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Mental Capacities of the Disconnected Minor Hemisphere Following Commissurotomy*

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Much of our information regarding lateral specialization of function in the human hemispheres has come in the past from patients with asymmetric cerebral damage. Some new approaches to the problem have now become possible through the availability of a series of commissurotomy patients that have undergone a surgical disconnection of the cerebral hemispheres for control of advanced intractable epilepsy. The surgery in these patients is quite uniform and involves an extensive midline division of the forebrain commissures performed in a single operation (Bogen & Vogel, 1962, 1963; Bogen, Fisher & Vogel, 1965). The corpus callosum is sectioned in its entirety as are also the smaller anterior and hippocampal commissures. Follow-up studies have shown that the right and left hemispheres continue to function in the separated state at a fairly high level.

In such patients the mental capacities of the surgically disconnected hemispheres can be assessed independently by the use of testing procedures that lateralize sensory input, central processing, and/or motor readout to one or the other hemisphere. The separate performance of each of the disconnected hemispheres can then be compared for the same test task. Particularly in patients having a minimum of cerebral damage, the separate

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testing of each hemisphere of the same individual on the same test performance offers special advantages.

Repeated examination of a series of 9 such patients of Vogel and Bogen has consistently confirmed the presence of strong lateralization and dominance in the left hemisphere of right handers for language and for calculation. The minor right hemisphere by contrast is unable to respond in speech or writing in the great majority of test situations; nor can it perform calculations except for simple additions for sums under 20. Following surgery the patient's behavior seems to be governed almost entirely from the more dominant leading left hemisphere, and in the great majority of tests conducted to date the left hemisphere is found to be far superior.

In contrast to the obvious superiority and dominance of the left hemisphere for speech, calculation, and related linguistic and symbolic activities, the corresponding specializations of the right, relatively mute, "minor" hemisphere have been much less easy to demonstrate. When we want to know what is going on in the left hemisphere, we have merely to ask the commissurotomy patient; but in the case of the mute minor hemisphere we are obliged to depend on special tests that utilize non-verbal forms of motor expression. There is a reluctance in some quarters to credit the mute illiterate minor hemisphere even with being conscious, a position taken by Eccles and MacKay, the suggestion being that it is carried along in a trance-like automatic state with consciousness remaining unified and centered postoperatively in the dominant hemisphere. It is our own interpretation, however, based on a large number and variety of non-verbal tests, that the minor hemisphere is indeed a conscious system in its own right--perceiving, feeling, thinking and remembering at a characteristically human level.

More than this, it has been shown that the minor hemisphere is distinctly superior to the leading hemisphere in these patients in the performance of certain types of tasks--as for example, in copying geometric figures, in drawing spatial representations, and in the assembling of Kohs blocks in block design tests. The interpretation of these earlier observations had remained uncertain in that it could not be determined whether the differential hemispheric capacities observed resided mainly in the executive expressive mechanisms (as was suggested in certain aspects of the evidence) or whether they involved also more central perceptual and cognitive processing mechanisms. In order to separate praxic skills from central processing, I devised a test which only required a simple motor read-out, namely pointing, but which required a rather complex understanding and manipulation of spatial relationships (Levy-Agresti & Sperry, 1968). For this test we contructed a set of 13 wooden blocks with 3 similar blocks in each set, each block differing from the other 2 within a set either in shape or in the relationship of textual surfaces. The patient felt one of the 3 blocks within a set with either his left or right hand, the hand hidden from view, thereby projecting the stimulus information to the right or left hemisphere, respectively. A card was then presented in free view to the patient on which was drawn two-dimensional representations of the 3 blocks in "opened-up" form. Slide 1 shows an example of one of the 13 sets. The patient was required to point to the drawing which represented the block he was holding. It was thus necessary for the subject to mentally fold the drawings in order to select the correct match.

A total of 156 trials were given per hand, each of the 13 sets being presented 12 times. Repeated presentations were possible because the patients at no time ever saw the blocks, nor were they told whether a choice was correct or not. We saw no evidence of learning over trials. The accuracy scores for the two hands on the twelfth replication were approximately the same as on the first.

With this procedure, although both hemispheres could see the choice card, only one hemisphere knew which block was being felt, and only one hemisphere could thus perform the visualization necessary for a correct selection. (slide off)

A total of six patients were tested. Of these, two, both having right hemisphere damage, failed to even grasp the concept of matching a two-dimensional drawing to a three-dimensional object, even after 45 minutes of careful instruction. It should be pointed out that a normal 7-year-old child understood the test immediately and performed with a high degree of accuracy. Of the other four patients, one, also having right hemisphere damage, performed at chance level with both hands. The results of the other three patients were all in the same direction: their left hands were superior to their right. Two of these were at chance level with their right hands, but above chance withtheir left. The other was above chance with both hands, but vastly superior with the left.

In addition to the quantitative superiority of the minor hemisphere, we noted a qualitative difference in performance in several respects. When the left hand was feeling a block, responses were quite rapid. On the other hand, when the right hand was feeling a block, the patients often took as much as 45 seconds to respond. In addition, when the right hand was feeling a block, there was a tendency for the patient to verbalize, saying such things as "A square, two rough sides, next to each other." It was difficult for us to inhibit such verbalizing. We also noted that the sets which were relatively easy and difficult for one hand were not necessarily those which were easy or difficult for the other hand. Since each set had been presented to each hand a total of 12 times, it was possible to derive a score for each of the 13 sets and to run a correlation between these scores for each hand. Interestingly, we found that the correlation between left hand scores of different subjects was higher than between the hands of the subject who had above chance scores with both hands. In other words, the right hemispheres of different people found the rank ordering of difficulty for the 13 sets to be more similar than the two hemispheres of the same individual. After inspecting those sets which were relatively easy or difficult for one or the other hemisphere, we concluded that the hemispheres processed the information in entirely different ways. Slide 2 shows the two sets which showed the largest disparity of difficulty for the two hemispheres. Set 7 yields itself to fairly simple analytic descriptions, but not easily discriminable visualizations. Set 2 contains figures which would be rather difficult to differentially describe, but which yield themselves to easily discriminable visualizations. It appeared that while the left hemisphere tried to solve the problem by means of verbal-symbolic analysis, the right hemisphere utilized simple visualization. The major hemisphere seemed to be unable to break away from the verbal-analytic mode. We were therefore led to the idea that a hemisphere which is capable of expressing itself in language does not merely have the capability of symbolic-analytic reasoning, but is, in fact, constrained to use such reasoning. Such a hemisphere thinks in terms of symbolic and not visual relationships. (Slide off)

This idea provides a basis for understanding why in man, but in no other animal, there is such a profound functional differentiation of the two half brains. Once the ancestral hominids acquired the capacity for language, there was an obvious adaptive advantage for that capacity to be confined to a single hemisphere, leaving the other free to carry on the perceptive Gestalt functions. Had both sides of the brain possessed language there would have been a loss in visualization abilities. That such a loss does, in fact, occur is confirmed by several studies with left handers. Left handers are known to have less well differentiated hemispheres than right handers. They more often suffer aphasia from lesions in either hemisphere and the aphasia is more transient. If they subsequently suffer a second lesion in the previously undamaged hemisphere after having recovered from a transient aphasia following a lesion in the other hemisphere, they again become aphasic, but this time permanently. We would therefore expect, if the foregoing analysis is correct, that sinistrals, having some language competency in both hemispheres, would show a particular deficit on perceptual tasks. Studies by Silverman and colleagues in 1966 and by William E. James and colleagues in 1967 do show such a perceptual deficit in left handers. We have compared matched groups of left- and right-handed male graduate science students on the verbal and performance scales of the Wechsler Adult Intelligence Scale and have found a very large difference in the two groups. The mean verbal I.Q.'s for the two groups was 142 for the sinsistrals and 138 for the dextrals, a nonsignificant difference. However, the P.I.Q.'s were 117 and 130 respectively for the left and right handed groups, a difference which is significant at less than the .002 level. Even more significant is the fact that the discrepancy between V.I.Q. and P.I.Q. was 25 I.Q. points for the left handers and 8 I.Q. points for the right handers, a discrepancy difference significant at less than .0002 (Levy, 1969). In view of Dr. Giannitrapani's findings (1970) of a certain similarity between sinistrals and females, it is interesting that, as Macfarlane Smith has pointed out in his book Spatial Ability (San Diego: Robert R. Knapp, 1967), girls, like left handers, tend to show a rather specific spatial disability as compared with boys. Porteus (1965) has also found, in testing children from dozens of cultures all over the world with his maze test, that girls are significantly inferior to boys in societies ranging from that of Australian aborigines to that of French school children. A recent report by Culver and associates (1970) that right- as well as left-handed females show a greater primary amplitude of evoked responses in the right hemisphere lends support to the idea that the cerebral mechanisms responsible for perceptual deficiencies are similar in women and sinistral males since an earlier study by Eason and colleagues (1967) found the same effect only in men who were left-handed. It is hard to reject the notion that a spatial-perceptive deficit in women is a sex-linked genetically-determined incapacity, an incapacity which possibly results from hemispheres less well laterally specialized than that of males. That the sex chromosomes do participate in determining spatial ability is given strong support by the finding that girls with Turner's syndrome, an XO condition, have a profound defect in spatial perception (Alexander *et. al.*, 1966).

In any case we have concluded that there are two modes of information processing, each specific to a given hemisphere, that these modes are mutually antagonistic, and that the evolutionary reason for lateral specialization is explained by this antagonism.

Several other recent studies from Dr. Sperry's laboratory have given results consistent with the foregoing: The minor hemisphere has been found by Zaidel and Sperry (1970) to perform at a substantially higher level than the major on a version of the Raven's Colored Progressive Matrices modified for split brain subjects by utilizing tactual presentation of the answer display and restricting this to left or right hand.

Also, in the performance of the commissurotomy patients in general, unrestricted (i.e., non-lateralized) tests, like the WAIS where the major hemisphere dominates, we find regularly a severe deficit in those spatial perceptual capacities attributed to the minor hemisphere.

Robert Nebes (1970) has devised a test consisting of a set of tactually perceivable segments of circles. He found that the left hand-R hemisphere of commissurotomy patients is much superior to the right hand in feeling such a segment and then selecting a complete circle from which the segment came, a task which is most easily handled by visualization, but only with much difficulty by an analytic reasoning process. Recent results of his also showed sinistrals to be deficient on this test. To solve such a problem via analytic reasoning would require a calculation of the ratio of the straight line distance of the two ends of the segment from each other and the total length of the segment, a task most of us would find exceedingly difficult, if not impossible. These results clearly add confirmation to the idea of a visualization superiority of the minor hemisphere.

In work initiated in April in collaboration with Colwyn Trevarthen (Levy, Trevarthen & Sperry, 1970a,b), we changed the basic paradigm of our tests. Instead of testing the two hemispheres separately and comparing their respective performances, we devised a method by which either hemisphere is free to respond. Kinsbourne and Trevarthen in unpublished work had found that when a stimulus such as a square is presented in the midline of the visual field of commissurotomy patients, each hemisphere, rather than perceiving the half-square which is actually projected to the hemisphere, perceives a complete square. There is, in other words, an hallucinated completion of the stimulus by each half-brain. Utilizing this completion phenomenon, we presented chimeric stimuli in midline. The next slide shows an example of a chimeric face. Such a stimulus, presented in midline to a split-brain patient, is not perceived as a chimera. In fact, such questions as, "Did you notice anything odd about what you saw?" invariably produced a puzzled expression and the statement that he saw nothing strange about it. A stimulus such as this is perceived as one face by one hemisphere and as another face by the other hemisphere. We presented different kinds of chimeric stimuli for 150 msec. in a tachistoscope while the patient fixated on a midline point. His task was then to point to the one of a set of non-chimeric whole stimuli presented in free vision which represented what he saw. Our results consistently showed that for faces, bisymmetric non-sense figures, line drawings of objects, and patterns of crosses and squares, the patients overwhelmingly pointed to the choice stimulus which represented what he had seen in the left half of the visual field, that is what had been seen by the right, minor hemisphere.

Only when we had the patients name what they had seen, rather than pointing to a matching stimulus, did they respond to the right field stimulus, and for faces and non-sense shapes verbal responses were barely above chance level. In other words, for those stimuli whose names had been only recently learned, the major hemisphere had great difficulty in matching a stimulus with its name. It should be pointed out that the patients typically took 10 to 15 minutes to learn the names of the 3 faces and the names of the 3 non-sense shapes prior to the verbal naming tests. They learned the 3 names in about a minute , but seemed to be unable to connect these names with the faces. Eventually they only learned the names by saying such things as "Dick has glasses, Paul has a moustache, and Bob has nothing," in other words by the noting of analytic details. It was clear that the major hemisphere suffered a severe Gestalt perceptive deficit.

In another type test (when) we presented drawings of object chimeras and told the patient to point to a choice which was similar to what he saw, we found very interesting results. In this test "similarity" could mean either conceptual similarity like an eating utensil and a cake or ~~structural~~ shape similarity like a cake on a cake plate and a hat with a brim. The stimuli used for chimeric presentation and the choice stimuli are shown in the next slide. When the right hemisphere responded, that is, when he pointed to a choice which was similar only to the left field stimulus, he pointed to a choice which was structurally similar. When the left hemisphere responded he pointed to a conceptually similar object. On any given trial one of the 3 possible responses would have been doubly correct, that is, similar in some respect to the stimuli in both half fields. For chimeric pairs 1-3, 2-1, and 3-2 the doubly correct response would have matched the right field stimulus on a conceptual level and the left field stimulus on a visual level. For chimeric pairs 1-2, 2-3, and 3-1, the doubly correct response would have been the reverse, that is, left field conceptual and right field visual matches. In fact, 24 out of the 27 doubly correct matches were visual matches with the left field and conceptual matches with the right field.

The results of this test showed very clearly the visual vs. conceptual modes of information processing and showed unambiguously the association between hemispheres and modes of matching. Another test also involved object chimeras, in this case chimeras of a rose, an eye, and a bee. The patients were shown as choice stimuli drawings of toes, a pie, and a key. Neither the names of the stimulus nor the choice objects were ever spoken aloud and the subjects were told to "point the picture whose name rhymes with the name of what you see." Although we had already found that with simple recognition the patients recognized preferentially the left field picutre, in this "rhyming objects" test, they invariably pointed to the object which rhymed with the right field picture. This test clearly demonstrated that where knowledge of auditory images was required, it was the left, major hemisphere which performed the task.

In contrast to the earlier tests, these chimeric tests not only show a difference in quantitative and qualitative capacity of the two hemispheres, they also show that the hemisphere which is superior for a function assumes control of the motor read-out. In these tests we had the patients point with the right and left hands and found no difference in the responses. When a particular test involved capacities for which the minor hemisphere was best equipped, the right hand as well as the left pointed to the left field stimulus. The results from these tests represent the first demonstration of minor hemisphere dominance for motor control in commissurotomy patients. Of theoretical interest here is "How does a disconnected hemisphere know it's superior?" Possibly an inferior hemisphere, confronted with a difficult task, simply makes no attempt to act. Or possibly the midbrain attention mechanism receiving inputs from the two hemispheres, selects the superior hemisphere for the given task, and selectively "turns on" that hemisphere. We have no clear evidence either way as of yet.

In summary, our studies show that the disconnected minor hemisphere is the superior and dominant brain for perceptual recognition of faces, non-sense figures, pictures of objects, patterns, in detecting structural similarity, but not conceptual similarity, and in performing perceptual transformations, as well as for the motor read-out which communicates the results of its processing.

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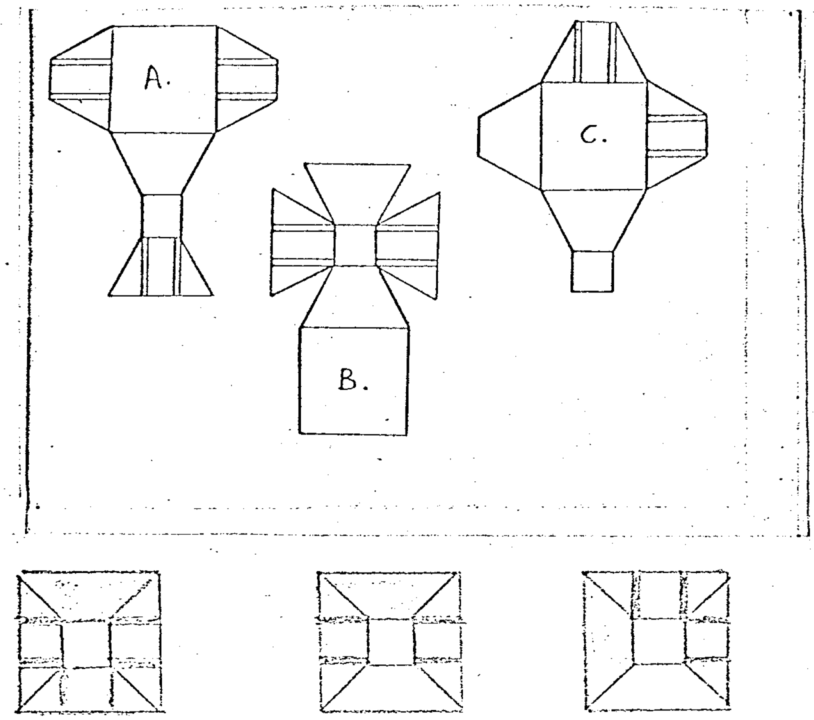
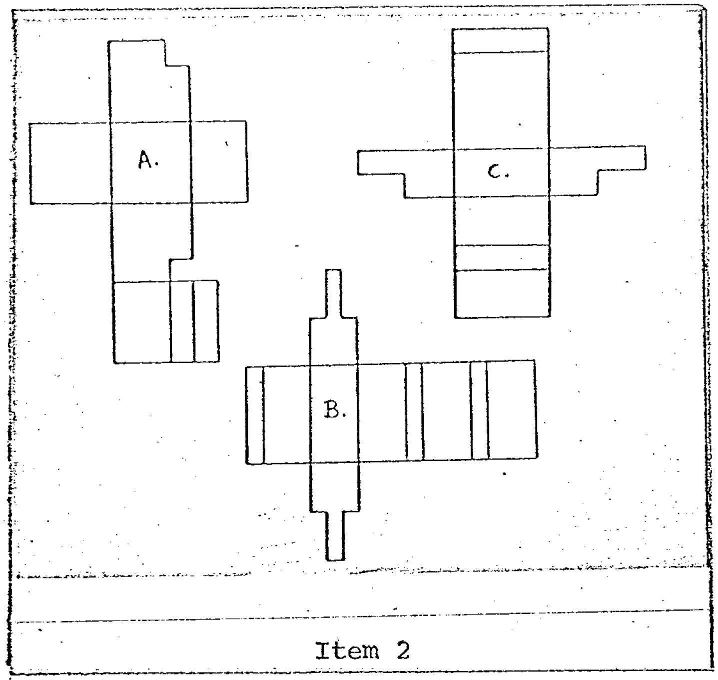
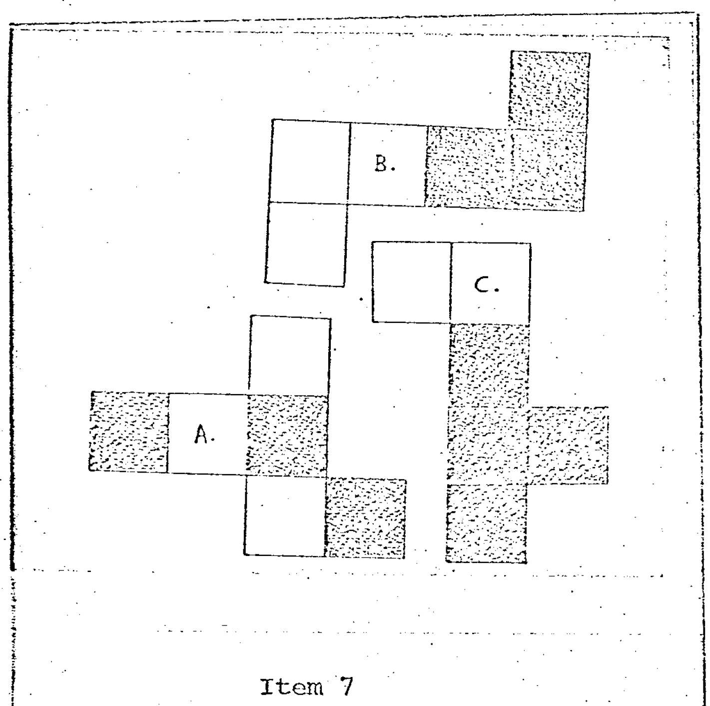


Fig. 1: Example of item from cross-modal matching test



RELATIVELY EASIER FOR MINOR HEMISPHERE



RELATIVELY EASIER FOR MAJOR HEMISPHERE

Fig. 2: Two items showing greatest difference in difficulty for the two hemispheres

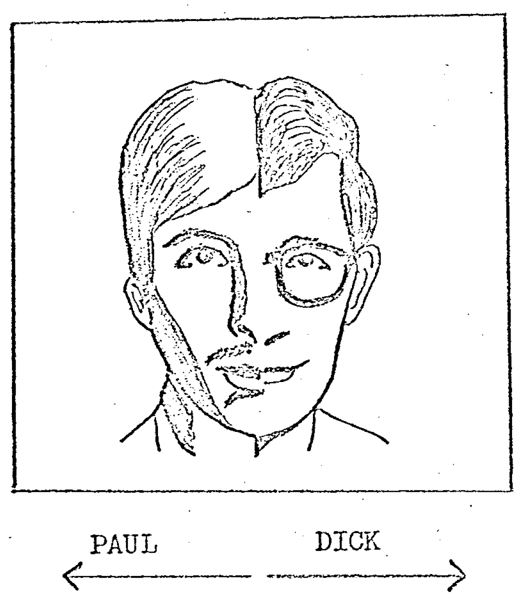


Fig. 3: Example of a facial chimera

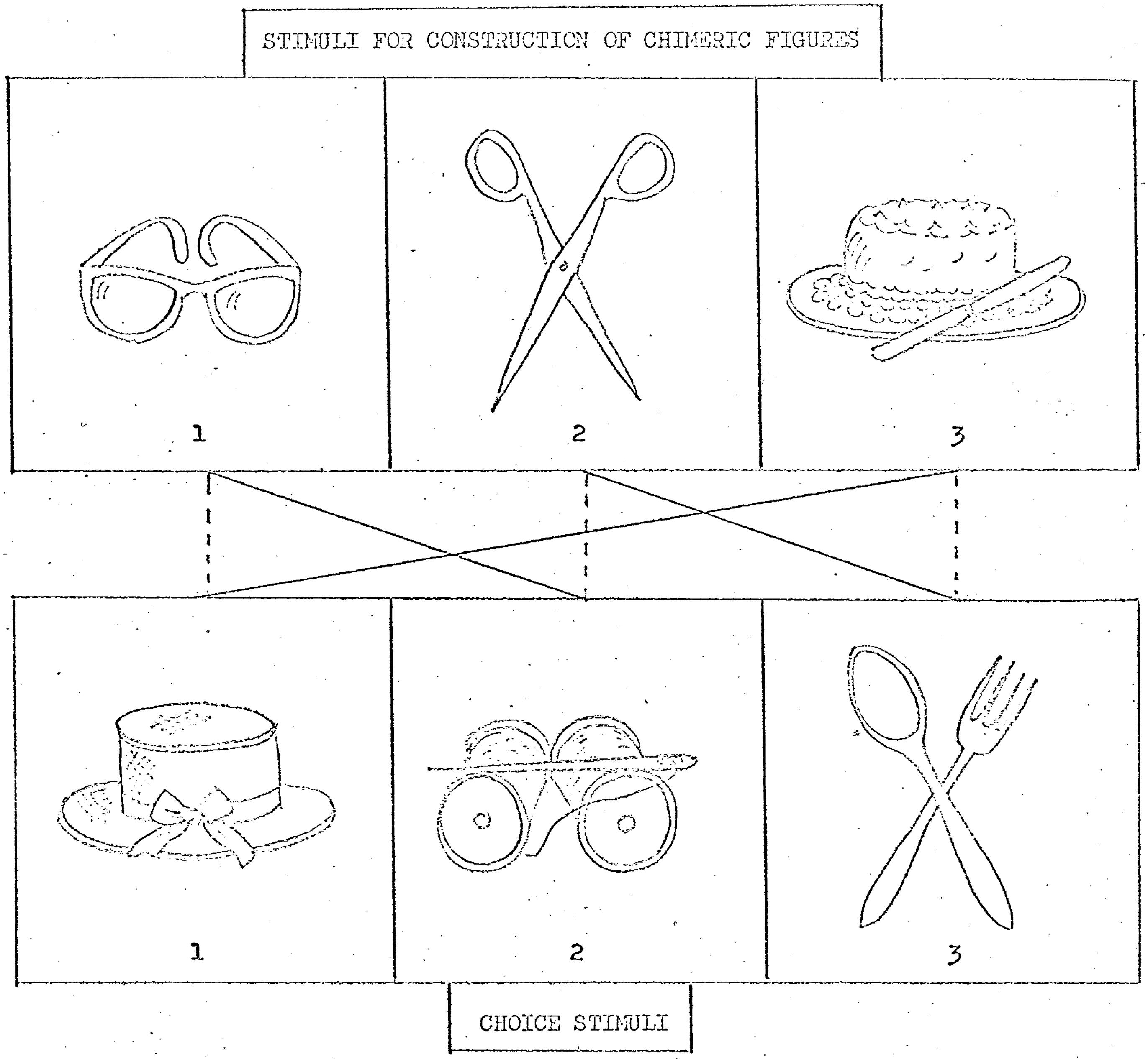


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Fig. 4: Stimuli for test of structual-conceptual matching