Associative symmetry generalizes to asymmetric pairs

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Abstract

For pairs of words ($A - B$) in which both items are drawn from the same stimulus pool, cued recall accuracy in the forward direction ($A \rightarrow ?$) is, on average, equal to accuracy in the backward direction ($? \leftarrow B$). This led to Gestalt psychologists suggesting that pairs are learned as holistic units rather than two separate forward and backward associations (Asch & Ebenholtz, 1962). Kahana (2002) pointed out that instead, direct evidence of holistic learning would be a near-perfect correlation between forward and backward probes of the same pair, which is mathematically independent of mean performance. We report that even when pairs are asymmetric in mean performance measures (pairing low-frequency words with high-frequency words), the forward–backward correlation remains high. Our findings force a re-evaluation of prior findings of asymmetries in heterogeneous pairs: namely, human participants can learn asymmetric pairs as holistic, non-directional associations.

Keywords: paired-associate learning; word frequency; associative symmetry; verbal memory

Introduction

Paired-associate learning has a long tradition of study in experimental psychology (Calkins, 1896). The nature of the association between paired items, $A - B$, has been hypothesized to be either made of separate, unidirectional associations (Wolford, 1971), referred to as the Independent Associations Hypothesis or as a holistic unit (Asch & Ebenholtz, 1962; Köhler, 1947), refered to as the Associative Symmetry Hypothesis. According to the Independent Associations Hypothesis, the association consists of two steps, where $A \rightarrow B$ is learned in a statistically independent step from $A \leftarrow B$. The consequence is that performance on forward probes of a pair, $A - ?$, are expected to be independent of backward probes of the same pair, $? - B$. In contrast, Associative Symmetry Hypothesis implies that forward and backward probes comprise a single Gestalt (Figure 1) and are learned as a single step.

Two methods have been proposed to test between the Independent Associations Hypothesis and the Associative Symmetry Hypothesis. Firstly, comparing mean performance in the forward and backward directions, Asch and Ebenholtz (1962) suggested that symmetry supports the Associative Symmetry Hypothesis whereas asymmetry (such as a forward-probe advantage) would support the Independent Associations Hypothesis. Secondly, by examining the correlation between forward and backward probe performance at the level of single pairs over successive tests (Kahana, 2002). Kahana (2002) pointed out that, symmetry of mean performance is irrelevant to the holistic nature of the pair and is not a direct test of the nature of the associative symmetry. While this is true from a mathematical perspective, it is not known whether they are separable in human behaviour. Here we attempt to empirically de-couple the two measures.

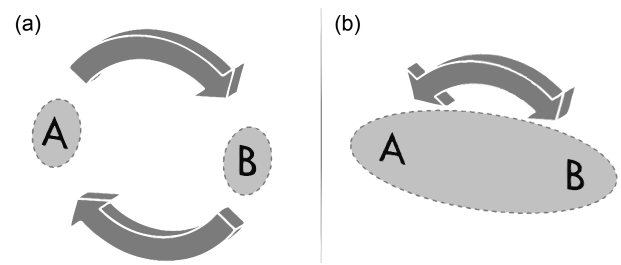

Figure 1. Visualizations of the Association Hypotheses. (a) Independent Association Hypothesis. (b) Associative Symmetry Hypothesis.

If a pair is learned equally well in both directions, there should be equal probabilities of cued recall in both the forward and backward directions (Levy & Nevill, 1974; Wollen, Allison, & Lowry, 1969). If the pair is learned as a Gestalt unit, the forward and backward cued recall should have nearly perfect correlation. Even if performance on forward and backward probes is independent, trial-to-trial variance in performance will induce a correlation. The correlation of forward and backward test performance has been demonstrated to be high, supporting the Associative Symmetry Hypothesis (Caplan, 2004, 2005; Caplan, Glaholt, & McIntosh, 2006; Rizzuto & Kahana, 2000, 2001; Sommer, Rose, & Büchel, 2007). However, it is important to note that in all these studies, mean performance was nearly symmetric.

To understand why the mean performance and correlation measures are distinct, consider the following example. Given the pairs SHROUD - RUMOUR and HELMET - MALICE, if SHROUD - ? and ? - MALICE are answered correctly by the

		FREQ	*Letters*	*ON*	*ONFREQ*	*PN*	*PNFREQ*	*CONBG*	*CONC*
High	Mean	224	4.58	7.5	36	14	52	5268	4.26
	StDev	278	0.73	5.7	46	10	119	3147	0.45
	Min	61	4.00	0.0	0	0	0	676	3.50
	Max	1787	6.00	24.0	247	65	755	21244	4.99
Low	Mean	1.9	4.57	7.4	29	14.5	42	4590	4.26
	StDev	1.5	0.72	5.0	38	8.6	104	2770	0.44
	Min	0.0	4.00	0.0	0	0.0	0	252	3.50
	Max	5.0	6.00	23.0	180	35.0	663	18281	4.97
	t	8.4*	0.1	0.1	1.3	-0.0	0.7	1.7†	0.0

Table 1. Word pool statistics. FREQ = word frequency (per million); ON = orthographic neighbourhood size; ONFREQ = average orthographic frequency (per million) of orthographic neighbours; PN = phonological neighbourhood size; PNFREQ = phonological frequency (per million) of phonological neighbours; CONBG = summed frequency that any two letter-pairs in the word occur together in the place that they are in the current word; CONC = concreteness rating. See Westbury and Hollis (2007) for more information on these measures. $^{\star}p < 0.05$, $^{\dagger}p < 0.10$.

participant, but ? - RUMOUR and HELMET - ? are answered incorrectly, the mean performance between the forwards and backwards is the same (50%), yet the pairs are uncorrelated and not learned holistically (Independent Associations Hypothesis). However, if the participant responded correctly for SHROUD - ? and ? - RUMOUR, but incorrectly for HELMET - ? and ? - MALICE were incorrect, the forward and backward mean performance are equal (i.e. 50%); however in this case the pairs are correlated,suggesting holistic learning (Associative Symmetry Hypothesis).

In a verbal paired-associates task, by manipulating a given property (i.e. word frequency or concreteness) of the paired words, it is possible to produce asymmetric mean performance (i.e., Ebbinghaus, 1885/1913; Horowitz, Norman, & Day, 1966; Lockhart, 1969; Paivio, 1968, 1971; Wollen & Lowry, 1971). We ask whether the correlation for such pairs might nonetheless remain high, suggesting that asymmetric pairs are also learned as holistic units. Words with high word frequency demonstrate decreased recognition but increased recall relative to low frequency words (Gregg, 1976; Hall, 1954; Karlsen & Snodgrass, 2003; Nelson & McEvoy, 2000; Paivio, 1971). We expect that pairs consisting of a high-frequency word and a low-frequency word (mixed pairs) would show asymmetric mean performance whereas pure pairs (both items either high or low frequency) would replicate symmetry in mean performance. By measuring the forward–backward probe correlation, we test whether the holistic nature of the association differs depending on mean symmetry versus asymmetry, namely, with a high correlation between forward and backward probes at the level of individual pairs.

We compare two predictions. The first is that despite the asymmetric mean performance (Associative Symmetry Hypothesis), the pairs are always learned holistically. The second, alternative hypothesis, is that the asymmetry of mean performance is an indicator that the Gestalt has broken down (Independent Associations Hypothesis). Our findings support the former view.

Methods

Participants

Thirty-nine undergraduate students (13 male and 26 female; mean age $\pm\,\sigma = 21.6 \pm 5.1$) participated in the study for partial fulfillment of an introductory psychology course requirement. All participants were required to have English as their first language.

Materials

Study sets were constructed from two pools of nouns: high frequency and low frequency (see Table 1 for item properties). Each pool contained 110 words, chosen from the CELEX Lexical Database (Baayen, Piepenbrock, & Gulikers, 1995), which were all used for each participant. Other properties (listed in Table 1) were controlled. For each participant words were drawn at random with equal numbers of pairs in each of the following pair types: high-high (HH), high-low (HL), low-high (LH), and low-low (LL), where L denotes low-frequency words and H denotes high-frequency words.

Procedure

Each participant participated in one practice round (excluded from analyses) followed by 10 experimental sets. Each round in the task consisted of the five phases: the study phase, a distractor task, a cued recall (Test 1), another distractor task, and finally another cued recall (Test 2) (Figure 2). Pairs were presented in random order but were subject to the constraint that every two consecutive study sets included four pairs of each pair type (HH/HL/LH/LL). In the distractor and test phases, participants typed their responses on the keyboard, and they were recorded by computer to be scored later for accuracy and response time. All visual presentations were done in white "Courier New" text, to ensure fixed letter width, on a black background.

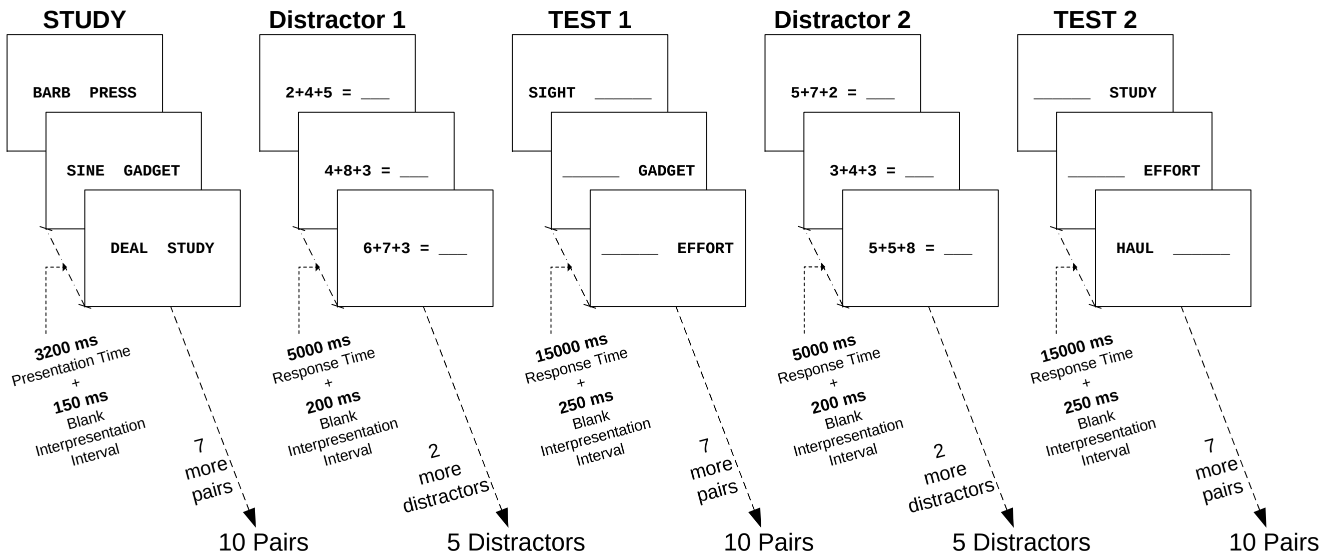

Figure 2. A single round of the task. Each box illustrates the computer screen at a particular stage in the task (text has been enlarged relative to the screen size to improve clarity of the figure). Each phase was directly followed by the next of the five phases, without pause. In both of the test phases, each pair presented during the study phase was tested only once, half of which were in the forward direction.

Paired nouns were simultaneously visually-presented in the centre of the computer screen with a presentation time of 3200 ms, followed by a 150 ms blank inter-stimulus interval. The sets were grouped into 8 pairs in each study set presented in random order.

The distractor task consisted of five equations in the form of A + B + C = ___ , where A, B, and C were randomly selected digits from 2 to 8. Each equation remained in the centre of the screen for 5000 ms. The participant was asked to type the correct answer on the computer during this fixed interval, after which the screen was cleared for 200 ms.

Cued recall consisted of a probe word and a blank line, either to the left or right of the word. The participant was instructed to recall the word that was paired with the probe during the study phase, and type it in the computer. The cued recall remained on the screen and the participant was given an interval of 15000 ms to respond, after which the screen was cleared for 250 ms.

If subjects could not recall a target item they were instructed to type “PASS”. Misspellings or variants of the correct word were scored as incorrect responses. At the end of each round, the task paused briefly and the participant was instructed to press “Enter” to begin the next round. The task was designed using Python programming language and the pyEPL experimental library (Geller, Schleifer, Sederberg, Jacobs, & Kahana, in press).

Data Analysis

Mean performance measures We performed a repeated measures ANOVA on PAIR TYPE [4] x TEST DIRECTION [2] and report with Greenhouse-Geisser correction for non-sphericity where appropriate. Effects are considered significant based on an alpha level of 0.05 and post-hoc pair-wise comparisons are always Bonferroni-corrected. Only effects reaching significance are reported.

Correlation of accuracy on successive tests We used Yule's Q as our measure of correlation between Test 1 and Test 2 probes. Yule's Q is a correlation measure optimized for dichotomous data. “Same” represents the correlation for test-retest reliability alone and will be the highest correlation when successive testing is done in the same direction (Forward-Forward and Backward-Backward). “Different” is based on the correlation between forward and backward directions and therefore is our actual measure of interest when Test 1 and Test 2 were in different directions (Forward-Backward and Backward-Forward). The “Control” is the lowest possible expected correlation and is designed to account for the correlation between unrelated pairs within the same round, one pair from Test 1 and a different pair from Test 2 (bootstrapping), in order to control for subject, test-retest, and round variability. Due to the nature of these measures, “Same” and “Control” demonstrate the effective range of the “Different” correlation. Yule's Q was evaluated using the log-odds ratio transform (Bishop, Fienberg, & Holland, 1975; Hayman & Tulving, 1989).

Results

Mean performance measures

Mean accuracy for each pair type in each test direction is presented in Figure 3. The main effect of PAIR TYPE is significant [$F(3,92) = 24.0$, $MSe = 0.029$, $p < 0.001$], as

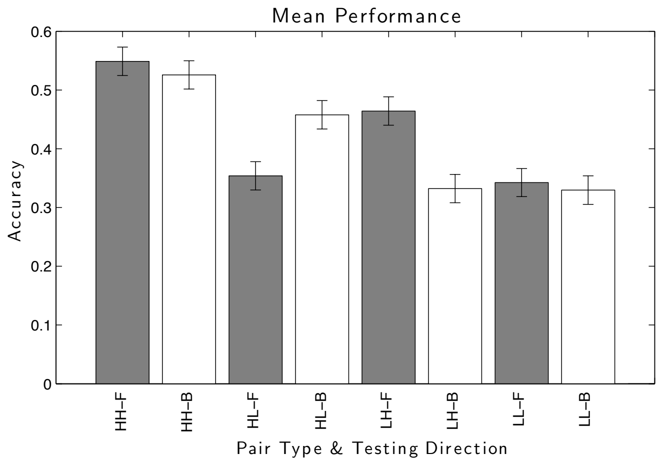

Figure 3. Accuracy. Pair types: high-high (HH), high-low (HL), low-high (LH), and low-low (LL). Testing directions: forward (F) and backward (B). Error bars are 95% confidence intervals.

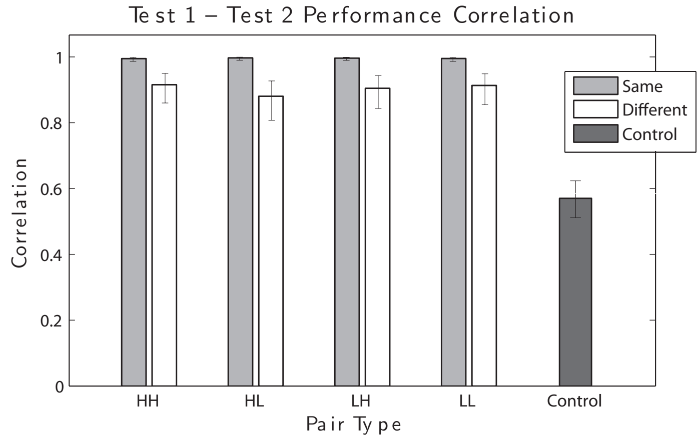

Figure 4. Correlation (Yule's Q) of Test 1 and Test 2 performance. "Same" denotes correlations between successive testing when done in the same direction (Forward-Forward and Backward-Backward). "Different" denotes correlations when Test 1 and Test 2 were in different directions (Forward-Backward and Backward-Forward). "Control" denotes the correlation between unrelated pairs found in the same round. Error bars are 95% confidence intervals.

well as the interaction of PAIR TYPE x TEST DIRECTION [$F(3,99) = 17.3$, $MSe = 0.012$, $p < 0.001$]. Post-hoc pairwise comparisons revealed that HH and LL are significantly different from each other and from the mixed pairs [all p's < 0.05], while the mixed pairs (HL & LH) were not significantly different from each other [$p > 0.5$]. As expected, pure pairs (HH & LL) demonstrated symmetric performance, replicating numerous similar findings (Karlsen & Snodgrass, 2003; Nelson & McEvoy, 2000; Paivio, 1971). HH pairs were more accurately recalled than LL pairs. In contrast, mixed pairs exhibited asymmetric mean performance. HL showed a backward-probe advantage and LH pairs showed a forward-probe advantage, replicating previous studies (Gregg, 1976); thus, when the target is a high frequency word, (see HL-B and LH-F in Figure 3) the accuracy is higher than that for a low frequency word (see HL-F and LH-B in Figure 3) .

Correlation of accuracy on successive tests

As illustrated in Figure 4, the "Different" correlations of the mixed pairs were not different than those for the pure pairs, supporting the prediction motivated by the Associative Symmetry Hypothesis and challenging at least a strong form of the Independent Associations Hypothesis. Pair-wise comparisons of the correlations supported the comparisons shown in Figure 4. No significant differences between pair types at a given correlation type (i.e. no differences from HH-Same to HL-Same, LH-Same, and LL-Same; and also true for the "Difference" correlations [all p's > 0.1]) were found. There were significant differences between the "Same" and "Different" for each of the pair types, as well as across pair types [all p's < 0.01]. All "Same" and "Different" correlations were significantly different from the "Control" [all p's < 0.05].

Discussion

Our main finding is that whereas mixed pairs are recalled with asymmetric mean performance (Figure 3), such pairs are nonetheless learned holistically (Figure 4).

A caveat is necessary. The "Different" correlations are significantly lower than what might be expected from a perfect Gestalt (namely, one would expect it to be equal to the "Same" correlation). This is consistent with prior values of the forward–backward correlation (Caplan, 2005; Caplan et al., 2006; Kahana, 2002; Rizzuto & Kahana, 2000, 2001). Nonetheless, the correlation is still quite high at the high end of the range set by the two boundaries correlations ("Same" and "Control" correlations). Thus, it is more accurate to conclude that the Associative Symmetry Hypothesis is not perfectly supported, but a close approximation of this hypothesis is supported. The key finding we report is that this high correlation is not disrupted further by the directionality evident in the mean performance measure. Beyond the non-difference finding, it should be observed that if a difference between mixed and pure pairs exists (i.e., the present power is insufficient to detect differences) then according to the confidence intervals, the difference would have to be smaller in magnitude than breakdowns of the Associative Symmetry Hypothesis that have been observed in cued recall parts of serial lists, but not in pair learning (Caplan, 2005; Caplan et al., 2006). Breakdowns have also been observed in special cases of between-domain associations, namely, object-location associations in which the paired object and location are presented sequentially (Sommer et al., 2007).

In conclusion, it is possible to manipulate the strength of an association between paired items as well as the symmetry of the association, but the Gestalt property of the pair is unaffected. These findings extend the boundary conditions for the Associative Symmetry Hypothesis. Thus, Gestalt, or at least Gestalt-like, learning of pairs may be a general phenomenon in human paired-associate learning.

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