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ABSTRACT

The effect of a relevant analogy and of subject visualization on the amount of cognitive capacity needed to process unfamiliar information about science was investigated. The dependent measure was reaction time on a secondary task while listening to six tape recorded passages about chemistry and physics in a 2 x 2 x 6 mixed design. The analogy treatment group required less cognitive capacity and the visualization treatment group required more cognitive capacity to process the materials. The analogy results support the theory that analogies make mental processing more efficient by modifying existing cognitive structures prior to processing the new information. The visualization results support a theory that visualizers devote more attention to the material being processed. A general similarity effect of organizing devices is suggested. (Author)

ANALOGIES, VISUALIZATION AND MENTAL PROCESSING OF SCIENCE STORIES

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Abstract

The effect of a relevant analogy and of subject visualization on the amount of cognitive capacity needed to process unfamiliar information about science was investigated. The dependent measure was reaction time on a secondary task while listening to six tap recorded passages about Chemistry and Physics in a 2 x 2 x 6 mixed design. The analogy treatment group required less cognitive capacity and the visualization treatment group required more cognitive capacity to process the materials. The analogy results support the theory that analogies make mental processing more efficient by modifying existing cognitive structures prior to processing the new information. The visualization results support a theory that visualizers devote more attention to the material being processed. A general similarity effect of organizing devices is suggested.

Science journalists are often advised that analogies can be used to help readers understand unfamiliar material (Funkhouser & Maccoby, 1971, 1973). Scientists themselves make extensive use of analogies both in explaining science and in the discovery process of science itself (Dreistadt, 1968; Koestler, 1964; Kaufman, 1980); so, it seems natural that persons learning about science would also find analogies helpful.

Three suggestions have been made about the influence of analogies on mental processing. One view is that analogies help structure existing memory, preparing it for new information (Rumelhart & Ortony, 1977; Gentner, 1983). In this case an analogy comparing electricity in wires to water in a pipe helps memory make more efficient connections between new information and already existing information structures. Such a "structuring" view predicts that the increased efficiency of well-prepared cognitive structures would reduce demand on cognitive capacity.

Another possibility is that analogies make new information more concrete and easier to imagine (Davidson, 1976). Thus the water in a pipe analogy might help processing of newly learned electrical principles by making them more imaginable and vivid. Since it requires an additional concurrent mental process to imagine the material, "concretization" would predict that processing new material under the influence of a relevant analogy would make greater demands on cognitive capacity than if no such analogy was cognitively available.

Related is the possibility that analogies may interact with mental visualization processes (Simons, 1982). Active visualizers of the material being processed may make different use of an available analogy than persons not visualizing. A visualization hypothesis predicts an interaction effect in which the effect of analogy is different at different levels of visualization.

Thus, if the availability of an analogy influences mental processing, the three mechanisms of that influence suggested above make different predictions about the resulting demands on cognitive capacity. Current research has not directly compared any of these proposed mechanisms. Rather one model of analogy action, usually a concretization or structuring model, has been assumed, and researchers have focused almost exclusively on the conditions under which analogies improve recall. However, it is worthwhile to review this literature for hints about the possible cognitive effects of analogy.

After reviewing analogy studies in the communication literature, Grunig (1979) found that such stylistic elements are less important than content in journalistic attempts to teach the public about science. Simons (1982) cites ten classroom-learning related studies that found significantly greater recall with analogies than without. But several other studies focusing on educational applications of analogies found mixed if any effect of analogies on recall (Bell & Gagne, 1979; Smith, 1980; Curtis & Reigeluth, 1983).

In some cases analogies seem to help high ability or high intelligence subjects more than low ability subjects, but in other studies that relationship has been reversed. Sternberg (1977) found high ability students benefited most from having an analogy available when learning complex material. However, Bell and Gagne (1979) found that recall for subjects with low quantitative scores on the SAT were better in the analogy condition while subjects with high SAT quantitative scores did better in the no-analogy conditions. Subjects who scored low on a measure of the development of logical thinking benefited more from analogies than did those who scored higher (Gabel & Sherwood, 1980). Bartholomew (1973) found that including analogies in articles about physics caused physics students to stop and think and to report more understanding. But the analogies did not have the same effect on journalism students, who presumably need more help in understanding science.

Clear evidence that subjects likely to have more developed cognitive structures are helped more by analogies than subjects without such structures would tend to support a theory that analogies help to prepare already existing cognitive structures. A clear no-difference result between the two groups would tend to support a "concretization" theory, since that approach is less dependent on already existing cognitive structures. Neither pattern can clearly be distinguished here.

The case for an interaction between mental visualization and analogies is largely anecdotal and suggestive. Analogies reported by scientists are frequently visual--Kekule's visual image of fiery snakes forming a ring inspired his insight into the structure of Benzene. Einstein visualized himself as a passenger riding on a ray of light holding a mirror in front of him (Koestler, 1964). In fact, Einstein specifically wrote to one researcher that it was visual and muscular images, not words, that informed his thought (Hadamard, 1945).

Some studies support these anecdotes. When measuring long-term retention of science information, Simons (1982) found an interaction between his analogy-no-analogy treatment and a visualizer-verbalizer dimension. Verbalizers in the no-analogy group were able to remember more than the verbalizers in the analogy group, but visualizers in the analogy group performed the best. Kaufman (1980) concluded that analogy production is mediated through visual imagery after almost all of his subjects reported visualizing while trying to find pictorial analogies for the solution to a problem. And, supplementing verbal description with animated graphic analogies was shown to help learning of concepts in Chemistry more than verbal description alone (Rigney & Lutz, 1976).

If a mental interaction between visualization and analogy exists, differences in scientists and non-scientists' ability to visualize the material they are trying to encode might explain some of the apparently contradictory results concerning intelligence and science ability. Ability to transform analogies into visual images may also be an important aspect of the process of using analogies.

However, the measures employed in most analogy studies tell little about covert mental processing. The most common measure, recall, reveals something about an analogy's influence on retrieving what has already been learned, but tells nothing about the ongoing mental processing involved in the subject's first contact with the material. What is needed is a measure of the amount of mental work involved in the initial processing of material about science.

One such measure depends on people's limited capacity to perform multiple mental tasks. If you ask a companion to solve a mathematical problem in his or her head while walking rapidly, that person will generally walk slower while trying to solve the problem. In fact, it is very likely that he or she will slow down in some proportion to the difficulty of the problem. Solving a mental problem appears to call on at least some of the mental resources required for walking--resources that are in short supply if the problem is difficult enough. The harder the problem, the more mental resources the person diverts from walking to solving the problem. An analogous procedure called a secondary task analysis can be used in the laboratory to measure how much mental capacity is required for a particular task (Navon & Gopher, 1979, 1980; Posner, 1978; Ogden, Levine & Eisner, 1979). Such procedures have only recently been applied to mass media presentations (Reeves, Thorson & Schleuder, in press; Thorson, Reeves & Schleuder, 1984).

To discover how much cognitive capacity a task requires, the subject is asked to perform that "primary" task (listen to an explanation of a scientific principle, for example). While performing the primary task, the subject must periodically perform a "secondary" task (pressing a button that records reaction time). The assumption is that mental processing of the primary and secondary tasks call upon many of the same mental resources--resources that are in short supply if the primary task is difficult enough. If the two tasks require a substantial number of the same mental resources and if that joint demand exceeds the available supply of those mental capacities, a change in the mental resources required for one task will change the mental resources available to the other task.

If the difficulty of the secondary task is held constant, the only explanation for a change in performance on that task is that the primary task is using more or less of the available mental capacity. It is possible for a person through practice to become so good at a task that the task requires little mental capacity (Anderson, 1980). But such automation is unlikely to be significant in a small number of trials with a complex task.

One tested method of performing a secondary task analysis with complex textual material is to have the experimental subject read or listen to the material with the goal of learning the material (Britton, et al., 1978; Britton, 1980; Britton et al.,1980). Periodically during the task, the subject is asked to respond to a probe signal as quickly as possible. The variation in reaction time to that signal is taken as a measure of the amount of cognitive capacity taken up by the primary task at that moment. Thus, the slower the reaction time on the secondary task the more cognitive capacity is assumed to be used by the primary task.

Such reaction time differences have been found for metaphors which were logically false but had some figurative or imaginative truth (Glucksberg, Gildea & Bookin, 1982).[1] Subjects spent significantly more time to declare a metaphor false than to declare more literal statements false, indicating that metaphors required additional mental processing despite the fact that the metaphors were as obviously false as the literal statements. The mental processing requirements of analogies have never been investigated.

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[1] The distinction between analogy and metaphor is not always made in the literature. In fact, the terms are often used interchangeably. The empirical evidence, however, supports distinguishing the two terms. Metaphoric capacity does not relate to ability to solve analogies (Pollio & Smith, 1980); a metaphor's meaning cannot be derived by breaking down a sentence into component parts according to rules (Hoffman & Honeck, 1980); metaphors as simple propositions are false (Honeck, 1980), and metaphors seem to produce a readiness for fanciful experience (Verbrugge, 1980). Analogies, on the other hand, seem to be ordinary, literal language that partially map an unfamiliar area of experience onto a more familiar area of experience (Gentner, 1983). While an analogy that compares water flowing through pipes to the flow of electricity through wires is not precisely true, it is not false, fanciful, and difficult to linguistically decompose in the same way as a metaphor like "A marriage is a refrigerator" or A poem is a pheasant."

What is crucial for analogies is not so much the mental demands of processing the analogy itself, but what influence mental availability (activation) of the analogy has on subsequent processing of unfamiliar information related to the analogy. Under those circumstances, if processing the target material required more mental resources, that would indicate that some additional mental process caused by the analogy is slowing reaction time, thus supporting a view that analogies cause mental processing to be more vivid and concrete. However, if analogies work by activating and modifying existing cognitive structures, making them more efficient at processing the incoming new information, the amount of mental capacity required to process the new information would be expected to decrease. Thus secondary task reaction times would be expected to be faster with an active analogy guiding the processing. Therefore, an appropriate secondary task analysis should distinguish between these two mechanisms of analogy influence. This can be stated more formally in terms of competing hypotheses.

Hypothesis 1: Subjects processing unfamiliar material about science when a relevant analogy is active will require more cognitive processing capacity to process that material than will subjects without such an analogy activated.

Hypothesis 1: (Alternative) Subjects processing unfamiliar material about science when a relevant analogy is active will require less cognitive processing capacity to process that material than will subjects without such an analogy activated.

The literature for visualization does not yield a clear prediction for the effect of active visualization during processing on the amount of cognitive capacity required. At least one study (Griffith & Johnston, 1973) found that a visualization mnemonic was associated with subjects expending less cognitive processing capacity while studying new material than did subjects using a rote mnemonic. Thus, it may be that visualization makes encoding more efficient. But a variety of studies (Anderson, 1980) indicate that the more complex the visualization task, the longer the latency to response. This would be compatible with a picture of visualization as an additional cognitive process taking up a share of limited cognitive capacity. Thus a task in which a subject is asked to visualize while encoding new material may shed light on which of these explanations is correct.

In addition, if an analogy is more likely to help an actively visualizing subject, one would expect to see the effect of analogy change across levels of visualization. The exact nature of this interaction depends on whether analogy increases or decreases the amount of cognitive capacity required. If analogy increases the amount of cognitive capacity required (Hypothesis 1) then the reaction times for the analogy group should increase with visualization more than the non-analogy group. However, if alternative hypothesis 1 holds, then reaction times for the analogy group should decrease with visualization more than the non-analogy group. Given these considerations about visualization, two additional hypotheses can be generated.

Hypothesis 2: Subjects who are visualizing while processing new information about science will require more cognitive capacity for that processing than will subjects not visualizing.

Hypothesis 3: Analogy and visualization treatments will interact so that the effect of analogy on cognitive capacity will be greater for the visualization group than for the no-visualization group.

Method

Preparation of Stimulus Materials

Seventeen analogy passages for concepts or processes in Chemistry and Physics were selected from a variety of sources including popularized science magazines, physical science texts, and popularized accounts of science written by scientists. Chemistry and Physics were purposely selected as being topics in which the available subjects (undergraduate journalism students) would have a uniformly low level of interest and knowledge, thus reducing between-subjects variance due to those factors.

The analogy passages were rewritten to shorten them and to present each analogy passage in a standard format. 1. A question title. 2 A short paragraph introducing the topic. 3. A paragraph explicitly introducing the analogy. 4. A paragraph explaining the scientific concept or process. (See Sample Passage: Appendix.) The format was specifically designed so that the rest of the material did not depend on the analogy paragraph for comprehension of the material or for continuity.

The passages were duplicated and assembled in a booklet, counterbalancing for presentation order. The booklets were distributed to students in two sections of an advertising copy and layout course. Subjects were given 40 minutes to rate all of the passages. The subjects were asked to rate the overall passage separately from the analogy. Since not every subject finished the booklet in the allotted time, sample sizes varied, but each passage was rated by no fewer than 30 subjects.

Subjects were asked to rate each specified quality on a scale of 0 to 10, in which 0 was specified as none of the quality and 10 was specified as being as much of that quality as the subject could imagine.

Since quality and understandability of the analogies have been issues in previous studies (Gabel & Sherwood, 1980; Hayes and Tierney, 1980) the mean ratings for the analogy portion of the passage were compiled for four qualities--"Connected" (to the overall passage), "Helpful" (in understanding the overall passage, "Visual" and "Understandable." The analogy passages were rank ordered according to their mean score on each of these qualities. A score of 10 was assigned to having the highest mean on a quality, 9 to the next highest mean and so on to 0. These scores were then added together for each analogy on the first three qualities mentioned above. The six highest scoring passages were also the six passages with the highest means for "Understandable" analogy. (See Table 1) These six analogies were selected as the analogy stimulus materials. The passage with the seventh highest overall score was selected for practice.

Insert Table 1 about here

To control the pace of the presentation and the location of the secondary task probe, the material was read by a male professional radio announcer who was naive to the purpose of the study and was recorded on audio tape. Probes to fire a secondary task strobe light were recorded on a second track of the audio tape using the following rules: two probes were randomly distributed in each of three sections of the passage (title-introduction, analogy paragraph, explanation paragraph) with one probe being randomly distributed in the first half of each section and one in the second half. (Six probes in each passage.) Probes were not allowed in the first or last five words of a section, and probes were not allowed within ten words of each other. The two probes in the title-introduction section were designated RTA (reaction time A) and RTB; the two probes in the analogy paragraph were designated RTC and RTD, and the two probes in the explanation paragraph were designated RTE and RTF.

The no-analogy treatment was prepared by editing out the analogy paragraph (including tones) when dubbing the passages to the cassette tapes used in the actual experiment. Note that the analogy and no-analogy treatments were different lengths and had different numbers of probes (6 vs. 4). It was felt that the alternatives (substituting an unrelated passage, two probes without passage, distributing the two probes through the rest of the passage) would be as likely or more likely to influence performance. The advantage of the current design is that, particularly for the last two probes in any passage, cognitive channel capacity expended is measured while the subject is reacting to exactly the same secondary task probes in exactly the same location in exactly the same material.

Subjects

Subjects were 40 undergraduate male and female volunteers from advertising, mass media and news writing classes. Subjects were randomly assigned to one of four conditions: no-analogy, no-visualization (NA-NV); no-analogy, visualization (NA-V); analogy, no-visualization (A-NV), and analogy, visualization (A-V) in a 2 X 2 factorial design. An equipment problem early in the experiment resulted in the results for four subjects being discarded because more than 20 percent of the RTE and RTF values were not recorded by the computer. In the end 36 subjects were used with 9 subjects in each of the four conditions.

Procedure

Subjects were told that their main task was to listen to and remember the material for a test given after each passage. But whenever they saw a flash of light, they were to press a button as quickly as possible.

All subjects were relaxed using a progressive muscle relaxation technique. In addition, V subjects were trained to visualize material similar to that they were going to hear, using a modified version of a technique used by Lang (1984). V subjects were instructed to continue visualizing the material they were about to hear--that this was an important part of the experiment. To reinforce the visualization instructions, V subjects were asked to rate their ability to visualize the previous passage after taking the recall test for each passage. To further strengthen the V treatment, V subjects were reminded to continue visualizing the material just before listening to each passage.

During the secondary task procedure, each subject was seated in the experiment room facing a blank white wall. Above them and to their right a strobe light was placed in a corner of the experiment room near the ceiling and aimed down into the room. The strobe light was attached to photo-stimulator (Grass Instruments Model PS-2D) in an adjacent observation room. The photo-stimulator was adjusted so that a flash from the strobe light could comfortably be detected by the subjects.

The stimulus tapes were played on a stereo cassette deck in the experiment room. The signal from the channel containing the stimulus material was fed into an amplifier in the observation room and played back over a speaker in the experiment room--with the volume adjusted to a comfortable listening level. The output of the tape channel containing the probes to trigger the strobe and to begin timing the secondary task was fed into another amplifier, and from there into an Apple II+ computer. When the computer detected a probe, a resident program activated a relay causing the photo-stimulator to fire the strobe. Simultaneously, a computer clock timed the interval from the flash firing to the subject pressing a reaction time button connected to the computer. The computer stored the reaction times by passage and by position within each passage.

After relaxation (and visualization training for the V subjects) all subjects went through the entire procedure outlined below using a practice passage (corresponding to that subject's particular A or NA treatment) to ensure that the subject understood the procedure, to stabilize reaction times, and to further encourage subjects to pay close attention to the primary task material.

For each passage, each subject listened to the audio tape and performed the secondary task procedure. After each tape there was a 5-second pause, then subjects were given a 90-second distraction task (counting backwards by three's from 5,000) to ensure that recall on the following recall task was not just a report of material still current in short-term memory. Subjects were then given a five-item recall test for material in the title-introduction and the explanation sections of the passage just heard. Subjects were not tested on material in the analogy. The recall tests were intended to help probe the relationship, if any, between the mental processing measures and recall.

The order of the passages was randomized for each subject to control for order effects across passages (fatigue, practice, etc.) The above procedure was repeated for the practice passage and each of the six test passages.

In addition, when subjects first entered the experiment room, information was gathered on age, gender, major, year in school, grade point average (both college and high school), number of science courses taken in school (both high school and college), self-ratings of interest in science and likelihood of reading a science article encountered in the print media as well as a list of broadcast science programs regularly watched and listened to. These were intended as measures of general intelligence, experience with science material, and interest in science to be used to ensure that the experimental groups did not differ significantly on these measures.

Results

Reaction times RTE and RTF (the last two reaction times measured in each passage) were used as the dependent variable in a 2 X 2 mixed factorial design with analogy and visualization treatments the independent variables. Each reaction time was nested within the corresponding passage and treated as a within-subject variable. Thus each subject was considered to have 12 repeated measures (RTE and RTF in six passages).

An analysis of variance (BMDP P2V) indicated that only the main effect for visualization was significant, $F(1,32) = 6.21$, $p < 0.02$.[2] The average visualization group reaction time was

[2] The data were visually inspected for obvious differences between the treatment groups on interest in science and science education variables. None were found. No obvious pattern emerged relating to the length of a passage and its

about 35 msec. slower than the average no-visualization group reaction time. (V = 321.53 msec.: NV = 286.51 msec.) (Figure 1). However, a power analysis indicated insufficient power, especially for detecting the modest effect size suggested by the results of the analogy X visualization interaction.

Insert Figure 1 About Here

The standard deviations of RTE and RTF were often very large (ranging up to 147 msec. for some passages) apparently due to very large individual subject variations in reaction time. Since RTA and RTB (the two reaction times in the title-introduction section) were responses to exactly the same material for all groups and since these reaction times were measured before analogy subjects were exposed to the analogy, they were considered appropriate measures of each subject's underlying reaction time. Thus, RTA and RTB were entered as covariates in an analysis of covariance--controlling for each subject's base

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performance under any of the conditions with either of the dependent measures.

reaction time to the secondary task (Cohen & Cohen, 1983). The resulting analysis of adjusted means showed a main effect for analogy, $F(1,31) = 4.78$, $p < .04$. (Figure 2) The adjusted mean for the analogy treatment group reaction time was about 12 msec. faster than the average no-analogy group adjusted mean reaction time. (A =298.02: NA = 310.01 msec.)

Insert Figure 2 About Here

It should be noted that since visualization group subjects received visualization training before listening to any of the passages, the visualization treatment was in effect for RTA and RTB as well as for RTE and RTF. Thus, using the first two reaction times as a covariate had the unfortunate side effect of removing the effect of the visualization treatment and eliminating the possibility that any analogy-visualization interaction would show up in this analysis.

For the recall measure, both the main effects and the interaction effect were not significant.[3]

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[3] An analysis of covariance using high school science courses taken and an interest in science scale as covariates yielded approximately the same results for the recall measure.

Discussion

The results support alternative hypothesis I, namely that processing new material about science under the influence of an activated analogy is more efficient and requires less cognitive processing capacity. One possible explanation for this is that an analogy literally prepares the way for the new information by activating and modifying existing cognitive structures so that they can operate more efficiently. Since recall for the analogy group was the same as the no-analogy group, this increased efficiency seems to come without any cost to performance.

Although the analogy X passage interaction was not significant, it is worth noting (Figure 3) that two of the passages (subatomic particles and relativity) had results in the opposite direction--reaction times were longer for the analogy group. These two passages were in the middle range of length and were sixth and second in the pretest overall ratings of quality, ruling out the two most obvious explanations for their different behavior. It is possible that the differences are purely accidental, but it is also possible that some non-obvious internal quality of analogy might determine the effect of an analogy. Although there are a few theories (for example, Gentner, 1983) not enough is known about what makes a "good" analogy.

Insert Figure 3 about here

The visualization manipulation was effective and powerful. Visualization group subjects used more cognitive channel capacity in processing the material than the no-visualization subjects--without any loss in performance on the recall measure. Thus hypothesis 2 appears confirmed. However, an examination of the simple main effect for visualization at each passage was significant for only two of the passages and nearly significant for a third; virtually all of the visualization effect is the effect of those three passages. It was not obvious what shared characteristics might have made only those three passages responsive to the visualization treatment. Again, not enough is known about what makes a good analogy.

Another troubling aspect is that the facilitating affect of visualization on long-term memory is well established in the psychological literature (for example, Anderson, 1980; Pavio, 1971; Delin, 1969; Bower, 1972; Pressley, 1977 a and b) yet there was no apparent affect of visualization on recall in the current study. It is possible that the recall measure used was not sensitive, but that seems unlikely since the scores were widely distributed more or less normally and show no evidence of floor or ceiling effects. Another more likely explanation is that psychological experiments on visualization and memory tend to use highly simplified stimulus material, and that the effects noted in such experiments are not generalizable to experiments using the more complex, more realistic stimulus material used here.

What limited resource, then, is the visualizing subject using more of? One plausible answer is that the visualizing subject may be applying more scarce attentional resources to the incoming material (Kinchla, 1980). That is, the visualizing subject is more engaged by the material he or she is listening to and therefore devotes more attention to the material.

An alternative explanation is that visualization is simply another task added to the subject's cognitive processing burden, a task that creates mental work without any particular cognitive rewards.

To distinguish between these two possibilities in the future, it might be helpful to gather self-report data indicating how helpful the subjects believed the visualization strategy to be and attitudes toward the material with and without visualization.

The results overall indicate that processing unfamiliar information about science is affected by analogies and visualization. In the case of analogy it appears that the presence of an active analogy allows the listener to expend less effort to process the information. That efficiency factor might explain why despite the mixed indications about the helpfulness of analogy in recalling information about science, the use of analogy has such broad appeal and is so often recommended.

The results for visualization are less clear. It may well be that active visualization of the kind practiced here may simply involve more cognitive work for the listener without any reward. But it is also possible that visualization makes processing the information about science more engaging, thus causing the listener to attend more closely to the material. The answer to that question may depend on a closer examination of the listener's own reports of involvement and engagement.

Finally, it should be noted that the observed effect may not be specific to analogies but may be true of other organizing devices used in written material such as examples and illustrations. Recently Meadowcroft (1985) found that viewing of children's adventure programs required reduced processing effort for children with high story schema skills. This may be linked to the current research in that it is possible that any device or skill that helps subjects compare new information to current knowledge may reduce the amount of cognitive effort needed to process the new information. This "similarity" effect warrants further investigation.

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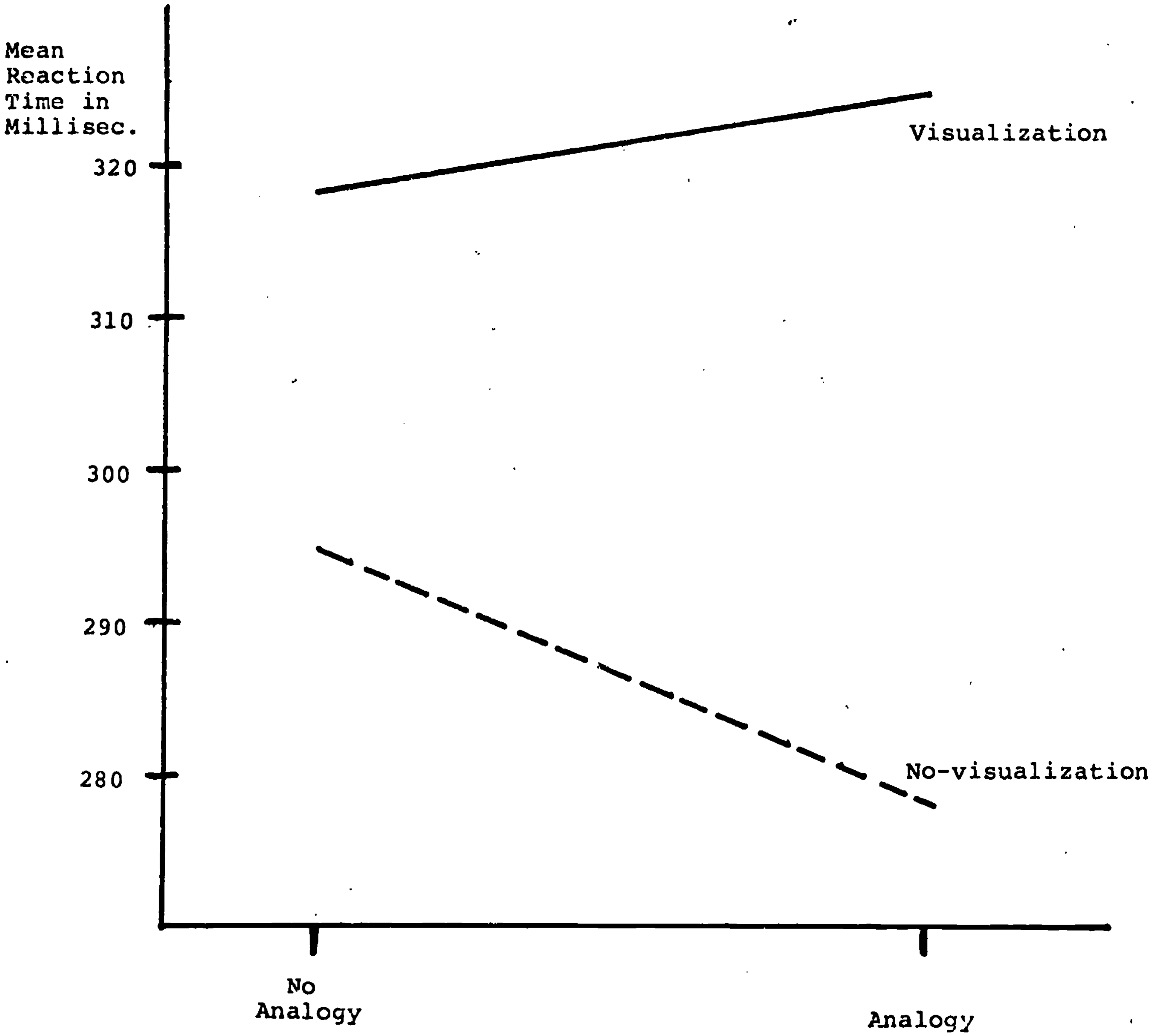
Table 1

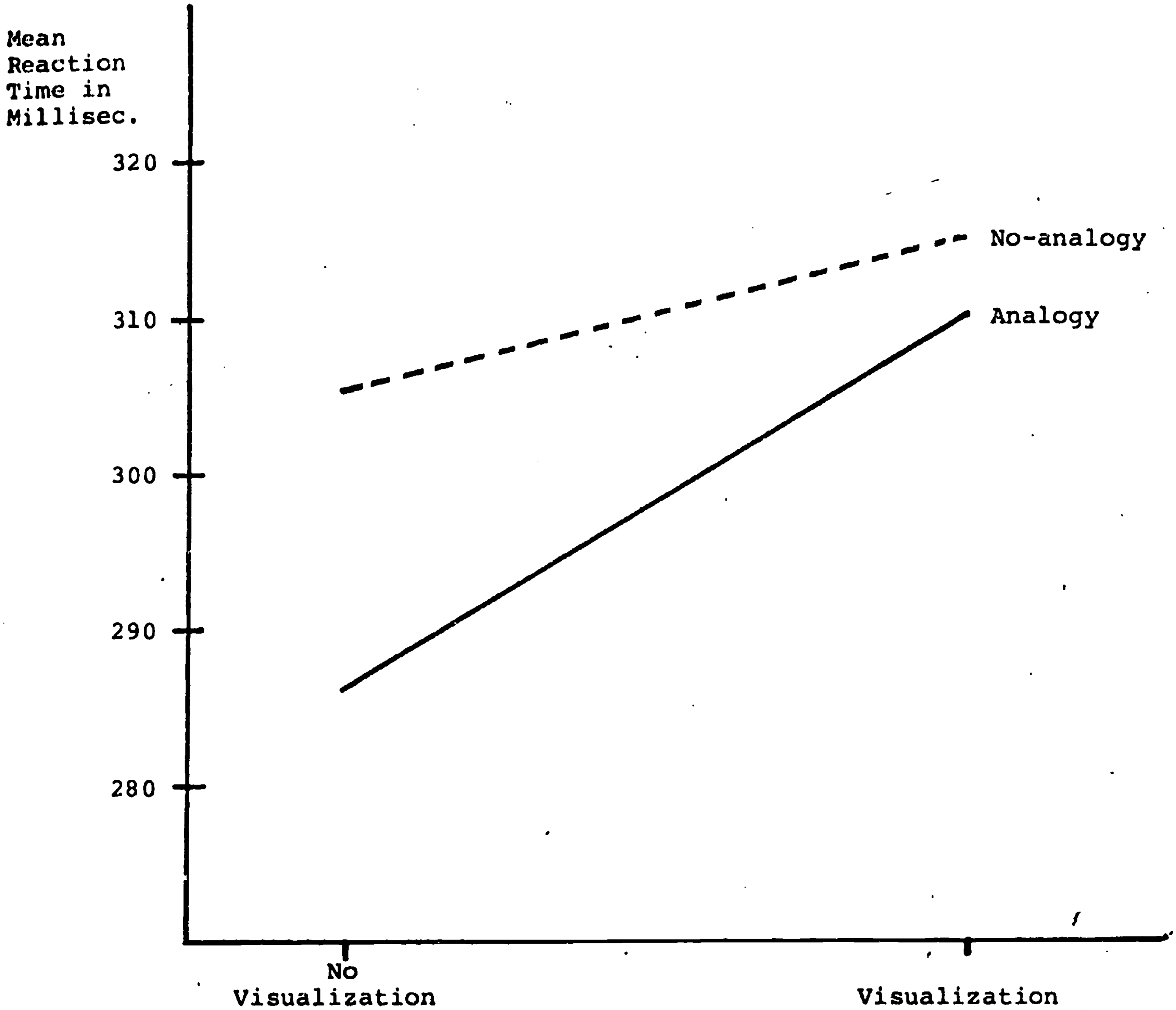
Concept-Analogy	"Connected" Mean for	Rank	"Helpful" Mean for	Rank	"Visual" Mean for	Rank	"Understandable" Mean for	Rank	Rank Score
Expanding Universe-Inflating Balloon	6.27	1	6.2	2	6.57	3	6.76	6	27
Relativity-Golf Course	5.96	2	6.52	1	6.70	1	6.85	4	29
Doppler Effect-Traveling Salesman	5.38	4	5.86	3	5.83	6	7.31	1	20
Radioactive Decay-Insurance Company	5.37	5	5.81	4	5.07	10	6.85	5	14
Speed of light traffic lights	5.32	6	5.52	5	6.04	4	7.00	3	18
Subatomic interaction-basketball	4.78	8	5.48	6	6.65	2	7.22	2	17

FIGURE 1



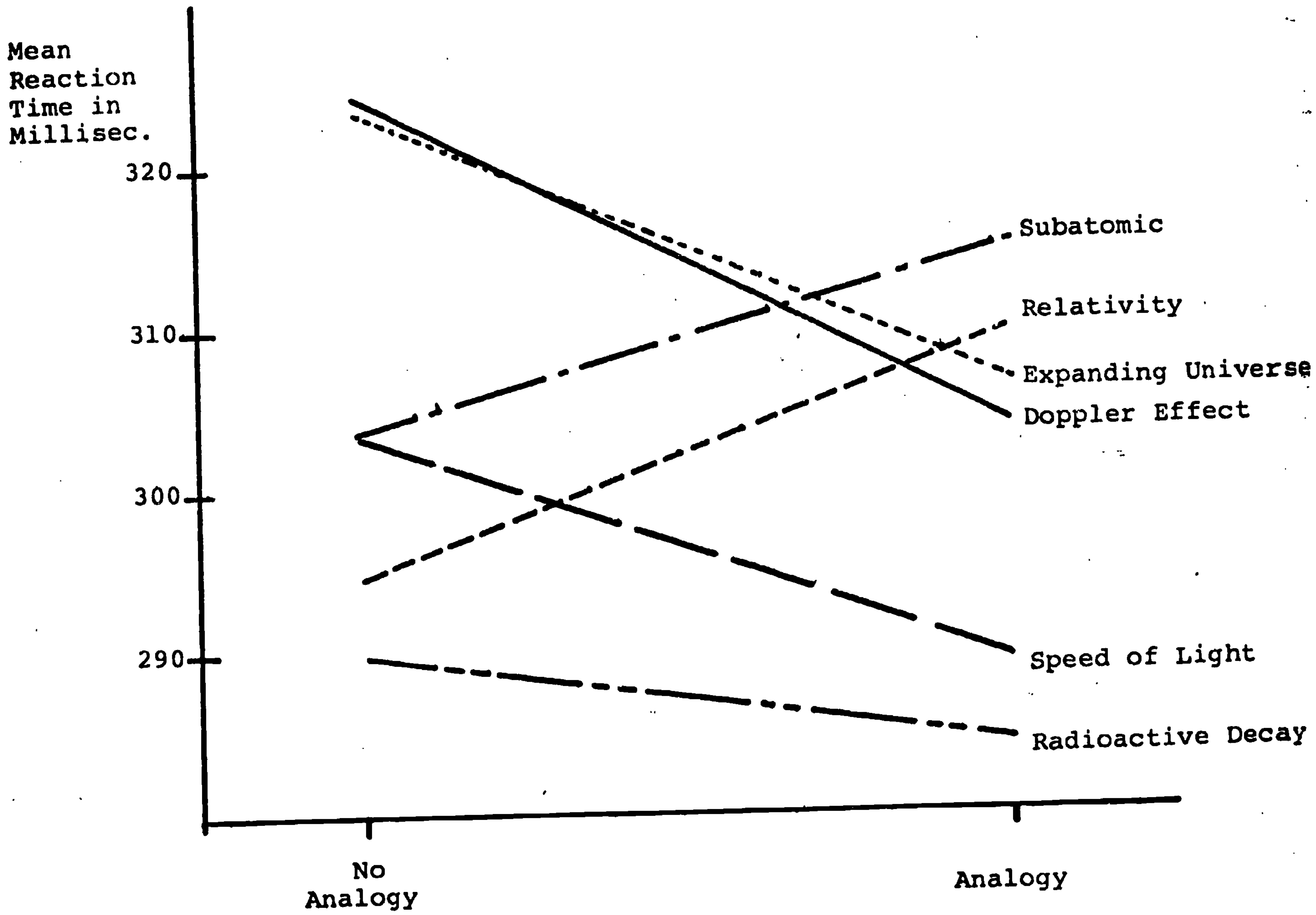
Mean of reaction times RTE and RTF for the visualization and no visualization groups.

FIGURE 2



Adjusted cell mean of reaction times
RTE and RTF for the analogy and no-analogy
treatment. (RTA and RTB used as Covariates).

FIGURE 3



Mean of reaction times RTE and RTF for the analogy and no-analogy groups by passages.

Appendix

Sample Passage

How do astronomers know that the universe is expanding?

A familiar property of any sort of wave motion is the Doppler effect. This says that the wavelength of a wave will appear to be shorter when the source of the wave is moving toward us and longer when the source is moving away from us.

This is analogous to a traveling salesman who sends a letter home once a week during his travels. While he is traveling away from home, each successive letter will have a little farther to go than the one before; so his letters will arrive a little more than a week apart. On the homeward leg of his journey, each successive letter will have a shorter distance to travel; so they will arrive more frequently than once a week.

When we observe a source of light at rest, the time between the arrival of wave crests at our instruments is the same as the time between crests as they leave the source. But if the source of light is moving away from us, the time between arrivals of successive wave crests is increased over the time between their departures from the source, because each crest has a little farther to go on its journey to us than the crest before. The time between crests is just the wavelength divided by the speed of the wave; so a wave from a source moving away from us will appear to have a longer wavelength than if the source were at rest. Similarly, if the source is moving toward us, the time between arrivals of wave crests is decreased, and the wave appears to have a shorter wavelength. When scientists look through telescopes at the most distant galaxies, they often record a spectrum of colors from the galaxy. Such spectra are crossed with hundreds of dark lines always found at the same colors. But these lines are consistently shifted toward the red end of the spectrum, indicating that these galaxies are moving away from us (and in fact from each other) at high speed.