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Factors Affecting the Difficulty of Verbal Analogies

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Abstract

The purpose of this study was to examine factors that affect the difficulty of verbal analogies in a psychometric exam. Two types of attributes were derived from theoretical cognitive models: (a) knowledge attributes, that were defined by word rarity and the degree to which the relation between the words was intensional, and (b) process attributes, that were defined by the existence of a negative component in the relation between the words, the order of the words, and the extent to which the relations were direct. A hundred and four analogies were characterized using these five attributes. Both knowledge and process attributes were found contributing to the difficulty of verbal analogies.

Factors Affecting the Difficulty of Verbal Analogies

Verbal analogies are used extensively in tests designed to predict academic success, such as the SAT and the GRE. These items have been the focus of much research dealing with identification of the cognitive processes involved in their solution and with individual differences with regard to these processes (e.g. Bejar, Chaffin, & Embretson, 1991; Gentile, Kessler, & Gentile, 1969; Sternberg, 1982; Whitely & Barnes, 1979). Few studies, however, have examined factors affecting the difficulty of verbal analogies (Buck, VanEssen, Tatsuoka, Kostin, Lutz, & Phelps, 1998; Duran, Enright, & Peirce, 1987; Freedle, Kostin, & Schwartz, 1987).

The purpose of this study is to offer a theoretical and empirical framework for research on factors affecting the difficulty of verbal analogies. Research on this issue has both theoretical and practical implications: Identifying the attributes that contribute most to item difficulty will contribute to theory development and to construct validation. In addition, such research may promote more efficient item writing.

To solve verbal analogies, examinees must find a relationship between the meanings of words. The items may be presented in several types of formats. The present research examined analogies that consisted of an initial pair of words called a “stem” and four additional pairs, one serving as a “key” (correct answer) and the others as “distractors”.

For example:

- | | | | |
|------|--------------|---|-----------|
| | to feed | : | satiety - |
| * 1) | to encourage | : | hope |
| 2) | to pierce | : | sharpness |
| 3) | to travel | : | speed |
| 4) | to lean on | : | support |

*Correct answer

Researchers have proposed different models for analyzing the stages involved in the solution of verbal analogies (e.g. Bejar, Chaffin, & Embretson, 1991; Gentile, Kessler, & Gentile, 1969; Sternberg, 1982; Whitely & Barnes, 1979). These models differ in many respects. Nevertheless, they all make the same distinction among three main components in the solution process: (a) components relevant to understanding the meaning of the words in the analogy, (b) components relevant to defining the relation between the words correctly, and (c) components relevant to choosing the correct answer from among the given options. The present study focused on the first two components¹.

The first component usually refers to knowing the meaning of the words in the analogy. It could be conceptually extended, however, to include any type of knowledge needed to find the solution. For example, to define correctly the relation between *malaria* and *mosquito*, it is essential to know that malaria is transmitted by mosquitoes.

The second component refers to the process of defining the relation between the words. The process component is based on the knowledge component but goes beyond it. It is based on it, because if a person does not possess the minimal knowledge needed to define the relation, the process component is meaningless. However, knowing the meaning of the words does not ensure producing a correct solution because the respondent still has to be able to define correctly the relation between the words.

Many of the aptitude tests that use verbal analogies also include a separate set of items specifically designed to test lexical knowledge (e.g. the SAT and the GRE). Thus, often, the process component of analogies is the main reason for their inclusion in a test battery. If this component does not affect the difficulty of analogies, the contribution of analogies to a test battery might be disputable.

The purpose of the present study was to identify some of the characteristics of analogies that contribute to the knowledge component and to the process component. In

addition, we tested whether the process component had a significant effect on the difficulty of analogies, an effect that transcended the effect of the knowledge component.

Factors affecting the difficulty of the knowledge component

Bejar et al. (1991) examined the correlation between the difficulty of analogies and the familiarity of the words in the stem and in the correct answer. Their measure of familiarity was based on objective word counts. The analogies were divided into ten separate categories according to the type of relation between the words in the stem, and each category was analyzed separately. Generally, word familiarity was negatively related to analogy difficulty, as expected. However, findings varied across categories: In some categories word familiarity explained up to 45% of the variance in the difficulty of the analogies while in others the two variables were not at all correlated. Bejar et al. (1991) noted that these inconsistencies indicate that the usage frequency of words is not the main factor determining the difficulty of analogies.

Understanding the meaning of the words is not the only knowledge component tested in analogies. Bejar et al. (1991) suggested the distinction between analogies in which the relation between the words is intensional and those in which the relation between the words is extensional. Intensional relations are inherent in the meanings of the words, and can be understood without reference to things outside the concepts used in the analogy.

Understanding extensional relations, however, requires additional knowledge. For example, Bejar et al. (1991) defined the relation between *farmer* and *person* as intensional, because part of the meaning of the word *farmer* is that a farmer is a *person*. In contrast, the relation between *farmer* and *tractor* is extensional, because not all farmers use tractors, and not all tractors are used by farmers. Thus, one of the factors that affect difficulty of extensional analogies is the extent of knowledge needed to define correctly the relation between the words. Chaffin, Peirce and Bejar (1990) validated the distinction between the two types of

relations by comparing the rate of success at solving analogies of examinees majoring in fields that emphasize verbal abilities and examinees majoring in fields that emphasize solving practical problems. They found that the verbal group did better on intensional analogies and the practical group did better on extensional analogies.

Factors Affecting the Difficulty of the Process Component

Much effort has been devoted in past research to devising categories for the different types of relations that exist between words in analogies. However, few studies have examined whether the different categories are related to psychometric characteristics. Ben-Simon, Stern, Ben-Shaz and Canaan-Yehoshafat (1991) assigned 98 analogies to six categories according to the type of semantic relation between the words in the stem and in the correct answer. In another study, Bejar, Chaffin and Embretson (1991) assigned 180 analogies to 10 categories. The taxonomy was based on the results of two previous studies in which the participants were asked to group together pairs of words with similar relations (Chaffin & Herrmann, 1984; Whitely, 1977). In both studies, no differences were found in the difficulty and discrimination indices among analogies assigned to the different categories. Bejar et al. (1991) also assessed the complexity of the relation between the words, by measuring the complexity of the sentence used to define that relation by subjects who tried to solve the analogies. No correlation was found between relation complexity and the difficulty of the analogies.

In sum, past research has been successful in measuring factors affecting the knowledge component in analogies, and assessing its contribution to the difficulty of solving this type of items. However, efforts directed at identifying and measuring the process component have been less fruitful.

The Present Study

We examined a series of variables that may affect the knowledge component and the process component. To assess the knowledge component we used variables that were found valid in past research: (a) word familiarity and (b) the degree to which a relation is extensional.

We defined the process component as the complexity of the relation between the words in the analogy. We reasoned that this complexity is related to the number of steps needed to define correctly the relationship between the words. We examined three process components: (c) the existence of a negative component in the analogy ($a \rightarrow b$; b is not a); (d) the order of the words in the analogy ($a \rightarrow b$; $b \rightarrow a$); and (e) the extent to which the relations were direct ($a \rightarrow c \rightarrow b$). Each of these factors entails a cognitive step beyond the correct definition of the words.

Knowledge components

(a) The rarity of the words in the analogy. We examined the correlation between the estimated rarity of the words in an analogy and the difficulty of the item. We hypothesized that item difficulty would be positively correlated with word rarity.

(b) Intensional and extensional relations. We set out to extend the distinction proposed by Bejar et al. (1991) between intensional and extensional relations. Bejar defined the two as having a dichotomous relation. We postulated however, that there is a continuum between relations that are purely intensional and relations that are purely extensional. A relationship that is always true is purely intensional (e.g., *choir : singing*); A relationship that is often true is more intensional than extensional (e.g., *soloist : singing*); a relationship that is true only sometimes is more extensional than intensional (e.g., *hoarse : singing*); etc.

The extent to which a relation is extensional may have opposing effects on its difficulty. First, to correctly define an intensional relation it is enough to know the meaning

of the two words in the pair. Conversely, to correctly define an extensional relation, additional information is needed. Therefore, it may be easier to solve analogies based on intensional relations than analogies based on extensional ones. However, an additional factor may have the opposite effect: When the relation between two words is not inherent in their meaning, it is possible to define it in several ways. For example, the relation between *singing* and *hoarse* may be defined as: “Singing may cause you to become hoarse,” “When you are hoarse, you find it difficult to sing,” or even, “You should not sing when you are hoarse.” Thus, to solve an extensional analogy it is enough to define correctly any one of these possible relations. In contrast, there is only one correct way to define an intensional relationship. Therefore, the examinees need more specific knowledge to solve analogies based on intensional relations than they need to solve analogies based on extensional ones. As a result, the former may be harder to solve than the latter.

It is difficult to hypothesize which of the options mentioned above has a greater effect on the difficulty of an analogy. If they have the same effect, there will be a very weak correlation between the difficulty of an analogy and the extent to which the analogy is based on an extensional relation. If, however, one of the two proposed options has a greater effect compared to the other, we shall find a relatively strong relation (positive or negative) between analogy difficulty and the extent to which the relation is extensional.

Process components

(c) The existence of a negative component in the relation. Past research has repeatedly shown that it is more difficult to process texts that include negative wording (e.g. Clark, 1974; Fodor, Fodor & Garrett, 1975; Johnson-Laird, 1983). The different models all support the conclusion that negative wordings add complexity to the processing of the text.

Negative components may exist in the relations between words as well. For example, the relation between *improvised* and *planning* is “improvised means without planning.” We

examined the effects of the existence of a negative component in the relations between the words in the stem and the words in the correct answer. We hypothesized that analogies with negative components in their relations would be harder to solve than analogies without such components.

(d) The order of the words in the analogy. In some verbal analogies the order of the words is perceived as being “natural”: it is easier to define the relation between the words by defining the first word in terms of the second than vice versa. In other analogies the order of the words is opposed to the “natural” order: it is easier to define the relation by defining the second word in terms of the first than vice versa. For instance, it is relatively easy to define the relation between *shady* and *cool*: “A shady place is generally cool.” Defining the relation between *cool* and *shady* is more complicated: “One of the possible reasons something is cool is because it is shady.” Research on processing sentences analogies has revealed robust order effects (Keane, 1997). The effect of order on word analogies, however, has not yet been examined.

We hypothesized that the order of the words would affect the difficulty of the analogy: analogies in which the order of the words was natural would be easier to solve than analogies in which the order was reversed.

(e) Direct and indirect relations. Between some pairs of words there is a direct relation that can be defined with very few words. Other relations are more complex and indirect. To define an indirect relation it is usually necessary to include a mediating object that connects the two words in the analogy. For instance, the relation between *loom* and *weaving* is a direct one: “A loom is used for weaving” In contrast, the relation between *candlestick* and *light* is indirect. To define the relation between these two words one must include something additional - a candle. The effect of directness on the difficulty of verbal analogies has not yet been examined. However, research on processing direct versus indirect

antonyms has revealed that processing direct antonyms is faster than processing indirect antonyms (Gross, Fischer, & Miller, 1989). We hypothesized that indirect analogies would be more difficult to solve than direct ones.

Summary of the hypotheses

First, we examined separately the effects of each of the above attributes on the difficulty of analogies. Then we examined whether the attributes related to the process component contribute to the difficulty of analogies above and beyond the contribution of the attributes related to the knowledge component. Our hypotheses were:

1. There is a positive correlation between the rarity of the words in an analogy and the difficulty of the analogy.
2. Extensional analogies and intensional analogies do not have the same level of difficulty.
3. Analogies that include a negative component are more difficult than analogies that do not include such a component.
4. Analogies in which the order of the words is natural are easier to solve than analogies in which the order is reversed.
5. Analogies in which the relations are indirect are more difficult than analogies in which the relations are direct.
6. Attributes related to the process component contribute to explaining the variance of the difficulty of verbal analogies beyond the contribution of attributes related to the knowledge component.

Method

Materials

One hundred and four analogies were selected randomly from the item pool of the Israeli Psychometric Entrance Test (PET). The PET is a selection instrument used in

undergraduate university admissions. The difficulty of the analogies was measured in calibrated delta units. The delta scale is a transformation of the percentage of those who answered correctly. The mean of the scale is 13, and its standard deviation is 4. The scale is calibrated so that the assessment of the difficulty of the items is not dependent on the ability of the specific pool of examinees that answered them. The mean difficulty of the analogies in the sample is 12.11 (SD=1.29).

Measures

The analogies were separated into their constituent word pairs, i.e., the stem and the correct answer². The word pairs were presented in a random order to groups of ten judges. The judges were drawn from the pool of expert item reviewers who routinely inspect the quality of items written for the PET. In almost all cases the different variables were assessed by different judges. The judges assessed the independent variables by determining the extent to which each pair of words was characterized by the assessed variable.

Knowledge variables

The rarity of the words in the analogy. The rarity of the words in previous research was assessed according to standard word frequency listings (e.g. Bejar et. al, 1991). This index is commonly assumed to assess the extent of familiarity with words and has been repeatedly found to affect adult word recognition (see Garlock, Walley & Metsala, 2001 for a review of this and other measures of word familiarity). In Hebrew, no up to date data of word frequency usage exists. Therefore, we developed a measure for assessing the rarity of the words in the analogies we studied. The pairs of words constituting the analogies were separated into single words that were ordered randomly. Ten judges assessed the level of rarity of each of the words based on the experienced frequency with which the words are used, by employing a seven-point scale (1 = used daily, 7 = rarely used). For 90% of the words, at least seven of the ten judges assessed the word's rarity within one level of difficulty

above or below the mean rarity. This measure lacks the objectivity of standard word counts. However, recently the use of subjective measures of word experience has gained support because objective word counts may not always reflect the actual frequency of experience with the words, and are subject to sampling biases (Garlock, Walley & Metsala, 2001; Gernsbacher, 1984, Gordon, 1985).

Intensional and extensional relations. Ten judges determined whether the relation between each pair of words was intensional, i.e. the relation always exists (for example, *fruit: apple* - an apple is always a fruit), or extensional, i.e. the relation does not always exist (for example, *singing: hoarse* - one does not always become hoarse when one sings, though sometimes one does). The degree of intensionality of a relationship was defined as the number of judges who agreed there was only one logically determined relation between the words. The values of this measure ranged from 0 to 10.

Process variables

The existence of a negative component in the relation. Ten judges determined whether the relation between each pair of words included a negative component. Relations were defined as “negative” when at least eight of the judges determined that they contained a negative component, and were defined as “non-negative” if at least eight judges determined that they did not contain a negative component. In all other cases, the relation was considered ambiguous.

The order of the words. Ten judges defined the relation between each pair of words twice and determined which of the two possible orders was more natural: the first word followed by the second word, or the second word followed by the first word. The order was defined as “reversed” if at least eight judges determined that the natural starting point for defining the relation was the second word. In all other cases, the relations were defined as “natural”.

We were concerned with the possibility that the measurement of this variable would be influenced by the order in which the words were first presented. To test this possibility we conducted a pretest in which the relations in 10 pairs of words were defined by two groups of judges. The first group received the words in the order in which they had originally appeared; the second group received them in the reversed order. The order in which the words were presented had no influence on the judges' determination of the natural starting point for defining the relation between the words.

Direct and indirect relations. Ten judges determined the extent to which the relation between each pair of words was direct. The "directness" of a relation was measured according to the number of judges who defined the relation as direct. The values of this measure ranged from 0 to 10.

Results

Knowledge variables

The rarity of the words in the analogy. We examined four indices for measuring the rarity of the words in analogies: (a) mean rarity of the four words in the stem and in the correct answer; (b) mean rarity of the two words in the stem; (c) mean rarity of the two words in the correct answer; (d) the rarity of the most rare word among the four. Though there is a close connection between the indices, they emphasize different aspects of the difficulty of the words that combine to form the analogy. First we will discuss the differences among the four indices, and then we will discuss the connection between each one of them and the difficulty of the analogy.

Table 1 about here

The mean rarity of the four words in the stem and in the correct answer was quite low (1.74). That is, most of the words in the stem and correct answer were judged as being in common daily use (table 1). The mean rarity of the rarest word (3.03) was significantly

higher³. Thus, in some of the analogies, at least one of the words in the stem or in the correct answer was considered by the judges to be rare, and it is likely that some of the examinees did not know its meaning.

Words in the stem ($M=2.21$) were judged to be more rare than words in the correct answer ($M=1.23$, $t(100)=8.14$, $p<0.05$). This difference may be the result of an item-writing policy that aims at making all the distractors as similar as possible in terms of word rarity, thus encouraging item writers to place the rarest word in the stem.

We hypothesized that there would be a positive correlation between the rarity of the words in an analogy and the difficulty of the analogy. The correlation between the four indices for the rarity of the words and the difficulty of the analogy appear in Table 2.

Table 2 about here

For all four indices there is a positive correlation between the rarity of the words and the difficulty of the analogy ($p<0.05$). Consistent with Bejar et.al (1991) the rarity of the words in an analogy correlated positively with the difficulty of the analogy.

One of the purposes of measuring the rarity of the words in verbal analogies was to examine whether this variable moderates the influence of other variables. We assumed that without understanding the words it is impossible to solve the analogy, even if the relations between the words are very simple. Therefore, we assumed that the process components would have more effect on the difficulty of analogies based on commonly used words that are understood by most of the examinees than on analogies that contained rarely used words.

In light of this consideration we divided the analogies in two groups: those including words judged to be in frequent daily use, and those including rare words. The first group consisted of analogies that included words from the bottom three quarters of the word rarity scores, and the second group consisted of analogies that included words from the top quarter.

In doing this, we determined rarity based on the rarest word among the four words of the stem and the correct answer.

Intensional and extensional relations. The more intensional the relation between the words the more difficult the analogy ($r=.21$, $p<.05$). There was a low and non-significant positive correlation between the two knowledge factors ($r=.17$).

Process variables

The existence of a negative component in the relation. We hypothesized that in analogies without rare words, the difficulty of analogies would be related to the existence of a negative component in the relation. More specifically, we expected that relations containing a negative element would be more difficult than relations not containing such an element. Findings supported this hypothesis (Table 3, $t(63) = 1.80$, $p<0.05$). This result is consistent with past research indicating that negative components raise the difficulty of processing verbal tasks (e.g. Fodor, Fodor, & Garrett, 1975).

Table 3 about here

The order of the words. The order in the stem and in the correct answer was determined by the judges to be reversed only in 15 of the analogies. Therefore, we did not analyze analogies with and without rare words separately. As hypothesized, analogies in which the order of the words was reversed were more difficult than analogies in which the order was natural (Table 4, $t(102)=2.01$, $p<0.05$).

Table 4 about here

Direct and indirect relations. We hypothesized that analogies in which the relations in the stem and in the correct answer were direct would be easier than analogies in which the relations were indirect. Table 5 presents the correlations between the relations in the stem and the correct answer and the difficulty of the analogy for analogies with rare words and without rare words.

Table 5 about here

The directness of the relations in analogies did not correlate with the difficulty of the analogies either for analogies with rare words or for analogies without rare words.

The distinctive contribution of the process components. We hypothesized that attributes related to the process components contribute to explaining the variance of the difficulty of verbal analogies above and beyond the contribution of attributes related to knowledge. To test this hypothesis, we conducted a hierarchical regression analysis. We first entered the knowledge components and then entered the process components. We included the four variables that had significant effects on item difficulty. The knowledge components were word rarity and the intensionality of the relationship. The process components were existence of a negative component and word order.

The two knowledge components correlated positively with item difficulty ($r = .30$, $F = 4.21$, $df = 82, 2$, $p < .05$). The addition of the two process components raised the correlation to $.39$. Only the contribution of the order component was significant ($F = 4.84$, $df = 81, 3$, $p < .05$). Thus, both the knowledge and process components had distinctive contributions to the difficulty of the items.

Discussion

The two knowledge variables (the rarity of the words and the intensionality of the relation) and two out of the three process variables (the existence of a negative component in a relation and the order of the words in a relation) that we examined have a significant influence on the difficulty of verbal analogies.

We did not find that the directness of the relation affected difficulty. We reasoned that indirect relations are more complex, and therefore are more difficult to define. Possibly indirect relations are not more complex; they merely need longer sentences to describe them.

Bejar et al. (1991) found no connection between length of sentence used to define the relationship between words and the difficulty of the analogies. It is possible that although the sentences used to define indirect relations are longer, the relations themselves do not require more complicated cognitive process for their definition.

In this study we analyzed the characteristics of existing analogies. The results could be validated using a different methodology: by writing analogies that differ in only one of their components and comparing the psychometric characteristics of the two versions. For example, one could examine the psychometric properties of two analogies identical in all respects except the order of the words in the stem, the correct answer and the distractors. This kind of experimental methodology would supply a firmer basis for causal interpretations of the factors related to the difficulty of analogies. Note however, that such a methodology is best suited for examining the effects of order of the words, because this entails only minimal differences between the analogies in the different experimental conditions. It is less suitable for examining the effects of variables such as the existence of a negative component because it would entail changing most of the words in the analogy.

We distinguish between two types of variables: those that are based on knowledge (the rarity of the words and intensionality), and those that are based on the complexity of the process needed to correctly define the relation (a negative component, the order of the words, and the directness of the relation).

The knowledge component in verbal analogies has been examined and validated in past research as well as in this study. It is easy to explain why this factor affects the difficulty of analogies. Obviously, if one does not understand the meaning of the words in an analogy, he or she cannot solve it. However, the reason for including verbal analogies in psychometric exams is not simply to test the knowledge component; these components are usually assessed with antonyms or vocabulary items. Analogies are included because of their supposedly

distinctive contribution to testing reasoning. We found that the process variables contribute to the difficulty of analogies above and beyond the effect of the knowledge component. Thus, the present findings support the contention that verbal analogies test cognitive ability, not merely knowledge.

The knowledge and process variables we examined explain only a small part of the variance of item difficulty. Other factors that might explain additional variance are strategies of choosing the correct answer among the distractors, and sub-populations and their different skills (Bejar et al. 1991; Duran, Enright, & Peirce, 1987; Freedle, Kostin, & Schwartz, 1987). In the introduction we presented three main components that have been identified by different authors as constituting the process of solving analogies (Gentile, et, al ,1969; Whitely & Barnes, 1979; Sternberg, 1982; Bejar et al., 1991): components relevant to understanding the words in the analogies; components relevant to a correct definition of the relations between the words; and components relevant to the identification of the correct answer among the distractors. In the present study we examined factors related only to the first two components. In the future it will be useful to examine the effects of distractors on the difficulty of analogies.

The results of the present study have practical implications for item writers. Writing analogies that have high discrimination coefficients for high ability examinees pose a constant challenge. The present results point to elements that could help writing analogies adapted for testing higher ability examinees.

Further research is needed to identify additional process variables that contribute to the difficulty of analogies independently from the knowledge factor. This will enhance deeper understanding of the cognitive processes that are involved in solving analogies. Such understanding is crucial for the construct validity of these items.

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Footnotes

1. The third component refers to choosing the correct answer from among the given options. This process depends heavily on factors beyond the scope of the present research such as decision-making processes, test-wiseness and test taking strategies.

2. The distractors are most relevant to the third component presented in p. 4 -- choosing the correct answer from among the given options; therefore, they are beyond the scope of the present research.

3. The two indices are dependent, since the mean of the four words in the stem and the correct answer includes the rarity estimate for the rarest word.

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Table 1

Means and Standard Deviation of Four Rarity Indices

Word Rarity Index	Mean	STD
The four words of the stem and the correct answer	1.74	0.62
The two words of the stem	2.21	0.81
The two words of the correct answer	1.23	0.90
The rarest word	3.03	1.02

Table 2

Correlations between Four Word Rarity Indices and Analogy Difficulty

Word Rarity Index	Correlation with Analogy Difficulty
The four words of the stem and the correct answer	0.21
The two words of the stem	0.17
The two words of the correct answer	0.18
The rarest word	0.22

Table 3

Mean Difficulty of Analogies as a Function of Word Rarity and Negative Component

Type of Analogies	n	Mean Difficulty	STD
Analogies with no rare words with a negative component	8	12.72	1.17
Analogies with no rare words without a negative component	57	11.87	1.26
Analogies with rare words with a negative component	15	13.02	1.09
Analogies with rare words without a negative component	7	12.15	2.10

Table 4

Mean difficulty of analogies as a function of the order of the words in the relation

Order of the words	n	Mean Difficulty	STD
Natural	89	12.00	1.22
Reversed	15	12.72	1.59

Table 5

Correlation between the Difficulty of the Analogy and the Directness of the Relation

	The whole sample	Analogies without rare words	Analogies with rare words
N	102	77	27
r	0.07	0.14	0.18