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ABSTRACT

Investigated were the role of mental imagery in children's logical reasoning and individual differences in children's use of imagery while reasoning. Fifth grade students assessed as being high imagers (HIS) and low imagers (LIS) completed conditional syllogisms of various kinds and were asked, after each of their responses, whether an image had occurred to them in the course of solving the problem. Results indicated that (1) HIS and LIS groups were differentiated in terms of their imagery reports when the content of the problem was low in imagery value; (2) both groups appeared to use imagery for inferences which do not yield either a definite "yes" or "no" conclusion; (3) for inferences of intermediate difficulty, LIS appeared to use imagery unsuccessfully, while HIS appeared to use it successfully. This difference does not seem to be due to a general difference in ability, as both groups' performance on a different, difficult memory task was equivalent. It is thought that this difference may stem from the fact that LIS may not have adequate procedures for integrating imagery with abstract verbal processes. A number of other results of general interest are also reported and discussed. Taken together, results provide preliminary evidence that the imageability of material included in problems does not have a facilitative effect for all students. A three-page list of references, nine data tables, and seven graphs are appended. (RH)

Individual differences in the use of mental imagery in deductive inference

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Abstract

This project investigates the role of mental imagery in logical reasoning in children, and, more specifically, individual differences in that respect. Previous results in this line of research have indicated that imagery appears to be used by children in deductive inference, at least in some cases, but that imagery is used successfully only when children have a basic understanding of the logic of the problem. To oversimplify, imagery appears to be used as an auxiliary when logical understanding is fragile (as opposed to abstract and well-developed); however, when logical understanding is absent altogether, imagery may be used but its use is unhelpful.

Fifth graders, assessed as being High imagers and Low imagers respectively, answered conditional syllogisms of various kinds and were asked, after each of their responses, whether an image occurred to them in the course of solving the problem. Results indicated that (i) the two groups of children were differentiated in terms of their imagery reports when the content of the problem was low in imagery value (as assessed previously in a separate task); when the content of the problem was high in imagery value, the two groups differed to a much lesser extent in terms of their imagery reports; (ii) both groups appeared to use imagery for most difficult inferences, that is, for those 'indeterminate' inferences which don't yield either a definite 'yes' conclusion or a definite 'no' conclusion; for those inferences, however, the (apparent) use of imagery did not improve performance in solving the problem, thus suggesting again that, in order to be effective, imagery must be monitored by logical processes of a deeper kind; however, (iii) for inferences of intermediate difficulty (Modus Tollens), which are known to be partly mastered by children of that age, an interesting difference occurred: Low imagers appeared to use imagery unsuccessfully, while High imagers appeared to use it successfully; this difference does not seem to be due to a general difference in ability between the two groups, as their performance on a different, difficult memory task was equivalent; it is speculated that this difference may stem from the fact that Low imagers, who don't tend to rely on imagery, may not have adequate procedures for integrating it with abstract verbal processes.

A number of other results of general interest are also reported and discussed.

From an educational standpoint, these results suggest in a preliminary way that the imageability of the material included in problems does not have a facilitative effect across the board; whether it does or not is related in a complex way to the current level of mastery of the logic of the problem, and to the verbal/imaginal style of the child. These conclusions are presented as preliminary because they are based at present on one specific study, one specific kind of inference (conditional inference) and

one specific kind of imageable or non-imageable material. The questions addressed here have not been addressed before. Clearly, the pattern of interactions obtained in this study needs to be examined further, and the questions pursued, before general conclusions can be drawn.

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Introduction

The aim of this project is to investigate the role of mental imagery in logical reasoning in children and, more specifically, to examine individual differences in that respect. This project is an outgrowth of a research program conducted for a number of years, focused on the development of logical competence in children (Falmagne, 1980, 1984a, 1984b). This work, as well as other results in the psychological literature, has made it clear that children of elementary school age are able to carry out certain kinds of deductive inferences embodied in language, but has also uncovered certain kinds of judgments that are particularly difficult, specifically those in which the child has to recognize that the initial information given to him/her is insufficient to determine whether a certain conclusion is logically true or logically false. Since logical competence requires being able to distinguish conclusions that are logically warranted from those that are not, that type of judgment is particularly crucial in the context of educational concerns.

It has been demonstrated abundantly that mental imagery plays an important role in a variety of verbal processes: it appears to improve memory for verbal material, to facilitate comprehension, etc. Results in the present line of research indicate that imagery also plays a role in logical reasoning, in particular, that children sometimes use mental imagery to reason about difficult problems, for which their linguistic resources are insufficient. However, it is well known that there are wide individual differences in people's ability to "visualize" (e.g., to form images of) information. Children in particular are apt to vary widely in that ability. The aim of the project, therefore, is to examine individual differences in the way in which imagery is used in logical reasoning, in the extent to which it is used, and in the successfulness with which it is used (i.e. in the extent to which the use of imagery seems to improve performance).

These questions are addressed in the context of a theoretical framework discussed in Falmagne (1980). Briefly, it is assumed that (a) reasoning with verbal material entails constructing a "functional representation" of the problem in working memory and transforming it to reach a conclusion; (b) the functional representation may be formal if the logical form instantiated by the problem is known by the subject at an abstract, formal level[1] and is identified in the problem at hand; (c) otherwise, the functional representation is content-specific (e.g., imaginal), and the problem is operated upon in that mode; (d) whether a problem is dealt with formally or not depends (positively) upon the availability of the relevant pattern of inference in the subject's current knowledge state, and the recognition of that pattern in its linguistic expression in the problem, and (negatively) upon the salience of other modes of representation (e.g., imaginal) for that particular problem. Furthermore, as discussed especially in Falmagne (1984a), it is assumed that mental imagery does not substitute for logical understanding; rather, imagery is seen as an auxiliary to logical processing, and, in order to be effective, the procedures associated with the use of imagery must be monitored by an understanding of the logic of the problem.

It was not until very recently that the role of imagery in reasoning began to receive attention within cognitive science. Recent approaches to this question (e.g. Kosslyn, 1980a; Lakoff, 1980) have been theoretical and partly speculative so far and have been driven to this question through an extension of previous analyses of mental imagery in other kinds of tasks (Kosslyn, 1980b) or through an extension of previous work on the role of imaginal processes in linguistic theory (Lakoff). Thus, in both cases, the initial focus was on imaginal processes in less complex contexts, and reasoning has been included as a new area of application of the previous work. In the present line of research, the outreach is in the opposite direction, i.e., the attention to the role of imagery in reasoning stems from an initial concern about reasoning processes. Thus, this specific topic is a novel area of investigation.

Previous studies in this line of research have examined various aspects of those questions (Falmagne, 1981, 1984b) and have provided initial support for the theoretical framework outlined above. Briefly, those previous results indicated that mental imagery does play a functional role in the deductive process for some kinds of inferences; those results also indicated that, although imagery appeared to be used, it was not always used in a manner that improved reasoning performance, i.e. that it was sometimes used 'irrationally'. (To anticipate, results of that kind are also obtained in the experiment to be reported here, and the specific sense in which certain uses of imagery are termed 'irrational' will be made clear at that point.)

Throughout this work, it became increasingly clear that an analysis of individual differences regarding the role of imagery in reasoning was not only needed for its own sake but potentially clarifying regarding previous results. This was the aim of the experiment reported here.

The aim of this experiment was to provide further clarification about the functional role of imagery in reasoning, and, particularly, to examine individual styles of reasoning in that regard. Subjects were children having just completed fifth grade, a particularly interesting transitional age regarding logical thinking. The focus of the study was on the children's responses to reasoning problems as a function of the kind of material included in the problem (material likely to elicit mental imagery and material unlikely to elicit imagery, as determined independently) and as a function of the subject's individual propensity to form mental imagery and to use it effectively. The reasoning problems used were conditional inferences, i.e. inference whose first premise is an "if . . . then" statement. Four kinds of conditional inferences can be constructed, two of which have a determinate answer ("yes" or "no") and two of which are indeterminate, i.e. for which the information given is not sufficient to yield a "yes" or a "no" conclusion. Examples of the four kinds of conditional inferences are presented in Appendix 1. The notations MP (Modus Ponens. Answer: "yes"), MT (Modus Tollens. Answer: "no"), AC (Affirming the Consequent. Answer: "can't tell"), and DA (Denying the Antecedent. Answer: "can't tell") will be used henceforth to denote those inferences. The content of each problem was assessed as high or low in imagery value on the basis of prior ratings given by the subjects in a separate session to the two component clauses of those problems, as described in the next section. Subjects were assessed as High imagers or Low imagers based on their answers to a well-known imagery scale, the VVIQ or Vividness of Visual Imagery Questionnaire (Marks, 1972; 1973; 1977; 1983) and on their performance on a prior memory task intended to provide a measure of the subject's ability to form images and to benefit from imagery, as described in the next section.

One important aspect of the procedure used is that the child was asked, after answering each problem, whether an image had occurred to him/her while thinking about the problem, and how clear that image was. This was done to provide an alternate assessment of the imagery value of problems (aside from their calibration based on the prior ratings to sentences), and also to permit an examination of the children's answers to problems as a function of whether or not they reportedly had an image to that problem.

Questions of particular interest to this study concern the extent to which the two subgroups of children appeared to use imagery in reasoning, the effectiveness with which each of the two subgroups appeared to use imagery (where "effectiveness" means improvement in performance when imagery is used) and the way in which both the frequency of imagery and its effectiveness are related to the logical form of the problem at hand. Regarding this last question, the theoretical assumptions discussed in Falmagne (1980, 1984b) predict that imagery will be used more often as the functional representation of the problem for those inferences which are difficult and not well mastered at an abstract level, but that imagery will be used successfully only when the child has some understanding of the logic of the problem (i.e. imagery cannot be a substitute for logical processing). On the other hand, the manner in which this process will be affected by the subject's individual style regarding used imagery was an open empirical question at the outset of this study.

Methods

Twenty-five children who had recently completed fifth grade in a Worcester elementary public school participated in this study. Children were tested individually in the Child Laboratory at Clark during the summer and were paid for their participation.

Each child participated in three sessions at approximately two-day intervals. Children received three kinds of tasks: two tasks designed to assess their propensity to form and to use mental images (the Memory task and the Vividness of Visual Imagery Questionnaire, or VVIQ); one task designed to calibrate the sentences to be used in the subsequent reasoning task in terms of their tendency to elicit visual imagery (the Sentence Imagery Rating task); and a Reasoning task consisting of two analagous sets of conditional inferences. Subjects received the Memory task and the Sentence Imagery Rating task during their first session, the first version of the Reasoning task during their second session, and the second version of the Reasoning task and the VVIQ during their third session.

The _Memory task_ included two lists of low imagery word pairs followed by two lists of high imagery word pairs. Each list consisted of twelve pairs, which were read aloud by the experimenter at a constant speed. After the end of the list, the experimenter read the first word of each pair (in a random order) and the subject was asked to recall the second word of that pair in response.

A number of previous results have shown consistently in a wide range of tasks (e.g. Bower, 1972) that high imagery material facilitates memory retention and recall. Thus, the magnitude of the improvement in performance between the low and the high imagery lists in this task was taken as a measure of the child's tendency to form and use mental images.

Words used in the two high imagery and two low imagery memory lists (24 words each) were selected based on their mean imagery rating according to the Paivio, Yuille and Madigan norms (1968). All words chosen for each list fell into relatively high Thorndike-Lorge frequencies (AA or A). Mean imagery ratings for low imagery lists were well differentiated from means for high imagery lists (List I, low, Mean (M)=3.06, Standard Deviation (SD)=.55; List II, low, M=3.06, SD=.47; List I, high, M=6.54, SD=.19; List II, high, M=6.53, SD=.21).

The two high imagery lists consisted of twelve high imagery pairs each. The low imagery lists consisted of ten low imagery pairs and two filler pairs which were high in imagery, thus resulting in a twelve-pair list. The two 'filler' pairs were added to equalize the length of the lists for the two conditions and to enable the child to succeed sometimes on the (difficult) low imagery lists; those pairs were not included in the scoring of responses. Subjects received the low imagery lists first, followed by the high imagery lists. Within each condition (high or low) the order of lists (I versus II) was counterbalanced. Four random orders of presentation of pairs were established for each list, and each of those orders was presented in sequence 1-12 for half the subjects and in sequence 12-1 for the other half, resulting in eight different orders per list across the group of subjects.

Prior to receiving the actual Memory task, subjects were given instruction, practice and feedback. For the low imagery lists, subjects were told to use a repetition strategy to improve their memory. For the high imagery list, subjects were instructed to form interactive images of each pair, namely to form an image where the two things named 'were in the picture together', in relation to one another. This procedure and these instructions have been shown to be effective in facilitating recall (e.g. Bower, 1972). Feedback was given during the practice task, but there was no feedback during the main Memory task. In the main Memory task, subjects first received the first low imagery memory list. Next, they participated in a structured break exercise in which they were asked to construct three of the object assembly puzzles from the Wisc-R. (Their responses to the puzzles were timed and scored; any inappropriate responses were noted.) After the break exercise, the second low imagery list was administered, followed by an unstructured break, and the first of the two high imagery memory lists. Before receiving the last high imagery list, subjects participated in one more short break.

Scoring of responses consisted of the number of correct responses among ten for the low imagery lists, and among twelve for the high imagery lists. For the data analysis, those were converted to percent correct to permit comparison between conditions.

In the Sentence_Imagery_Rating_task, subjects were read 70 sentences and were asked to report for each of them, immediately after it was read, whether an image had come to mind spontaneously ('whether a picture popped into your head by itself') or not, and, in the affirmative, how clear that image was ('very clear', 'pretty clear', or 'fuzzy'). Thus, judgments were made on a four-point scale.

Subjects received these sentences during the first session. Instructions were given as to how the ratings should be made, with a few practice sentences and minor feedback (only if necessary) given as well. The sentences were read off 2' x 3' index cards and then given to the subject to look over. There were frequent breaks in the administration of the 70 sentences. The mean imagery ratings obtained in this task for each sentence were used to select the materials for the Reasoning task, as described below.

The Reasoning_task consisted of lists of sixteen conditional inferences, four of each logical form (Modus Ponens, or MP; Modus Tollens, or MT; Affirming the Antecedent, or AC; Denying the

Consequent, or DA; see Appendix 1). For each of these, two inferences included high imagery material and two included low imagery material. Two such lists of problems were given during Session II, and two during Session III.

The materials for the Reasoning task were constructed based on the ratings given in the Sentence Imagery Rating task by the first 19 subjects. The means and standard deviations of ratings to each sentence were tabulated, and 32 sentences were selected that represented the two extremes (high or low imagery), in terms of their mean rating, and also had a relatively small standard deviation. These 32 sentences were paired to construct 8 nditional sentences for each kind of imagery material - 8 high imagery conditional sentences and 8 low imagery conditional sentences.

Once the conditional sentences were determined, each of them was used to construct four different conditional inferences (see Appendix 1). Four sets of reasoning problems were constructed. Each set contained 2 high imagery and 2 low imagery MP, 2 high imagery and 2 low imagery MT, 2 high imagery and 2 low imagery AC, and 2 high imagery and 2 low imagery DA. Subjects received two different sets of conditional problems during Session II and two during Session III.

The conditional inferences were typed clearly on 4" x 6" index cards. They were read slowly by the examiner, and reread by the child before response. Subjects received 6 practice problems (involving different, non-conditional inferences) with feedback, and instruction, if necessary, prior to the main reasoning task. There were three breaks in administration of the main task, each after a block of approximately 5 problems.

Subjects' possible response to each problem consisted of "yes", "no", or "can't tell". Subjects received instruction as to the meanings of these answers with examples of each from other types of logic problems (not conditional problems). After answering each conditional inference, the child was asked to state whether an image had occurred spontaneously while solving the problem, and how clear that image was, if any, according to the same 4-point scale used in the imagery ratings of the previous session.

Session II consisted solely in the explanation of the Reasoning task and administration of that task. A few days later, on Session III, subjects received a brief recap of the instructions, the practice problems with feedback, and the two remaining sets of conditional inferences.

The Vividness of Visual Imagery Questionnaire (VVIQ) is a brief 16-item questionnaire with a test-retest reliability coefficient of 0.74 (n=68) and a split-half reliability coefficient of .85 (n=150) (Marks, 1973). Each of the 16 items consists in evoking an image corresponding to the brief verbal description of a scene read by the experimenter, and mentally focusing on specific parts of that image. (See Appendix 2 for examples.) Each of these specific images is rated on a 5-point scale of vividness. The definition of the various ratings was adapted for children from the definitions given in Marks (1973), as follows: 1 - 'perfectly clear and sharp as if you were looking at it normally'; 2 - 'clear and sharp, but not as clear as if you were looking at it normally'; 3 - 'sort of clear and sharp'; 4 - 'fuzzy and blurred'; 5 - 'you can't see it at all, you only know that you are looking at it'.

Administration of the VVIQ included instruction about the imagery ratings, practice images, and minor feedback. Occasionally during presentation of materials and response, the subject was asked to describe the image in addition to rating it (this gave the tester, and perhaps the testee, a sense of reality about the imagery judgments). Items 1 through 16 were given to the subject while his/her eyes were open. If s/he closed them, s/he was asked to open them. Before the subject was asked to close his/her eyes for the next part, there was a short break. Items 1 through 16 were given once more, this time with the subject's eyes closed. This procedure followed the procedure used in Marks (1973) and other studies.

On the basis of total scores on the VVIQ, the 12 highest scorers (mean rating 2.455) and the 13 lowest scorers (mean rating 1.677) were selected to form two experimental groups: 'low' and 'high' imagers respectively.

Subjects received this task on the third session after completing the second administration of the Reasoning task.

Results

A first, preliminary question is to assess the relationship between the two measures of individual imagery style. The 25 subjects were rank-ordered according to their score on the VVIQ on the one hand, and, on the other hand, according to the magnitude of their increase in performance from the low to the high imagery condition in the memory task. The Spearman rank-order correlation coefficient between those two measures yielded a modest positive value of .24. This value, however, was not significant. Similarly, an examination of the mean percent correct in each Memory task for subjects that had been assessed as High imagers (Hs) or Low imagers (Ls) by the VVIQ, indicated a pattern in the predicted direction, but a nonsignificant one; specifically, the High imagers did better than the Low imagers in the High imagery condition, and worse than the Low imagers in the Low imagery condition. The High imagers' improvement from the Li to the Hi condition was, therefore, greater, as expected. However, again this interaction is not significant. The relevant values are shown in Table 1.

Table 1 about here

Given the weakness of the relationship between the two measures, the VVIQ score alone was used henceforth, to assess the subjects as being High or Low imagers, since the VVIQ has been used and validated in a number of prior studies in the literature (see Brunn, Cave, and Wallach, 1983; Marks, 1977, 1983; Poltrock and Brown, in press).

Several kinds of results will be presented: (a) first, global results concerning the imagery reports of the two groups of subjects, irrespective of problem type, in order to assess the overall relation between VVIQ assessment and imagery reports in our task; (b) second, the imagery reports to the various problem types for each group of subjects; (c) the percent correct to the various problem types for each group of subjects; (d) results concerning the direct relationship between imagery and response to problems.

It will be recalled that imagery ratings were obtained in two tasks: the preliminary, Sentence Rating task, whose data were used to construct the subsequent problems, and the Reasoning task itself. Figure 1 and the corresponding Table 2 display the distribution of imagery ratings in the Sentence Rating task for the two groups of subjects.

Figure 1 and Table 2 about here

Clearly, those subjects assessed as Low imagers by the VVIQ report less frequent imagery (as indicated by the frequencies of NP, 'No Picture'), and the images that they report aren't as clear (as indicated by the frequencies of VC, 'Very Clear').

Next, Figure 2 and the corresponding Table 3 show the distribution of imagery reports to *problems* (irrespective of problem type) for the two groups of subjects. Again, the two groups are clearly differentiated in terms of the frequency and clarity of images reported to problems.

Figure 2 and Table 3 about here

An interesting observation can be made by comparing Figure 1 and Figure 2 (or Table 2 and Table 3): in both groups, subjects report more frequent and more vivid imagery to *sentences* than to *problems*. Potential implications from this result will be examined in the final discussion.

The next set of results concerns the pattern of imagery to the various problem types in the Reasoning task. First, as a baseline result, the overall percent of images reported to the four problem types is shown in Figure 3. It can be seen that the frequency of imagery reports is roughly equivalent across problem types, a result in accord with that of previous studies in this line of research (with the exception that DA was found sometimes to yield somewhat lower imagery in prior studies).

Figure 3 about here

The questions of central interest to this study, however, concern the comparison of the Low imagers and the High imagers in terms of their pattern of imagery to the various kinds of problems. Figure 4 and Table 4 present the relevant data. (In addition, Table 4 also presents results pooled for determinate inferences [MP and MT] versus indeterminate [AC and DA] for simplicity.)

Figure 4 and Table 4 about here

One first observation of interest is that, for high imagery material (white bars), High and Low imagers respond in the same manner, i.e. with a relative frequency of imagery reports close to 1. Thus, high imagery material does not differentiate the two groups. In contrast, for low imagery material (striped bars), the frequency of imagery reports decreases considerably for the Low imagers (bottom graph) while it decreases to a much lesser extent in the High imagers (top graph). Indeed, for those subjects, the frequency of imagery reports for DA inferences is equivalent in the two conditions. (It is of some interest to note that in a previous study results showed that the difference between high imagery and low imagery material regarding frequency of imagery reports virtually disappeared for indeterminate inferences. It is possible that the subject sample in that study vicariously included a majority of High imagers.)

Thus, overall, High and Low imagers seem to be differentiated by their response to low imagery material only, or, more accurately, by their frequency of imagery reports to that kind of material.

A more sensitive look at this comparison may be provided by examining the frequencies of "Very Clear" reports only. Figure 5 and Table 5 show the relevant data (organized in a way parallel to the organization of Figure 4).

Figure 5 and Table 5 about here

Two observations are suggested by Figure 5. High imagery and low imagery material are sharply differentiated for each kind of inference but most markedly for MP and AC, i.e. those inferences whose premises don't include a negative statement[2] ; and both groups of subjects exhibit the same pattern in that respect. Considering these data along with those of Figure 4, it seems that (to oversimplify), High imagers report images with approximately equal frequency for both types of material, but those images are clearer for high imagery material than for low imagery material. This is particularly striking regarding indeterminate inferences in those subjects; therefore, a reexamination of the results from previous studies seems required since the data analysis in those studies only included the frequency of images, as opposed to the frequency of "Very Clear" images reported.

The next set of questions concerns the percentage of correct responses to the various problem types in relation to the subject's characteristics and to the nature of the material. First, Table 6 presents those data for both groups combined, for high imagery material and low imagery material, respectively.

Table 6 about here

Looking at the bottom part of the table in which the inferences are pooled as determinate versus indeterminate, it is clear that the percentage of correct responses is equivalent for both types of material (HI versus LI).

The next table presents a similar analysis for the two groups of subjects separately.

Table 7 about here

Again, there is no clear difference between the two kinds of material (Hi or Li), for any of the inference types and for either group of subjects. However, regarding between-group comparison, a surprising finding is that the Low imagers answer correctly to the indeterminate inferences (specifically to DA) more often than the High imagers.

Previous studies in this line of research have indicated that children sometimes seem to use imagery in an irrational way, i.e. that they sometimes tend to answer 'no' or 'can't tell' to the problem when they report not having had an image while thinking about the problem, and to answer 'yes' to the problem, when they report having had an image, as if they consulted the presence or absence of an image to find the answer to the problem. It is possible that the Low imagers' apparent superiority regarding indeterminate inferences might stem from such a process.

The next analyses are relevant to that question and examine the subjects' responses in relation to their imagery report on the same problem. First, Table 8 presents the percent correct responses as a function of whether the child reported 'having a picture' or 'no picture' on the same problem. Looking at the bottom of the table, it appears that for indeterminate problems,

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Table 8 about here

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those problems that were at question in the previous table, the Low imagers answer correctly more often when they report not having a picture (21% correct, as opposed to 9% with picture, $p<.05$). The main body of the table displays the corresponding data for each inference separately: the pattern just described holds for both AC and DA in Low imagers. In contrast, no such pattern obtains for High imagers.

Thus, it seems that at least part of the superiority of the Low imagers for this kind of problem, is associated with cases in which they did not have an image. Before this phenomenon can be labeled 'irrational use of imagery', however, one must verify that it occurs when 'can't tell' is an erroneous response as well as when it is the correct response, as was the case here. Specifically, for determinate inferences (MP and MT), two kinds of errors are possible: 'can't tell' and either 'no' (for MP) or 'yes' (for MT). The question of interest is whether the frequency of 'can't tell' responses is higher when the subject reports 'no picture' than when he/she reports 'picture'. Those two values are respectively .10 and .05 for Low imagers, thus exhibiting a (weak) trend in the predicted direction. Those values are based on a small number of observations (only 19 errors in total for both MT and MP combined, for a total of 300 responses), and their difference is not significant. However, it does support the previous interpretation regarding an irrational use of imagery in Low imagers in some cases.

Another result, perhaps pointing in the same direction, concerns these subjects' responses to Modus Tollens. The correct response to a MT inference is 'no'. Previous results have also suggested that children sometimes appear to rely on the presence or absence of an image to answer 'yes' and 'no', respectively.

Table 8 indicates that Low imagers answer 'no' (correctly) more often to MT when they reportedly don't have an image (.95 versus .75 for 'No Picture' versus 'Picture', respectively, $p<.05$). This, in itself, is not necessarily an index of irrational use of imagery; however, it converges with the previous result to support that interpretation. Again, in order to legitimate that interpretation, one must verify that those same subjects also answer 'no' more often without an image than with an image when 'no' is an error (in this case, an error to an indeterminate inference); the relevant frequencies are .47 and .40, which is a weak difference but in the predicted direction. Those data for Low imagers are shown in Figure 6, which presents the percent of 'yes' and 'no' responses as a function of whether an image to that problem was reported or not, separately for those problems for which 'yes' or 'no' were the correct responses (top graph) and for indeterminate problems, to which 'yes' or 'no' are errors (bottom graph)

Figure 6 about here

As shown in Figure 6, for both kinds of problems, Low imagers tend to say 'yes' more often when they have an image to the problem, and 'no' more often when they don't have an image, thus displaying an irrational use of imagery, as discussed previously.

Figure 7 shows the corresponding data for High imagers: clearly, the irrational use of imagery appears to be present for indeterminate inferences (bottom graph) but not for determinate inferences (top graph). This is in accord with what one might intuitively predict: given that indeterminate inferences are difficult for children, it is possible that they attempt to use other resources aside from purely deductive processes. However, as argued in Falmagne (1984b), mental imagery can only be an auxiliary to basic logical understanding, it does not substitute for logical processing. Thus, if a logical understanding of the indeterminate conditional inferences is lacking, imagery may be operative for those inferences, but not in a way that leads to correct responses; this is indeed the case, as reflected in Figure 7 (bottom graph) showing that the proportion of (erroneous) "yes" or "no" responses to indeterminate inferences is related to the presence or absence of an image, and in Table 8, showing that the percent correct responses to those inferences is unaffected by that factor.

Within the same framework, imagery is expected to be helpful for those inferences for which a logical understanding exists but for which this understanding is fragile. Table 8 indicates that this seems to be the case for Modus Tollens for these high imager subjects: the percent correct is higher with an image than without an image for those subjects. Similarly, Table 7 shows that the percent correct to Modus Tollens is higher with high imagery material than with low imagery material, for High imagers.

The difference between the pattern of results just described for High imagers and the corresponding results for the Low imagers will be discussed in the next section, in terms of its potential significance.

It is interesting to reexamine some of the data presented above, from a different point of view. The following analysis is not directly relevant to the focus of this study on individual differences in the use of imagery, but it is relevant to previous theoretical discussions of logical development (Falmagne, 1980, 1984b). The indeterminate inferences, AC and DA, are known to be difficult for children, even for older children such as those in the present experiment. Indeterminate inferences are usually treated as determinate, i.e. children (and, often, adults) tend to answer 'yes' to AC and 'no' to DA. It is of interest to reexamine the various responses given to each of the four inferences, in order to see whether both indeterminate inferences (AC and DA) 'behave' in the same manner; and whether each of them is treated as the corresponding determinate inference by children. Table 9 presents the relevant data (for both groups of subjects combined).

Table 9 about here

First, comparing the distributions of the various responses to MT and DA, it can be seen that those two inferences are treated in the same manner, that is, children treat DA as if it was an MT inference, answering 'no' most of the time. They rarely answer 'yes' and rarely answer 'can't tell' (the correct response), and this pattern is not affected by whether children 'have a picture' or not. In contrast, it seems that the other indeterminate inference, AC, is partly differentiated from the corresponding determinate inference, MP. While MP yields almost exclusively 'yes' responses (correctly so), AC shows a different pattern: when 'a picture' is reported, the responses are predominantly 'yes' (92%), although there are some correct 'can't tell' responses (5%); in contrast, when 'no picture' is reported, the frequency of 'yes' decreases considerably (66%), and many responses are either 'can't tell' (17%) or 'no' (17%). Pooling the 'no' and 'can't tell' categories, the distribution of responses to AC with 'no picture' is significantly different from that with 'picture' ($p<.01$). This pattern suggests that children are relying on imagery to answer the problems, at least part of the time, saying 'no' or 'can't tell' when they don't have an image. Thus, children would use imagery 'irrationally' in that case, as discussed previously for other cases.

Interestingly, such a pattern of responses does not seem to occur for DA. The import of these two findings together will be discussed in the next section.

Discussion

Those results concerning individual differences in the use of imagery will be examined first and followed by a discussion of some results of general interest.

First, subjects assessed by the VVIQ as High imagers (Hs) and Low imagers (Ls), respectively, are clearly differentiated regarding their imagery ratings to both isolated sentences and logic problems in this study: the Hs group reports more frequent imagery and clearer images overall. This constitutes a validation both of the VVIQ as an assessment measure, and of the judgments obtained in the Sentence Rating task and in the Reasoning task.

Regarding the locus of this difference, it is interesting to note that the two groups are differentiated for low imagery problems primarily: the Hs group reports more frequent imagery than the Ls group on these problems, whereas the two groups don't differ markedly for high imagery problems. However, the clarity of images does differ between the two groups for both kinds of material: for both Hi and Li material, the Hs group reports a higher proportion of 'very clear' images. Thus, for high imagery material (for which, presumably, conventional associative images are highly available), Ls report images as frequently as Hs subjects, but their images aren't as clear as those of Hs subjects; for low imagery material (for which imagery is presumably more idiosyncratic), the images reported by the Ls group remain less clear and, in addition, are less frequent than those reported by the Hs group.

The primary focus of this study was on the use of imagery in reasoning. Therefore, a central question is to examine whether the differences just discussed bear a relation to measures of deductive performance. A preliminary, indirectly relevant observation is that the error rate to the various problem types is generally similar for Hi and Li material (see Table 6); thus, it is not simply the case that availability of imagery improves performance, an observation which concurs with results from previous studies in this line of research. Analysis of those previous results and of others, as well as rational argument, suggests that there is a complex relation between mental imagery and deductive processing. As discussed elsewhere (Falmagne, 1980, 1984b), use of imagery is only useful when it is guided by a deeper logical understanding of the problem: imagery is an auxiliary to, not a substitute for, deductive processes, although it can be helpful, as an auxiliary, when the existing logical understanding is fragile.

With this in mind, it is interesting to observe that several results point to an "irrational" use of imagery by Ls subjects. That is, some of the time, these subjects appear to consult the presence or absence of a mental image to give their answer to the problem. Thus, those subjects' frequency of (correct) "can't tell" responses to indeterminate inferences is higher for Li material than for Hi material; and this apparently paradoxical result is clarified when observing that those subjects answer "can't tell" (to any problem) more often when they don't have a mental image than when they do report an image. The result concerning indeterminate inferences is thus a spurious consequence of this fact. The same subjects exhibit a similar pattern for "no" responses, thus answering "no" (correctly) to MT inferences more often when the material is low in imagery; and this result, again, seems to be a spurious consequence of their (irrational) tendency to answer "no" when they don't have an image of the problem.

In contrast, High imagers, while exhibiting an "irrational" use of imagery for indeterminate inferences, do not exhibit such a pattern for MT and indeed appear to benefit from mental imagery for that inference as if, having a base logical understanding of that inference, they were able to use imagery effectively as an auxiliary.

In relation to this differential finding, one might conjecture that perhaps the Ls subjects are lower either in general intellectual ability or in ability to handle this experimental situation. However, this hypothesis is unsupported by the results of the initial Memory task: both groups of subjects performed equally on the Memory task, which is a highly taxing and test-like task (see Table 1). Another, more interesting possibility is that the Ls subjects, being less prone to have mental imagery in response to verbal material, do not have effective procedures for using their imagery effectively and indeed may not know how to integrate it with purely verbal processes. This possibility is supported, again, by the results of the initial memory task: the Ls subjects do better than the Hs subjects for low imagery material (perhaps due to their general bias toward a linguistic code in verbal processing), and worse than Hs subjects for high imagery material (perhaps because of a more limited ability to use imagery effectively in verbal processing). Although this interaction only approaches significance, it does support the hypothesis advanced here. This interesting possibility clearly needs to be investigated further, by use of converging measures of those two modes of processing (in a manner similar to Kosslyn, Brunn, Cave, and Wallach, 1983; Poltrock and Agnoli, in press; Poltrock and Brown, in press).

Turning now to results of general interest, though not focused on individual differences, it may be recalled that the ratings to the problems indicate less frequent and less clear imagery than the ratings to isolated sentences. This may, of course, result from the fact that in the Sentence Rating task the primary focus of attention is whether an image is elicited or not, unlike the requirements of the Reasoning task. However, aside from this attentional phenomenon, it is possible that one kind of mental imagery becomes attenuated when a considerable amount of verbal or inferential processing must be carried out. In the discussion of a previous study (Falmagne, 1984a), it was speculated, very tentatively, that there might be two kinds of images: literal and constructed. 'Literal' images would be elicited spontaneously in the ordinary course of sentence comprehension. 'Constructed' images would be created as auxiliaries to the deductive process. Were this distinction valid, it might underlie the present result: if 'literal' imagery decays when complex processing occurs, the images reported for problems may be predominantly 'constructed' images and would presumably be less frequent.

A second result of general interest was described in relation to the data of Table 9: different patterns of responses are given to the two indeterminate inferences, AC and DA. Specifically, it seems that DA is completely treated as if it was a MT inference; that is, in that case, child en treat the conditional relation 'if p then q' as if it was biconditional ('if p then q, and if q then p'). Thus, they answer 'no' (correctly in one case, incorrectly in the other) equally often, whether they have an image or not. They do not seem to rely on the presence or absence of an image to give their answer. In contrast, the other indeterminate inference, AC, does seem to be somewhat differentiated from its determinate counterpart, MP. While children almost always answer 'yes' to MP (whether or not they have an image), their answer to AC seems to be related to the presence or absence of an image: their frequency of 'yes' responses decreases when they don't report an image and they display a relatively high proportion of 'no' or 'can't tell' responses in their case, as if they (irrationally) consulted the presence or absence of an image to answer the problem.

The interest of this finding is that, if children were truly treating AC as if it was determinate, that is, if children truly had a biconditional interpretation of the conditional, one would expect their pattern of responses to AC to be similar to that for MP. Instead, some children exhibit a pattern which can be speculatively taken to indicate an attempt to answer the more difficult indeterminate inference, an inadequacy in the deductive procedures that would enable them to do so, and a tentative (unsuccessful) use of imagery as a basis for the response.

Such a pattern does not occur for DA, perhaps because it is a more difficult inference and is not at all differentiated from MT.

This, along with the finding just discussed for AC, would suggest that children are in a transitional phase in their comprehension of conditional inference, in which they are beginning to differentiate between MP and AC. This phenomenon would be consonant with Piagetian characterization of this age range as a transitional stage towards formal operational thinking. Interestingly, in relation to our conceptualization of the role of mental imagery (Falmagne, 1984b), those children who do use imagery in their attempt to solve the difficult AC inference, would do so unsuccessfully because their understanding of the logic of the problem is too fragile to monitor a correct use of auxiliary imagery.

From an educational standpoint, these results suggest in a preliminary way that the imageability of the material included in problems does not have a facilitative effect across the board; whether it does or not is related in a complex way to the current level of mastery of the logic of the problem, and to the verbal/imaginal style of the child. These conclusions are presented as preliminary because they are based at present on one specific study, one specific kind of inference (conditional inference) and one specific kind of imageable or non-imageable material. The questions addressed here have not been addressed before. Clearly, the pattern of interactions obtained in this study needs to be examined further, and the questions pursued, before general conclusions can be drawn.

Footnotes

1 It is not assumed that the subject has explicit or conscious knowledge of that logical form, but rather that it is represented mentally as part of the subject's current state of knowledge. For example, many rules of syntax are presumably known in that abstract, formal manner, since children and adults are able to use those rules in novel sentences or with newly acquired vocabulary items; however, children and adults do not necessarily have conscious knowledge of those rules and are typically unable to express them explicitly. This is the sense in which some logical relations and patterns of deductive inference are assumed to be known at a formal level in this article.

2 This is consistent with the results of a previous, exploratory study, in which imagery reports to negative sentences was shown to be less frequent and less clear than imagery to the corresponding affirmatives.

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Appendix 1

Logical form of the four conditional inferences, and examples of each

<u>Modus Ponens</u> (MP)

If Stanley goes to school, then he is carrying a book.	If p then q
Stanley goes to school.	p
He is carrying a book.	∴ q

<u>Modus Tollens</u> (MT)

If Stanley goes to school, then he is carrying a book.	If p then q
Stanley is not carrying a book.	not q
He is not going to school.	∴ not p

<u>Denying the antecedent</u> (DA)

If Stanley goes to school, then he is carrying a book.	If p then q
Stanley is not going to school.	not p
? (indeterminate)	∴ ?

<u>Affirming the consequent</u> (AC)

If Stanley goes to school, then he is carrying a book.	If p then q
Stanley is carrying a book.	q
? (indeterminate)	∴ ?

Appendix 2

Instructions and items adapted from the VVIQ (Marks, 1973)

In this task, I am going to name some things, and then I'll ask you some questions about the pictures that pop into your head. For example, I may ask you to imagine your room at home. While you are looking at this image, tell me if you can see the shape of your bed, the color of the bedspread or cover, what's lying in the corner of your room. When these parts of the image pop into your head, I'll ask you if they are: 1) Perfectly clear and sharp as if you were looking at it normally; 2) Clear and sharp, but not as clear as if you were looking at it normally; 3) Sort of clear and sharp; 4) Fuzzy, blurred; 5) You don't see it at all, you only "know" that you are thinking of it. I don't want you to force the images of these things into your head, just let them pop into your head naturally. Sometimes you may see them clearly and sometimes you may not be able to see them at all. There are no right or wrong answers. First, I want you to think of some relative or friend whom you see a lot. Look at the image that pops into your head and tell me if you can see:

1. the exact shape of this person's face, head, shoulders and body.
2. the way the person holds their head, and the positoin of the body.
3. the way this person walks, length of step, etc.
4. the different colors of an outfit that this person wears a lot usually.

Now, I'd like you to image a rising sun. Carefully look at the picture that pops into your head and tell me if you can see:

5. the sun rises above the horizon into a hazy sky.

6. the sky clears an surrounds the sun with blue.

7. clouds. A storm blows up, with flashes of lightening.

8. a rainbow appears.

Now, I'd like you to image that you see the front of a shop which you often go to. Carefully look at this image and tell me if you can see:

9. what the shop looks like overall from the opposite side of the street.

10. what is in the window of the shop, the things that are for sale, their colors, their shapes, and their details.

11. You are near the entrance. The color, shape, and details of the door.

12. You enter the shop and go to the counter. The salesperson serves you. Money changes hands.

Imagine a country scene which involves trees, mountains and a lake. Look carefully at this image and tell me if see:

13. the landscape and its borders.

14. the color and shape of the trees.

15. the color and shape of the lake.

16. a strong wind blows on the trees and on the lake and it makes waves.

Table 1

Percent correct for high and low memory conditions as a function of whether subject was high or low imager as assessed by VVIQ [(a)]

	Low Imagery	High Imagery
Low Ss	15	70
High Ss	10	77

(a) 240, and 288 observations per cell for low Ss, respectively; 260, and 312 observations per cell for high Ss, respectively.

Table 2

Distribution of imagery ratings (in percent) in the sentence rating task for high and low imagers

	Percent Reported			
	NP	F	PC	VC
High Ss (840 obs)	8	13	18	60
Low Ss (910 obs)	14	17	26	43

Table 3

Distribution of imagery ratings (in percent) in the logic task for high and low imagers

	Percent Reported			
	NP	F	PC	VC
High Ss (400 obs)	16	14	25	46
Low Ss (368 obs)	23	18	26	33

Table 4

Percent Images Reported by Low and High Imagers to the Various Problem Types, for Low and High Imagery Material, Respectively [(a)]

	Low Ss		High Ss	
	Li	Hi	Li	Hi
MP	64	96	78	98
MT	64	91	70	90
AC	56	100	78	98
DA	63	87	82	82
Det. (MP & MT)	64	94	74	94
Indet. (AC & DA)	59	94	80	90

(a) 92, 100 observations per cell for Low and High imager subjects, respectively.

Table 5

Percent "Very Clear" Imagery Reports by Low and High Imagers to the Various Problem Types, for Low and High Imagery Material Respectively (a)

	Low Ss		High Ss	
	Li	Hi	Li	Hi
MP	11	54	20	80
MT	17	46	30	48
AC	17	72	30	74
DA	11	37	32	50
Det. (MP & MT)	14	50	25	64
Indet. (AC & DA)	14	54	31	62

(a) 92, 100 observations per cell for Low, and High imager subjects, respectively.

Table

Percent Correct to the Various Inferences Types for High Imagery Material and Low Imagery Material Respectively [(a)]

	Hi	Li	Overall
Modus Ponens	97	97	97
Modus Tollens	90	86	88
Affirming the Consequent	6	8	7
Denying the Antecedent	11.5	4	8
Determinate (MP and MT)	93.5	91.5	92.5
Indeterminate (AC and DA)	9	6	7.5

(a) 25 subjects, 96 observations per cell

Table 7

Subjects Assessed as High and Low Imagers in the VVIQ:
Percent Correct to the Various Problems for
Hi and Li Materials, Respectively [(a)]

	High Ss		Low Ss	
	Hi	Li	Hi	Li
MP	98	100	96	93
MT	98	90	83	81
AC	0	4	12	12
DA	4	0	19	8
Det	98	95	90	87
Indet	2	2	15	10

(a) Number of observations per cell: 92, and 100 for Low, and High subjects, respectively.

Table [illegible]

Percent Correct As A Function of Whether An Image Was Reported or Not, for Low and High Imagers, Respectively [(a)]

	Low		High	
	Pic	No Pic	Pic	No Pic
MP	98	89	99	100
MT	75	95	95	85
AC	10	25	0	8
DA	7	17	3	0
Det	87	92	97	93
Ind	9	21	1	4

(a) 92, and 100 observations per row for Low and High Imagers, respectively 184, and 200 observations per cell per marginal row (DET vs. IND)

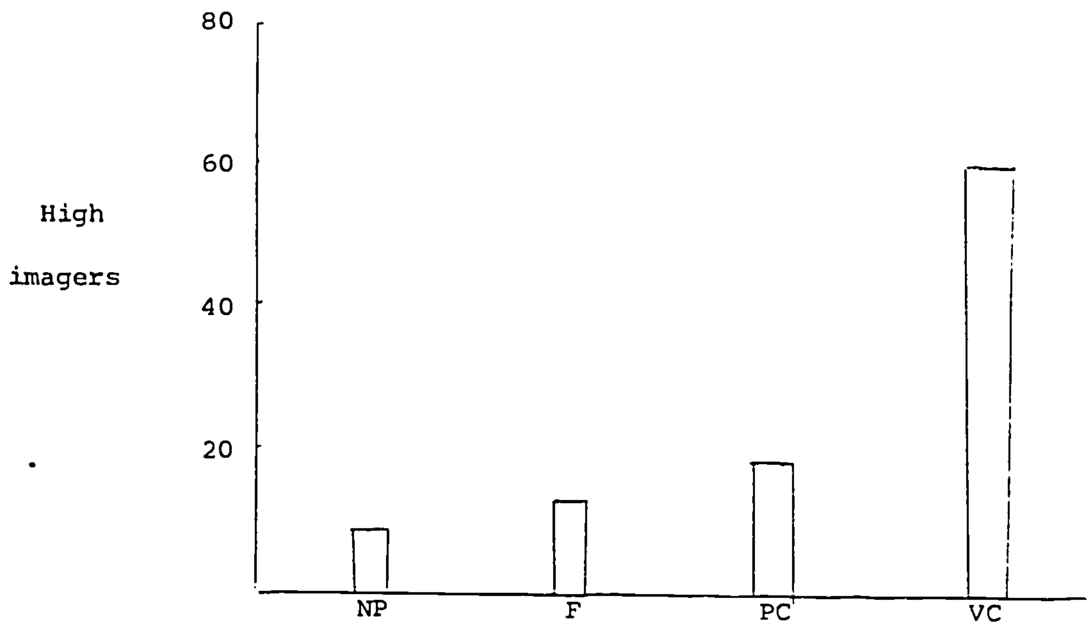
Table 9

Distribution (in percent) of responses to each of the four inferences, respectively, for problems to which an image was reported ("pic") and for problems to which no image was reported ("no pic"). The correct response to each inference is underlined.

Inference	MP			AC			MT			DA		
	<u>yes</u>	no	ct	yes	no	<u>ct</u>	yes	<u>no</u>	ct	yes	no	<u>ct</u>
pic	99	--	--	92	3	5	7	86	6	4	92	5
no pic	94	3	6	75	18	18	5	90	7	2	88	10
All	97	1	2	89	6	8	6	87	6	3	91	6

Figure 1

Distribution of imagery ratings (in percent) in the sentence ratings task for high and low imagers



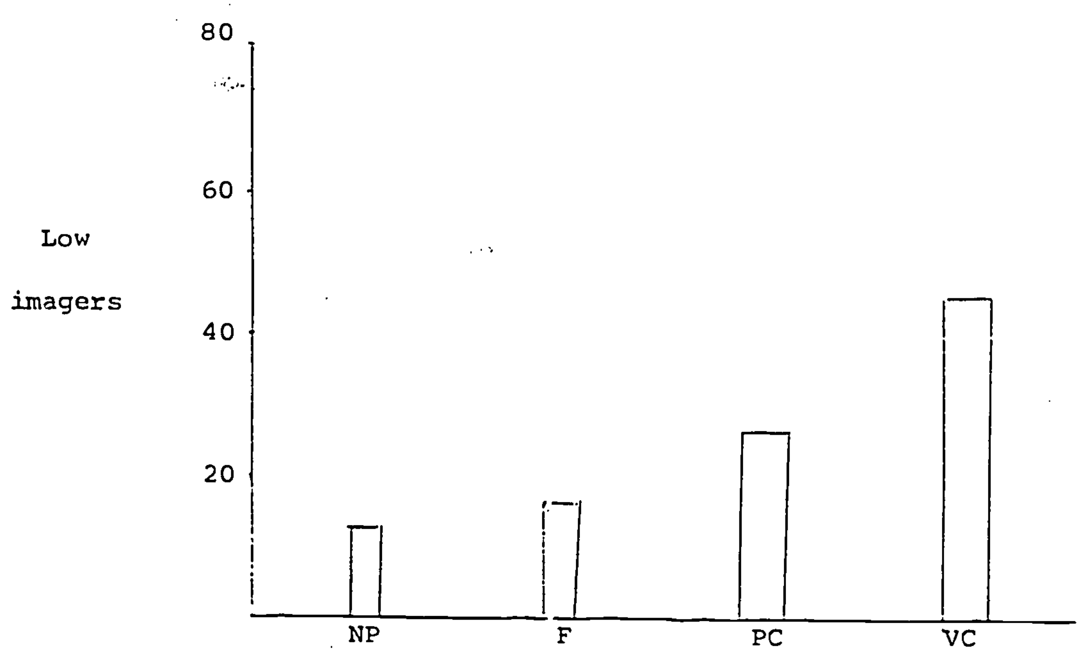


Figure 2

Distribution of imagery ratings (in percent) to problems in the logic task for high and low imagers

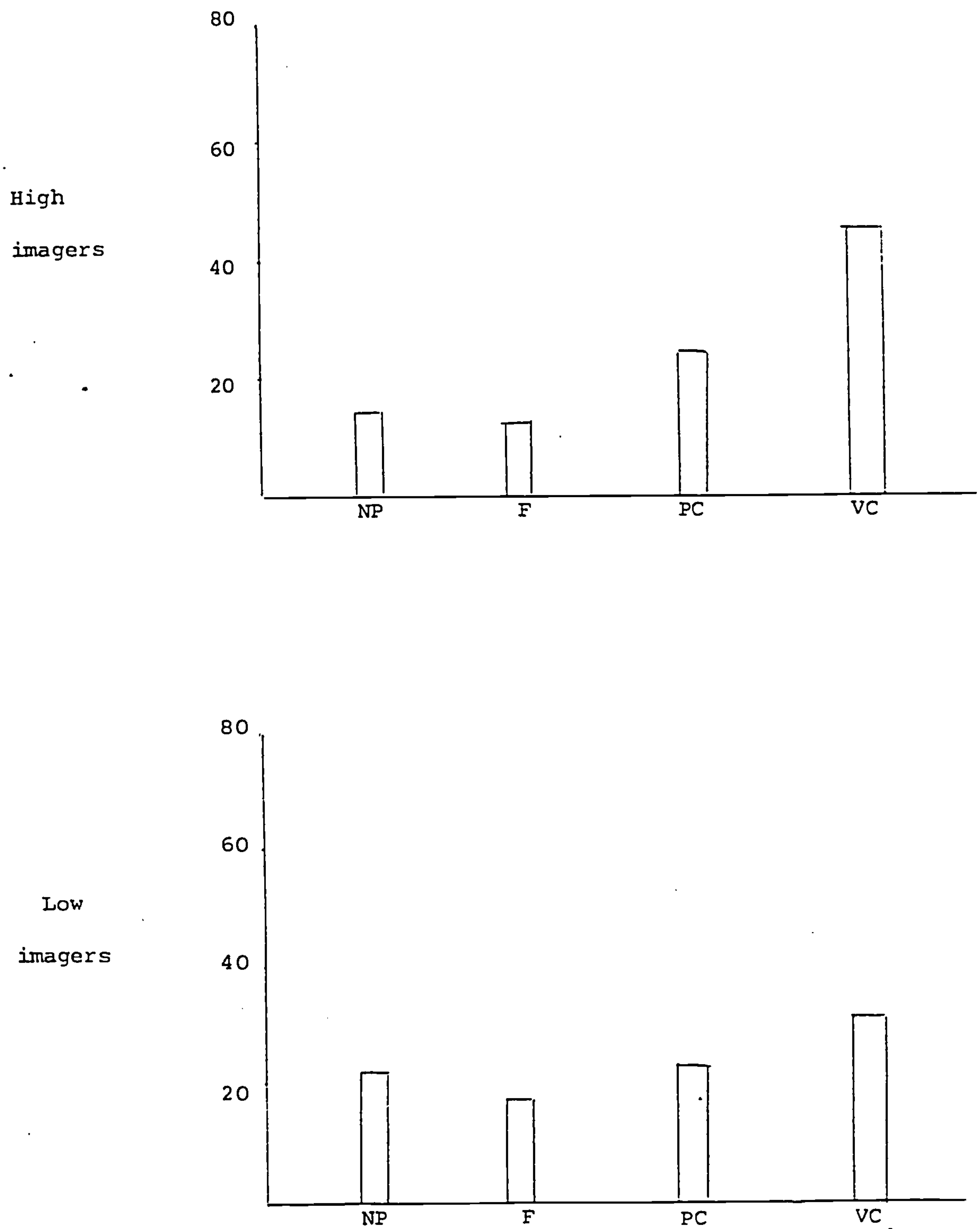


Figure 3

Percent of Images Reported for the Four Problem Types

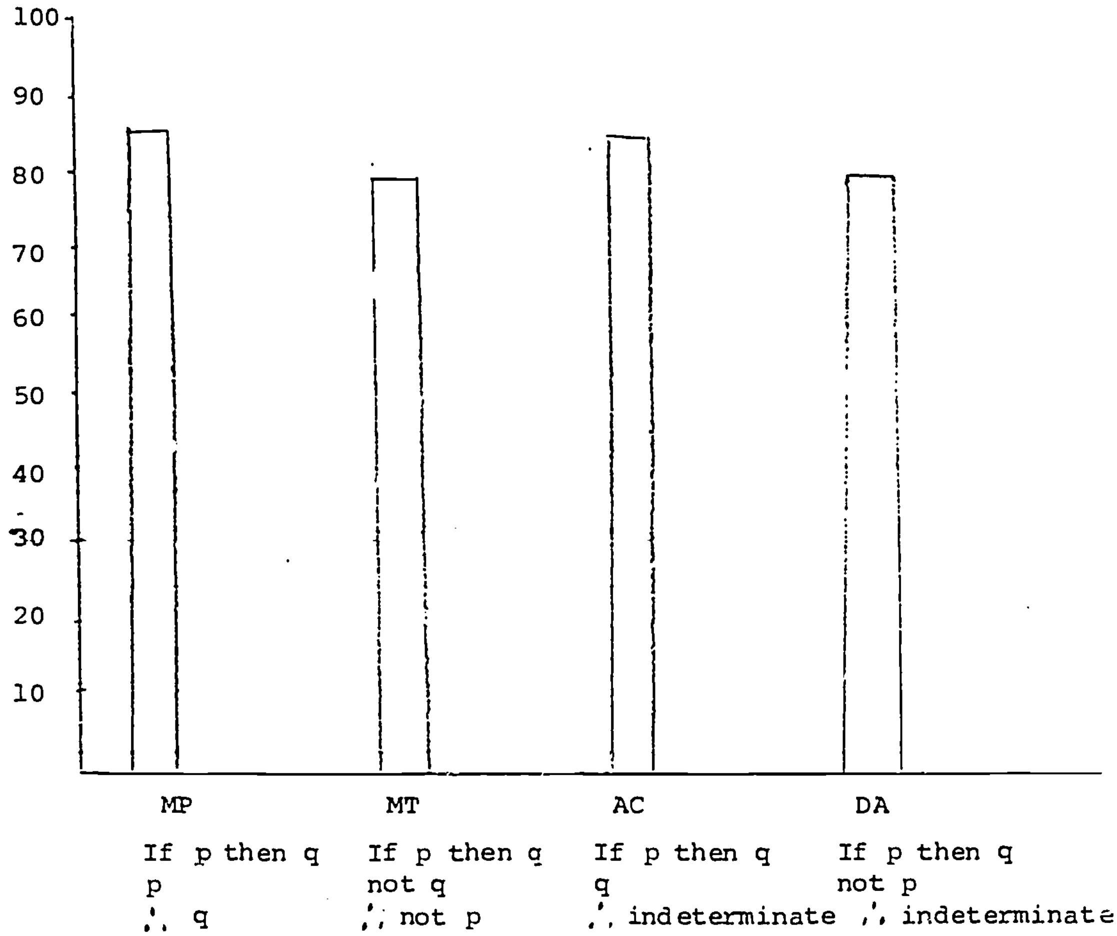
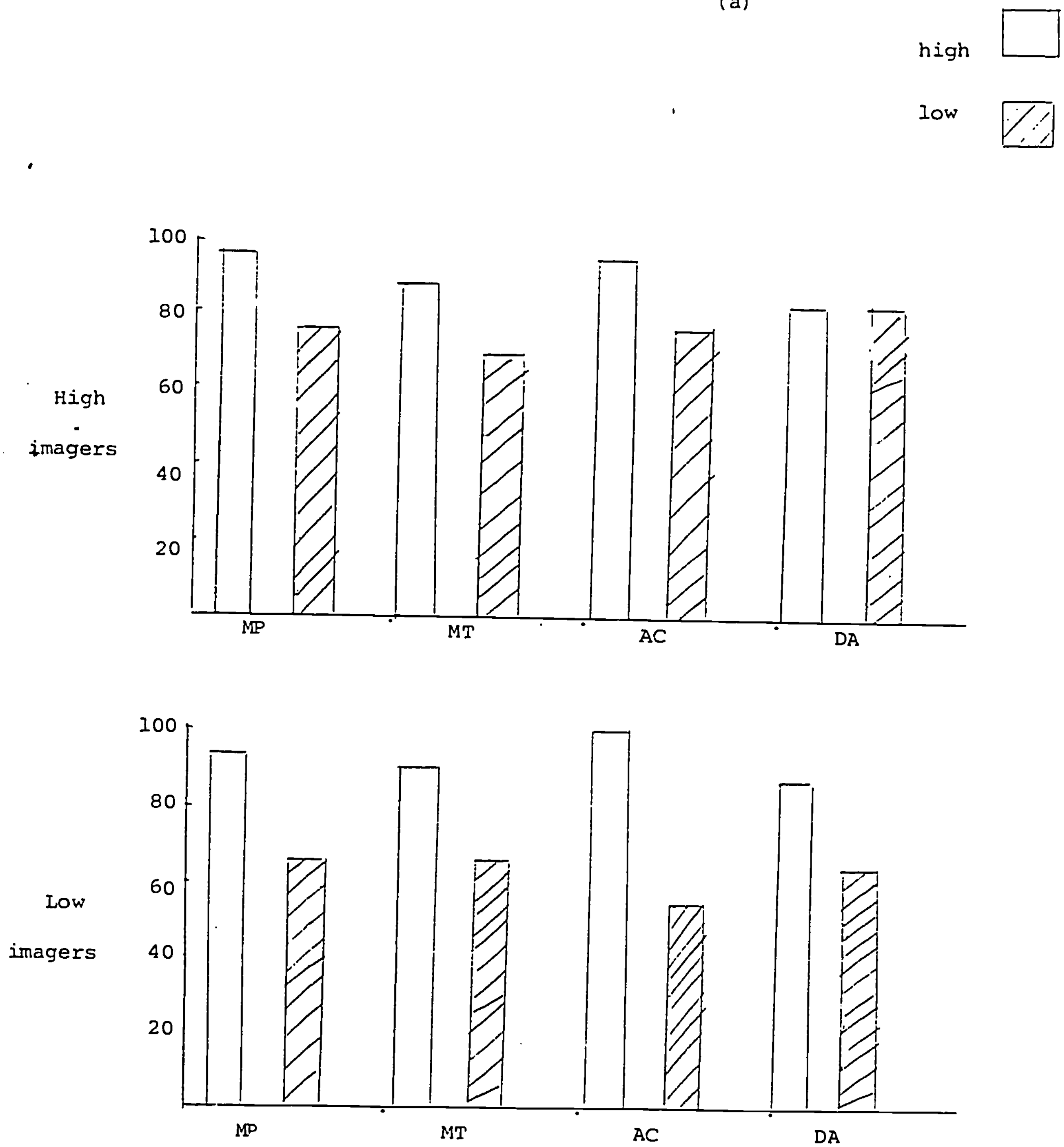


Figure 4

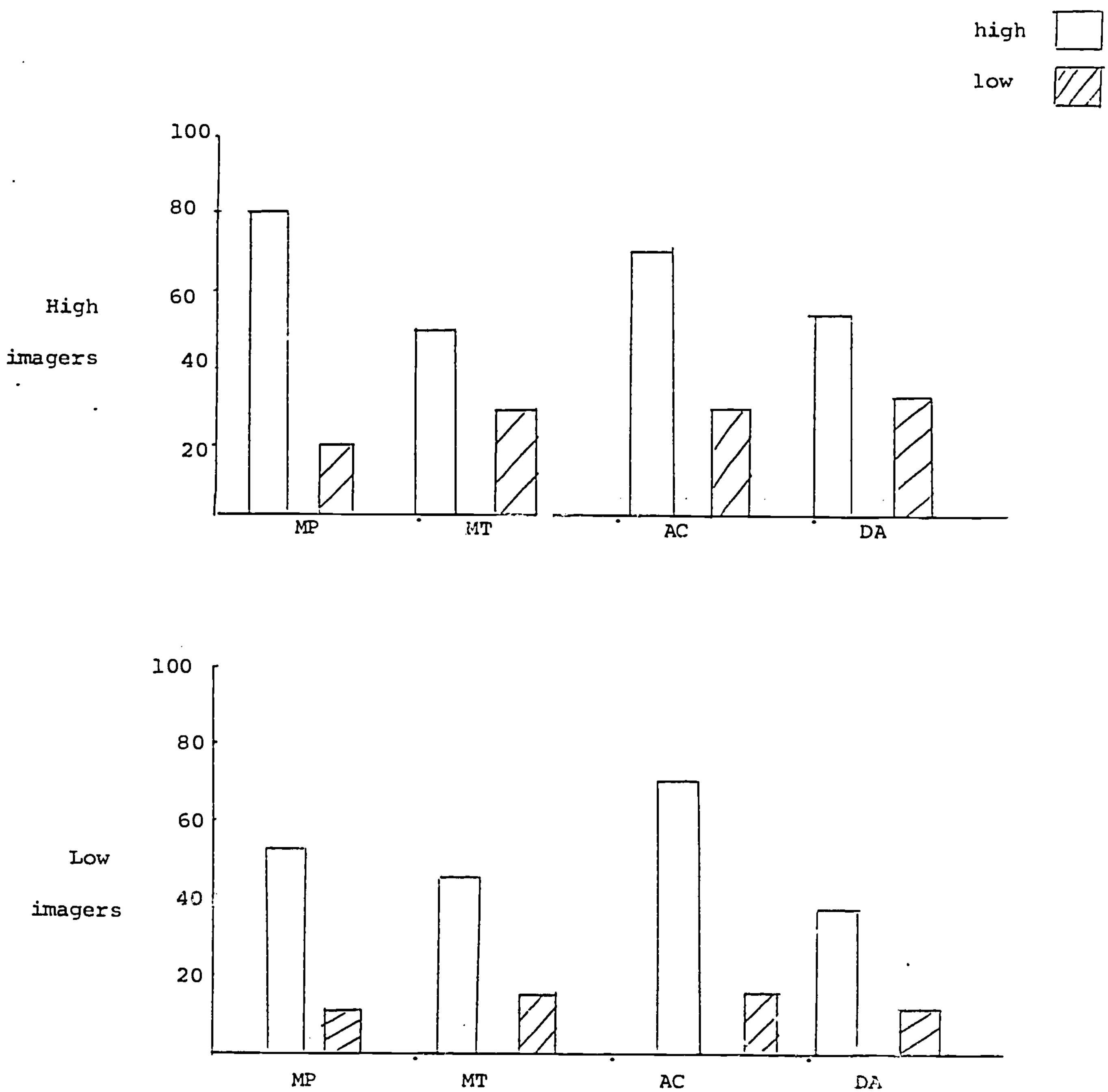
Percent Images Reported by High Imagers (top) and Low Imagers (bottom) to the Various Problem Types for high and low imagery material [(a)]



(a) 92, and 100 observations per cell for Low, and High imager subjects, respectively.

Figure 5

Percent of "Very Clear Image" Reports by High and Low Imagers to the Various Problem Types, for High and Low Imagery Material, Respectively (a)



(a) 92, 100 observations per cell for Low, and High imager subjects, respectively

Figure 6

Percent of Yes and No as a function of whether an image was reported (VC,PC) or not, for Low Imager subjects

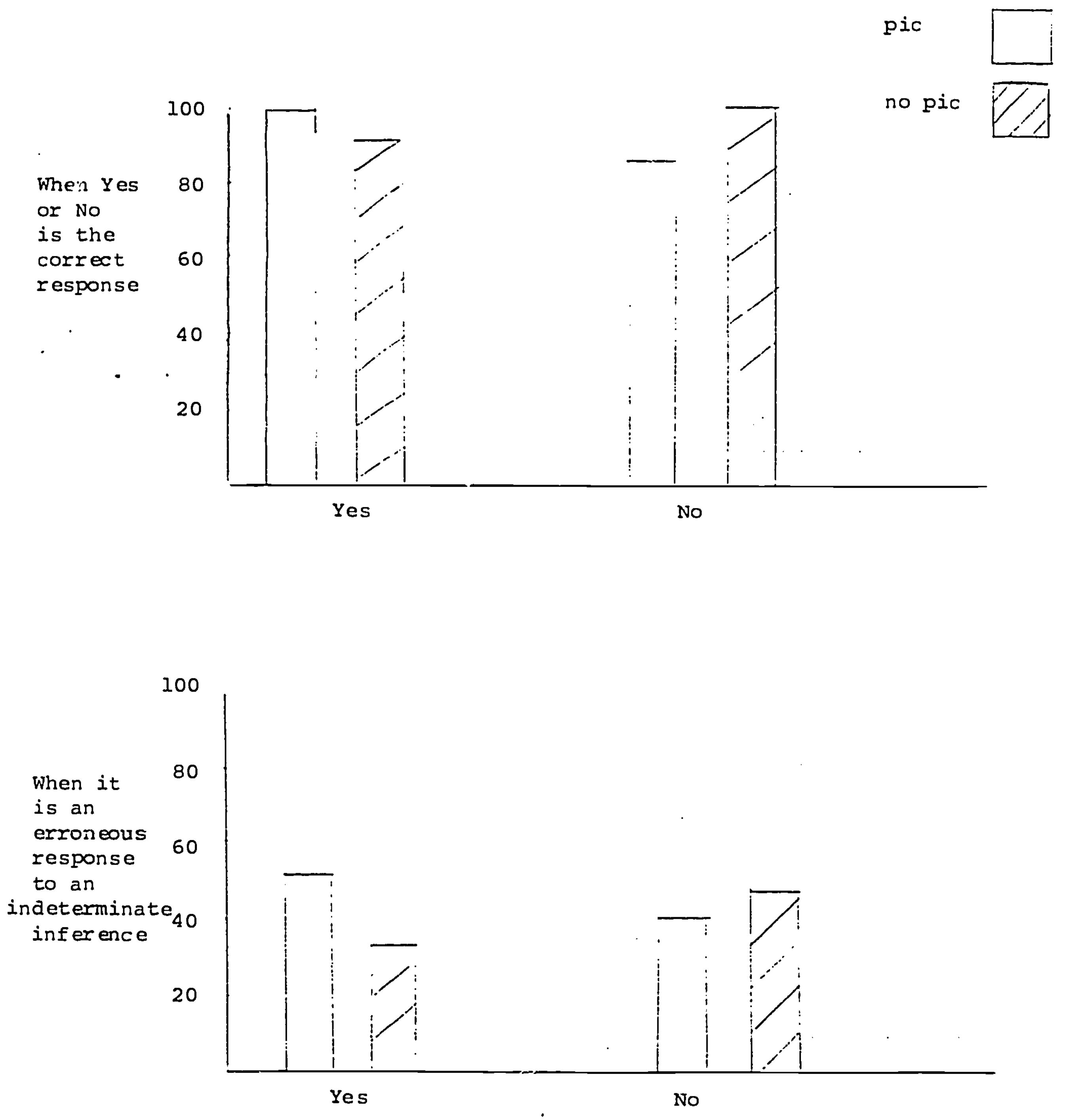


Figure 7

Percent of Yes and No as a function of whether an image was reported (VC,PC) or not, for High Imager subjects