



Interhemispheric communication of abstract and specific visual-form information

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Abstract

Pairs of letters were compared after being viewed in different visual fields (i.e. across-hemispheres, AH) or in the same visual field (i.e. within-hemisphere, WH). In an abstract-category comparison task, participants decided whether two letter exemplars belonged to the same abstract category (e.g. “k” and “K”) or not (e.g. “k” and “P”) and performed more accurately in AH trials than in WH trials. In a specific-exemplar comparison task, they decided whether two letters within the same abstract category were the same specific exemplars (e.g. “k” and “k”) or not (e.g. “k” and “K”) and performed more accurately in WH trials than in AH trials. This pattern of results was observed when the exemplars in a category were visually similar (e.g. “k” and “K”, “a” and “a”) but not when they were visually dissimilar (e.g. “a” and “A”). The reversed association technique was used to confirm the independence of subsystems underlying abstract category and specific-exemplar comparisons. Most important, the results support the theory that a specific-exemplar subsystem is more detrimentally affected by interhemispheric transfer of information than an abstract category subsystem.

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1. Introduction

Recent evidence suggests that visual-form recognition may be accomplished in two different ways ([35]; for a review, see [36]). Dissociable neural subsystems appear to underlie recognition of the abstract category to which a to-be-recognized form belongs (e.g. the category for a/A versus the category for b/B) and recognition of the specific-exemplar to which the to-be-recognized form corresponds (e.g. the exemplar “a” versus the exemplar “A”). Although both an abstract category subsystem and a specific-exemplar subsystem appear to operate in parallel in each hemisphere, an abstract subsystem operates relatively more effectively than a specific subsystem in the left cerebral hemisphere (LH), and vice versa in the right cerebral hemisphere (RH) [35]. To date, however, little is known about interhemispheric communication among these subsystems. For both empirical and theoretical reasons, a specific subsystem may be more detrimentally affected by interhemispheric transfer of information than an abstract subsystem.

In this article, we report a study testing this possibility. The results help to further test the dissociability of these subsystems, putative properties of their representations, and more general aspects of interhemispheric communication.

1.1. Across- versus within-hemisphere presentations

A useful way to investigate interhemispheric communication of visual information is to examine performance in letter comparison tasks when two letters are presented across the two hemispheres versus within a single hemisphere. In across-hemisphere (AH) trials, one item is presented briefly in the left visual field and the other in the right. Thus, information *must* cross brain commissures for the two items to be compared. In within-hemisphere (WH) trials, both items are presented in the same visual field, thus, interhemispheric transfer of information is *not required* to make a comparison (for methodological considerations, see [6]).

Several investigators have compared AH and WH performance to examine interhemispheric communication of visual information (e.g. [2,3,7,14,15,24,25,26,32,46]). A variety of interesting effects have been observed, and a review of the evidence suggests that differential AH and WH performance may be determined in large part by tradeoffs

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between a *benefit* of distributing information processing across the hemispheres and a *cost* of requiring information to be transferred across brain commissures [4]. Advantages of distribution may be observed because each hemisphere has its own limited processing resources, and distribution serves to reduce the levels of resources that are taxed per hemisphere [1,16,17,18,27,28].¹ However, for distribution to occur, information must cross brain commissures, hence that information is susceptible to any negative effects of transfer. The information that crosses brain commissures is relatively degraded by the transfer, according to neurophysiological evidence from single-cell recordings in non-human primates and neuroimaging evidence from humans. For example, inferior-temporal neurons with bilateral receptive fields respond less strongly to ipsilateral than contralateral visual input, and they have receptive-field centers located less often in the ipsilateral than contralateral half-field (e.g. [21]). Also, the amplitude of functional magnetic resonance signals is lower for ipsilateral than contralateral cortical regions when visual patterns are presented in the left or right visual fields [45].

Influential examples of the use of AH and WH presentations to test interhemispheric processing of visual information come from Banich and Belger [2]; see also [7]. In one task, participants decided whether two uppercase letters were visually identical (e.g. “A” and “A”) or not (e.g. “A” and “B”) and performed more efficiently in WH trials than in AH trials (producing a “WH advantage”). However, in another task, participants decided whether two visually distinct uppercase and lowercase letters had the same name (e.g. “A” and “a”) or not (e.g. “A” and “b”) and performed more efficiently in AH trials than in WH trials (producing an “AH advantage”). The different WH and AH advantages for these two tasks suggest that the costs of transfer outweigh the benefits of distribution in the visual-identity task, but the benefits of distribution outweigh the costs of transfer in the name task.

1.2. Dissociable abstract and specific visual-form subsystems

The results from Banich and Belger [2,7] appear to be in line with the theory that abstract and specific subsystems are neurally dissociable. The visual-identity comparison task may make use of processing in a specific-exemplar subsystem, because this subsystem recognizes and distinguishes specific exemplars of shapes. In contrast, the “name” comparison task may make use of an abstract category subsystem, because this subsystem recognizes the categories to which different exemplar shapes belong. If so, the results may help to dissociate the abstract and specific subsystems. In particular, the reason why the costs of transfer are greater

in the visual-identity comparison task than in the “name” comparison task may be that a specific subsystem is more detrimentally affected by interhemispheric transfer than an abstract subsystem is.

In addition to the suggestive empirical results, theoretical reasons can be offered for the possibility that a specific subsystem is more detrimentally affected by interhemispheric transfer than an abstract subsystem. The kinds of visual information processed by the two subsystems may be affected by callosal degradation in different ways.

First, we have hypothesized that an abstract subsystem learns to produce output representations that indicate the abstract category to which an input form belongs (e.g. the category for a/A). This subsystem learns categories through feedback from post-visual subsystems indicating that different input shapes (even fairly dissimilar shapes) are associated with the same name, common semantic information, etc. To accomplish this task, it would be useful for an abstract subsystem to store the visual information that varies little across the different specific exemplars in one abstract category of form, and *not* to store the visual information that varies substantially across such exemplars. In other words, this subsystem should process the relatively invariant features of input forms that are diagnostic of their categories. Indeed, recent evidence supports this reasoning. Previously unseen prototype forms of newly learned shape categories were classified more efficiently than other exemplars when they were presented directly to the LH, but not when they were presented directly to the RH. This suggests that an abstract subsystem in the LH stores features-based, relatively invariant information effectively, because the prototypes contained a greater number of relatively invariant features than any of the other forms in the categories [34]. In addition, a recent neural network modeling study supports this reasoning. Networks were trained to simultaneously perform both abstract category and specific-exemplar categorizations of the same visual inputs. Those that had different subnetworks for performing the abstract and specific tasks in parallel outperformed networks that had an undifferentiated, unified architecture. Moreover, during training, the abstract subnetworks discovered and utilized a features-based processing strategy, in which sub-whole features of an input form were represented independently of each other in the internal representations of the subnetworks [36].

Second, we have hypothesized that a specific subsystem learns to produce output representations that indicate the specific exemplar to which an input form corresponds (e.g. the exemplar “a”). This is useful for recognizing forms in a manner that allows access to exemplar-specific information in post-visual subsystems. To accomplish this task, it would be useful for a specific subsystem to store the visually distinctive information that differentiates specific exemplars, even those in the same abstract category. Nearly all of the visual information in one input form may be needed to differentiate it from other exemplars; thus, this subsystem should process the wholes of input forms effectively.

¹ Here and throughout this article, when we refer to a benefit of neural distribution, we consider conditions in which multiple stimuli are presented simultaneously rather than sequentially [43].

Indeed, recent evidence supports this reasoning. Letter case specific repetition priming for words has been observed when test items were presented directly to the RH but not when they were presented directly to the LH [12,37,39]. Moreover, this letter case specific priming effect was observed only when the visual context above the test item was the same form that appeared above the prime word (for that test item) during initial encoding and when the test items were presented directly to the RH. This suggests that a specific subsystem in the RH stores whole-based, visually distinctive information effectively, because specific priming required the same holistic information between encoding and test [38]. In addition, the previously mentioned neural network models also support this claim. During training, the specific subnetworks discovered and utilized a whole-based processing strategy, in which sub-whole features of an input form were not represented independently of each other in the internal representations of the subnetworks [36].

The important repercussion for interhemispheric communication is that the kind of visual information processed by a specific subsystem should be more susceptible to the detrimental effects of callosal transfer than the kind of visual information processed by an abstract subsystem. First, in behavioral tasks involving processing of relatively complex shapes (i.e. letters), the important information transferred across brain commissures appears to be high-level visual representations of shapes rather than lower-level retinotopic representations (cf. [40]). Indeed, the callosal fibers connecting visual areas across hemispheres increase in density from those connecting primary visual cortex to those connecting higher-level visual areas [29]. Second, the transfer of information across brain commissures degrades the information, as measured in firing rates of cortical neurons (e.g. [21]) and in magnetic resonance signals [45].

Callosal degradation of visual-form information should have a large detrimental effect on representations of the visually distinctive wholes that are useful for processing specific exemplars. This is because *any* change to a representation of a distinctive whole per se should be detrimental; every aspect of the *whole* is an important aspect of the representation. This sort of detrimental effect should be especially critical for a specific subsystem, because it performs the function of distinguishing specific exemplars. In other words, nearly all cases of callosal degradation should negatively affect visual comparisons that are made in a specific subsystem. This may be the reason why no benefits of distribution can be accrued in a specific comparison task and hence WH advantages are observed.

In contrast, callosal degradation of visual-form information may have a smaller effect or no effect on representations of the relatively invariant features that are useful for processing abstract categories. This is because an abstract subsystem performs the function of categorizing different exemplars together, apparently by recognizing the sub-whole features that are common to different input shapes corresponding to the same category. This allows the subsystem

to generalize effectively when categorizing new exemplars that have not been processed before (but fit the visual category). To the extent that interhemispheric transfer creates a situation in which one of two comparison items is relatively degraded, an abstract subsystem may be able to generalize effectively when comparing whether the two items belong to the same category. In other words, on average over many trials, callosal degradation should have less of a negative impact on post-transfer processing in an abstract subsystem than in a specific subsystem. This may be the reason why the benefits of distribution can be accrued in an abstract comparison task and hence AH advantages are observed.

1.3. *New predictions for similar and dissimilar exemplars*

In the present study, we examined novel tests of the theory that abstract and specific subsystems are differentially affected by interhemispheric transfer. The new predictions stem from considerations of the differences between processing visually similar exemplars in the same category (e.g. “k” and “K”) and visually dissimilar exemplars in the same category (e.g. “a” and “A”).

When processing in a specific subsystem is required to accomplish a comparison task, callosal degradation should have a larger impact on comparisons of similar exemplars than on comparisons of dissimilar exemplars. The visually distinctive, whole-based information that is needed to distinguish highly similar exemplars typically is so subtle (e.g. compare “k” and “K”) that nearly any callosal degradation should have a large negative impact on processing. Contrastingly, the visually distinctive information that is needed to distinguish dissimilar exemplars may be pronounced enough (e.g. compare “a” and “A”) that callosal degradation should have less of a negative impact. For example, a degraded “a” may be distinguished from a non-degraded “A” relatively easily. Thus, an untested prediction is that a WH advantage in specific exemplar comparisons should be greater for similar exemplars than for dissimilar exemplars.

However, when processing in an abstract subsystem is required to accomplish a comparison task, the benefits of hemispheric distribution should be greater for comparisons of similar exemplars than for comparisons of dissimilar exemplars. The relatively invariant, features-based information that is available to classify visually similar exemplars to the same category typically is a larger amount of feature information, as measured by proportion to the input forms, than that available to classify dissimilar exemplars. For example, the information common to “k” and “K” is a larger proportion of the total information in either of those two forms than is the information common to “a” and “A”. Given that an abstract subsystem performs the function of categorizing different shapes together, the greater the amount of relatively invariant feature information for a category, the greater the chance that callosal transfer can be accomplished with little to no detrimental effect on abstract comparisons. Thus, an untested prediction is that an AH

advantage in abstract category comparisons (taking advantage of the benefits of distribution) should be greater for similar exemplars than for dissimilar exemplars.

2. Experiment 1

We tested the above predictions using two comparison tasks. In the *abstract category task* (similar to the name task used by Banich and Belger [2,7]), participants determined whether two letter exemplars belong to the same abstract category (e.g. “a” and “A”) or not (e.g. “a” and “F”). According to the dissociable neural subsystems theory, an abstract subsystem should be useful to accomplish this task, because it categorizes familiar letter forms into the appropriate letter categories. However, a specific subsystem should not be able to accomplish this task, because the forms are always different exemplars of letters. Contrastingly, in the *specific exemplar task*, participants determined whether two letters from the same abstract category are the same specific exemplar (e.g. “a” and “a”) or different specific exemplars (e.g. “a” and “A”). According to the subsystems theory, this task requires processing in a specific subsystem, because an abstract subsystem should not differentiate exemplars within the same category. We examined both tasks when stimuli were presented in AH and WH conditions. We also manipulated the visual similarity between comparison items. Half of the letters in this experiment had lowercase and uppercase visual structures that are similar (e.g. k/K); these forms were used as *similar-exemplar items*. The other half of the letters had lowercase and uppercase visual structures that are dissimilar (e.g. a/A); these forms were used as *dissimilar-exemplar items*.

Following the reasoning in Section 1, the following predictions were tested. In the abstract category task, a greater AH advantage should be obtained for similar-exemplar than dissimilar-exemplar items. Whereas, in the specific exemplar task, a greater WH advantage should be obtained for similar-exemplar than dissimilar-exemplar items.

2.1. Method

2.1.1. Participants

Forty-eight students at the University of Arizona (24 females and 24 males) volunteered to participate for course credit in an introductory psychology class. All participants were right-handed, as assessed through the Edinburgh Handedness Inventory (mean laterality quotient = 0.76; [41]). In addition, all were native speakers of English and had normal or corrected to normal vision. None participated in any of the other experiments reported in this article.

2.1.2. Materials

Eight letters of the English alphabet were used. Four of the eight letters have dissimilar lowercase and uppercase visual structures (a/A, f/F, n/N, and q/Q), and the other four

have similar lowercase and uppercase visual structures (k/K, s/S, p/P, and u/U), as assessed through the use of judged similarity measures and cluster analyses reported by Boles and Clifford [10]. Each group had one vowel and three consonants, and each group was judged to be balanced roughly for letter frequency in the English language. Two of the letters in each group had lowercase and uppercase versions that were of the same height (f/F and q/Q; k/K and p/P; the other two had lowercase and uppercase versions with different heights (a/A and n/N; s/S and u/U). The largest characters subtended a maximum of 0.61° horizontally and 0.61° vertically.

A pound sign (“#”) of the same size as the largest target letters was used for distractor items in the visual displays. In addition, a 2 mm dot (subtending 0.23° of visual angle) served as a central fixation point. All characters were presented in black against a white background in a 24-point, bold Helvetica font.

The stimuli were presented on an AppleColor High Resolution RGB Monitor with a Polaroid CP-50 filter placed over it to reduce glare. A Macintosh II computer controlled stimulus presentation and recorded responses through the use of a connected Apple Extended Keyboard II. Finally, a chin rest was used to keep each participant’s eyes approximately 50 cm from the monitor.

2.1.3. Procedure

Each participant was tested individually in a single experimental session, and each performed two tasks, an abstract category task and a specific exemplar task. Participants performed each task in two different blocks of trials, using different hands to make responses in the two different blocks per task. Thus, each experimental session consisted of four blocks, with 2 min breaks interposed between them. Order of presentation for these blocks was counterbalanced across participants.

The abstract category task was similar to the name-comparison task used by Banich and Belger [2,7]. In each trial, two target letters and two distractor items appeared. One target letter was presented in lowercase, and the other was presented in uppercase. Participants were asked to decide as quickly and accurately as possible whether the two letters corresponded to the same letter of the alphabet (e.g. “a” and “A”) or to different letters of the alphabet (e.g. “a” and “F”). This task presumably requires processing in an abstract category subsystem for it to be accomplished in the visual system, because the judgment must be based on whether the two letters belong to the same abstract category of visual form. A specific exemplar subsystem would not be useful because the two letters were always two different specific exemplars.

In each trial of the specific exemplar task, two target letters and two distractor items appeared. The two target letters corresponded to the same letter of the alphabet in every trial, but in half of the trials they were presented in the same letter case and in the other half they were presented in different

letter cases. Participants were asked to decide as quickly and accurately as possible whether the two letters had exactly the same shape (e.g. “a” and “a”) or different shapes (e.g. “a” and “A”). By hypothesis, this task requires processing in a specific exemplar subsystem because the judgment must be based on whether the two letters correspond to the same specific exemplar of visual shape. An abstract category subsystem would not be useful because the two letters always belonged to the same abstract category of form.

For both tasks, each trial began with a presentation of the fixation point, which appeared at the center of the monitor for 500 ms. Immediately thereafter, a stimulus array appeared for 183 ms. Participants pressed the “s” key or the “d” key on the computer keyboard to indicate a same or different judgement, respectively. Participants rested their index and middle fingers directly on the two keys so that they could respond as quickly as possible. The next trial began automatically 1 s after the “s” or “d” key was pressed.

In each trial for both tasks, we utilized the presentation format used previously by Banich and Belger [2,7], in which four items appear in the form of a trapezoidal array (Fig. 1). Two distractor forms (pound signs; “#”) accompanied the two target letters in each trial to assure that perceptual information load was the same for AH and WH trials; two items were displayed in the left visual field and the other two in the right visual field. In the trapezoidal array, the two closer items (one a target and one a distractor) appeared 1.4° apart laterally, the two farther items (one a target and one a distractor) appeared 2.8° apart laterally, and both of the two top items and both of the two bottom items appeared 1.4° from the horizontal midline. The trapezoidal array pointed up in half of the trials and down in the other half. In all of the trials, one target letter was in the top row and the other was in the bottom row. In this way, both AH and WH trials required comparisons between diagonally aligned target letters. This is important because if target items were aligned on the same axis (horizontal for AH trials and vertical for WH trials), observed AH or WH advantages could be due

to left–right or up–down scanning preferences rather than interhemispheric communication per se [6].²

Each of the four blocks consisted of 136 trials, including eight filler trials at the beginning which were used for warm-up judgments and were not included in the analysis. For the remaining 128 trials, half (64 trials) required a “same” judgment and the other half (64 trials) required a “different” judgment for a correct response. In half of the same trials (32 trials) and half of the different trials (32 trials), one letter was presented in each visual field (AH trials), whereas in the other half of the same trials (32 trials) and the other half of the different trials (32 trials) the two letters were presented in the same visual field (WH trials). Half of the AH trials (16 same and 16 different) were presented with the bottom letter in the left visual field (b-LVF trials); the other half (16 same and 16 different) were presented with the bottom letter in the right visual field (b-RVF trials). Likewise, half of the WH trials (16 same and 16 different) were presented with the bottom (and also the top) letter in the LVF (w-LVF trials); the other half (16 same and 16 different) were presented with the bottom (and also the top) letter in the RVF (w-RVF trials). For the 16 trials in each of the conditions described above, half (8 trials) had dissimilar-exemplar items and half (8 trials) had similar-exemplar items. Finally, half of each of the dissimilar-exemplar trials (4 trials) and half of each of the similar-exemplar trials (4 trials) had lowercase letters as the bottom items, the other halves (4 dissimilar trials and 4 similar trials) had uppercase letters as the bottom items. The letter case of the top item was determined by a combination of the task and whether it was a same or different trial.

Furthermore, in the abstract category task, the pairings of letters for the different trials was accomplished within dissimilar-exemplar and similar-exemplar letter groups. Each letter in one group (e.g. “a”) was combined with every one of the other three letters in that group (e.g. “F”, “N”, and “Q”) in such a manner that all combinations were used an equal number of times across trials for any one participant. In general, the assignment of letters and arrangements to all of the different conditions was done so that all stimuli and pairings were counterbalanced across participants.

Finally, in each of the four blocks, the 128 experimental trials were presented in a different pseudo-random order for each participant. The orders were random with the constraints that no more than three same or different trials, AH

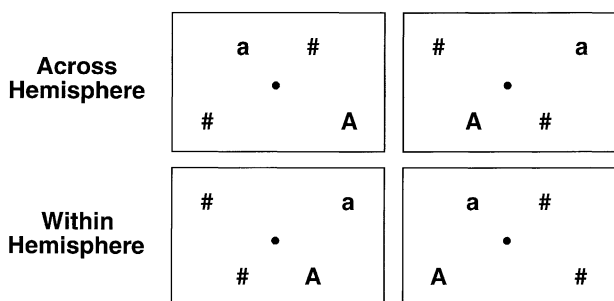


Fig. 1. Examples of trapezoidal stimulus arrays used for across-hemisphere and within-hemisphere presentation conditions in Experiment 1. These examples have a pair of dissimilar-exemplar items that should be given a “same” response in the abstract category task, but a “different” response in the specific exemplar task.

² In this paradigm, an ideal situation would be for the letters to be equidistant in both AH and WH trials. However, the only way that this can be done while simultaneously requiring comparison of diagonally aligned letters would be for the eccentricity of the outside letter in a WH trial to be extreme. In other words, to balance letter distance across AH and WH trials would require that the largest eccentricity (and accompanying amount of degradation of the input) be confounded with AH/WH. We chose instead to keep the largest eccentricity balanced (and not extreme) and to allow the confound of letter distance, given that stimulus degradation demonstratively affects hemispheric asymmetries (for reviews, see [13,44]) but we know of no strong indication that letter distance per se should do so.

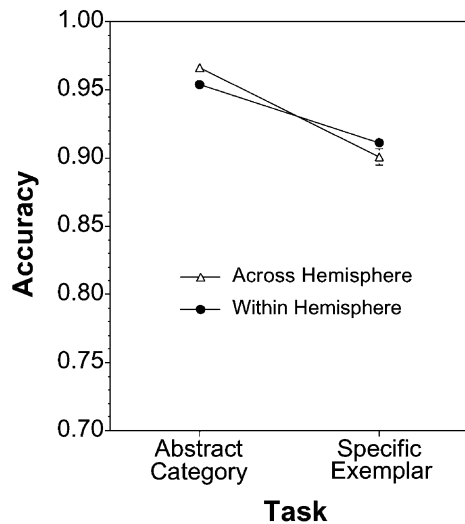


Fig. 2. Results from Experiment 1. Mean accuracy (proportion) is presented as a function of task (abstract category vs. specific exemplar) and type of visual presentation (across-hemisphere vs. within-hemisphere). Error bars indicate standard errors of the mean.

or WH trials, dissimilar-exemplar or similar-exemplar trials, or b-LVF/w-LVF or b-RVF/w-RVF trials appeared consecutively.

2.2. Results

In this experiment and in the subsequent experiments, we assessed performance using two dependent measures: mean accuracy rates and mean response times for correct responses.³ These measures were submitted to separate repeated-measures analyses of variance (ANOVAs) with participant as the random variable and four within-participant independent variables: task (abstract category versus specific exemplar), type of visual presentation (AH versus WH), visual similarity of the comparison letters (dissimilar-exemplar or similar-exemplar), and hemisphere of initial presentation of the lowest comparison letter (LH versus RH).

2.2.1. Accuracy

2.2.1.1. Interhemispheric communication. The accuracy results, collapsed across visual similarity of the comparison letters (dissimilar-exemplar versus similar-exemplar), are shown in Fig. 2. The interaction between task (abstract category or specific exemplar) and type of visual presentation (AH or WH) was significant, $F(1, 47) = 19.5$, $P < 0.001$, $MS_e = 0.00116$. For the abstract category task, participants performed more accurately in AH trials (0.966)

³ In all experiments, mean response times per cell per participant were calculated following an outlier analysis. Within each cell, response times greater than 2.5 times the mean response time were eliminated from the analysis before calculating means.

than in WH trials (0.954), $F(1, 94) = 11.6$, $P < 0.005$, $MS_e = 0.00112$ for the simple effect contrast. However, for the specific exemplar task, performance was greater in WH trials (0.911) than in AH trials (0.901), $F(1, 94) = 8.70$, $P < 0.01$, $MS_e = 0.00112$ for the simple effect contrast. This important pattern of results replicates an analogous pattern in Banich & Belger [2].

Even more important, the three-way interaction between task (abstract category or specific exemplar), type of visual presentation (AH or WH), and visual similarity of the comparison letters (dissimilar-exemplar or similar-exemplar) was significant, $F(1, 47) = 9.52$, $P < 0.01$, $MS_e = 0.00135$, indicating that exemplar similarity did affect interhemispheric communication. The left side of Fig. 3 depicts the main results for similar-exemplar items, and the right side of Fig. 3 depicts the main results for dissimilar-exemplar items. The interaction contrast between task (abstract category or specific exemplar) and type of visual presentation (AH or WH) for the similar-exemplar items was significant, $F(1, 94) = 27.7$, $P < 0.001$, $MS_e = 0.00125$. For similar-exemplar items, accuracy in the abstract category task was greater in AH trials (0.984) than in WH trials (0.967), $F(1, 188) = 11.3$, $P < 0.005$, $MS_e = 0.00118$, for the simple effect contrast, but accuracy in the specific exemplar task was greater in WH trials (0.860) than in AH trials (0.838), $F(1, 188) = 18.5$, $P < 0.001$, $MS_e = 0.00118$, for the simple effect contrast. In contrast, for dissimilar-exemplar items, the interaction contrast between task (abstract category or specific exemplar) and type of visual presentation (AH or WH) was not significant, $F < 1$. Thus, for dissimilar-exemplar items, accuracy in the abstract category task did not differ significantly between AH trials (0.948) and WH trials (0.941), $F(1, 188) = 1.75$, $P > 0.15$, $MS_e = 0.00118$, for the simple

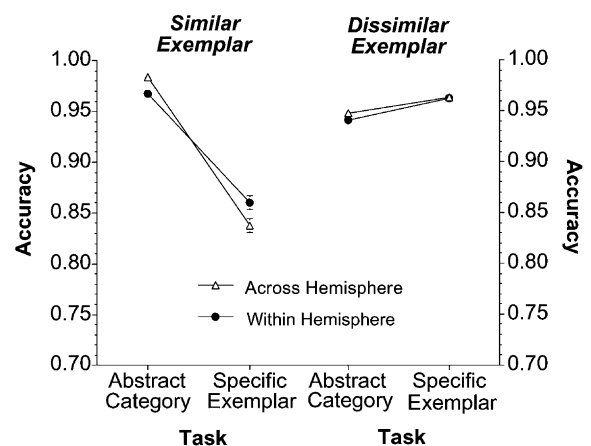


Fig. 3. Results from Experiment 1, broken down by exemplar similarity. Mean accuracy (proportion) is presented as a function of task (abstract category vs. specific exemplar), type of visual presentation (across-hemisphere vs. within-hemisphere), and exemplar similarity (similar-exemplar items, shown on the left side, and dissimilar-exemplar items, shown on the right side). Error bars indicate standard errors of the mean.

effect contrast, and accuracy in the specific exemplar task did not differ significantly between WH trials (0.962) and AH trials (0.963), $F < 1$, for the simple effect contrast.

2.2.1.2. Other effects. The only other significant effects in the analysis of accuracy rates were the following (all other P s > 0.08). In a main effect of task, $F(1, 47) = 147$, $P < 0.001$, $MS_e = 0.00383$, accuracy was greater in the abstract category task (0.960) than in the specific exemplar task (0.906). In a main effect of visual similarity of the comparison letters, $F(1, 47) = 101$, $P < 0.001$, $MS_e = 0.00322$, accuracy was greater for dissimilar-exemplar items (0.953) than for similar-exemplar items (0.912). In addition, in line with the reasoning in the Introduction, performance in the abstract category and specific exemplar tasks differed depending on exemplar similarity. The interaction between task (abstract category or specific exemplar) and visual similarity of the comparison letters (dissimilar-exemplar or similar-exemplar) was significant, $F(1, 47) = 226$, $P < 0.001$, $MS_e = 0.00448$. In the abstract category task, accuracy was greater when similar-exemplar items were presented (0.976) than when dissimilar-exemplar items were presented (0.944), $F(1, 94) = 24.8$, $P < 0.001$, $MS_e = 0.00385$, for the simple effect contrast. The reverse was true for the specific exemplar task; accuracy was greater when dissimilar-exemplar items were presented (0.963) than when similar-exemplar items were presented (0.849), $F(1, 94) = 322$, $P < 0.001$, $MS_e = 0.00385$, for the simple effect contrast.⁴

2.2.2. Response times

2.2.2.1. Interhemispheric communication. In the analysis of mean response times for correct responses, neither the two-way interaction between task (abstract category or specific exemplar) and type of visual presentation (AH or WH), nor the three-way interaction between task (abstract category or specific exemplar), type of visual presentation (AH or WH), and visual similarity of the comparison letters (dissimilar-exemplar versus similar-exemplar) approached

significance (for both, $F < 1$). Thus, the important results reported above for accuracy rates were not compromised by any tradeoffs between speed and accuracy.

2.2.2.2. Other effects. Analogous to the accuracy data, response times in the abstract category and specific exemplar tasks differed depending on exemplar similarity. The interaction between task (abstract category or specific exemplar) and visual similarity of the comparison letters (dissimilar-exemplar or similar-exemplar) was significant, $F(1, 47) = 188$, $P < 0.001$, $MS_e = 3712.4$. In the abstract category task, participants performed faster when similar-exemplar items were presented (772 ms) than when dissimilar-exemplar items were presented (819 ms), $F(1, 94) = 64.3$, $P < 0.001$, $MS_e = 3297.4$, for the simple effect contrast. In contrast, in the specific exemplar task, performance was faster when dissimilar-exemplar items were presented (823 ms) than when similar-exemplar items were presented (897 ms), $F(1, 94) = 159$, $P < 0.001$, $MS_e = 3297.4$, for the simple effect contrast.

In addition, the four-way interaction between task (abstract category or specific exemplar), type of visual presentation (AH or WH), hemisphere of initial presentation of the lowest comparison letter (LH or RH), and visual similarity of the comparison letters (similar-exemplar or dissimilar-exemplar) was significant, $F(1, 47) = 6.06$, $P < 0.05$, $MS_e = 1794.4$. Most interesting, for similar-exemplar items presented in WH trials, performance was faster when letter pairs were presented directly to the RH (890 ms) than when they were presented directly to the LH (919 ms), $F(1, 376) = 8.85$, $P < 0.005$, $MS_e = 2280.8$, for the simple effect contrast. However, for dissimilar-exemplar items presented in WH trials, performance was not faster when letter pairs were presented directly to the RH (782 ms) than to the LH (776 ms), $F < 1$, for the simple effect contrast.

The only other significant effects in the analysis of response times were the following (all other P s > 0.07). In a main effect of task, $F(1, 47) = 17.3$, $P < 0.001$, $MS_e = 46602.2$, participants responded faster in the abstract category task (795 ms) than in the specific exemplar task (860 ms). In a main effect of type of visual presentation, $F(1, 47) = 23.3$, $P < 0.001$, $MS_e = 1858.0$, AH trials were processed faster (820 ms) than WH trials (835 ms). In a main effect of visual similarity of the comparison letters, $F(1, 47) = 12.8$, $P < 0.001$, $MS_e = 2882.3$, dissimilar-exemplar items were processed faster (821 ms) than similar-exemplar items (835 ms). Finally, the two-way interaction between task and hemisphere of initial presentation of the lowest comparison letter was significant, $F(1, 47) = 6.24$, $P < 0.05$, $MS_e = 1411.3$. The specific exemplar task was performed faster when the lowest comparison letter was presented directly to the RH (854 ms) than to the LH (867 ms), $F(1, 94) = 9.07$, $P < 0.01$, $MS_e = 1788.8$, for the simple effect contrast, whereas the abstract category task was not performed faster when the lowest comparison letter was presented directly to the RH

⁴ In addition to the analysis of accuracy rates, we also analyzed sensitivity, using signal detection analysis, to assess a measure of performance that is independent of any bias to respond “same” or “different.” In all experiments, we used the modified d' measure recommended by Macmillan and Creelman [33] as appropriate for our same/different tasks. Also, when d' scores were computed, a 100% hit or false-alarm rate was set at a rate computed from 0.5 less than the maximum possible observations per cell per participant. This rate was 96.875% (for 15.5 of 16 observations) in Experiment 1 and 98.4375% (for 31.5 of 32 observations) in Experiments 2 and 3. Similarly, a 0% hit or false-alarm rate was set at a rate computed from 0.5 more than the minimum possible observations per cell per participant. This rate was 3.125% (for 0.5 of 16 observations) in Experiment 1 and 1.5625% (for 0.5 of 32 observations) in Experiments 2 and 3. Most important for the d' analysis in this experiment, all of the effects that were significant and non-significant in the accuracy analysis reported in the text were also significant and non-significant, respectively, in the analysis of sensitivity.

(796 ms) than to the LH (795 ms), $F < 1$, for the simple effect contrast.

2.2.3. Same versus different trials

To further test predictions from our theory, we conducted additional accuracy and response-time analyses. They were conducted like the analyses above, but they included a fifth within-participant independent variable, correct response for a trial (same versus different). Different predictions can be generated for performance in the specific exemplar and abstract category tasks.

In the specific exemplar task, results from same-response and different-response trials should differ in predictable ways. As argued in Section 1, callosal degradation should have a greater negative impact on similar-exemplar items than dissimilar-exemplar items in the specific task (causing the previously reported WH advantage for similar-exemplar items but not for dissimilar-exemplar items). Interestingly, this reasoning applies more strongly toward the different-response trials than toward the same-response trials. In the different-response trials, callosal degradation should have a large negative impact on distinguishing similar-exemplar items that have subtle whole-based differences (e.g. “K” and “k”), but not on distinguishing dissimilar-exemplar items that have more pronounced whole-based differences (e.g. “A” and “a”). However, in the same-response trials, callosal degradation should not have a larger effect on deciding that two items are exactly the same when they are similar-exemplar items (e.g. “K” and “K”) versus when they are dissimilar-exemplar items (e.g. “A” and “A”); in both cases, all of the whole-based information matches. In line with these predictions, an interaction between type of visual presentation (AH versus WH), visual similarity of the comparison letters (dissimilar-exemplar versus similar-exemplar), and correct response (same versus different) was observed in the specific task, $F(1, 94) = 4.31$, $P < 0.05$, $MS_e = 0.00284$, for the interaction contrast in the accuracy analysis. (This interaction contrast did not approach significance in the response-time analysis; $F[1, 94] = 1.25$, $P > 0.25$, $MS_e = 4894.2$). Accuracy was greater in WH trials (0.822) than in AH trials (0.778) when similar-exemplar items were presented in different-response trials, $F(1, 376) = 30.3$, $P < 0.001$, $MS_e = 0.00311$, for the simple effect contrast. However, no WH advantage was observed when similar-exemplar items were presented in same-response trials (0.895 versus 0.898, for WH and AH trials, respectively), $F < 1$, for the simple effect contrast, or when dissimilar-exemplar items were presented in same-response trials (0.942 versus 0.951), $F(1, 376) = 1.28$, $P > 0.25$, $MS_e = 0.00311$, for the simple effect contrast, or when dissimilar-exemplar items were presented in different-response trials (0.979 versus 0.973), $F < 1$, for the simple effect contrast.

In contrast, in the abstract category task, results from same-response and different-response trials should be very similar. As argued in Section 1, the greater the amount

of relatively invariant feature information for a category, the greater the chance that callosal transfer can occur with little negative impact on abstract comparisons (allowing the previously reported AH advantage for similar-exemplar items but not for dissimilar-exemplar items). This reasoning applies for both the same-response and different-response trials. In the same-response trials, the larger amount of relatively invariant feature information in similar-exemplar items (e.g. K and k) compared with dissimilar-exemplar items (e.g. A and a) allows an AH advantage for the former but not for the latter. And, in the different-response trials as well, the similar-exemplar items have a larger amount of relatively invariant feature information per letter (e.g. a large amount for K/k’s and a large amount for P/p’s as well) than the dissimilar-exemplar items (e.g. a small amount for A/a’s and a small amount for F/f’s as well). Thus, even when deciding that two items belong to different categories, more effective callosal transfer should occur for similar-exemplar items (e.g. K and p) than for dissimilar-exemplar items (e.g. A and f), allowing an AH advantage for the former but not for the latter. In line with these predictions, and in contrast with performance in the specific task, the interaction between type of visual presentation (AH versus WH), visual similarity of the comparison letters (dissimilar-exemplar versus similar-exemplar), and correct response (same versus different) did not approach significance in the abstract task, $F < 1$, for the interaction contrast in the accuracy analysis, and $F(1, 94) = 2.65$, $P > 0.10$, $MS_e = 4894.2$, for the interaction contrast in the response-time analysis.

2.3. Discussion

Participants performed the abstract category and specific exemplar comparison tasks differently depending on whether stimuli were presented in AH or WH conditions and depending on the visual similarity of comparison items. They performed the abstract task more effectively in AH trials than in WH trials, but only when similar-exemplar items were presented and not when dissimilar-exemplar items were presented. In addition, they performed the specific task more effectively in WH trials than in AH trials, but only when similar-exemplar items were presented and not when dissimilar-exemplar items were presented. These findings support the neural subsystems theory.

An apparent problem in this experiment, however, is that the results do not replicate analogous results from a previous study. Using dissimilar-exemplar items throughout their study, Banich and Belger [2] found (a) an AH advantage in their abstract task, and (b) a WH advantage in their specific task, but only when (both or the bottom-most) target items were presented directly to the RH. In contrast, when dissimilar-exemplar items were presented in Experiment 1, we found (a) no AH advantage in the abstract task (see right side of Fig. 3), and (b) no WH advantage in the specific task when (both or the bottom-most) target items were

presented directly to the RH (in fact, the trend in response times was for an AH advantage in that condition—810 ms versus 823 ms).

What could explain these discrepancies? There are several differences in the procedures used in this experiment and in the Banich and Belger [2] study, but we hypothesize that the crucial difference underlying the seemingly contradictory results lies in the number of comparisons that were made per trial. In the present experiment, only two letters were presented in each trial, but in Banich and Belger's experiment, three letters were presented in a triangular array in each trial. In their study, participants were asked to compare the bottom letter of the triangle with the two letters at the top vertices of the triangle, one of which was in the same visual field and the other of which was in the different visual field compared with the bottom letter.

This procedural difference may help to explain the discrepant results. When visual forms are being compared, the greater the number of comparisons to be made per trial, the greater the chance that one comparison between two shapes will be affected by the information in the additional shapes that also must enter into comparisons. In subsystems that process visual shape information, the additional shape information from additional comparison items may interfere with one comparison in a manner not unlike how stimulus presentation conditions (added noise, distortion of input, or the like) can cause perceptual interference. In other words, the additional comparison items in the previous study may have introduced some degree of perceptual interference in the processing of the critical target pairs—interference that was not present in Experiment 1 of this study, because only single comparisons were made. The greater perceptual interference from multiple comparisons in Banich and Belger's [2] study may have resulted in a greater benefit to be gained from AH distribution of processing of the critical target pairs, compared with Experiment 1 of the present study (cf. [1]). When the processing of the critical target shapes can be distributed across hemispheres, the separation may help to avoid the potential perceptual interference caused by additional visual comparison items. This may explain why they found an AH advantage in their abstract task, whereas we did not (for dissimilar-exemplar items).

In addition, a potentially important finding in the hemispheric asymmetry literature is that visual-perceptual interference tends to disrupt processing in direct LH presentations to a greater degree than direct RH presentations (e.g. [22]; for reviews, see [13,44]). This may explain why Banich and Belger found a WH advantage in their specific task during RH presentations, whereas we did not (for dissimilar-exemplar items). Their procedure may have created a situation in which potential contributions from LH subsystems were tethered (LH subsystems are more detrimentally affected by interference of the sort that additional comparison items may cause), at least more so than our procedure. In Experiment 2, we tested these potential explanations.

3. Experiment 2

Trials in this experiment were conducted in the same manner as the dissimilar-exemplar trials in Experiment 1, but the visual arrays contained three letters and one non-letter distractor character, instead of two letters and two non-letter distractor characters as in Experiment 1. In this way, the procedure was like that used by Banich and Belger [2]. Participants were encouraged to make multiple comparisons per trial, as different pairs in the set of three presented letters could have matched (in each comparison task).

Following the reasoning above, we predict two results in particular: (a) an AH advantage in the abstract task, and (b) a WH advantage in the specific task, but only when (both or the bottom-most) target items are presented directly to the RH. Such results would replicate analogous results in Banich and Belger [2] and would support our hypotheses for why discrepant results were obtained between their study and our Experiment 1.

In addition, the WH-presentation results from this experiment, combined with WH-presentation results from Experiment 1, provided us with an opportunity to conduct a particularly strong test of the theory that dissociable subsystems underlie abstract category and specific exemplar comparisons. Dunn and Kirsner [19] introduced the reversed association technique for directly testing the independence of cognitive processes. When performance in one task (e.g. specific exemplar comparisons) is plotted as a function of performance in another task (e.g. abstract category comparisons) for each of three or more conditions, an observed non-monotonic relation between the two tasks unequivocally indicates that a common process could not support both. Thus, we performed such an analysis to further test the abstract and specific subsystems theory.

3.1. Method

3.1.1. Participants

Forty-eight students at the University of Arizona (24 men and 24 women) volunteered to participate for course credit in an introductory psychology class. All participants were right-handed, as assessed through the Edinburg = Handedness Inventory (mean laterality quotient = 0.73; [41]). In addition, all were native speakers of English and had normal or corrected to normal vision. None participated in either of the other experiments reported in this article.

3.1.2. Materials and procedure

The materials and procedure in this experiments were the same as those in Experiment 1, with the following exception: eight letters (a/A, f/F, n/N, q/Q, b/B, e/E, h/H, and l/L), all with dissimilar lowercase and uppercase visual structures [10], served as target items. In each trial, three letters and one pound sign were displayed. For trials in which the correct response was "same," two of the letters matched according to the task, and the third was a

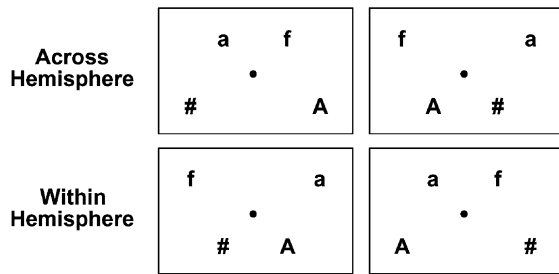


Fig. 4. Examples of trapezoidal stimulus arrays used for across-hemisphere and within-hemisphere presentation conditions in Experiment 2. These examples have a target pair of dissimilar-exemplar items that should be given a “same” response in the abstract category task, but a “different” response in the specific exemplar task.

different letter of the alphabet. For trials in which the correct response was “different,” none of the three pairwise comparisons matched according to the tasks. The three letters in the array were positioned such that a lower target letter formed a triangle with the two remaining letters that were placed in the upper vertices in the display. A pound sign was positioned in the visual field opposite the lower target letter (Fig. 4). In the abstract category task, participants were asked to determine as quickly and accurately as possible whether any two of the letters corresponded to the same letter of the alphabet. In the specific exemplar task, participants were asked to determine as quickly and accurately as possible whether any two of letters had exactly the same shape.

3.2. Results

We analyzed performance using two dependent measures: mean accuracy rates and mean response times for correct responses, as in Experiment 1.⁵ Each measure was submitted to separate repeated-measures ANOVAs with participant as the random variable and three within-participant inde-

⁵ As in the other experiments, we were interested in performance differences between conditions that required interhemispheric communication versus those that did not. In this experiment, however, due to the task instructions and the three-letter array construction, “different”-response trials *always* required interhemispheric communication. In contrast, “same”-response trials required interhemispheric communication only if the matching letters were in different visual fields; if they were in the same visual field, interhemispheric communication was not required. These restrictions necessitated that accuracy be computed using the same rates for AH and WH “different”-response trials in this experiment, because those two conditions did not differ from each other in their requirements of interhemispheric communication. Hence, accuracy in this experiment is comparable to accuracy in Experiment 1, however, the variance in AH and WH trials reflects only performance on “same”-response trials. Similarly, we computed mean response times by using performance on “same”-response trials only. Thus, for both measures, these procedures allowed comparisons between trials in which interhemispheric communication was required and those in which it was not in the ANOVAs (note that these measures are similar to the analogous ones used by Banich and Belger [2], which is important for comparability).

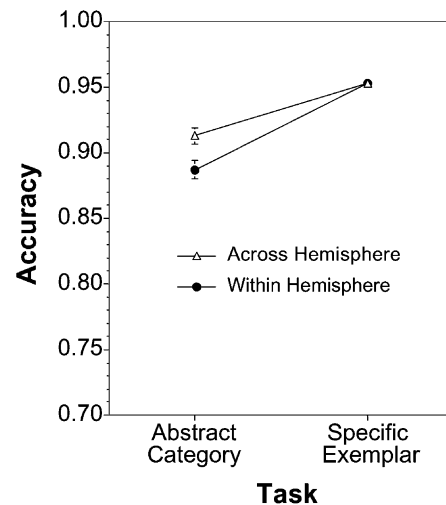


Fig. 5. Results from Experiment 2. Mean accuracy (proportion) is presented as a function of task (abstract category vs. specific exemplar) and type of visual presentation (across-hemisphere vs. within-hemisphere). All stimuli in this experiment were dissimilar-exemplar items, and multiple pairs of comparison items were presented in each trial. Error bars indicate standard errors of the mean.

pendent variables: task (abstract category versus specific exemplar), type of visual presentation (AH versus WH), and hemisphere of initial presentation of the lowest letter (LH versus RH).

3.2.1. Accuracy

3.2.1.1. Interhemispheric communication. The main accuracy results are shown in Fig. 5. Important for the first of the main predictions in this experiment, the interaction between task (abstract category or specific exemplar) and type of visual presentation (AH or WH) was significant, $F(1, 47) = 13.0$, $P < 0.001$, $MS_e = 0.00118$. In particular, in the abstract category task, accuracy was higher in AH trials (0.913) than in WH trials (0.887), $F(1, 94) = 21.4$, $P < 0.001$, $MS_e = 0.00137$, for the simple effect contrast. This is in line with the first major prediction for the experiment. In the specific exemplar task, accuracy was not greater in AH trials (0.953) than in WH trials (0.953), $F < 1$, for the simple effect contrast.

3.2.1.2. Other effects. The other significant effects in the analysis of accuracy were the following (other P s > 0.20). Accuracy was higher in the specific exemplar task (0.953) than in the abstract category task (0.901), $F(1, 47) = 58.7$, $P < 0.001$, $MS_e = 0.00439$, for the main effect of task. Accuracy was higher in AH trials (0.933) than in WH trials (0.921), $F(1, 47) = 8.97$, $P < 0.01$, $MS_e = 0.00155$, for the main effect of type of visual presentation. Accuracy was higher when the lowest letter was presented directly to the RH (0.935) than to the LH (0.918), $F(1, 47) = 22.9$, $P < 0.001$, $MS_e = 0.00118$, for the main effect of

hemisphere of initial presentation of the lowest letter. Finally, the interaction between type of visual presentation (AH or WH) and hemisphere of initial presentation of the lowest letter (left or right) was significant, $F(1, 47) = 16.8$, $P < 0.001$, $MS_e = 0.00094$. In AH presentations, accuracy was not significantly different when the lower letter was presented to the right hemisphere (0.935) than when it was presented to the left hemisphere (0.931), $F < 1$, for the simple effect contrast. But, in WH presentations, accuracy was significantly higher when the lowest letter was presented to the right hemisphere (0.936) than when the lowest letter was presented to the left hemisphere (0.906), $F(1, 94) = 39.7$, $P < 0.001$, $MS_e = 0.00107$, for the simple effect contrast.⁶

3.2.2. Response times

3.2.2.1. Interhemispheric communication. Similar to the analysis of accuracy rates, the two-way interaction between task (abstract category or specific exemplar) and type of visual presentation (AH or WH) was significant, $F(1, 47) = 53.9$, $P < 0.001$, $MS_e = 2767.2$. Participants performed the abstract category task faster in AH trials (849 ms) than in WH trials (918 ms), $F(1, 94) = 78.9$, $P < 0.001$, $MS_e = 2896.9$, for the simple effect contrast; but they did not perform the specific exemplar task faster in AH trials (732 ms) than in WH trials (721 ms), $F(1, 94) = 2.00$, $P > 0.15$, $MS_e = 2896.9$, for the simple effect contrast. These findings indicate that the important results reported above for accuracy rates were not compromised by any tradeoffs between speed and accuracy.

Important for the second of the major predictions in this experiment, the two-way interaction between task (abstract-category or specific-exemplar) and type of visual presentation (AH or WH) was modulated by hemisphere of initial presentation of the lowest letter (LH or RH) in a significant three-way interaction, $F(1, 47) = 4.54$, $P < 0.05$, $MS_e = 2082.1$. As predicted, WH trials (698 ms) were performed faster than AH trials (741 ms) when participants performed the specific exemplar task and the lowest letter was presented directly to the RH, $F(1, 188) = 14.7$, $P < 0.001$, $MS_e = 3010.2$, for the simple effect contrast. However, WH trials (745 ms) were not performed faster than AH trials (723 ms) when participants performed the specific exemplar task and the lowest letter was presented directly to the LH, $F(1, 188) = 3.86$, $P > 0.05$, $MS_e = 3010.2$, for the simple effect contrast. This three-way interaction did not approach significance in the accuracy-rates analysis, $F < 1$, which precludes the possibility of a tradeoff between speed and accuracy.

3.2.2.2. Other effects. The only other significant effects in the analysis of response times were the following effects that paralleled those in the analysis of accuracy rates (other $P > 0.25$). Participants performed the specific exemplar task (726 ms) faster than the abstract category task (883 ms), $F(1, 47) = 80.3$, $P < 0.001$, $MS_e = 29485.6$, for the main effect of task. They performed faster in AH trials (790 ms) than in WH trials (819 ms), $F(1, 47) = 26.8$, $P < 0.001$, $MS_e = 3026.6$, for the main effect of type of visual presentation. Also, they performed faster when the lowest letter was presented directly to the RH (794 ms) than to the LH (816 ms), $F(1, 47) = 16.8$, $P < 0.001$, $MS_e = 2610.4$, for the main effect of hemisphere of initial presentation of the lowest letter. Finally, the interaction between type of visual presentation and hemisphere of initial presentation of the lowest letter was significant, $F(1, 47) = 41.1$, $P < 0.001$, $MS_e = 4165.0$. Participants responded faster in AH trials when the lowest letter was presented directly to the LH (780 ms) than when it was presented directly to the RH (801 ms), $F(1, 94) = 6.25$, $P < 0.05$, $MS_e = 3387.7$ for the simple effect contrast; but they responded faster in WH trials when the letters were presented directly to the RH (788 ms) than when they were presented directly to the LH (851 ms), $F(1, 94) = 56.2$, $P < 0.001$, $MS_e = 3387.7$ for the simple effect contrast.

3.2.3. Reversed association

Finally, results from this experiment were combined with results from Experiment 1 to use the reversed association technique [19] to directly test the independence of the abstract category and specific exemplar subsystems. In a separate analysis of response times, we examined performance in WH trials only for the dissimilar-exemplar condition of Experiment 1 and for the (all dissimilar-exemplar) data of Experiment 2. We plotted specific exemplar task performance as a function of abstract category task performance for each of the following conditions: Experiment 1/LH presentations, Experiment 1/RH presentations, Experiment 2/LH presentations, and Experiment 2/RH presentations (Fig. 6). In this way, we were able to inspect whether any non-monotonic relation exists between the two tasks hypothesized to be supported by dissociable visual-form subsystems. Such a non-monotonicity was evident: Experiment 2/RH presentations yielded significantly faster response times (701 ms) than Experiment 1/RH presentations (823 ms) in the specific exemplar task ($P < 0.001$) and also significantly slower response times (877 ms) than Experiment 1/RH presentations (822 ms) in the abstract category task ($P < 0.05$). Thus, monotonicity would be violated if another condition produced significantly slower response times than Experiment 2/RH presentations in *both* tasks. Indeed, Experiment 2/LH presentations yielded significantly slower response times (746 ms) than Experiment 2/RH presentations (701 ms) in the specific exemplar task ($P < 0.001$) and also significantly slower response times (962 ms) than Experiment 2/RH presentations (877 ms)

⁶ As in Experiment 1, we also analyzed sensitivity, using signal detection analysis, to assess a measure of performance that is independent of any bias to respond “same” or “different.” All of the effects that were significant and non-significant in the accuracy analysis reported in the text were also significant and non-significant, respectively, in the analysis of sensitivity.

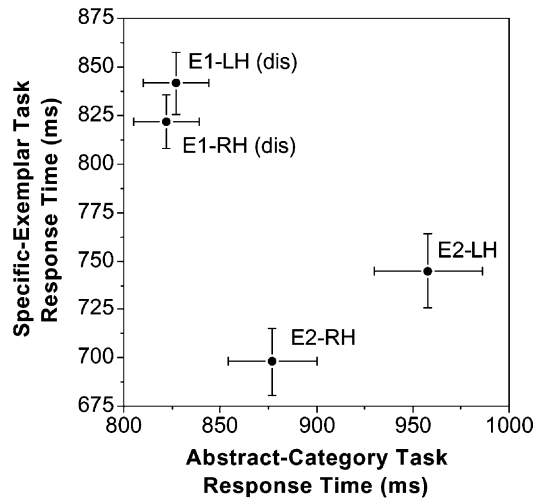


Fig. 6. Results from within-hemisphere trials only for the dissimilar-exemplar condition of Experiment 1 and for the (all dissimilar-exemplar) data of Experiment 2. Mean response time in the specific exemplar task is displayed as a function of mean response time in the abstract category task for Experiment 1/LH presentations, Experiment 1/RH presentations, Experiment 2/LH presentations, and Experiment 2/RH presentations. Error bars indicate standard errors of the mean; vertical bars for specific exemplar task performance, and horizontal bars for abstract category task performance.

in the abstract category task ($P < 0.001$). This pattern defines a non-monotonic relation between specific exemplar and abstract category task performance, unequivocally dissociating the subsystems underlying those two tasks ([19]).

3.3. Discussion

In an experiment requiring multiple comparisons of dissimilar-exemplar items, we obtained two important effects that were observed in Banich and Belger [2] but not in our Experiment 1. First, we observed an AH advantage in the abstract category task. Our theory is that additional comparison items cause perceptual interference in processing of the critical target pairs of visual forms. This creates a situation in which a greater benefit can be gained from AH distribution of the critical target pairs (to decrease the effect of the potential interference from additional comparison items), compared with a situation in which only single comparisons were made (Experiment 1 of the present study). By this theory, if similar-exemplar items were used in an experiment requiring multiple comparisons, an AH advantage should be observed in the abstract task for the reason that it was in Experiment 1 (because the benefits of distribution of processing outweighs the costs of interhemispheric transfer of similar-exemplar items; see Section 1) as well as for the reason that it was in Experiment 2 (because the benefits of distribution are increased by avoiding perceptual interference from additional comparison items).

Second, we also observed a WH advantage in the specific exemplar task, but only when (both or the bottom-most) of the critical target items were presented directly to the RH. Our theory is that the perceptual interference from additional comparison items likely disrupted LH subsystems to a greater degree than RH subsystems, allowing a WH advantage to be observed in the specific task but only when the critical target items were presented directly to the less-disrupted RH. By this theory, if similar-exemplar items were used in an experiment requiring multiple comparisons, a WH advantage should be observed in the specific task (as it was in Experiment 1, due to the costs of transfer outweighing the benefits of distribution; see Section 1), and that advantage should be greater when the critical target items were presented directly to the RH than to the LH (as it was in Experiment 2, because RH subsystems are less disrupted by perceptual interference from additional comparison items).

Another important finding was that abstract category and specific exemplar subsystems were dissociated through the reversed association technique. In several previous studies, single and double dissociations have been used to support the hypothesis that abstract and specific subsystems operate at least relatively independently in the brain (e.g. [12,34–39]). However, such dissociations may not provide unequivocal evidence for independent subsystems; single-system theories can account for many such dissociations [19]. Thus, we used Dunn and Kirsner's reversed association technique to strongly dissociate abstract category and specific exemplar subsystems. In line with our theory, specific exemplar task performance was not a monotonic function of abstract category task performance, in data from both Experiments 1 and 2.

Thus, differences in results were obtained between some of the analogous conditions of Experiments 1 and 2. This indicates that procedural factors can influence the effects in interhemispheric communication experiments, and this is one reason why we decided it was prudent to attempt to replicate the most important results from Experiment 1. We attempted such a replication in Experiment 3.

4. Experiment 3

The AH and WH advantages reported in Experiment 1 were obtained with one group of letters (similar-exemplar items; e.g. “k” and “K”) but not with another group of letters (dissimilar-exemplar items; e.g. “a” and “A”). The important difference between these letters groups presumably was that the exemplars in the former group were more similar to each other than the exemplars in the latter group. However, there may have been other differences between those groups of letters (e.g. any other differences between K's and A's) that could be responsible for the important differences in results. In this experiment, we tested whether exemplar similarity was the crucial factor for producing the AH and WH advantages.

The experiment was conducted in the same manner as Experiment 1, except only letters with dissimilar lowercase and uppercase forms were used. Instead of manipulating letter case to create different (dissimilar) exemplars in the same abstract category (e.g. “a” and “A”), we manipulated font within the same letter case to create different (similar) exemplars in the same abstract category (e.g. “A” and “A”). If the visual similarity of the comparison items determines whether an AH advantage will be obtained in the abstract category task and a WH advantage will be obtained in the specific exemplar task, then those effects should be found in this experiment (replicating the results from similar-exemplar items in Experiment 1, but now using the letters of the alphabet that represented the dissimilar-exemplar items in Experiment 1).

4.1. Method

4.1.1. Participants

Forty-eight students at the University of Arizona (24 men and 24 women) volunteered to participate for course credit in an introductory psychology class. All participants were right-handed, as assessed through the Edinburgh Handedness Inventory (mean laterality quotient = 0.80; [41]). In addition, all were native speakers of English and had normal or corrected to normal vision. None had participated in either of the other experiments reported in this article.

4.1.2. Materials and procedure

The materials and procedure in this experiment were the same as those in Experiment 1 with the following exceptions: eight letters (a/A, f/F, n/N, q/Q, b/B, e/E, h/H, and l/L), all with dissimilar lowercase and uppercase visual structures, served as target items. Note that four of these letters were used for the dissimilar-exemplar items in Experiment 1, and all of these letters were used in Experiment 2.

In the abstract category task, the two targets were always shown in the same letter case, but in two different fonts of approximately the same size on the computer display (24-point Helvetica and 28-point Courier). In half of the trials the targets were from the same letter of the alphabet (e.g. “A” and “A” in different fonts) and in the other half of the trials the targets were from different letters of the alphabet (e.g. “A” and “F” in different fonts). Participants were asked to determine as quickly and accurately as possible whether the two letters corresponded to the same letter of the alphabet or different letters of the alphabet.

In the specific exemplar task, the two targets were always shown in the same letter case, but in half of the trials they were shown in the same font (both letters in Helvetica or both letters in Courier) and in the other half of the trials they were shown in different fonts (one letter in Helvetica and one letter in Courier; for an example of such a visual display, see Fig. 7). Participants were asked to determine as quickly and accurately as possible whether the two letters had exactly the same shape or different shapes. In both tasks, uppercase

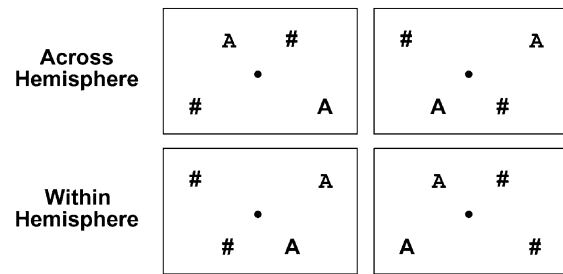


Fig. 7. Examples of trapezoidal stimulus arrays used for across-hemisphere and within-hemisphere presentation conditions in Experiment 3. These examples have a pair of similar-exemplar items that should be given a “same” response in the abstract category task, but a “different” response in the specific exemplar task.

letters were used in half of the trials and lowercase letters were used in the other half of the trials. Finally, the font of lowest target letter was counterbalanced across letters, and the letter and font combinations were counterbalanced across participants.

4.2. Results

We analyzed performance using two dependent measures: mean accuracy rates and mean response times for correct responses, as in the previous experiments. Each measure was submitted to separate repeated-measures ANOVAs with participant as the random variable and three within-participant independent variables: task (abstract category versus specific exemplar), type of visual presentation (AH versus WH), and hemisphere of initial presentation of the lowest letter (LH versus RH).

4.2.1. Accuracy

4.2.1.1. Interhemispheric communication. The accuracy results are displayed in Fig. 8. Most important, the interaction between task (abstract category or specific exemplar) and type of visual presentation (AH or WH) was significant, $F(1, 47) = 15.0$, $P < 0.001$, $MS_e = 0.00139$. A simple effect contrast revealed that, in the abstract category task, accuracy was greater in AH trials (0.955) than in WH trials (0.945) in an effect that approached significance, $F(1, 94) = 2.91$, $P < 0.10$, $MS_e = 0.00173$. However, in the specific exemplar task, accuracy was greater in WH trials (0.738) than in AH trials (0.719) in a significant effect, $F(1, 94) = 10.2$, $P < 0.005$, $MS_e = 0.00173$, for the simple effect contrast. This pattern of results replicates the analogous results observed with similar-exemplar items in Experiment 1.

4.2.1.2. Other effect. The only other significant effect in the analysis of accuracy was the main effect of task (all other P s > 0.20). Accuracy was greater in the abstract category task (0.950) than in the specific exemplar task (0.729),

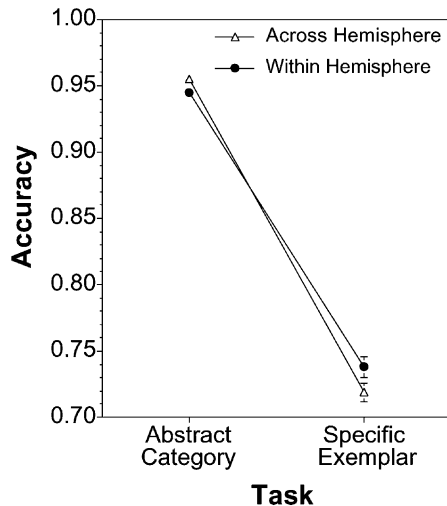


Fig. 8. Results from Experiment 3. Mean accuracy (proportion) is presented as a function of task (abstract category vs. specific exemplar) and type of visual presentation (across-hemisphere vs. within-hemisphere). All stimuli in this experiment were similar-exemplar items. Error bars indicate standard errors of the mean.

$F(1, 47) = 693, P < 0.001, MS_e = 0.00676$, for this main effect.⁷

4.2.2. Response times

4.2.2.1. Interhemispheric communication. In the analysis of mean response times, the interaction between task (abstract category or specific exemplar) and type of visual presentation (AH or WH) was not significant, $F(1, 47) = 2.12, P > 0.15, MS_e = 839.8$, indicating that the analogous interaction in the accuracy analysis was not compromised by a tradeoff between speed and accuracy.

4.2.2.2. Other effect. The only significant effect in the analysis of response times was the main effect of task (all other P s > 0.06). Similar to the pattern in the accuracy analysis, responses were faster when participants performed the abstract category task (719 ms) than when they performed the specific exemplar task (850 ms), $F(1, 94) = 50.9, P < 0.001, MS_e = 32024.5$, for the main effect.

4.3. Discussion

The results from this experiment replicated the analogous results from the similar-exemplar items in Experiment 1. These findings indicate that the differing results between dissimilar-exemplar items and similar-exemplar

items within Experiment 1 likely were not due to (theoretically uninteresting) differences that may exist between the different sets of letters of the alphabet that were used to represent those conditions. Instead, they likely were due to the visual similarity of the exemplars in a category. These findings also further support the hypothesis that abstract category and specific exemplar subsystems are affected by interhemispheric communication in different ways.

5. General discussion

The main conclusion from this study is that a specific exemplar subsystem is more detrimentally affected by interhemispheric transfer of visual information than an abstract category subsystem. This result, in addition to the finding that performance in one task (specific or abstract) was not a monotonic function of performance in the other, helps to dissociate specific and abstract subsystems and uncover their respective properties.

An interesting aspect of the predictions derived from the neural subsystems theory is that properties of the representations in abstract and specific subsystems were used to generate predictions about interhemispheric communication. These properties have been discovered through previous research in which interhemispheric communication per se was not investigated [12,34–39]. A somewhat different approach to theorizing about interhemispheric communication is to consider broader principles that may apply in a more general manner to many, if not all, lateralized subsystems (cf. [3,5,24–26,32,42]). For example, a general characterization of interhemispheric communication may be that the greater the complexity or difficulty of a task, the greater the likelihood of an AH advantage. The relative complexity of two tasks can be operationalized through the number of processing stages required for task performance (and other manipulations, such as the number of items to be compared per unit of time). The relative difficulty of two tasks can be measured directly through behavioral performance (relative error rates and response times across tasks). The reasoning in these theories is that the benefits of distributing a multi-process task or a difficult task (through a division of labor; cf. [30,31]) may outweigh the costs of interhemispheric transfer, producing an AH advantage. In contrast, less complex or easy tasks may produce WH advantages, because the benefits of distributing a single-process task or an easy task may not outweigh the costs of transfer [2,7,23]. Note that such general theories could apply to any two tasks and the neural subsystems that underlie their performance.

In the present study, however, the complexity or difficulty of tasks did not predict the pattern of AH and WH advantages. It has been suggested that the name and the physical-identity comparison tasks differ in terms of complexity [2,7]. Name comparisons may require two stages of processing, a perceptual processing stage (to recognize each letter) as well as a phonological or semantic processing

⁷ As in Experiments 1 and 2, we also analyzed sensitivity, using signal detection analysis, to assess a measure of performance that is independent of any bias to respond “same” or “different.” All of the effects that were significant and non-significant in the accuracy analysis reported in the text were also significant and non-significant, respectively, in the analysis of sensitivity.

stage (to access whether the letters are associated with the same name). In contrast, physical-identity comparisons may require only one stage of processing (perceptual). By this theory, there is no a priori reason to expect different results between processing of dissimilar-exemplar and similar-exemplar items. Both should be processed through perceptual and phonological/semantic stages in the abstract task, but only through a perceptual stage in the specific task. Hence, for both dissimilar-exemplar and similar-exemplar items, AH advantages should be observed for abstract comparisons, whereas WH advantages should be observed for specific comparisons. However, the AH advantage in the abstract task was observed when similar-exemplar items were presented (in Experiments 1 and 3) but not when dissimilar-exemplar items were presented (in Experiment 1), and a WH advantage in the specific task was observed when similar-exemplar items were presented (in Experiments 1 and 3) but not when dissimilar-exemplar items were presented (in Experiment 1).

In addition, another possibility is that the name and physical-identity comparison tasks differ in relative difficulty [2,23]. The name task may require more arduous comparisons than relatively simple physical comparisons, which may be why AH advantages have been observed in the name task but WH advantages have been observed in the physical-identity task in previous research. By this theory, in the abstract task, dissimilar-exemplar items should be more difficult to categorize than similar-exemplar items, hence an AH advantage in that task should be greater for dissimilar-exemplar items than similar-exemplar items. Furthermore, in the specific task, dissimilar-exemplar items should be easier to process than similar-exemplar letters; hence a WH advantage in that task should be greater for dissimilar-exemplar items than similar-exemplar items. In fact, the abstract task was more difficult for dissimilar-exemplar items than similar-exemplar items, but an AH advantage was observed for similar-exemplar items and not for dissimilar-exemplar items (in direct comparisons in Experiment 1). Also, in fact, the specific task was easier for dissimilar-exemplar items than similar-exemplar items, but a WH advantage was observed for similar-exemplar items and not for dissimilar-exemplar items (in direct comparisons in Experiment 1). Neither the complexity nor difficulty of the tasks predicted the patterns of AH and WH advantages in this study.

We should note that our explanation for the different patterns of results between Experiments 1 and 2 does not appeal to differences in complexity or difficulty per se (even though the critical manipulation was the number of comparisons made per trial). We observed an AH advantage in the abstract task for dissimilar-exemplar items in Experiment 2 (with multiple comparisons per trial) but not for dissimilar-exemplar items in Experiment 1 (with one comparison per trial). Our theory is that the difference in number of visual comparisons leads to a difference in the amount of perceptual interference in visual-form subsystems caused by

additional comparison items, which helps to predict AH and WH advantages. Banich and Belger [2] instead appealed to differences in complexity to predict that the greater the number of comparisons the more likely an AH advantage would be observed. An advantage that our theory has over a very general complexity theory is that our theory also predicted the second main result in Experiment 2: a WH advantage in the specific task when both or the bottom-most target items were presented directly to the RH but not when they were presented directly to the LH (this was a pattern of results was observed with dissimilar-exemplar items in Experiment 2 but not with dissimilar-exemplar items in Experiment 1). Our theory is that the perceptual interference from additional comparison items likely disrupted LH subsystems to a greater degree than RH subsystems, which helps to predict AH and WH advantages. It is unclear whether or how a general notion of complexity (understood either as the number of stages of processing required for the task or as the number of comparisons to be made) would predict this pattern of results. Also, we should note that, although we hypothesize that complexity or difficulty do not determine AH and WH advantages in visual-form comparison tasks, we remain agnostic about whether they determine such advantages in non-visual-form tasks. Different neural subsystems may have different properties relevant to predicting interhemispheric communication.

One important aspect of the present theory is that an abstract category subsystem is hypothesized to store abstract *visual-form* information, not phonological or other post-visual information. As described in Section 1, this subsystem should learn the relatively invariant visual information that is common across different exemplars (even dissimilar ones) belonging to the same abstract category. In line with this reasoning, Bowers [11] found greater cross-case repetition priming than auditory-to-visual repetition priming for dissimilar letter case words, indicating that word-form representations can be letter case abstract but still visual in nature. Also, Marsolek [35] found greater cross-exemplar repetition priming than word-to-object repetition priming for objects, indicating that object-form representations can be exemplar-abstract but still store visual object information per se. Furthermore, in an abstract comparison task similar to that used in the present study, Boles [8] found that participants make more visually related errors than phonologically related errors, suggesting that the relevant representations are visual, not phonological, in nature. We suggest that visual representations per se can be used in the abstract category task. Indeed, in the present study, AH advantages in the abstract task were observed with similar-exemplar items but not with dissimilar-exemplar items, inconsistent with the notion that non-visual representations supported performance in the abstract task.

A different way to hypothesize how a visual subsystem (without the use of phonological representations) could perform the abstract task has been offered by Boles [9]. According to this theory, one or both of the comparison items

in different-case pairs quickly activates a visual representation of its opposite-case form, allowing an abstract task to be performed through visual comparisons of generated and actually presented forms. The distinctive evidence supporting this theory is that different-case pairs like “Q” and “g,” in which each item is visually similar to the opposite-case form of the other (“Q” is similar to “G,” and “g” is similar to “q”), lead to relatively poor performance in abstract tasks. The claim is that the less efficient performance reflects the confusion produced by generating opposite-case forms (e.g. “G”) that are similar to actually presented forms (e.g. “Q”), even though the correct response for the trial is “different.” However, an alternative explanation is that, because “Q” and “G” are similar, they share some subset of the relatively invariant features that signal the categories for q/Q and g/G; thus, each should weakly activate the representation of the other in an abstract category subsystem. The same should be true for “g” and “q.” If so, pairs like “Q” and “g” should be especially difficult for an abstract category subsystem to process concurrently, leading to inefficient performance in the abstract task. In fact, it may be important to note that the generation theory leads to a prediction that was not supported by the present study. That theory would predict that the abstract task should be performed less efficiently with similar-exemplar items than with dissimilar-exemplar items. The opposite-case forms generated for similar-exemplar stimuli (e.g. an “S” generated for “s,” and a “p” generated for “P”) should cause the same kind of confusion as in the “Q” and “g” example above. The generated items (e.g. “S” and “p”) would be very similar to actually presented items (e.g. “s” and “P”), which is a problem when the correct response for the trial is “different.” However, in Experiment 1, the abstract task was performed *more* efficiently with similar-exemplar items than with dissimilar-exemplar items (compare the left and right sides of Fig. 3), in line with predictions from the abstract and specific subsystems theory.

An important aspect of the neural subsystems theory is that both abstract and specific subsystems operate in each hemisphere. Consistent with this claim, Eviatar and Zaidel [20] found that three (complete) commissurotomy patients were able to perform both abstract and specific letter comparisons following direct presentations to either hemisphere, even though the specific task was performed more effectively in RH presentations than in LH presentations and the abstract task was performed more effectively in LH presentations than in RH presentations. Although there are important differences, their theory is similar to ours (e.g. they also suggest that abstract and specific processes are performed in parallel in each hemisphere rather than in sequence).

In conclusion, a specific exemplar subsystem appears to be more detrimentally affected by interhemispheric transfer of visual information than an abstract category subsystem. The present results further dissociate these visual subsystems and uncover their respective properties. Such findings also help to clarify whether the distinctive properties of the relevant

underlying subsystems are crucial for predicting effects of interhemispheric communication of visual information.

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