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Visual–Spatial abilities and goal effect on strategies used to solve a block design task

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ABSTRACT

In this experiment we studied the effect of goal setting on the strategies used to perform a block design task called Samuel. Samuel can measure many indicators, which are then combined to determine the strategies used by participants when solving Samuel problems. Two experimental groups were set up: one group was given an explicit, difficult goal; the other was not given a goal. The two groups were comparable in their average visual–spatial abilities. The results indicated that the goal had an effect on the cognitive strategies used. The participants with a goal had a higher anticipation index, which is strongly linked to visual–spatial abilities. This beneficial effect of a specific, difficult goal occurred regardless of the participants' initial visual–spatial abilities, that is, anticipation was greater in the groups with a goal, whether they had good or poor visual–spatial abilities. However, insofar as the model-viewing frequency was higher in the goal group, the goal did not have an effect on synthetic-strategy use, which was the most strongly correlated with visual–spatial abilities.

1. Framework

The purpose of the present study, conducted in the framework of goal-setting theory (Latham & Locke, 2007), was to assess how goals affect performance and strategies on intelligence tests. Taking a goal-setting perspective, many studies have shown that performance enhancement depends on both the strategies available for the task (Seijts & Latham, 2005) and the participants' cognitive abilities (Seijts, 2009). Here, we used a computerized tool to study performance and strategies on Kohs Block Design Task (Rozencwajg & Corroyer, 2002), a task that is tightly linked to visual–spatial abilities. The original Kohs Block Design Task was published by Kohs in 1920 (Kohs, 1920).

1.1. Goal-setting theory

1.1.1. Assigning a goal and directing attention

For several decades, the goal-setting paradigm has provided a framework for explaining the effect of motivation on performance. Many studies have shown that assigning participants a goal that is both specific and difficult leads to better performance than a vague goal such as “Do your best” (Latham & Locke, 2007; Locke & Latham, 1990; Locke & Latham, 2002), where a specific goal is one that clearly states what level of performance the participant should strive to attain. According to Locke and Latham (2002), “This is because do-your-best goals have no external referent and thus are defined idiosyncratically. This allows for a wide range of acceptable performance levels, which is not the case when a goal level is specified” (p. 706). Indeed, specifying the performance level to be attained will attract the participant's attention to the task aspects most relevant to the specified goal. Locke and Bryan (1969), for example, who used an automobile-driving task with multiple feedbacks about various aspects of the task, showed that performance increased only on dimensions related to the assigned goal. A specific goal alone, however, is not enough to lead to higher performance. The goal must also be difficult (for a review, see Latham & Locke, 2007, and Locke & Latham, 2002). A difficult goal is one that only a small number of individuals can attain. In a text-learning task, Laporte and Nath (1976) showed that a specific but easy goal (attained by 80% of the participants in the do-your-best group) did not give rise to better results than a vague, do-your-best goal. On the other hand a specific, difficult goal (attained by 10% of the participants in the do-your-best group) significantly improved performance as compared to a vague goal or a specific, easy goal.

Locke and Latham (2002) explained the positive effect of a specific, difficult goal on performance not only in terms of attention but also in terms of effort. In an experiment by Rothkopf and Billington (1979), subjects spent more time studying texts when they had such a goal. Similarly, in Rozencwajg and Fenouillet's (2012) study using a visual–spatial construction task, participants were able to reach the goal by maintaining a high level of effort throughout task execution.

1.1.2. Importance of strategies and cognitive abilities with a goal

But simply allocating more effort may not always suffice because participants also need to have an adequate strategy for carrying out

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the task. Such strategies are available for the computerized Kohs Block Design Task (Samuel), except in cases of low intelligence (Rozencwajg, Aliamer, & Ombredanne, 2009).

Another modulator of the goal effect on performance is cognitive abilities. According to Kanfer and Ackerman (1989), individuals who have lower cognitive abilities (measured by a cognitive test with the general, perceptual, and speed factors) must exert more effort than individuals with high cognitive abilities in order to concentrate on the activity and reach the goal. For these individuals, a specific, difficult goal increases the amount of effort and directs attention to relevant aspects of the task. By contrast, individuals with high cognitive abilities automatically allocate more effort and are thus in lesser need of a goal aimed at increasing their effort level or directing their attention to relevant task elements.

As in a number of other studies (Kanfer & Ackerman, 1989; Latham, Seijts, & Crim, 2008; Seijts & Crim, 2009), our previous study using a block design task called Samuel (Rozencwajg & Fenouillet, 2012) found that setting a specific, difficult goal was the most beneficial to individuals with poor visual–spatial abilities. By means of various indexes, we were able to show that a specific, difficult goal allowed individuals with low visual–spatial abilities to improve certain strategical aspects of their problem-solving behavior and also to concentrate more. However, to reach the goal set for them, these participants did not modify their cognitive strategies in a fundamental way but only changed certain peripheral aspects. In short, the time allotted to subjects with lesser visual–spatial abilities allowed them to attain the goal without necessarily using the most efficient strategies for this type of task. Studies on Samuel have shown that the most effective problem-solving strategies are used mainly by individuals with high visual–spatial abilities (Rozencwajg, Cherfi, Ferrandez, Lautrey, Lemoine, & Loarer, 2005a; Rozencwajg, Corroyer, & Altman, 2002; Rozencwajg & Huteau, 1996). The question raised in this new study concerns the impact of assigning a goal that might "force" individuals with low visual–spatial abilities to use strategies they would not employ under normal conditions (because they call for high visual–spatial abilities).

As in other studies, and in direct connection with the observations made in our earlier work, we can assume that subjects with low cognitive abilities will benefit more from a specific, difficult goal. If so, then this would mean that low-ability individuals are capable of applying enough effort to mobilize strategies that they are not normally able to use. In other words, cognitive abilities would not be fixed as one might assume, but can be enhanced by effort. In order to look more specifically at the implications of this hypothesis in our study, we must first describe the task used.

1.2. Samuel, a computerized tool for studying performance and strategies in Kohs Block Design Task

1.2.1. Samuel, a test of general intelligence

The Kohs Block Design Task is usually considered to be a general intelligence test that is highly saturated in factor *g*. Royer, Gilmore, and Gruhn (1984), for example, reported a correlation of .80 between Kohs blocks and IQ assessed on Binet's test. Wechsler used it as a subtest on his child and adult scales. For example, the *g*-loading of Kohs blocks in WISC-IV is .67 (Flanagan & Kaufman, 2004), and its correlation with Weschler's overall score is also high (.59, Wechsler, 2005). For Royer et al. (1984), "It serves, then, as a very good measure of general intelligence, as well as of performance abilities" (p. 1474). Kohs Block Design Task is also classified as a measure of visual processing *Gv*. The *Gv*-loading of Kohs blocks in WISC-IV is .84 (Flanagan & Kaufman, 2004).

1.2.2. Samuel, a test of strategies

The Samuel task, which is derived from Kohs Blocks, was constructed to study the cognitive psychology of problem solving, where the processes and strategies underlying performance on psychometric tests are analyzed (Rozencwajg, 2007; Rozencwajg & Bertoux, 2008; Rozencwajg & Corroyer, 2002; Rozencwajg, Schaeffer, & Lefevbre, 2010). In this task, subjects use red and white colored squares to reproduce two-dimensional, red-and-white square designs composed of geometric figures.

The Samuel task involves copying four model designs consisting of geometric figures displayed on the left-hand side of the screen, using the red, white, and red-and-white squares shown at the bottom of the screen (see Fig. 1). The screen is divided into three main parts. On the left, the test design appears whenever the subject requests and remains on the screen until the subject clicks on a square, at which point the design disappears. Below this, the subject can select a square (an all-red one, an all-white one, or one of four red-and-white ones each oriented in a different way) and drag it up into the black reconstruction area on the right to reproduce the design. The device records the subject's moves for later analysis.

All of the subject's actions (looking at the model, putting a particular square with a specific orientation in a given place, removing it) are recorded automatically. Based on these recordings, two strategy indexes can be calculated: anticipation (number of attempts) and model-viewing frequency. The anticipation index represents the extent to which the subject constructs the design using trial and error, or is able to correctly fill all cells on the first try. For each cell in the design, we obtain a ratio of 1/1 if the cell is correctly filled on the first try, a ratio of 1/2 if the subject takes two tries, a ratio of 1/3 for three tries, etc. The different ratios are added and then divided by the total number of tries. If a cell contains an incorrect square in the end, regardless of the number of tries, the ratio for that cell is 0. For example, for a four-square design where the subject takes one, three, and two tries, respectively, to correctly fill the first three cells, and fills in the last cell with the wrong square in a single try, the calculation would be $(1/1 + 1/3 + 1/2 + 0/1) / (1 + 3 + 2 + 1) = .26$. The anticipation index varies between 0 and 1 (0 if the subject ends up with only incorrectly filled cells, 1 if all cells are correctly filled on the first try). The model-viewing frequency was calculated by dividing the number of times the design was displayed, by the total number of actions.

These indexes are then used to assess the strategy employed by the subject to solve the task. The anticipation index is greater in the analytic and synthetic strategies than in the global strategy, and the model-viewing index is greater in the analytic strategy than in the synthetic strategy. For a sample of 30 subjects 17 years old, anticipation and model-viewing frequency are respectively equal to .76 and .30 for the synthetic strategy, and .80 and .54 for the analytic strategy. For the global strategy, anticipation is equal to .61.

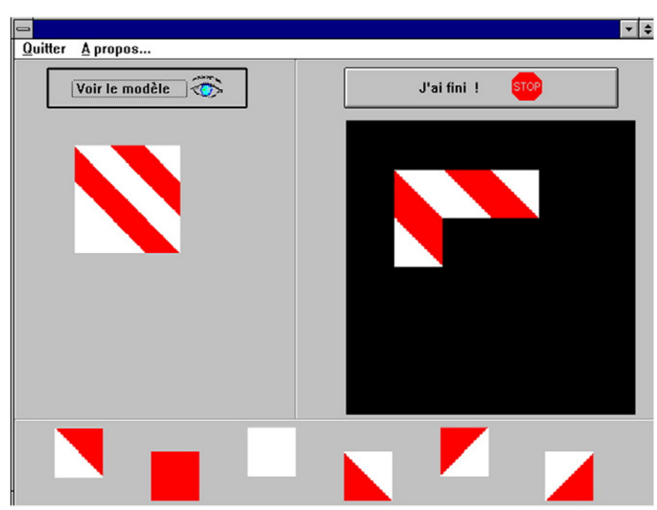

Fig. 1. Samuel screen during design reconstruction.

The strategy used — analytic or synthetic — is identified by combining the different indexes. A distance (a "city-block distance", also known as "the Manhattan distance") between each subject and each theoretical strategy is computed, and the subject is classified in terms of the strategy he or she preferentially used. The shorter the distance from theoretical strategy X, the more often strategy X was implemented (for more details, see Rozencwajg & Corroyer, 2002).

1.2.3. Performance and strategies on Samuel, and flexibility of closure

The findings of a previous study indicated that the Group Embedded Figures Test (GEFT) score — used to measure flexibility of closure — discriminates performance levels on block designs and also differentiates strategies used on the computerized task Samuel (Rozencwajg & Huteau, 1996; Rozencwajg et al., 2002; Rozencwajg et al., 2005a). In particular, subjects who obtain a low score on the GEFT tend to have a low anticipation score (below the mean for their age group). On the other hand, there is no link between model-viewing frequency and the GEFT. A low GEFT score is linked to global-strategy use, and a high GEFT score is linked to synthetic- and analytic-strategy use.

1.2.4. Samuel, a test of cognitive development

Several studies have also shown that the strategies implemented in Samuel evolve with age. In particular, the analytic strategy and the synthetic strategy are used most frequently by young adults, and the anticipation index is at its highest in this age group (Rozencwajg & Corroyer, 2002; Rozencwajg et al., 2002; Rozencwajg et al., 2005a).

2. Hypotheses

In our earlier study based on the goal-setting paradigm (Rozencwajg & Fenouillet, 2012), we found an effect of a time goal on certain strategy indexes only. More specifically, the model-viewing frequency changed, whereas the anticipation index (visuospatial performance) did not. In the discussion, we advanced the hypothesis that the strategical indexes affected by the goal were more malleable than those that did not change. It would seem, then, that certain problem-solving indexes are less sensitive to learning and thus less modifiable than others. Moreover, it turned out that the model-viewing index was not linked to general intelligence, whereas the anticipation index was. It therefore seemed tempting to hypothesize that the reason why the time goal did not change the anticipation index was a result of its link to general intelligence. In this second study, we hypothesized that due to the lack of a relationship between the anticipation index and the effect of a specific, difficult goal would be linked to the nature of the goal. Indeed, the anticipation index is calculated from the number of errors and tries, while the goal set in our earlier study pertained to execution time. So in the present study, the goal assigned to participants pertained to the number of errors.

Also in the first study, the goal assigned was beneficial to participants with low cognitive abilities but did not change the strategical indexes of the participants with high visual–spatial abilities. We can hypothesize that this result might be due to the fact that the participants were young adults whose visual–spatial cognitive abilities are, on average, at a maximum (Kaufman, Reynolds, & McLean, 1989; Rozencwajg & Corroyer, 2002; Rozencwajg et al., 2005a; Salthouse, 1987). In the present study, we therefore chose participants with a lower level of cognitive development than that of the young adults in the first study. The lower cognitive–development level of the subjects in this second study was inferred from their age and number of years of schooling. We hypothesized that the goal would allow participants with high visual–spatial abilities to progress too.

Based on the above considerations, we can set forth the following three hypotheses:

1) We expected the participants with high visual–spatial abilities to have a higher anticipation index and to use the analytic and synthetic strategies more than participants with low visual–spatial abilities, but visual–spatial abilities were not expected to have an effect on model viewing.
2) We expected the participants with a specific and difficult goal to have a higher anticipation index and a greater model-viewing frequency than participants with no goal. The goal participants were also expected to use the analytic and synthetic strategies more often than the no-goal participants, due to the nature of the goal.
3) We expected the goal to be beneficial not only to the low visual–spatial-ability group but also to the high visual–spatial-ability group, insofar as the participants were not fully developed from the cognitive standpoint. However, we expected a greater performance difference between the goal and no-goal groups for participants with low visual–spatial abilities than for ones with high visual–spatial abilities.

3. Method

3.1. Characteristics of the sample and experimental design

Fifty female and forty-two male high school students participated voluntarily in the study. Their mean age was 16 years 4 months (SD = 10 months). The 92 participants were randomly assigned to the no-goal (standard) condition or the goal condition. The no-goal group and the goal group each contained 46 participants.

3.2. Materials and procedure

3.2.1. Samuel, a computerized Kohs Block Design Task

Samuel includes 10 trials, 6 trials with 4 blocks and 4 trials with 9 blocks. The task lasts about 30–45 min. Samuel was administered (after the GEFT) to small groups of participants, with each participant working individually. For each subject, several indexes were computed: anticipation, model-viewing frequency, and strategy employed.

3.2.2. Experimental manipulation of the specific, difficult goal

The group with a goal was compared to the group without a goal (standard condition). We assigned an accuracy goal to test its effect on anticipation. As advocated by Locke and Latham (1990), a difficult goal must be attainable by only a small percentage of individuals. In our study, the accuracy goal assigned to the goal group was equal to the total number of errors made by only 10% of the reference group, based on Wood and Bandura's (1989) consideration that a goal at 10% is truly difficult. The goal was defined with respect to the number of errors made by the first 34 participants tested in the no-goal group. In our study, three participants in the no-goal group made at most six errors on all ten model designs (which correspond to the score attained by 8.8% of the 34 participants), so this was the number of errors retained for the goal group. An error occurred when a piece was removed from the reconstruction area, either because it was not in the right place or because it was not the right piece.

During a given trial, the participant first saw the goal displayed in the lower left quadrant of the Samuel screen (see Fig. 2). The goal was expressed by the following sentence: "Try not to make more than 6 mistakes, all trials included". If the participant took away a square, the error counter was incremented by $+1$. The error counter was displayed in the lower right-hand corner of the screen, with the sentence "You have removed 0 square(s)". As the number of errors went up, the "0" became a "1", then a "2", and so on (see Fig. 2).

Finally, when the individual had finished reproducing the model, he or she was to click on "I'm finished" shown in the area above the reconstructed figure. Note that the counter was not reset at zero when each new model was displayed.

3.2.3. Group Embedded Figures Test

The Group Embedded Figures Test (see Fig. 3) was administrated individually. The subject has to recognize the simple figure that is embedded in the complex one. If he or she recognizes it correctly, one point is

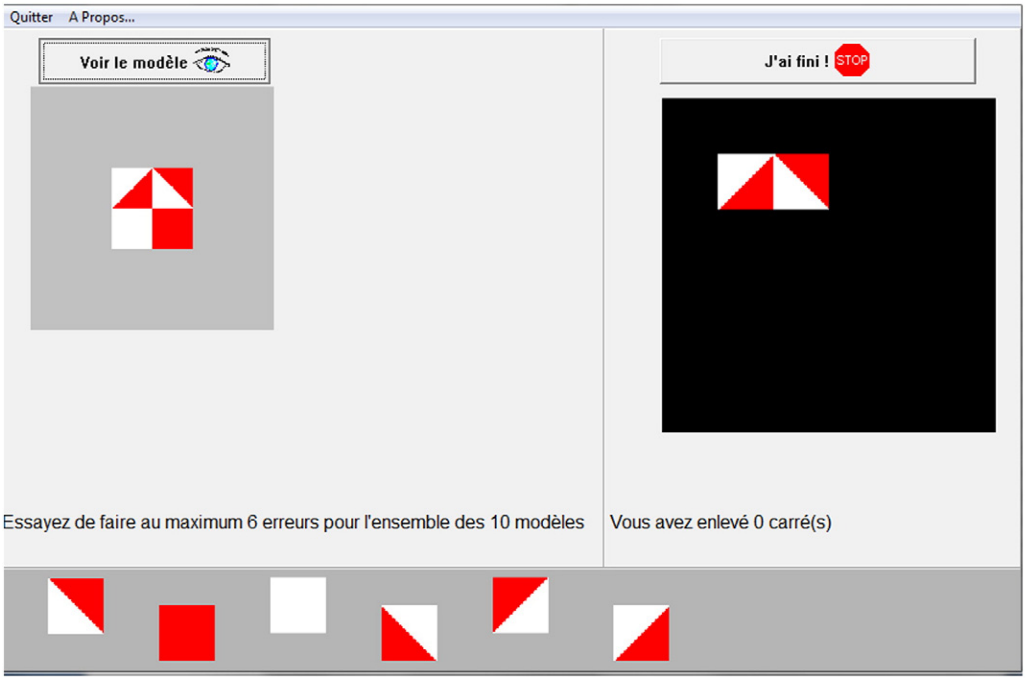

Fig. 2. Goal display in Samuel.

scored. There are 18 trials, so the score varies between 0 and 18 points. The observed median was 10 points. The subjects were classified into two groups, low visual–spatial abilities and high visual–spatial abilities, on the basis of whether their GEFT score was below or above the median.

4. Results

4.1. Preliminary experimental check

First we used a 2 × 2 design with visual–spatial ability (GEFT score below or above the median) and goal (standard do-your-best condition versus difficult-goal condition) to see if these two variables had equal values in the two conditions. The visual–spatial ability (GEFT score) was indeed found to be equivalent in the two experimental groups, i.e., the standard do-your-best condition and the difficult-goal condition ($F[1,90] = 1.46$, $p = .2303 > .05$, $\eta^2 = 2\%$) (see Table 1).

4.2. Hypothesis 1: main effect of visual–spatial abilities

In line with our first hypothesis, visual–spatial abilities, as measured by the GEFT score, had a significant effect on the anticipation index ($F[1,88] = 21.59$, $p < .001$, $\eta^2 = 20\%$). Participants with a high GEFT score had better anticipation indexes, which means that they made fewer errors than participants with a low GEFT score (see Fig. 4). Visual–spatial abilities (GEFT score) had a significant effect on the use of the analytic strategy (see Fig. 5) ($F[1,88] = 6.50$, $p < .05$, $\eta^2 = 7\%$) but also and especially on the use of the synthetic strategy (see Fig. 6) ($F[1,88] = 20.26$, $p < .001$, $\eta^2 = 19\%$).

By contrast, there was no GEFT effect on model viewing ($F[1,88] < 1$, $p = .60$, $\eta^2 < 1\%$), which confirms that this indicator is not linked to visual–spatial abilities (see Fig. 7).

4.3. Hypothesis 2: main effect of goal

The goal had a significant effect on the anticipation index ($F[1,88] = 21.43$, $p < .001$, $\eta^2 = 20\%$). Participants assigned a specific, difficult goal

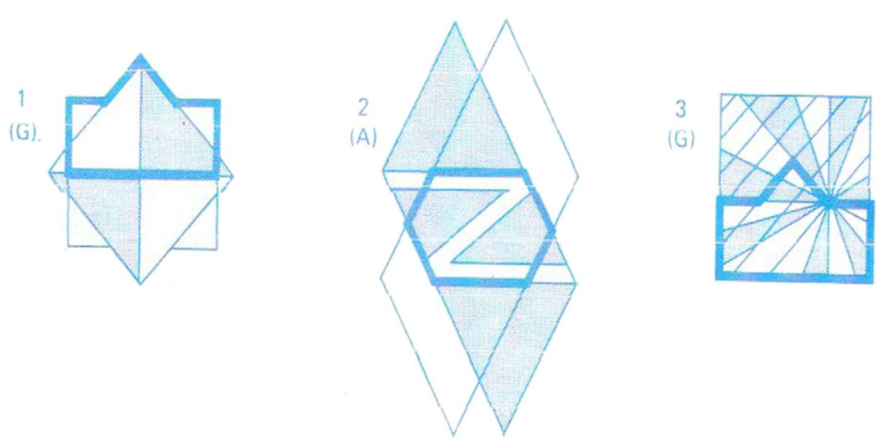

Fig. 3. Examples of the GEFT (Witkin, Ottman & Raskin, 1971). The GEFT is a paper and pencil test.

Table 1
Distribution of participants in each experimental condition.

	N	GEFT score		*N*	GEFT score
No-goal condition	46	10.45 (5.20)	GEFT < 10	21	5.52 (3.02)
			GEFT ≥ 10	25	14.60 (2.80)
Goal condition	46	9.21 (4.61)	GEFT < 10	27	6.03 (2.81)
			GEFT ≥ 10	19	13.74 (2.26)

got higher anticipation indexes, which means that they made fewer errors than did participants with no goal (see Fig. 4). We also obtained a goal effect on model viewing ($F[1,88] = 46.40$, $p < .001$, $\eta^2 = 35\%$). Participants who had a goal looked at the model more often (see Fig. 7). Lastly, we found a goal effect on the distance from analytic-strategy use ($F[1,88] = 15.95$ $p < .001$, $\eta^2 = 15\%$) (see Fig. 5) but not on the distance from synthetic-strategy use ($F[1,88] = 2.02$, $p = .16$, $\eta^2 = 2\%$) (see Fig. 6). These results indicate no simple effect of goal on synthetic-strategy use, although the goal did have an effect on the anticipation index. We discuss the implications of these findings in the Discussion section.

4.4. Hypothesis 3: interaction between the goal and visual–spatial abilities

As explained above, we can expect an interaction here between goal and visual–spatial abilities (GEFT) because the goal was assumed to have a greater effect on performance for participants with low visual–spatial abilities than for ones with high visual–spatial abilities. This time, the high visual–spatial-ability participants with a goal obtained a higher anticipation index than did the participants with no goal, and the difference between the goal and no-goal groups was not greater for participants with low visual–spatial abilities ($F[1,88] < 1$, $p = .54$, $\eta^2 < 1\%$) (see Fig. 4). We can assume that this arose from the fact that their cognitive development was not yet complete. Use of the analytic strategy was also higher in both groups (low and high visual–spatial abilities) ($F[1,88] < 1$, $p = .65$, $\eta^2 < 1\%$) (see Fig. 5).

5. Discussion

The results of this study corroborate those of our previous work, which showed that goal setting can have an effect on the cognitive strategies used by participants. In a previous study (Rozencwajg & Fenouillet, 2012), participants saved time by looking less often at the model to satisfy the time goal set for them. They exerted more effort

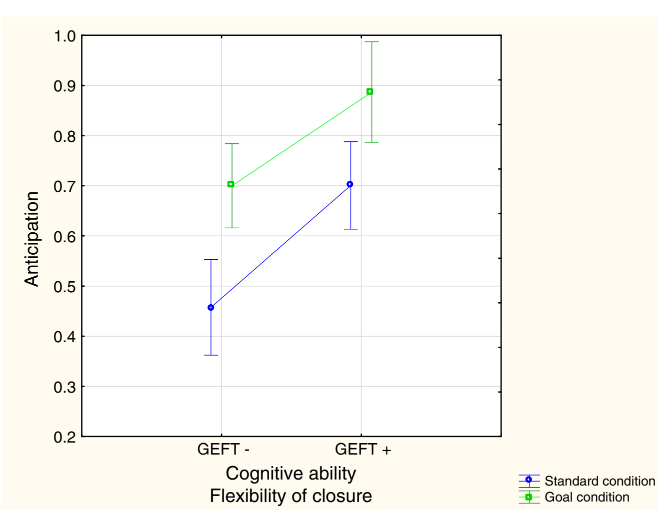

Fig. 4. Effect (with standard error bars) of visual–spatial abilities (Hypothesis 1), experimental condition (goal vs. no goal, Hypothesis 2), and their interaction (Hypothesis 3) on anticipation.

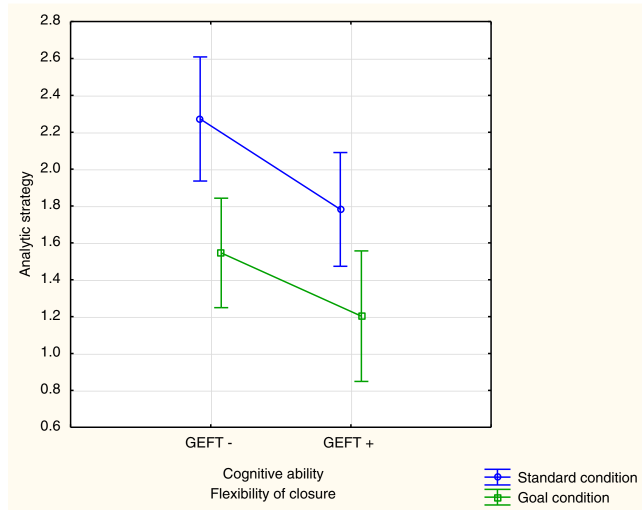

Fig. 5. Effect (with standard error bars) of visual–spatial abilities (Hypothesis 1), experimental condition (goal vs. no goal, Hypothesis 2), and their interaction (Hypothesis 3) on the distance from the analytic strategy.

since saving time did not decrease anticipation, which remained unchanged by the goal.

In the present study, participants looked at the model more often in order to reach the accuracy goal (make fewer errors, thereby allowing anticipation to increase). The rise in these two indexes favored the analytic strategy, which also increased substantially, since this strategy consists of reducing the number of errors by looking frequently at the model. But the increase in these two indicators is incompatible with the synthetic strategy, which consists of making few errors and looking infrequently at the model. Thus, the goal did not lead to greater use of the synthetic strategy (which remained unchanged). However, in the new results obtained in this study, we can see that the anticipation index was not a fixed indicator but was motivation-sensitive. Here (second study), the participants looked at the model more often and made fewer errors to attain the accuracy goal. Whereas in the previous study we had no simple goal effect on the anticipation index, we did find an anticipation effect in this second study. The anticipation index (which must be high in the synthetic strategy) is therefore not only related to visual–spatial abilities, but also to participant motivation.

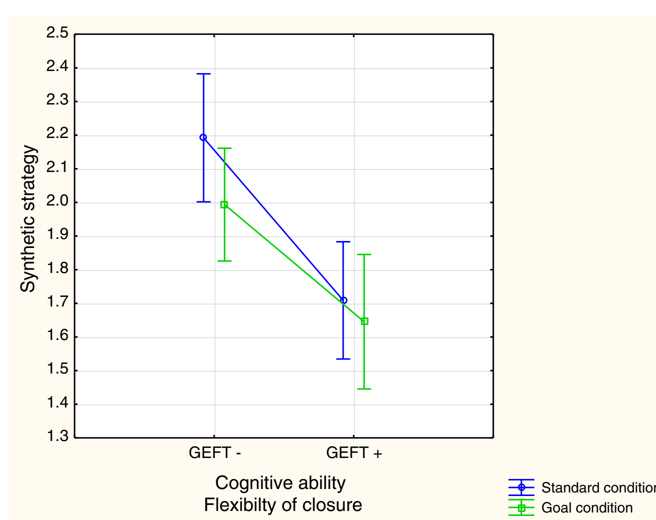

Fig. 6. Effect (with standard error bars) of visual–spatial abilities (Hypothesis 1), experimental condition (goal vs. no goal, Hypothesis 2), and their interaction (Hypothesis 3) on the distance from the synthetic strategy.

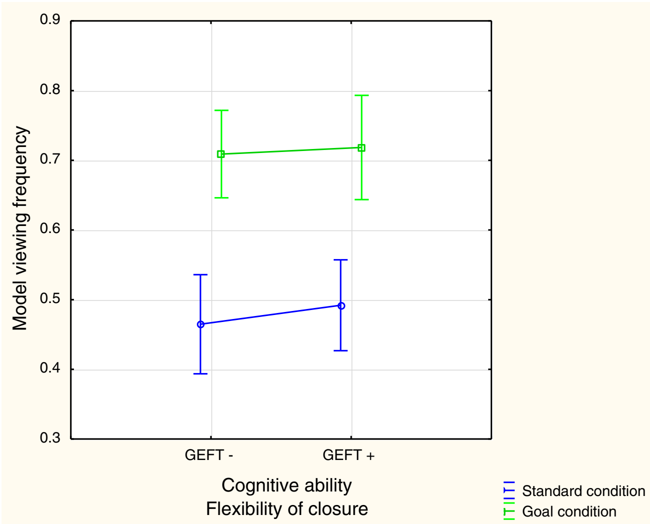

Fig. 7. Effect (with standard error bars) of visual–spatial abilities (Hypothesis 1), experimental condition (goal vs. no goal, Hypothesis 2), and their interaction (Hypothesis 3) on model viewing.

A third study with a combined speed-and-accuracy goal is thus needed to test the limits of the goal effect on the various strategies and indexes. In such a study one could hypothesize, for example, that only those subjects with high visual–spatial abilities would reach this dual goal and increase their use of the synthetic strategy. One could also test for the effect of a third factor, cognitive development. One could then hypothesize that only those participants with high visual–spatial abilities and/or young adults would manage to implement the synthetic strategy. Earlier studies have shown that the synthetic strategy is the most difficult one and can virtually disappear with aging (Rozencwajg et al., 2005a), unless the aging subjects already have a high degree of visual–spatial expertise, as in architects (Loarer, Lautrey, Lemoine, Rozencwajg & Ferrandez, 2005) and air-traffic controllers (Rozencwajg, Lemoine, Rolland-Grot, & Bompard, 2005b). Among the elderly without any particular visual–spatial expertise, however, good anticipation would require frequent model viewing, and hence, the disappearance of the synthetic strategy. Such a study would thus require designing a dual goal involving both speed and accuracy, while also manipulating the cognitive–development factor.

In sum, and contrary to our first study (Rozencwajg & Fenouillet, 2012), the goal set in the current study profoundly modified the participants' strategies, causing anticipation and model viewing to increase. Furthermore, the goal led to progress in both visual–spatial-ability groups (low but also high). The accuracy goal thus allowed both groups to make the most of their initial level of visual–spatial abilities; hence the absence of an interaction. If the participants had been young adults who, in the visual–spatial cognitive domain, are at their maximal level of development, would we still have found a lack of interaction between the goal and visual–spatial abilities?

6 . Acknowledgment

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