably caused by the differential allocation of attention (Sommer, Rose, & Büchel, submitted). Furthermore, the corner positions were easier to remember in both retrieval cue conditions (Sommer et al., 2005; Sommer et al., 2005). The isolation of one element of an association by distinctiveness, as it is the case in the serial and spatial position effect, results in superior memory for both paired-associates (Newman, 1965).

Based on these considerations, we aimed to reduce the variability in the goodness of encoding by removing those “easy” associations from the correlation analysis and thereby expected a decline of the correlation.
Results

A Greenhouse-Geiser adjustment was applied if necessary and the lucky guess corrected frequency of the 5 RCs, as well as the overall frequency of incorrect responses, were used to analyze accuracy. Only significant (p<.05) results are reported.

Influence of the serial position on accuracy

To test for an affect of serial position, we conducted cue-type × serial position ANOVAs for the frequency of the 5 RCs. Only the frequency of RC1 responses varied dependent on the serial position (F(9.4,271.8)=13.7, MSe=346) and no effect of cue-type was observed. HSD test revealed a strong primacy effect for the first two positions and a trend for positions 3 and 4. The frequency of incorrect responses decreased over serial positions (F(9.4,271.4)=3.6, MSe=199.6).

Influence of the spatial position on accuracy

The effect of the spatial position in the array of boxes during the encoding phase was analyzed by comparing the influence of the number of direct-neighbours (2, 3 or 4) on memory specificity. The frequency of the RCs in the three classes of positions were compared by cue type × spatial position ANOVAs. RC1 was more frequent at corners (F(1.8,52.9)=25.5 , MSe=88.2, HSD p<.00), RC 2 more frequent in the middle (F(1.9, 54.5)=3.9, MSe= 34.7, HSD p <.05), RC 3 less frequent at corners than at the border (F(1.8,52.8)=5.5, MSe= 33.4, HSD 1 < 2 p<.00) and RC 5 less frequent at corners than in the middle (F(1.7,50.1)=4.7, MSe= 44.5 HSD 1 < 3 p<.05).

Correlation

To reduce the variability in the goodness of encoding, associations presented at serial positions 1 to 4 and at corner positions were excluded because they were more efficiently encoded than the remaining associations. The correlation over the remaining events yielded \( \tau_{\text{congruent}} = .63 \) (for all
events .67) and $\tau_{\text{incongruent}}=.62$ (for all events .63). Compared with the correlation over all events, the reduction due to the extremely well encoded associations resulted in a significant decline in the correlation ($F(1,29)=4.4$, $MSE=.006$, $p<.05$), but again no difference between congruent and incongruent was observed.

**Discussion of the additional analysis of experiment 1**

The reduction in the variability of the goodness of encoding resulted in a modest decline of the congruent as well as incongruent correlations. The employed stimulus material is standardized on variables of relevance to memory and cognitive processing (Snodgrass & Vanderwart, 1980). Together with the pre-familiarization phase, it seems thus reasonable to assume uniformity of the items. This view is supported by the results of a previous study with the same stimulus material where no correlation between word frequency, familiarity, and recognition performance for individual items was observed (Sommer et al., 2005). The short sessions are expected to minimize fluctuations in attention, thus the serial and spatial position effect should be the major remaining source of variability in the goodness of encoding.
Experiment 2

The goal of the second experiment was twofold. First, we aimed to explore the effect of output encoding on the retrieval performance and to estimate the magnitude of this confound on the correlations observed in experiment 1. Second, we were interested in how the employed experimental manipulation might differentially affect the performance in response to both retrieval cues and the relation between congruent and incongruent correlations.

Output encoding refers to the phenomena that a memory test even without feedback in some instances boosts the performance of a successive test (Kahana, 2000). This is a common source of variance in both tests of individual paired-associates and could potentially lead to an artificial increase in the observed correlation.

Of particular interest in this context of the IAH-ASH controversy is the question if output encoding boosts performance exclusively in the congruent retrieval direction or if it strengthens the associative bonds independent of direction. The latter case would be indirect evidence for a dependency of the two associative bonds.

The only study using the method of successive testing to study paired-associates which discussed the potential confound of output encoding did not observe a boost in performance in either direction (Wollen et al., 1969). However, stable performance over successive tests is not the critical argument for negating output encoding. A performance boost might be masked by the parallel decay of memory traces that would lead - without output encoding - to a decline in performance, both processes could potentially be in balance.

We did not observe a decline in performance for the second test in experiment 1. To test, if this stability might be a result of output encoding, we conducted experiment 2, where only half of the
paired-associates were tested twice, interrupted by a demanding distraction task, whereas the other half was only tested at one occasion after the distraction.

The introduction of a demanding distraction task between the two successive tests for half of the items allows us to explore if i) the performance in response to both retrieval cue types and ii) the congruent and incongruent correlations are differentially affected by this experimental manipulation.

**Methods**

**Participants.** 20 volunteers participated for payment (9 female; age range, 21-32 years; mean age, 25.6 years; recruited by advertisement).

**Procedure.** Only the retrieval phase differed from experiment 1 insofar as only half of the associations were tested twice. The retrieval phase was therefore divided into 2 sub-phases separated by an additional distraction phase. During the first retrieval sub-phase, only 8 associations were tested to allow output encoding, 4 queried by the object and 4 by the location. The additional distraction phase was introduced to boost forgetting and increase the potential effect of output encoding. Subjects were asked to count backward for 2 minutes in steps of 7 from a random number between 400 and 500. In the second retrieval sub-phase, all 16 associations were tested. From the eight associations tested the second time, 4 were tested in a congruent and 4 in an incongruent manner. Of the remaining 8 associations tested only one time, 4 were queried by the object and 4 by the location.

**Results**

Accuracy during encoding was again high (97.8 %). 99.4 % of all responses in the object and 99.1% of all responses in the location retrieval cue condition fell into the 5 RCs. We used the lucky guess corrected frequencies of the 5 RCs and the frequency of incorrect responses to
compare the performance in terms of accuracy. A Greenhouse Geiser adjustment was applied if necessary. Only significant (p<.05) results are reported.

**Accuracy**

In an initial analysis, we tested if the frequency distribution of experiment 2 replicated that of experiment 1. For this reason, we averaged performance only over the retrieval trials of associations which were tested twice and were comparable to experiment 1 with the only difference being the distraction phase. Experiment ( 1 and 2) × RC ANOVAs for the 5 RCs revealed no effect of experiment for RC1 to RC4 but for RC5 (F(1,48)= 61.9, MSe=252.5), indicating lower frequency in experiment 1 (Table 1).

In the consecutive analysis, we were interested in the effect of output encoding on performance. To this end, we compared for both retrieval cue conditions the performance in the 4 possible sub-conditions: first retrieval before the distraction phase, second retrieval congruent, second retrieval incongruent, and first retrieval after the distraction phase. For RC1, the cue-type × sub-condition ANOVA revealed an effect of sub-condition (F(2.6, 49.6)=12.9, MSe= 85, p<.00), where HSD test showed that only the performance in the first retrieval after distraction sub-condition (without output encoding) was significantly lower (p<.00). Furthermore, RC5 was less frequent in the first retrieval before distraction than in the other sub-conditions (F(2.4, 44.9)=9.3, MSe=56.6 p<.00, HSD p<.05) and more frequent in the location retrieval cue condition (F(1,19)=5.9 MSe=274.6 p<.05, HSD <.05) (figure 5).

**Correlation**

The correlation in the congruent and incongruent retrieval condition was computed as before with Kendall’s τ for tied ranks and the incorrect responses were excluded from the analysis. This
analysis revealed $\tau_{congruent} = .64$ (SD .19) and $\tau_{incongruent} = .55$ (SD .18), which differed significantly ($t(19)=2.4$, $p<.05$) (table 2). A comparison with experiment 1 revealed a main affect of condition ($F(1,2)=8.2$, $MSe=.10$), where HSD tests showed that only the difference between experiment 1 congruent and experiment 2 incongruent condition reached significance ($p<.05$).

**Discussion experiment 2**

We begin with a discussion of the implications of the observed output encoding for the interpretation of the correlations as measured in experiment 1. Thereafter, we will relate the pattern of performance to the ASH-IAH controversy.

*Impact of output encoding on performance*

The effect of output encoding was of the same magnitude for i) congruent and incongruent retrieval, and ii) for the object and location retrieval cue conditions. It was limited to RC1 responses.

Because output encoding boosts performance in the congruent as well as in the incongruent retrieval direction one would expect a similar increase in both correlations. The magnitude of a correlation in a particular experimental design is only interpretable for direct comparison when the congruent correlation serves as the control condition (Kahana, 2002). An artificial increase of equal magnitude in both coefficients would thus mean that output encoding is of minor relevance for the interpretation in our design, even if it affects the absolute magnitude of the coefficient.

The effect of output encoding has been investigated mostly in the context of the recognition failure paradigm. In this paradigm, the learning of paired-associates is followed first by a recognition test and subsequently by cued recall. If some items are only tested in the cued recall test, they are less likely to be recalled than items which were presented before in the recognition
test (Humphreys & Bowyer, 1980; Kahana et al., in press), where performance is only slightly boosted when recognition failed for that item (Donnelly, 1988).

Previously, the effect of output encoding has also been demonstrated for the cued recall of paired-associates (Richardson & Gropper, 1964; Wollen, 1962): using the anticipation method without feedback, the forward and backward performance increased over retrieval attempts. In the single learning trial procedure, only subtle effects were observed (Allen, Mahler, & Estes, 1969; Estes, Hopkins, & Crothers, 1960). This latter approach is the one most similar to ours and the finding of only slight improvements confirms our results and conclusions.

**Differential effects on behavioral measurements**

In the second part of this discussion, we will attend to the main goal of the current paper, the ASH-IAH controversy. On the one hand, we observed a similar impact of the first retrieval on the second retrieval performance independent of the direction. This is per se evidence in favor of the ASH: if output encoding in one direction also supports subsequent retrieval in the opposite direction, this is only explainable by a dependency of the two associative bonds. Similarly, it was argued that equal retroactive interference in both retrieval directions suggests symmetric associations (Birnbaum, 1966; Keppel & Underwood, 1962; Murdock, 1956).

On the other hand, we observed a differential impact of the distraction phase on the congruent and incongruent correlation: only the latter one suffered from this experimental manipulation. On average, the associative bonds are equipotent as indicated by the equal response performance for both retrieval cues before and after the distraction. On the level of individual associations, the distraction revealed some asymmetries, which are reflected in the relatively smaller incongruent correlation. Because the observed congruent correlation did not differ from experiment 1, we conclude that the attenuation of the incongruent correlation is not just the consequence of “noise”
on retrieval performance caused by the distraction phase. On the contrary, we hypothesize that this retrieval condition is able to disclose subtle asymmetries in individual associations, which were not statistically detectable in experiment 1. Thus, one has to deduce from this performance pattern that two distinct but highly correlated pointers exist between the mental representation of an object and the associated location.
Experiment 3

The third experiment was similar to the second and also motivated by two goals. On the one hand, the influence of another confound on the correlations of successive memory test needed to be explored. We chose as an experimental manipulation the induction of time pressure and unspecific distraction during half of the retrieval trials. On the other hand, we wanted to gain further insight into the nature of the object-location associations by the analysis of performance changes provoked by this challenging condition.

Variability in cognitive processes during retrieval adds separate variance to each test of a particular item. Thus, this confound could potentially lead to a decline of the observed correlation. Variability is induced by fluctuations i) in attention, ii) in the level of retrieval cue processing, iii) in the applied response criteria, and iv) in the willingness to finish the memory search process. These factors interact and influence memory performance non-systematically in both tests.

One goal of experiment 3 was thus to obtain an estimation of the magnitude of this potential attenuation of the correlation by inducing variability in behavior during retrieval. Half of the retrieval trials were accomplished under time pressure and a distracting ringing sound (retrieval stress condition). We expected that this manipulation would lead to a reduction of attention to retrieval processes, a higher probability of premature terminated memory search process, and a lowering of the response criterion. In terms of performance, we hypothesized a reduction in accuracy as well as correlation by this experimental manipulation.

The second goal was to explore if the expected changes in accuracy and correlation affect i) the average accuracy in both retrieval cue conditions, and ii) the congruent and incongruent correlation differentially.
Method

Participants. 30 volunteers participated in the experiment for payment (17 female; age range, 18-31 years; mean age, 24.2 years; recruited by advertisement).

Procedure. Only the retrieval phase differed from experiment 1 insofar as half of the retrieval trials were assigned as “retrieval-stress condition”. Distracting stress was induced in these trials by presenting an old fashion telephone bell ringing over headphones simultaneously with the appearance of the retrieval cue. This ringing sound was continuously present until the subject indicated the end of the retrieval trial by clicking the right mouse button. In addition, a green bar was presented in the center of the screen after the offset of the retrieval cue while the subject select the object or location associated with the retrieval cue. Analogue to an hourglass, this bar was increasingly hidden by a red bar as an indication of elapsing time. There was no time limit, but the instructions heavily emphasized response speed in the retrieval stress trials and to adjust the speed/accuracy trade-off accordingly. To increase the impact of the distracting sound on the level of processing of the retrieval cue, it was only presented for 500 ms.

Results

Accuracy during encoding was again high (94.7 %). 98.3 % of all responses in the object and 97.1% of all responses in the location retrieval cue condition fell into the 5 RCs. We used the lucky guess corrected frequencies of the 5 RCs and the frequency of incorrect responses to compare the performance in terms of accuracy. Again if necessary a Greenhouse-Geiser adjustment was applied. Only significant (p<.05) results are reported.
Response Latencies

Response latencies (RL) were calculated from the start of the presentation of the retrieval cue to the selection of the first object/location, or the indication of a forgotten object/location. For each subject, the median RL for each RC was calculated. We began the analysis with a comparison of the RLs in responses to both retrieval cues and in both retrieval conditions (control and stress). A cue type × retrieval-condition × RC ANOVA revealed no main effect of retrieval-condition (control vs. stress), but a significant cue type × retrieval-condition interaction \( F(1,4)=11.2, \text{MS}_e=2.3\times10^6 \). HSD tests first replicated the finding of experiment 1, that under the normal retrieval condition, the RLs in response to a location cue are longer. Secondly, retrieval stress lead to a significant decline in RLs in the location retrieval cue condition \( (p<.05) \); the decline in RLs in the object retrieval cue condition failed to reach significance. Next, we were interested if within the location retrieval cue condition stress affects the different RCs differentially. A retrieval-condition × RC ANOVA revealed a significant interaction \( F(1.8,12.6)=4.3, \text{MSe}=1.0\times10^6 \). HSD tests showed that without stress, subjects respond significantly faster with RC1 than RC 3 to RC5 \( (p<.05) \), whereas under stress only the difference between RC1 and RC5 reached significance \( (p<.00) \).

In two succeeding analyses, we investigated if the RLs of correct and incorrect responses in both retrieval cue conditions differ. In the object as well as in the location retrieval cue condition, the retrieval-condition × accuracy × RC ANOVAs revealed a significant retrieval-condition × accuracy interaction \( F(1,2)=8.2, p<.05, \text{MSe}=1.1\times10^6, p<.05; F(1,2)=15.2, \text{MSe}=3.5\times10^5, p<.05 \). HSD tests showed that only in the control condition were the incorrect responses significantly slower than in the correct responses, whereas under stress correct and incorrect responses were equally fast.
To analyze the impact of the instructions on the total time subjects needed for their responses, the total response time was calculated from the start of the presentation of the retrieval cue until the response was terminated by clicking with the right mouse button. The indication of a forgotten response results in the same latency as before. A cue-type × retrieval-condition × RC ANOVA revealed a significant cue-type × retrieval-condition interaction ($F(1,4)=21.7$, $MSe=2.2*10^6$). HSD tests indicated that subjects needed more time to terminate their responses in the location retrieval cue condition ($p<.00$) and that only in the location retrieval cue condition did the effect of stress on latency reach significance ($p<.00$).

Separate RC × retrieval-condition × accuracy ANOVAs for both retrieval cue-types resulted in the object cue conditions in a significant accuracy × retrieval-condition interaction ($F(1,8)=10.9$, $MSe =1.1*10^6$). HSD tests indicated that only without stress are incorrect responses slower than correct ones. Also, the effect of RC reached significance ($F(1.4,11.3)=8.6$, $MSe=1.9*10^6$). HSD tests indicated that RC4 and RC5 responses were slower ($p<.00$). In the location retrieval cue condition, none of the comparisons reached significance.

It should be noted that the analysis of both reaction time parameters during retrieval (start and end of the retrieval) suffered from reduced statistical power due to unbalanced ANOVAs. In the retrieval stress condition, several subjects never selected 3 and 4 objects/locations, which resulted in missing cells. An inspection of Figure 7, where the group means are plotted suggests differences in reaction times for both retrieval conditions in response to both retrieval cues.

Comparison of accuracy with experiment 1

The retrieval cues were presented in experiment 3 for only 500 ms instead of 3 sec as in experiment 1. Because a between subject analysis with experiment 1 was planned, we compared first the frequency distribution of the RCs in experiment 1 and the control condition in
experiment 3 (Table 1). None of the experiment (1 and 3) × cue-type ANOVAs reached significance. Therefore, we concluded that both experiments are comparable with respect to the observed correlation.

Accuracy

The influence on performance of the stress-induction was analyzed for all RCs (Figure 6, Table 1). RC1 was less frequent in the location retrieval cue condition under stress than in all other conditions (object retrieval cue as well as location retrieval cue control conditions, (F(1,29)=15.2, MSe= 48.2, , HSD p<.00). RC2 and RC3 were overall less frequent under retrieval stress (F(1,29)=16.7, MSe= 10.8, p<.00; F(1,29)=16.7, MSe=8.6 p<.00). RC4 was less frequent in response to a location cue (F(1,29)=12.6, MSe=33.5 p<.00). RC5 and incorrect responses were more frequent in response to a location cue and even more frequent under retrieval stress (F(1,29)=36.5, MSe=14.5, HSD p<.00; F(1,29)=20.8, MSe=25.2; HSD p<.00).

Correlation

The correlation in the congruent and incongruent retrieval condition was computed as before with Kendall’s τ for tied ranks; incorrect responses were excluded from the analysis. The congruent and incongruent correlation differed significantly τ_{congruent} = .50 and τ_{incongruent} = .41 (t(29)=3.4, p<.00) (table 2). A closer inspection of the correlation in experiment 3 by subdividing into the 4 sub-conditions [i) twice by an object, ii) cued by a location, iii) cued first by an object, and iv) cued first by a location] revealed a significant effect (F(2.5,69.9)=4.6, MSe=.03), where HSD tests indicated that the congruent condition (both times cued by an object) was more correlated than the other three sub-conditions (p<.05). We also compared the congruent and incongruent correlation with experiment 1 in a condition (congruent-incongruent) × experiment
ANOVA. Both correlations in experiment 3 are significantly lower (F(1,58)=31.9, MSe=.03, p<.00).

Under stress, significantly more incorrect responses occur in the location retrieval cue condition. Similar to previous analyses, these were excluded from calculating the correlation because they might bias the result. Therefore, as in experiment 1, we calculated Yule’s Q which also differed significantly between congruent and incongruent retrieval: $Q_{\text{congruent}} = .87$ and $Q_{\text{incongruent}} = .83$ ($t(29)=2.1, p<.05$). In addition, the comparison with experiment 1 replicated the result of Kendall’s $\tau$: retrieval stress resulted in a significant decline in the correlation (F(1,58)=26.3, MSe=0.01, p<.00). The validity of the result was confirmed in a further analysis, where incorrect responses were included as RC6 in the computation of Kendall’s $\tau$. This analysis lead to $\tau_{\text{congruent}} = .52$ and $\tau_{\text{incongruent}} = .48$, whose difference was not significant ($t(29)=1.8$). Again, both correlations were lower than the same coefficient from experiment 1 (F(1,58)=46.6, MSe=.015, p<.00). Congruent and incongruent correlation in experiment 1 using this coefficient and including the incorrect responses as RC6 did not differ ($\tau_{\text{congruent}} = .66$ and $\tau_{\text{incongruent}} = .65$, t(29)=1.05).

**Discussion experiment 3**

In experiment 3, we aimed to induce fluctuations in the cognitive processes during retrieval by applying time pressure and an unspecific distractor. In particular, the experimental manipulation was expected to lead to prematurely terminated memory search processes, lowering of the response criterion, shallower encoding of the retrieval cue and attenuated attention to retrieval processes. This was done with the goal i) to study the effect of such variability, which occurs also naturally, on the correlation of successive tests, and ii) to investigate if retrieval stress affects the various performance measures differentially.
In experiment 3, the retrieval cue was presented for only 500 instead of 3000 ms as in the other experiments of this study. We have shown before that even the reduction of presentation time to 250 ms results in literally an exact replication of the results obtained by 3000 ms in experiment 1 with respect to average as well as correlational performance measurements. This experimental manipulation was incorporated to introduce fluctuations in retrieval cue processing; but due to the absence of any effect, the data are not presented in detail in this paper. The independence of retrieval performance from cue presentation time indicates that the results of experiment 3 are comparable with the remaining experiments.

*Impact of variability during retrieval on the observed correlation*

We begin the discussion again with a comparison of the correlation coefficients in experiments 1 and 3. The induced variability during retrieval affects the observed correlation quite strongly. Both correlations were significantly and substantially lower than without retrieval stress, whereby the incongruent retrieval correlation suffered more than the congruent. In particular, the congruent correlation was reduced by 25%, the incongruent by so much as 40%.

Due to the retrieval stress, subjects were more likely to produce incorrect responses. Therefore, we were concerned that excluding incorrect responses from the analysis, as in previous analyses, might bias the measured correlation under this experimental manipulation. To control for that possibility, two additional correlation coefficients that included incorrect responses were computed: Yule’s Q as in experiment 1 and Kendall’s $\tau$, where incorrect responses were ranked as RC6. Both coefficients show exactly the same pattern as the Kendall’s $\tau$ based only on correct responses from experiment 1.

Upon reviewing this substantial lowering of the coefficients, it is important to note that the experimental manipulation was rather harsh and probably exaggerates spontaneously occurring
fluctuations. This view is supported by the fact that the decline in the correlation is at least partly a direct consequence of the unidirectional decline of accuracy in the location retrieval cue condition. Neither in experiment 1 nor experiment 2 were such differences in accuracy between retrieval cue conditions observed. This indicates that variability in retrieval processes that primarily affect the location cue condition do not play a crucial role in our paradigm.

Differential effects on behavioral measurements

We observed striking differences in the impact of the experimental manipulations on the retrieval of objects and locations: the retrieval of an object associated with a location is more substantially accelerated than the response to an object retrieval cue (Figure 7). In addition, the impact of retrieval stress on the accuracy was also more prominent in the location retrieval cue condition (Figure 6).

For the interpretation of these results, especially regarding the object retrieval cue condition, it seems crucial to consider that the upholding of equal memory performance under divided attention conditions usually leads to prolonged response latencies (Baddeley, Lewis, Eldridge, & Thomson, 1984; Carrier & Pashler, 1995; Naveh-Benjamin & Guez, 2000). Due to the speed instructions, subjects also responded in our experiment in the object retrieval cue condition with shortened latencies, at least subtly, under retrieval stress and thus did not compensate for the distraction. One can conclude from this that the retrieval of a location associated with an object relies on processes that are not mainly vulnerable to distraction and time pressure, two characteristics of automatic processes.

This conclusion is supported by findings that the automatic, familiarity driven retrieval of item memory is - compared to effortful, associative memory - only marginally impaired by distraction
during retrieval (Dehn & Engelkamp, 1997; Jacoby, 1991; Naveh-Benjamin & Guez, 2000) and a fast processes (Dehn & Engelkamp, 1997; Gronlund, Edwards, & Ohrt, 1997; Hintzman, Caulton, & Levitin, 1998; Johnson, Kounios, & Reeder, 1994). Altogether, our results imply that the retrieval of the location associated with an object relies predominantly on automatic processes and thus parallels the encoding of locations (Ellis, 1990; Hasher & Zacks, 1979; Kohler et al., 2001).

Another conclusion derived from the results in the location retrieval cue condition concerns the applied experimental manipulation. The retrieval stress was induced with the intention to provoke a relative decrease in i) attention, ii) the level of retrieval cue processing, iii) response criteria, and iv) the willingness to finish the memory search process. A decrease in attention as well as hasty memory search processes do not impact automatic memory processes and is thus consistent with the observed stable memory performance under retrieval stress. In contrast, lowered response criteria as well as shallower encoded retrieval cues should impair automatic as well as effortful processes. The result in the object retrieval cue condition suggests that subjects neither changed their response criterion nor encoded retrieval cues less efficiently under retrieval stress.

Contrary to the so far discussed retrieval of a location, the retrieval of an object associated with a location was accelerated substantially and memory performance suffered significantly under retrieval stress. As discussed in experiment 1, the RLs in the location retrieval cue condition are the result of an interaction of mnemonic and visual search processes, both of which become more demanding under retrieval stress. We proposed before that subjects neither changed their response criterion nor encoded the objects as retrieval cue less efficiently under retrieval stress. A generalization of this behavior to the location retrieval cue condition implies that the decline in performance under distraction can be caused only by a decrease in attention, premature
terminated memory search processes, and the hasty visual search that led to shallower encoded objects during retrieval. The differential contribution of these three factors to the decline in accuracy under distraction cannot be disentangled. However, because the first two factors predominantly impair effortful mnemonic processes, one can speculate that the retrieval of an object might rely to a certain degree on voluntary processes. This possibility is supported by the fact that, in all experiments, subjects stated that they felt it was more difficult to retrieve an object, which is odd given the equal performance in both retrieval conditions in experiments 1 and 2. In the literature, there is only one indirect indication that the assignment of an object to a location relies on processes which can be impaired by articulatory suppression (Postma & De Haan, 1996).

All in all, the differential impact of stress on both retrieval conditions may have disclosed slight differences in the contribution of automatic and effortful processes to the retrieval of an object and a location. This conclusion would be similar to the result from experiment 2, where only the incongruent correlation decreased due to the distraction phase was taken as evidence for two independent, but under “normal” conditions, highly correlated pointers.
Experiment 4

The general goal of experiment 4 was to explore if the highly correlated associations observed in experiments 1 and 2 were due to the very particular presentation mode of object-location associations. Gestalt psychologists defined coherence as the general fact that we relate given experiences to each other in a manner that unifies them. Further, they suggested a distinction between coherence within a unit and coherence of one unit with another (Asch, 1969). They hypothesized that the relationships between stimuli control for the course of acquisition and the resulting memory. To empirically study the impact of these relationships on memory, they used perceptual characters which were presented in varying figure-ground, part-whole, and constitutive aspects (Asch, 1969; Asch et al., 1960; Köhler, 1941). They observed, in fact, a strong impact of the relationship between stimuli during encoding on memory performance. Subsequently, it was shown that spatial coincidence suffices to produce associative symmetry during retrieval (Asch & Ebenholtz, 1962).

Object-location stimuli can be presented at identical positions in time and space, similar to the stimuli used by the Gestalt psychologists. In experiment 1, it was shown that the presentation of an object-location stimuli in this manner led to associative symmetry during retrieval. The fourth experiment aimed to investigate if the spatial and temporal coincidence of object-location associations is a necessary condition for the formation of symmetric associations. Therefore, the somewhat natural coincidence was disintegrated and both elements were presented i) in a temporal order and ii) on different spatial locations. More specifically, first the particular location was indicated, followed by an ISI of 1 sec after which the associated object appeared in the center of the screen.
Method

Participants. 20 volunteers participated in this experiment for payment (13 female; age range, 18-30 years; mean age, 23.2 years; recruited by advertisement).

Procedure. Only the encoding phase differed from experiment 1. During the encoding phase, the particular location was indicated as in experiments 1 through 3 by changing the color of the frame of one of the 16 black boxes to white for 500 ms. 500 ms later this box “lost” its color and changed to the background color grey for 1 sec. After one more second, the box turned to black again. In the center of the screen, the associated picture was presented for 2 sec and subjects had to make a natural/artificial judgment by pressing one of two response buttons, as in the previous experiments. The ISI from the change in frame color until the presentation of the particular picture was jittered between 1.5 and 2.5 sec.

Results

Accuracy during encoding was again high (98.1 %). 98.7 % of all responses in the object and 99.1% of all responses in the location retrieval cue condition fell into the 5 RCs. We used the lucky guess corrected frequencies of the 5 RCs and the frequency of incorrect responses to compare the performance in terms of accuracy. A Greenhouse Geiser adjustment was applied if necessary. Only significant (p<.05) results are reported.

Accuracy

The frequencies of the 5 RCs were equal in response to both retrieval cue types. A RC × retrieval-condition ANOVA revealed a significant interaction (F(2.6,50.2)=3.7, MSe=19.0). HSD test revealed that overall RC1 responses were more frequent, and in the location cue
condition RC5 was more frequent than RC 2 to 4 (p<.05). There was no significant effect of retrieval cue type (figure 2, table 1).

**Comparison with experiment 1**

Experiment (1 and 4) × cue type ANOVAs for all RCs were computed and revealed only a main effect of experiment for RC2 (F(1,48)=4.8, MSe=48.5), indicating that this RC was less frequent in experiment 4.

**Response Latency**

Subjects were faster in responding to an object cue (cue-type × RC ANOVA, main effect of cue-type F(1,9)=16.2, MSe=1.1*10^7, p<.00) and faster when responding with high specificity (RC1 and RC2) than with lower specificity (main effect RC F(1.5,13.4)=6.6, MSE=3.6*10^6, p<.05; HSDs p<.05) (Figure 3). In a second analysis, correct and incorrect responses were compared (cue-type × accuracy × RC ANOVA) and revealed that incorrect responses were significantly slower than correct ones (F(1,8)=10.5, MSe=1.5*10^6, p<.05). The main effect of retrieval cue and RC again reached significance (F(1,8)=84.5, MSe=2.2*10^6, p<.00; F(1.7,13.5)=7.9, MSe=1.7*10^6, p<.00). The comparison with experiment 1 revealed no significant difference in a RC × cue-type × experiment ANOVA.

**Correlations**

The correlation in the congruent retrieval condition was $\tau_{\text{congruent}}=.65$ (SD=.19) and in the incongruent retrieval condition $\tau_{\text{incongruent}}=.50$ (SD=.24); the difference was significant (t(19)=2.7, p<.05). The comparison with experiment 1 revealed a significant interaction
(F(1,48)=4.1, MSe=.02, p<.05) indicating that the incongruent correlation in experiment 4 is lower than the others.

The corresponding Qs did not differ significantly in experiment 4: $Q_{\text{congruent}}=.95$ (SD .04) and $Q_{\text{incongruent}}=.90$ (SD .14) (t(19)=1.3). The comparison with experiment 1 also showed no statistical difference.

The correlations were again computed for the four sub-conditions separately: two times cued by an object $\tau=.13$, two times cued by a location $\tau=.19$, initially cued by an object then by a location $\tau=.10$ and vice versa $\tau=.08$. The correlations in these four sub-conditions revealed a significant effect of congruence (F(1,19)=1.5, MSe=9.04), indicating incongruent response latencies were less correlated. All correlations were significantly greater than 0 (t(19)=3.9, 4.6, 2.1, 2.3). The comparison with experiment 1 revealed no significant result.

The reaction time of the encoding task had no influence on the subsequent memory performance (cue-type × RC ANOVA F(3.1,27.4)= 1.3, MSe= 22847). Again, the comparison with experiment 1 revealed no significant difference.

**Discussion experiment 4**

In experiment 4, the performance in response to both retrieval cue types was equal, whereas the incongruent correlation was significantly lower than the congruent, but still far from being 0. Thus, whereas the associative bonds were on average equally strong, individual associations were not always equipotent when objects and location were presented successively. Apart from the lower incongruent correlation, the performance in experiment 4 resembles that of experiment 1 with respect to all computed dependent variables. Subjects executed the encoding task with the same speed, which indicates that they did not spend more time with voluntary associative processes during encoding. The average accuracy in both experiments was also equal,
which shows that both tasks were of the same difficulty. Whereas the equal average accuracy after the spatial separation is in accordance with the findings from Asch et al. (1960), contrary to our results, they reported a general substantial decline in performance following a separated presentation of the figures. This finding discloses a fundamental difference between the stimuli used by Gestalt psychologists and object-location associations which are encoded with the same efficiency independent of the presentation mode. Remarkably, even the RLs during retrieval were similar after encoding the associations in the differing presentation modes. We argued in experiment 3 that encoding and retrieval of a location associated with an object might rely, for the most part, on automatic processes. The result of experiment 4 suggests that the distortion of the natural spatial and temporal coincidence of object-location associations does not preclude automaticity, because an increased contribution of voluntary mnemonic processes would have led to relatively prolonged RLs. Together with the stable average accuracy over presentations modes, we conclude that the results of the encoding processes in experiment 1 and 4 were not qualitatively, but only quantitatively different. This partly confirms the “principle of associative symmetry” that states that direction is not part of the associative process. However, the significantly lower incongruent correlation in experiment 4 discloses variability in strength within individual paired-associates which was not seen after simultaneous presentation. The lower incongruent correlation is not consistent with the “principle of associative symmetry”, because the two associative bonds of an individual association are partly independently modifiable. The magnitude of the effect of successive presentation on the symmetry on individual associations is comparable to the attenuation observed in experiment 2 as a consequence of the distraction phase between both memory tests.
Effects of simultaneous vs. successive presentation on symmetry

In experiment 4 we wanted to explore the suggested difference in coherence within and between units. As already outlined, we did not observe major differences when using object-location associations as stimuli, which was only partly consistent with the results of Asch et al (1962). In the following section, we therefore relate these findings to the studies using verbal material. Facing the absence of studies that compared varying relations between stimuli explicitly, we analyzed the impact of increasing successiveness between studies. We argued before (experiment 1) that the factor intentional vs. incidental learning does not influence the symmetry during retrieval. To exclude a major confound, only studies ensured equal item availability were considered.

In the majority of experiments presenting the paired-associates simultaneously in the visual or auditory modality, symmetric associations were formed (Asch & Ebenholtz, 1962, exp. 5; Epstein et al., 1977; Kahana, 2002; Mandler et al., 1981; Murdock, 1965, 1966; Schild & Battig, 1966, exp. 2, w-condition), whereas only two studies reported a forward advantage (Lowry & Wollen, 1969; Newman & Campbell, 1971).

On the other hand, a forward advantage was observed in most studies using the anticipation method or separating the stimuli by a short time gap in the visual or auditory modality (Asch & Ebenholtz, 1962, exp. 6 and 7; Battig & Koppenaal, 1965; Giurintano, 1972; Wollen, 1968; Wollen & Allison, 1968; Wollen et al., 1969). Only in one case did such a procedure lead to symmetrical retrieval (Wollen & Lowry, 1971).

At first sight, there are only a few exceptions from the otherwise obvious pattern of causality between presentation mode (simultaneous vs. successive) and the retrieval performance (symmetrical vs. asymmetrical). Wickelgren (1977) therefore concluded - based on his literature review and emphasizing the experiments by Wollen and colleagues (1970) - that backward
retrieval is weaker when a clear order of processing is experimentally controlled. Besides the remaining inconsistencies, unlearning paradigms have shown a symmetric impairment even using the anticipation method which provides a undoubted order of processing (Birnbaum, 1966; Keppel & Underwood, 1962; Murdock, 1956).

After a detailed analysis of the exact experimental procedures, we came to a different conclusion and reason that differences in presentation and retrieval rate explain a large part of the results. The commonly used procedure of several learning trials in the same direction leads to an automatization of producing the response term cued by the stimulus (Logan, 1998). This automatization is reflected in declining response latencies with practice long after the association of an item and its cue has been successfully established (e.g. Eimas & Zeaman, 1963). The automatization and the accompanying response latency decline occurs only in the direction of learning (Waugh, 1970). Response latencies are thus not only a function of memory trace strength (Hockley & Murdock, 1987), but also of the degree of automatization of that response after several learning trials. Thus, the application of a speeded memory test after several learning trials in the same direction may not allow the less automatized response to be produced from memory. The potential importance of this confound is shown by the fact that backward retrieval suffers relatively more from time pressure than the automatized forward retrieval (Battig & Koppenaal, 1965).

The two studies which observed asymmetry despite simultaneous appearance of the paired-associates (Lowry & Wollen, 1969; Newman & Campbell, 1971) presented the stimuli repeatedly for only 1 sec. Such a fast presentation rate results in a clear direction of processing similar to successive presentation and, subsequently, in the observation of asymmetry if the retrieval test is speeded. The other studies which presented the stimuli successively and found
asymmetry also used speeded tests (Giurintano, 1972; Wollen & Allison, 1968; Wollen et al., 1969).

The studies using simultaneous presentation that found symmetric performance presented the stimuli for at least 2 sec. This time span is sufficient to process the paired-associates in both directions by looking back and forth, as eye tracking data have shown in an incidental task (McCormack & Haltrecht, 1965, 1966). The studies which observed symmetry during retrieval despite successive presentation used self-paced retrieval or allowed a minimum of 6 sec. for retrieval. 6 sec. is probably sufficient to allow backward retrieval, even at lower availability of the item as a response term (Epstein et al., 1977; Mandler et al., 1981; Murdock, 1965, 1966; Schild & Battig, 1966; Wollen & Lowry, 1971).

In conclusion, we hypothesize that the confound of several learning trials in the same direction and/or speeded retrieval tests have led to the hasty conclusion that backward associations are weaker when the temporal order of learning is controlled (Wickelgren, 1977), as they need more time to be produced voluntarily from memory. On the contrary, we hypothesize that verbal paired-associates are also retrieved symmetrically when sufficient time is provided and the less automated response can thereby be produced from memory. We would like to emphasize that the results by Wollen et al. (1970) explicitly support this hypothesis. In their experiment, learning and test trials alternated, both in a speeded manner. In learning trials, subjects pronounced the paired-associates in A-B order, in test trials alternating the A- or the B-term served as a retrieval cue. In the beginning, forward and backward performance was equal; in the intermediate learning stage they observed a forward advantage; and after overlearning the list, the performance was equal again. We state that the forward advantage in the intermediate learning stage is a result of a difference in automatization, because the paired-associates were pronounced twice as often in the forward direction as in the backward direction.
General Discussion

The main objective of the current study was to shed new light on the ASH-IAH controversy by using variations of an improved experimental design (Kahana, 2002), object-location associations as stimuli and by systematically varying encoding and retrieval conditions. A secondary goal was to estimate the magnitude of design inherent confounds in the employed method of successive testing (Kahana, 2000).

Memory for object-location associations

In all three relevant experiments (1, 2, and 4), we observed equal average accuracy in both retrieval directions. Moreover, although the incongruent correlation differed significantly from the congruent correlation under certain experimental conditions, it was still substantially greater than 0 in all instances. Thus, our results clearly reject independence as postulated by the IAH (Wolford, 1971), but also reject less rigid formulations of associative asymmetry that hypothesize a general advantage for one retrieval direction. On the other hand, these results are also inconsistent with theories that assume a holistic representation. Altogether, we conclude from the overall pattern of performance that the mental representations of associated objects and locations are connected by two highly correlated memory traces that are on average equipotent but not necessarily equipotent for individual paired-associates. Furthermore, this conclusion is not restricted to the specific spatial and temporal coincidence in which object-location associations naturally appear. Successive presentation also leads to highly dependent associations, where it is important to point out that the correlation is quantitatively lower than after simultaneous appearance.

In experiment 1, we adapted the method of successive testing from Kahana (Kahana, 2002) and arrived at similar conclusions using object-location associations as stimuli. We observed similar
congruent and incongruent correlations, consistent with symmetrical as well as highly correlated associations. The results of experiment 2 provided further evidence for this conclusion, because output encoding by the first retrieval equally boosted performance in both retrieval directions upon a second testing. Moreover, the demanding distraction phase between the successive memory tests exclusively attenuated the incongruent correlation; an observation that is only compatible with the existence of two highly correlated associations. Thus, the ambiguity of the former findings is resolved. The differential effect of stress during retrieval on the average accuracy in both retrieval directions in experiment 3 suggested the existence of conditions that exclusively impair the formation of associative bonds from a location to an object, but not vice versa. This interpretation adds further support for two distinct, but under normal conditions highly correlated associations. Whereas in experiment 2 the demanding distraction phase during retrieval disclosed subtle strength differences on the level of individual associations, in experiment 4, the successive presentation during encoding resulted in a comparably strong attenuated incongruent correlation. All remaining performance measurements, in particular encoding as well as retrieval RLs and the average accuracy, were similar in experiments 1 and 4. Therefore, we hypothesize that the lower incongruent correlation is just a quantitative, but not a qualitative difference and is probably induced by higher variability of processes during encoding. This led us to conclude that the nature of the associations might be the same after both encoding conditions.

The RLs were significantly longer in all experiments when an object had to be retrieved from memory, which is at least partly due to visual search processes, but could also be caused by differences in mnemonic processes. Subjects consistently reported in all experiments that it was more difficult to retrieve an object than a location, despite equal average performance. Moreover, only this retrieval direction was speeded up at the cost of accuracy, as apparent from experiment
3. Studies of encoding object-location associations claim that during identification of an object, the location is for the most part automatically encoded (Ellis, 1990; Kohler et al., 2001). These findings, together with our observation of the described differences during retrieval and one report that the assignment of an object to a location can be impaired by articulatory suppression (Postma & De Haan, 1996), led us to speculate that the retrieval of objects and locations rely partly on processes that differ with respect to automaticity.

Confounding factors in successive memory tests

The empirical estimation of the magnitude of confounding factors in the method of successive testing led us to the conclusion that these are of minor importance in our paradigm. In particular, variability in the goodness of encoding as well as output encoding affected both retrieval directions equally, and only marginally increased the observed correlations. Variability in cognitive processes during retrieval also seems to be of minor practical relevance in our paradigm. This was concluded from the observation that such fluctuations primarily concern the retrieval of an object. Under “normal” retrieval conditions, the performance in both retrieval directions was equal, which thus precludes the existence of major fluctuations. Altogether, the stochastic hypothesis can be accepted for our paradigm (Hintzman & Hartry, 1990). The measure of associations in our paradigm is directly interpretable as a theoretically meaningful statement and does not substantially depend on the nature of the experimental design.

Acknowledgments: This work was supported by the Volkswagen-Stiftung, DFG and BMBF. We thank Eszter Schoell for helpful comments.


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Table 1. Summary of the accuracy the 4 experiments in lucky guess corrected frequency of the 5 RCs (%) (SD).

<table>
<thead>
<tr>
<th>response categories</th>
<th>object retrieval cue condition</th>
<th>location retrieval cue condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>experiment 1</td>
<td>42,7</td>
<td>11,0</td>
</tr>
<tr>
<td></td>
<td>(16,4)</td>
<td>(6,2)</td>
</tr>
<tr>
<td>experiment 2</td>
<td>43,3</td>
<td>11,6</td>
</tr>
<tr>
<td>control condition</td>
<td>(18,0)</td>
<td>(7,9)</td>
</tr>
<tr>
<td>without output</td>
<td>33,1</td>
<td>11,1</td>
</tr>
<tr>
<td>encoding</td>
<td>(17,7)</td>
<td>(6,3)</td>
</tr>
<tr>
<td>experiment 3</td>
<td>41,3</td>
<td>13,3</td>
</tr>
<tr>
<td>control condition</td>
<td>(21,1)</td>
<td>(8,8)</td>
</tr>
<tr>
<td>retrieval stress</td>
<td>40,6</td>
<td>11,5</td>
</tr>
<tr>
<td>condition</td>
<td>(20,2)</td>
<td>(7,6)</td>
</tr>
<tr>
<td>experiment 4</td>
<td>40,0</td>
<td>8,3</td>
</tr>
<tr>
<td></td>
<td>(23,7)</td>
<td>(5,5)</td>
</tr>
</tbody>
</table>

Response category 1 - subjects selected the correct location/object; category 2 - subjects selected two locations/objects; category 3 and 4 – the same as category 2, but with 3 or 4 selected locations/objects respectively; category 5 - subjects indicated that they forgot the location/object.

See method section for the rationale of the “lucky guess” correction of the hit rate.
Table 2: Summary of the correlation coefficients (Kendall’s τ for tied ranks) in the four experiments, Mean (SD)

<table>
<thead>
<tr>
<th>Retrieval condition</th>
<th>congruent</th>
<th>incongruent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 1</td>
<td>.67 (.15)</td>
<td>63 (.10)</td>
</tr>
<tr>
<td>Experiment 1 (add. analysis)</td>
<td>.63 (.18)</td>
<td>.62 (.13)</td>
</tr>
<tr>
<td>Experiment 2</td>
<td>.64 (.19)</td>
<td>.55 (.18)</td>
</tr>
<tr>
<td>Experiment 3</td>
<td>.50 (.24)</td>
<td>.41 (.23)</td>
</tr>
<tr>
<td>Experiment 4</td>
<td>.65 (.19)</td>
<td>.50 (.24)</td>
</tr>
</tbody>
</table>
Figure 1. Description of the task. In the encoding phase (upper part) each trial consisted of an orienting cue indicating the position of the next object in an array of 16 black boxes and - after a jittered ISI - the picture of a common object appeared. Subjects were asked to make an artificial/natural-judgment. In the retrieval phase (lower part) each object-location association was tested twice in randomly intermixed order: i) by the object and ii) by the location serving as retrieval cue. In the object retrieval cue condition one of the studied objects appeared in the centre of the screen followed by the same array of black boxes. The task was to indicate by selecting one or more locations dependent on the memory specificity which object was associated during the encoding phase. In the location retrieval
cue condition the 16 locations appeared on the screen one of it with a white question mark followed by the same 16 objects randomly rearranged in two rows in the middle of the screen. The task was to indicate by selecting one or more objects dependent on the specificity of memory which object was associated with the location during the encoding phase.
Figure 2. Frequency distribution of the 5 response categories in exp 1 and 4. The relatives proportion of the various response categories (category 1-4: number of selected locations/objects, category 5: the indication of a forgotten location/object) in both retrieval conditions. The blue (object cue) and green (location cue) bars indicate the frequency of correct responses, the red bars of incorrect responses. The errorbars indicate the standard error of the mean.
Figure 3. Frequency distribution of the 5 response categories in the 3 sub-conditions in experiment 1. The relatives proportion of the various response categories (category 1-4: number of selected locations/objects, category 5: the indication of a forgotten location/object) in both retrieval conditions. The blue (object cue) and green (location cue) bars indicate the frequency of correct responses, the red bars of incorrect responses. The errorbars indicate the standard error of the mean. Sub-condition I: first retrieval; sub-condition II: second retrieval in the congruent condition (second time object- or second time location-cue); sub-condition III: second retrieval in the incongruent condition.
Figure 4: Response latencies in experiment 1 and 4. Response categories (category 1-4: number of selected locations/objects, category 5: the indication of a forgotten location/object) in both retrieval conditions. The blue (object cue) and green (location cue) lines indicate the median response latency of correct responses in a category, the red bars of incorrect responses. The errorbars indicate the standard error of the mean. Response latencies were calculated as time span until the selection of the first object/location.
Figure 5. Frequency distribution of the 5 response categories in the 3 sub-conditions in experiment 2. The relatives proportion of the various response categories (category 1-4: number of selected locations/objects, category 5: the indication of a forgotten location/object) in both retrieval conditions. The blue (object cue) and green (location cue) bars indicate the frequency of correct responses, the red bars of incorrect responses. The errorbars indicate the standard error of the mean. Sub-condition I: first retrieval before the distraction phase; sub-condition II: second retrieval in the congruent condition after the distraction phase; sub-condition III: second retrieval in the incongruent condition after the distraction phase, sub-condition IV: first and unique retrieval after the distraction phase.
Figure 6. Frequency distribution of the 5 response categories in the two sub-conditions of experiment 3. The relatives proportion of the various response categories (category 1-4: number of selected locations/objects, category 5: the indication of a forgotten location/object) in both retrieval conditions The blue (object cue) and green (location cue) bars indicate the frequency of correct responses, the red bars of incorrect responses. The errorbars in both panels indicate the standard error of the mean. Sub-condition I: control condition; sub-condition II: retrieval stress condition.
Figure 7: Response latencies in experiment 3. Response categories (category 1-4: number of selected locations/objects, category 5: the indication of a forgotten location/object) in both retrieval conditions. The blue (object cue) and green (location cue) solid lines indicate the median response latency of correct responses in a category. The dashed lines indicate the time span until the end of a response. The errorbars in both panels indicate the standard error of the mean. Response latencies were calculated as time span until the selection of the first object/location, the end of a response was the point in time when subject indicated the end of their response by asking for the next cue.