DOCUMENT RESUME

ED 291 791 TM 011 081

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TITLE	The Origin of Information and Its Effect on Problem Solving.
PUB DATE	87
NOTE	28p.; Paper presented at the Annual Meeting of the American Psychological Association (95th, New York, NY, August 28-September 1, 1987).
PUB TYPE	Speeches/Conference Papers (150) -- Reports - Research/Technical (143)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	Cognitive Ability; *Cognitive Processes; Cognitive Psychology; College Students; Higher Education; *Imagination; *Perception; Perception Tests; Postsecondary Education; *Problem Solving; Visual Perception

ABSTRACT

The difference in cognitive resources required for imagination and perception was tested in two experiments by examining the reduced substitutability of imagination and perception in problem solving by college undergraduates. Eighty subjects in Experiment 1 drew capital letters from lines or descriptions of lines in a seven-page booklet. The results indicate that imagined information and perceived information were integrated with equivalent accuracy and strategies. When the problems became more cognitively demanding and mental combinations of lines into figures contained four elements, different strategies were used. Sixty-eight subjects were given explicit instructions on how to identify imagined or perceived lines as letters. When strategies were restricted, integrating imagined information was less accurate than integrating perceived information. Several factors, many of which were related to the cognitive demand difference from these two origins, influence the substitutability of imagination and perception. To describe cognitive processing of information from internal and external origins, researchers should use multiple performance measures. (SLD)

Abstract

The difference in cognitive resources required for imagination and perception was tested in two experiments by examining the reduced substitutability of imagination and perception when solving problems. The results of Experiment I indicated that when the problems were easy, imagined and perceived information was integrated with equivalent accuracy and strategies. When the problems were more cognitively demanding, the accuracy of integrating information from the internal and external origins was equivalent but different types of strategies were used. Experiment II showed that when the strategies were restricted, integrating imagined information was less accurate than integrating perceived information. The conditions that affect the substitutability of imagination and perception are discussed along with the metacognitive process of optimizing the use of cognitive resources in solving problems.

Abstract

The difference in cognitive resources required for imagination and perception was tested in two experiments by examining the reduced substitutability of imagination and perception when solving problems. The results of Experiment I indicated that when the problems were easy, imagined and perceived information was integrated with equivalent accuracy and strategies. When the problems were more cognitively demanding, the accuracy of integrating information from the internal and external origins was equivalent but different types of strategies were used. Experiment II showed that when the strategies were restricted, integrating imagined information was less accurate than integrating perceived information. The conditions that affect the substitutability of imagination and perception are discussed along with the metacognitive process of optimizing the use of cognitive resources in solving problems.

The origin of information and its effect on problem solving

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Finke (1980), Marks (1977) and Shepard & Podgorny (1978) are among the many researchers who have propcsed that the qualities of the images and perceptions very similar and the cognitive processing of images and the perceptual processing of visual stimuli involve many of the same component processes. These similarities would permit some degree of substitutability of imagination and perception. The concept of substitutability has been developed in economic and behavioral models and refers to the amount of exchangability in the value of products or behaviors (see Rachlin, Kagel, & Battalio, 1980 for a detailed description of substitutability). One implication of a high degree of substitutability within a cognitive perspective is that people could exchange information from an internal origin (ima·ination) with information from an external origin (perception) without a change in cognitive processes and behavior. The studies on mental rotation (Shepard & Cooper, 1982) and visual image construction (Murphy & Hutchinson, 1982; Peterson, Holsten, & Spevak, 1975) have demonstrated the similarities between mentally transforming imaginations and perceptions and support the hypothesis that imagination and perception were highly substitutable.

There are differences between imagination and perception which are also important to identify. Johnson & Raye (1981) proposed that one difference is the amount of cognitive operations required to generate memories from imagination and perception; imagination typically requires more effortful operations while perception typically involves automatic operations. Furthermore, the effortful cognitive operations require more of a person's limited cognitive resources than automatic operations (Hasher & Zacks, 1979). Baddeley's (1981) and Baddeley & Hitch's (1974) model of limited capacity of working memory, and Kahneman's (1973), and Norman and Bobrow's (1975) concept of resource limitation all reflect this general limitation in cognitive resources. The difference in cognitive resources required for imagination as compared to perception could decrease the substitutability of imagination and perception when the resource demands of the problem exceed the individual's available resources. Consequently, problem solving behavior and cognitive strategies might be different when solving problems in one's head versus in the environment.

Imagination and perception occur during the construction of the initial state, the goal state, and the problems space, the three components of problem solving (Newell & Simon, 1972). The initial state represents the available information concerning the solver's present circumstance. It is composed of information from both origins, the memories and imaginations activated by the perceptions of the immediate environment. A problem is created when the goal state is not the same as the initial state. The goal state represents the desired cir~umstance and the origin of the goal state is fundamentally internal. Since a person can not perceive what does not phvsically exist and the goal state does not yet exist, the goal state can only be imagined.

The problem space is the third component of problem solving and refers to the set of strategies from which the individual must select and execute in order to transform the inital state into the goal state. The problem space can be represented by information from interal as well as external origins. If an individual is mentally manipulating the initial state to create the goal state, the individual's strategy is of an internal origin. If the individual is physically operating on his or her environment to create the goal state, the individual's strategy is of an external origin. Often, the problem space is composed of internally as well as externally generated strategies.

Once the goal is defined and strategy executed, the solver must recognize when the transformed initial state has become the goal state. This recognition process is a basic component of means-ends analysis. In sum, problem solving involves the generation of the initial state, the transformation of the initial state, and the recognition of the goal, with each process using information from internal and/or external origins.

The substitutability of imagination and perception is an important issue in problem solving because there are always time and resource limitations placed on the solver. That is, people solve problems in a closed rather than open system. Burkhard, Rachlin, & Schrader (1978) and Rachlin & Burkhard (1978) have made this same point in developing their behavioral model and many of the issues raised in the present cognitive perspective of problem solving have their parallel in Rachlin's behavioral model of choice. The focus of the present experiments is the reallocation of cognitive resources caused by solving problems within a closed system. If all resources are utilized in performing multiple activities and an increased allocation of resources is required for one activity, there must be a decreased allocation of resources for other activties.

If imagination and perception are completely substitutable then there would be no need to reallocate cognitive resources. The generation of inital and goal states, the transformation of the initial state, and the recognition of the goal state should be the same when imagining and perceiving the same information content. But if imagination does require more cognitive resources, the required resources must be subtracted from other cognitive activites. Imagining the inital state should lead to a decrement in the tranformation and/or recognition processes as compared to perceiving the initial state.

Experiment I

Method

Subjects. Eighty undergraduates at the C.S.U., Long Beach received course credit for their participation.

Materials. Seven-page booklets were constructed with either lines or descriptions of lines on each page. The complete set of lines consisted of four straight lines (vertical, horizontal, sloping up from left to right, & sloping down from left to right) and four semi-circles (open side facing up, down, left, & right). When a booklet contained only lines, each page had some combination of two lines or some combination of four lines. Each page of four lines contained both the lines from the two-element subset plus two lines that functioned mostly as distrastors. Matching sets of booklets were constructed which presented the verbal descriptions of the lines rather than the lines themselves.

Procedure. Subjects were run in groups of 2 to 5 and were randomly assigned to one of the four presentation conditions. They were instructed that each page of their booklets had two (or four) lines (or descriptions) and their task was to mentally combine the lines to form as many upright, capital letters in the English alphabet as possible. Subjects were told that they could change the relative position and size of the lines and could use one or all of the lines when mentally constructing letters. They could use the same line more than once when constructing letters but they could not rotate lines when combining them. Subjects had one minute to write down the letters in the order they constructed them at the bottom of each page before they were instructed to turn to the next page.

Analysis. The letters generated were classified into two groups, one-line and two-line letters. The letters C, I, and U were one-line letters because they could be identified from only one of the presented lines or verbal descriptions. Eight and ten one-line letters could be identified in the two-element and four-element conditions, respectively. The letters B, D, E, F, H, J, L, M, N, O, P, S, T, V, W, X, Y, and Z were two-line letters because they could be constructed from two different lines or verbal descriptions. Twenty and twenty-four two-line letters could be constructed in the two-element and four-element conditions, respectively.

To assess the recognition strategy subjects used to identify working memory representations as letters, the order in which the letters were constructed was examined. There were two types of general strategies; subjects could work forward or work backward. If subjects worked backward, they would start each trial by working from the alphabet (the set of goal responses) and evaluate if each letter could be decomposed into the set of presented lines or descriptions. Since the alphabet has a definite sequential structure, the order of the letters constructed should be consistent with the order of letters in the alphabet If subjects always worked backward, all their responses would be alphabetically ordered and they would get scores of 100%. A working forwards strategy would begin with the generation and mental manipulation of the elements. The recognition of letters would occur if the constructed representation matched the features of a letter If subjects were working forward from the set of lines to the goal of the letters, not using any strategy in particular, consecutive letters should be alphabetically ordered as often as non-alpabetically ordered. These subject would get scores equal to zero.

Results

Figure 1 shows the mean percent correct identification of one-line letters for each group. Overall, correctly identifying a single line as a letter was significantly more difficult when presented with four elements than when presented with two elements (F (1,76)= 28.54, p <.05). There were no signficant differences in identification between the imagination and perception groups in either the two-element condition (F (1,38)= 1.12, p >.10) or four-element condition (F (1,38)= 2.16, p >.10) [1].

Figure 2 shows the mean percent correct construction of two-element letters. Again, the four-element condition had a significantly lower rate than the two-element condition (F (1,76)= 123.00, p <.05) and there were no significant differences between imagination and perception in each of these conditions (F (1,38)< 1.0, F (1,38)= 2.25, p >.10, respectively). There was also no significant difference between the accuracy of one-line and two-line letters for the two-element and four-element conditions ($F(1,39) = 3.06$, $p > .05$; $F(1,39) < 1.0$, respectively)

Figure 3 shows the mean percentages of alphabetically order letters for all four groups. Overall, subjects in the two-element condition had a significantly greater percentage of alphabetically ordered sequences than subjects in the four-element condition ($F(1,76) = 8.55$, $p < .05$). It was also found that subjects imagining two lines were just as likely to work backward as subjects perceiving two line ($F(1,38) < 1.0$). In contrast, subjects who imagined four lines were significantly less likely to work backward than those who perceived four lines ($F(1,38) = 5.11$, $p < .05$).

Discussion

Two conflicting conclusions can be drawn from the findings from Experiment I. The accuracy in identifying one-line and two-line letters indicates that imagination and perception were completely substitutable processes in both the two-element and four-element conditions while the measure of working forwards or backwards indicates that imagination did not completely substitute for perception in the more cognitively demanding task.

The two mental operations required to recognize one-line letters are the generation of each element either by imagination or perception and the recognition of an element as a letter. The reduced accuracy of one-line letters in the four-element condition probably reflects a decreased accuracy in the recognition process and not in the generation process. The lines and descriptions were equally discriminable in the two-element and four-element conditions so the generation of the individual elements should have remained the same. The lower identification of one-line letters may have been produced by subjects having difficulty generating all four elements in the one minute period. But if time was a major contributing factor, it would be expected that the imagination group should have been less accurate than the perception group; reading the four descriptions must have taken more time than looking at four lines. This was not the case; the performance of the imagination and perception groups was equivalent.

The greater number of generations probably lead to an increased allocation of cognitive resources to the generation processes and consequently decreased the cognitive resources available for recognition. The decrement in one-line letter identification was probably due to a reduced ability to compare the goal response with the individual elements.

The increased resources needed to generate four elements could lead to a decreased availability of resources for the transformation process. If the transformation process was affected, then the two-line letters should have been more difficult to identify than the one-line letter in the four-element condition. This was not the case. The equivalent rates of identifying both types of letters in the two-element and four-element conditions indicates that the transformation processes had a high priority and/or the transformation processes were relatively effortless. If the accuracy of the generation and transformation processes were not compromised, then the only process left to be compromised was recognition.

The one variable that did show a significant difference between imagination and perception was the assessment of the two recognition strategies of working forward and working backward. Imagining four elements reduced the probability of subjects working backward in this higher resource demanding condition.

Why was there a shift in strategy? One reason may be that working forwards is a less resource demanding strategy. Working forwards involves the generation and transformation of information to produce a working memory representation that should automatically activate a letter recognition response. The letter recognition response is more of an automatic, data-driven process because it is similar to the automatic letter recognition involved in reading. In contrast, working backwards from the alphabet to the set of elements is more of an effortful, conceptually-driven process. Since working backwards has a greater resource demand, subjects could choose the less demanding, working forwards strategy to compensate for the more demanding imagination of four elements. Since only the imagination group shifting to working forwards, a conclusion to draw is that imagination has a greater resource demand than perception. The inability to substitute imagination and perception was reflected by the type of recogition strategy even though the data concerning the accuracy of strategies showed complete substitutability.

Experiment II

In the first experiment, subjects had the choice of working forward or backward. It appears that subjects took advantage of this opportunity to work forward as a way of reducing cognitive resource demands when they had to imagine four elements. In the second experiment, subjects were explicitly instructed to work forward or backward when solving four-element problems. By restricting the type of recognition strategy, subjects would still have to find a compromise allocation of cognitive resources but changing the type of recognition process was not possible. If imagination and perception are not completely substitutable, compromising the accuracy of processes is the only option.

Method

Subjects. 68 undergraduates from the C.S.U., Long Beach participated in the experiment for course credit.

Materials & Procedure The materials were used in Experiment II as in the four-element, imagination and perception conditions of Experiment I. The only diffence in the procedure was that subjects were given explicit instructions on how to work forward or backward in identifying the imagined or perceived lines as letters. Half of the subjects were told that on each trial they should start by going through the alphabet, beginning with A and go in order to Z, and test if each letter could be constructed from the elements presented. The other half of the subjects was told that on each trial, begin with the left-most line and go from left to right to test whether they could construct a letter from only one line, then from two different lines, and finally from three different lines.

Results

As shown in Figure 4, the mean percentage of alphabetically ordered letters was high in the working backwards instruction groups and was significantly greater than the working forwards instruction groups ($F(1,64) = 56.44$, $p < .05$). Figure 4 also shows that there were no significant differences between the imagination and perception groups when they worked forward or backward ($F(1,26) < 1.0$; $F(1,38) < 1.0$, respectively).

Overall, working backwards or forwards did not significantly improvethe identification of one-line letters ($F(1,64) = 3.05$, $p > .05$). There was no significant difference between the perception and imagination groups when they worked forwards ($F(1,26) < 1.0$). But as shown in Figure 5, the perception group benefited from the strategy of working backwards. By working backwards, the perception group recognized a significantly greater percentage of one-line letters than the imagination group ($F(1,38) = 11.56$, $p < .05$).

Figure 6 shows the mean percent correct construction of two-line letters. Overall, there was no significant difference between working forwards and backwards ($F(1,64) < 1.0$). The perception groups constructed significantly more letters than the imagination groups when they worked backward as well as when they worked forward (F (1,38)= 6.00, p <.05; F (1,26)= 5.90, p <.05, respectively). Comparisons of the one-line and two-line letters show that there were no significant differences when working forward (F (1,27)< 1.0). Again, a different result occurred when subjects worked backward. Two-line letters were significantly less accurate than one-line letters (F (1,39)= 14.75, p <.05). In sum, there were more similarities between imagination and perception when subjects worked forward as compared to when subjects worked backward.

Discussion

The instructions to work forward controlled the type of recognition strategy both imagination and perception subjects used to identify letters. Comparisons of the alphabetic scores of the working forward groups of Experiment II and the four-element, imagination group of Experiment I indicate that the latter group was working forward as was proposed. When the working forward subjects in Experiment II had the simple task of identifying one-line letters, imagination and perception were substitutable processes. Even though four elements presented, working forward subjects would start each trial by examing one element at a time. Thus, only one element had to be maintained in working memory and cognitive demand difference between imagination and perception did not affect the accuracy of the generation and recognition processes. As found in Experiment I, imagination and perception were substitutable when a task is low in its cognitive demand.

Once working forward subjects had the additional demand of transforming the four lines, the lower demand of perception produced more accurate letter identification. The results indicate that the transformation and generation processes were not compromised because there was no difference between one-line and two-line letters when working forwards. To optimize resource allocation, subjects couldn't change the type of recognition strategy so they had to compromise the accuracy of the recognition strategy.

There were a number of differences between working forwards and backwards. First, imagination subjects were less accurate at identifying both one-line and two-line letters when working backwards, indicating that imagination was not substitutable with perception in identifying either the simple or complex letters. Second, two-line letters were identified less frequently than one-line letters when subjects worked backward. The process of transforming the elements appears to have been compromised by the more cognitively demanding strategy of working backwards.

The accuracy of one-line letters in the working backwards, perception condition is also comparable with the accuracy of one-line letters in the two-element condition of Experiment I. If the performance level of the two-element condition represents the performance ceiling due to data-limitation factors, then working backwards appears to maximize performance in this cognitively demanding circumstance. The reason for this may be that working backwards probably ensured that all letters were available to compare with the presented set of lines. This benefit had a cost. Imagination could not completely substitute for perception when subjects were forced to use the more demanding strategy of working backwards.

Conclusions

Two experiments demonstrated that the substitutability of imagination and perception can be influenced by a number of factors, many of which are related to the cognitive demand difference of information from these two origins. The results suggest that subjects decided to shift the accuracy level and type of recognition strategy in accordance with the problem demands. When problems had a low demand, the similarities between imagination and perception resulted in a high degree of substitutability. But when the problem demands exceeded the individual's limited resources, the differences between imagination and perception reduced substitutability. Subjects using internally generated information consistently choose a different compromise of accuracy and strategy than subjects using externally generated information when engaging the more demanding working backwards strategy. To make these choices, the individuals must perform metacognitive assessments of a task's demands and allocate cognitive resources in an attempt to optimize problem solving success. In addition to defining a problem's intitial state, goal state, and problem space, the solver must consider the availability of cognitive resources and budget its allocation.

The dissociation of accuracy and strategy measures in both experiments reinforces an important methodological issue in studying the similarities between imagination and perception. Researchers should employ multiple performance measures in order to completely describe the cognitive processing of information from our internal and external origins. The multiplicity of cognitive processes that are coordinated in the performance of a task present people with a wide variety of options to choose their compromise. The subjects' compromises, dictated by the particulars of the task, might severely reduce the generalization of findings and theories if too few measures are used.

Footnote

1. In a factorial design, the traditional sources of variance, main effect of A, main effect of B, and the interaction of A X B, can be repartitioned into the independent sources, B at each level of A, and the main effect of A (Keppel, 1982). The second method of variance partitioning was used for the present experiments because it directly answered the questions concerning the differences between imagination and perception under different cognitive demands. Thus, the three 1 df test for the 2 X 2 design were: (a) the difference between the imagination and perception for two-element problems, (b) the difference between the imagination and perception for the four-element problems and (c) the overall difference between the two-element and four-element problems. This statistical design was use to analyze both the percentage of correct responses and the percentage of responses that were alphabetically ordered.

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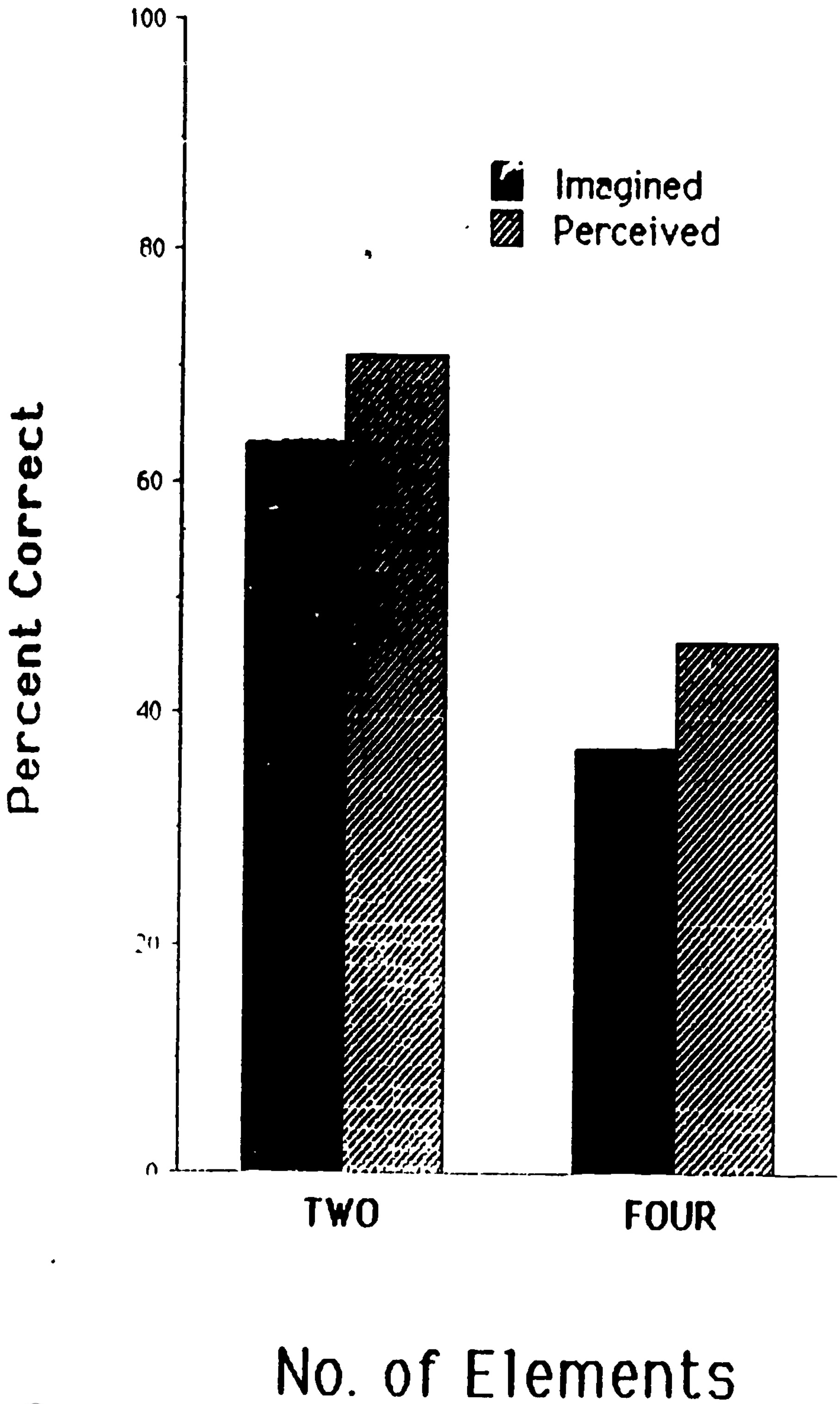
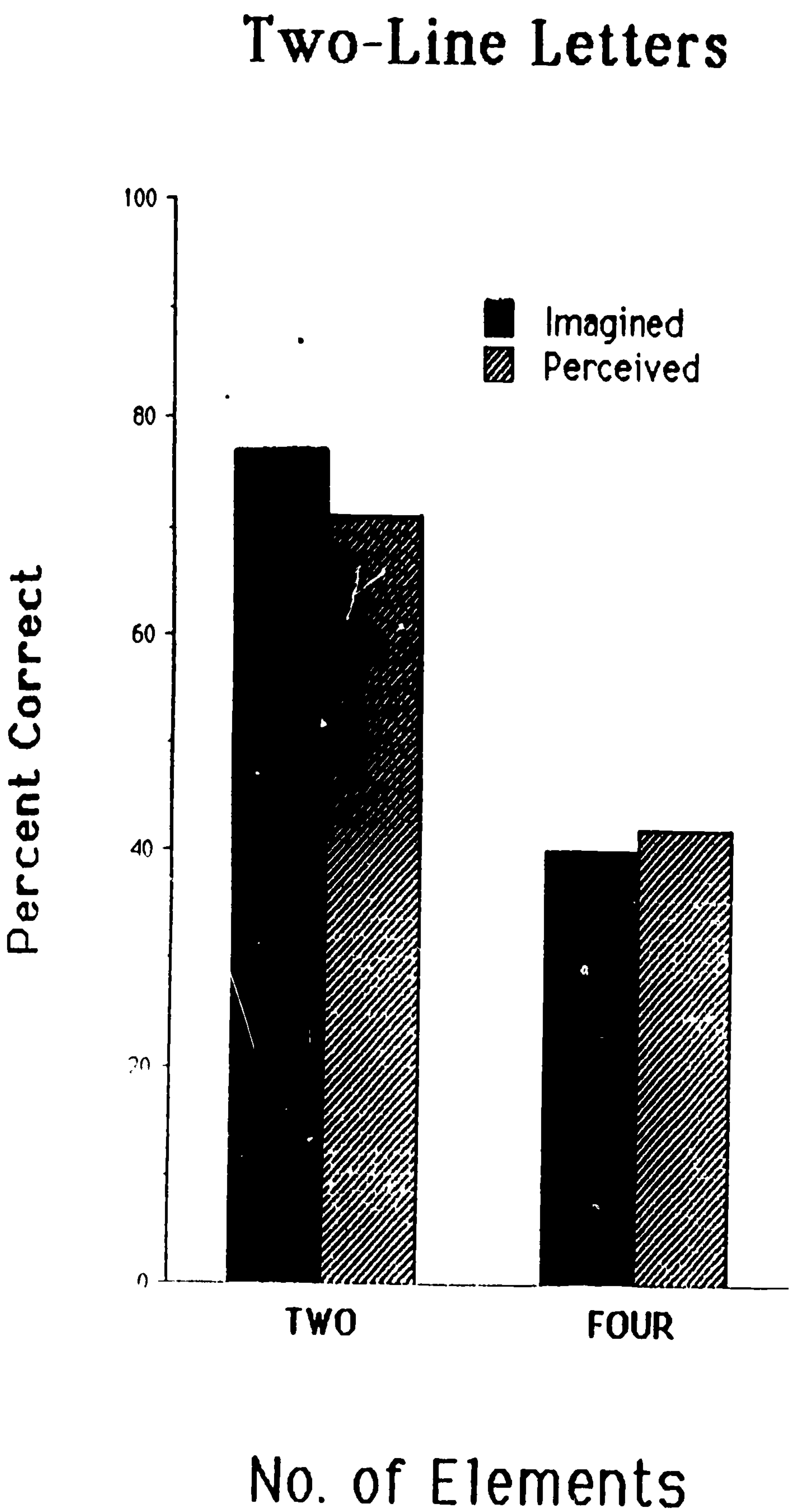
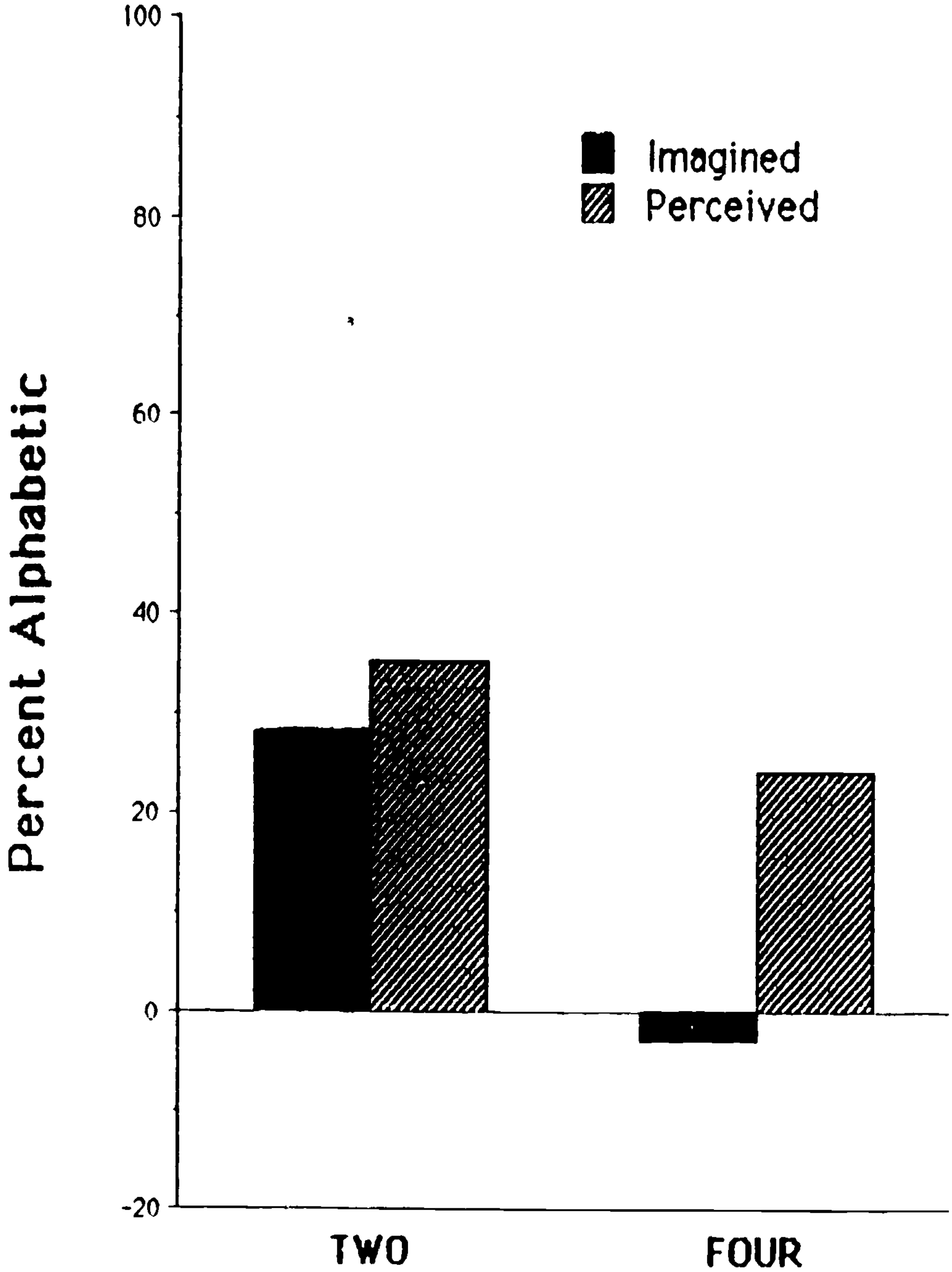
One-Line Letters




Two-Line Letters
100
80
60
40
20
0
Percent Correct
Imagined
Perceived
TWO
FOUR
No. of Elements

Recognition Strategy



No. of Elements

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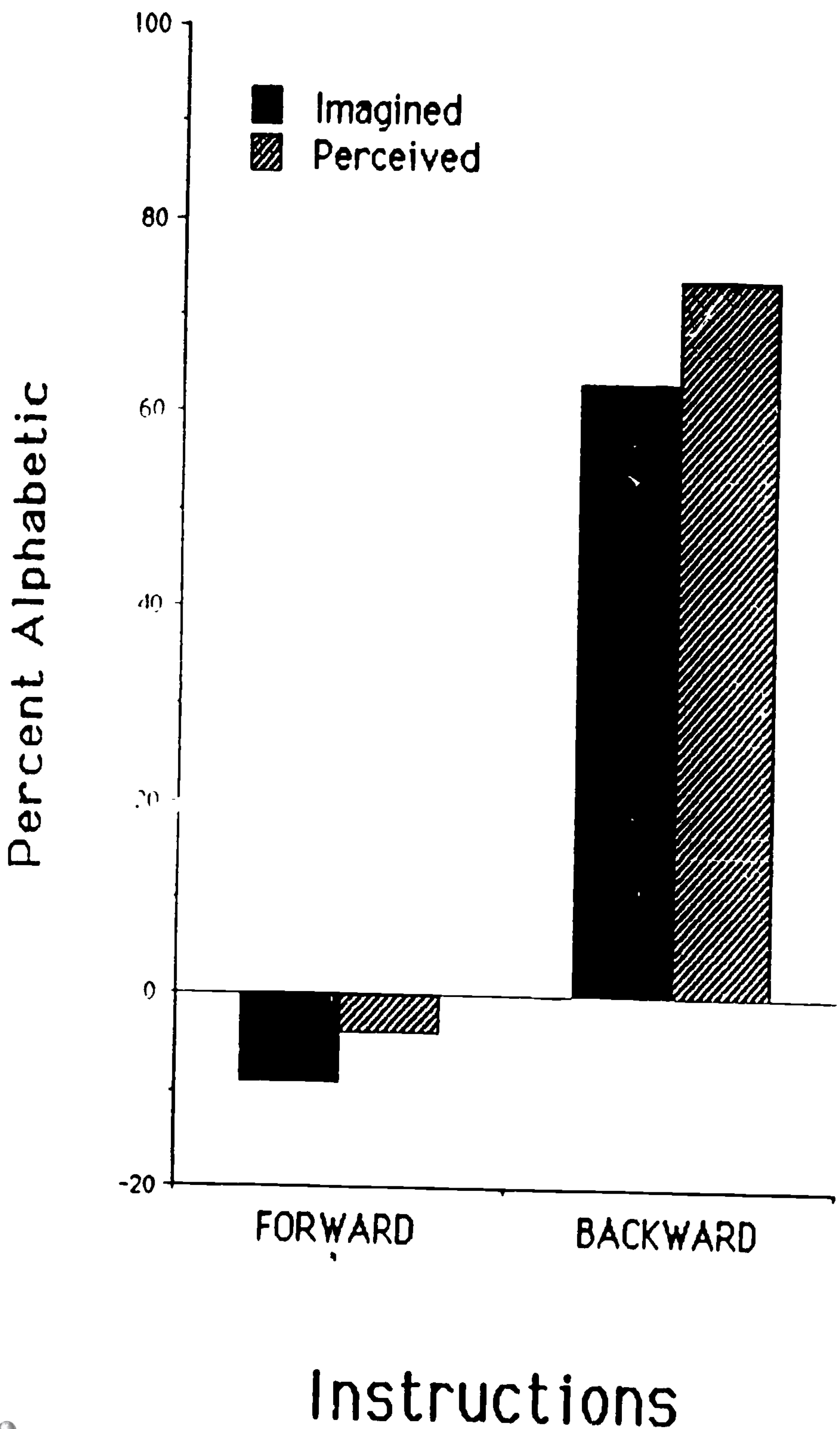
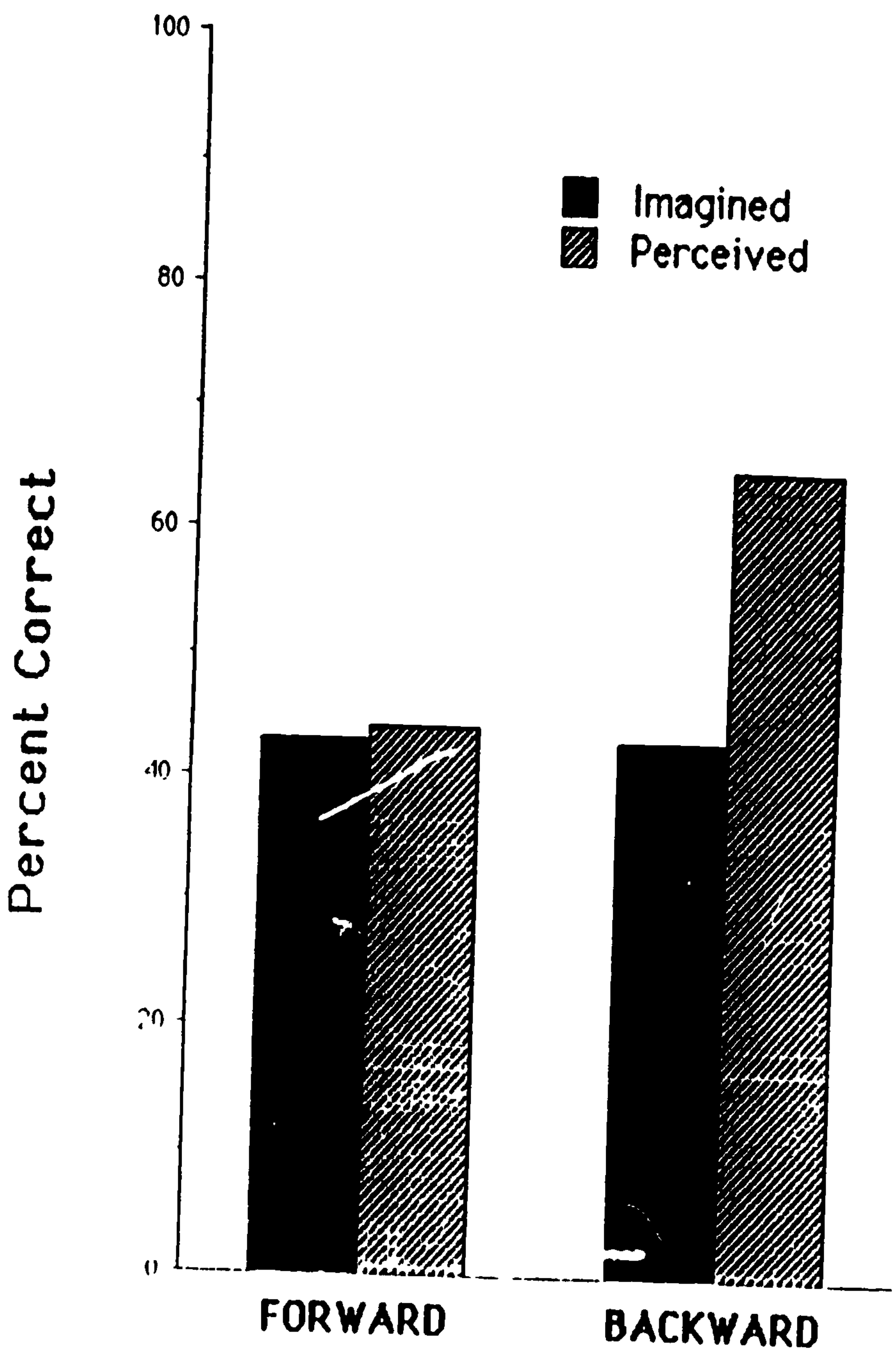


One-Line Letters



Instructions

Two-Line Letters