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Mental imagery rotation and graph comprehension of IS-LM macroeconomic models

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Abstract

The aim of this study was to determine if the ability to rotate mental imagery influenced the comprehension of graphs in economics. A sample of 140 Business Administration undergraduates familiar with economic analysis using graphs were administered the Measure of the Ability to Rotate Mental Images (MARMI). Moreover, participants completed an ad hoc graph comprehension test consisting of six exercises of increasing difficulty with graphs developing the IS-LM model described in conventional macroeconomic textbooks. Both the ability to rotate mental imagery and graph complexity (the number of quadrants in each graph) were found to significantly influence the number of correct graph comprehension responses.

KEYWORDS
economics, graphical representation, mental images, mental rotation

INTRODUCTION

Initially, mental imagery was believed to be unitary, until studies in cognitive psychology and neuroscience (Kosslyn, 1994a; Kosslyn & Koenig, 1992) identified two subtypes of imagery: spatial imagery and object imagery (Blajenkova et al., 2006). "Spatial imagery" refers to relations between objects, objects in movement, objects in space, and so forth, whereas "object imagery" refers to the analysis of objects' color, shape, size, and so forth (Blajenkova et al., 2006). Besides object imagery and spatial imagery, other studies have added a further subtype referred to as image rotation (Burton & Fogarty, 2003; Eliot & Smith, 1983).

Mental imagery plays a crucial role in all cognitive processes (for reviews, see Campos, 1998, and Paivio, 1979). Visual artists, such as painters and sculptors, mainly use object imagery, whereas scientists, physicist, engineers, and architects primarily use spatial imagery (Campos & Fuentes, 2016; Kozhevnikov et al., 2005; Kozhevnikov et al., 2010; Motes et al., 2008; Pérez-Fabello et al., 2016; Pérez-Fabello et al., 2018). Image rotation is linked to spatial tasks involving movement, the interpretation of complex graphs, and mathematical problem-solving (Campos & Campos-Juanatey, 2019a; Reingewertz, 2013; Sanchez & Wiley, 2014; Van Garderen, 2006; Zhao & Della Sala, 2018).

Campos and Campos-Juanatey (2019a) found that individuals with a high ability to rotate mental imagery obtained more correct responses in understanding you-are-here maps than individuals with low ability to rotate mental imagery. Campos and Campos-Juanatey (2019b) found significant correlation between the ability to rotate mental imagery and the ability to orient oneself on you-are-here maps.

In economics, as in other disciplines (for a review see Kosslyn, 1994b), and STEM fields (science, technology, engineering, and mathematics) in particular, undergraduates often use graphs to understand the relations between an array of both macroeconomic (Reingewertz, 2013) and microeconomic factors (Marangos & Alley, 2007). Harle and Towns's (2011) review of studies on image rotation and the learning of several tasks in science found imagery rotation influenced learning in chemistry and in STEM fields (Uttal & Cohen, 2012), as well as the learning of geometry (Kirby & Boulter, 1999).

Graphs are used in economics to facilitate the understanding of mathematical concepts and models. The ability to rotate mental imagery was found to influence the comprehension of mathematical problems (Hegarty & Kozhevnikov, 1999; Sheckels & Eliot, 1983; Van Garderen, 2006; Van Garderen & Montague, 2003). In a sample of 81 community college students administered a battery of tests, including rotation tests, Sheckels and Eliot (1983) found that undergraduates performing well on visual rotation tasks also performed well in mathematical problem-solving. Similar results were obtained in studies analyzing the relation between image rotation and performance in mathematical problem-solving (Hegarty & Kozhevnikov, 1999; Van Garderen, 2006; Van Garderen & Montague, 2003).

Graphs in economics may be either simple, with few variables, or complex with several interacting variables. The former are easier to understand, and obtained more correct responses and fewer errors in comprehension (Kosslyn, 1994b; Shah et al., 1999). In tasks involving the mental rotation of figures, the more complex the graph or the more the rotations required led to more comprehension errors. For example, more errors were observed when squares or geometric figures were rotated 180° degrees than at 90° (Cooper, 1975; Metzler & Shepard, 1974; Piccardi et al., 2011). The understanding of you-are-here maps was faster with more correct comprehension responses and fewer errors in better oriented maps requiring fewer rotations (Campos & Campos-Juanatey, 2019c).

Several studies (Kozhevnikov & Hegarty, 2001; Liesefeld & Zimmer, 2012) state that the ability to rotate mental images is related to spatial orientation, and spatial orientation is pivotal for graphic comprehension when graphics have to be rotated to be more quickly apprehended.

Among the most common graphic models on macroeconomic training and macroeconomic policy is the IS-LM model, which persists as one of the most used in economic teaching at grade level since its inception by (Hicks, 1937). This model aims to represent the macroeconomic equilibrium in a synthetic way and is useful for working on comparative statics when it comes to seeing the effects of certain changes in the said equilibrium. Its resultant graphic representations, by way of the four-quadrants graphic, enable analysis of up to four economic variables simultaneously. In this way, it significantly eases relationship comprehension and allows a logical construction of the chain of effects of the monetary and fiscal framework.

At times, interpreting the IS-LM model requires graphic mental rotation and function shifting. It has been noted that even the simplest macroeconomic models, such as the IS-LM, may turn out to be too complex for certain students (Reingewertz, 2013). As these methods are spatially visualized, it sounds reasonable to consider the differences in students' spatial ability, especially the ability to rotate mental images, which may well be related to the level of complexity with which they perceive these graphics.

Thus, the aim of this study was to assess the influence of the ability to rotate mental imagery and graph complexity on graph comprehension of the IS-LM model in the learning of economics. It was hypothesized that the ability to rotate mental imagery and graph complexity would influence graph comprehension. It was expected that participants with high scores on mental rotation would have a more accurate graph comprehension and less failures than participants with low scores on mental rotation ability. The independent variables were the ability to rotate mental imagery and graph complexity, and the dependent variables were the number of correct responses and the number of errors in the comprehension of IS-LM graphs in economics.

METHOD

Participants

The sample of this study consisted of 140 second-year Business Administration undergraduates (73 women and 67 men), mean age 21.06 years ($SD = 2.71$ years), who were familiar with economic analysis using graphs.

Instruments

The Measure of the Ability to Rotate Mental Images (MARMI; Campos, 2012) was administered. This test measures each participant's ability to rotate mental imagery, and consists of an unfolded cube that participants had to reassemble mentally and rotate, prior to responding to each of the 23 questions referring to the cube. Each question has four responses: two correct and two false (see Figure 1). The total test score is obtained by adding the correct responses and subtracting the incorrect ones. Participants are allowed a maximum 5-min period to complete the test. The MARMI is preferred instead of the usual Mental Rotation Test (MRT; Vandenberg & Kuse, 1978) simply because the MARMI is more recent and there is a high correlation between both tests ($r = .40$, $p < .01$; Campos, 2012). Moreover, participants completed six exercises with graphs similar to Figures 2 and 3, and eight questions referring to each graph.

Procedure

A total of 140 second-year Business Administration undergraduates were divided into groups of around 25 undergraduates. In the context of a lecture on the subject of Economic Policy, the IS-LM Model was referred to as a framework for the

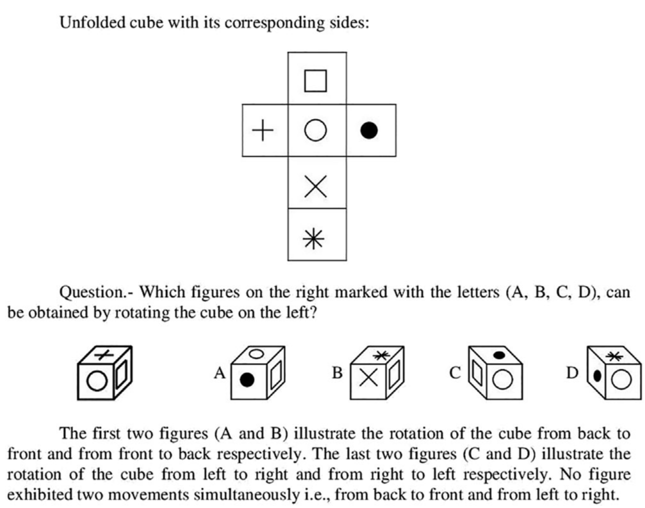

FIGURE 1 Example of an item on the Measure of the Ability to Rotate Mental Images

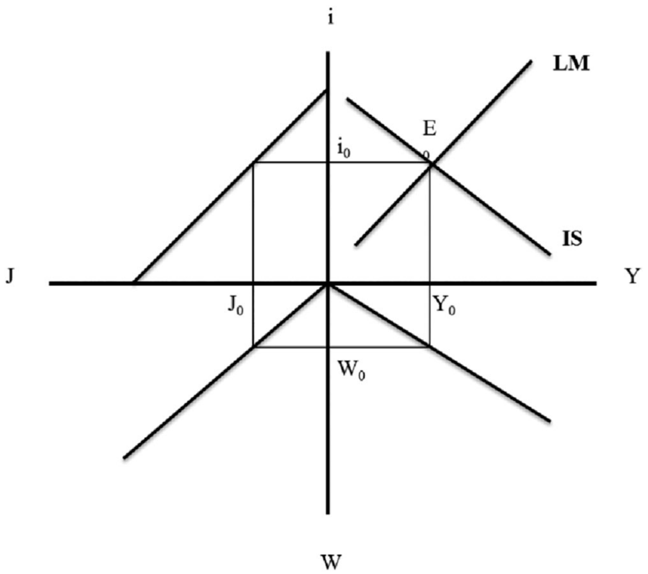

FIGURE 2 Four-quadrant IS-LM model from the IS perspective. This graph illustrates the effects of changes in variables in the market for goods and services

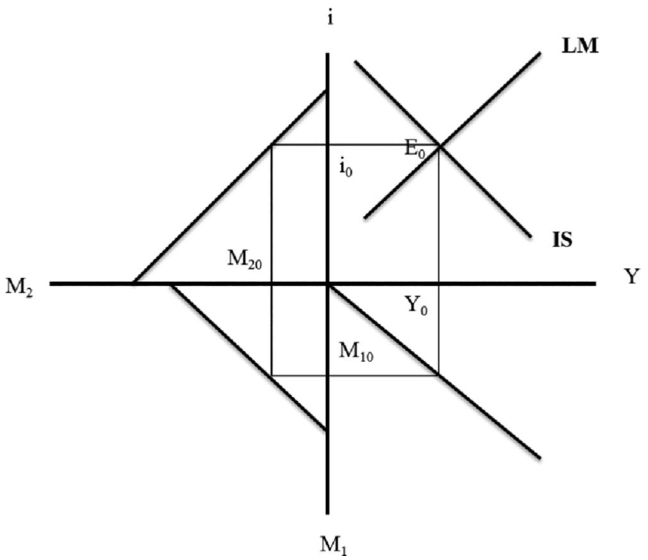

FIGURE 3 Four-quadrant IS-LM model from the LM perspective. This graph illustrates the effects of changes in monetary variables

analysis of the effects of macroeconomic policy. Thereafter, following an interactive session on the same subject, undergraduates were applied the following instruments: the MARMI, and a graph-comprehension task of the IS-LM Model consisting of six graph-comprehension exercises. All individuals were classified on the basis of high and low scores on spatial image skills according to whether their scores on the MARMI were, respectively, above or below the group mean ($M = 4.88$; $SD = 6.38$; individuals high on the MARMI, $n = 95$, individuals low on MARMI, $n = 44$). All participants went through the same tests.

The graph-comprehension exercises were based on the four-quadrant version of the IS-LM Model. This version could be used to analyze the relations between variables in the same quadrant, in two different quadrants, or in four quadrants on the graph. Furthermore, the model could be analyzed graphically either from an IS perspective (point of macroeconomic equilibrium where investment I is equal to savings S), or from an LM perspective (point of macroeconomic equilibrium where monetary demand L is equal to monetary supply M). "IS" represents points of equilibrium in the market for goods and services, whereas "LM" refers to points of equilibrium in the money markets. The intersection point of IS and LM is the general macroeconomic equilibrium.

Participants completed six graph-comprehension exercises of a four-quadrants version of the IS-LM Model. Each of the six exercises contained eight questions on the relationship between two specific variables in the model. Two of the exercises enquire about relationships between variables that are in a single quadrant (one exercise from the IS perspective, the other from the LM perspective); two other exercises enquire about relationships between variables that are in different quadrants (again, one from the IS perspective and the other from the LM perspective); and finally two more exercises enquire about variable relationships that require considering the four quadrants at a time (same as before, from the IS and LM perspectives, respectively).

The first type of exercise consists of interpreting relationships between variables from a single quadrant in the graphic. On occasions, it is necessary to make an effort with regard to interpretation since rotating the graphic is required in order to place it on the first quadrant. This quadrant is most frequently considered in these kinds of analyses and implies a variant increase when it is displaced to the right in the horizontal axis and another variant increase when it moves upwards in the vertical axis. The second type of exercise is similar to the previous one but in this case, the problem must be solved by relating variables from two different quadrants. That is, the point is relating a variable represented in the axis of a quadrant with another variant represented in the axis of another quadrant. The third type of exercise involves considering the four quadrants all together and implies displacing a function to be able to properly answer the questions.

Below is an example question of one of the six exercises, which were numbered 1 to 6, with the questions appearing in italics):

1. Relations between variables in one quadrant from an IS perspective

If income rises (Y), what happens to the interest rate (i)?

2. Relations between variables in the same quadrant from an LM perspective

If income falls (Y), what happens to the sum of money disposable for transactions (M_1)?

3. Relations between variables in two different quadrants from an IS perspective

If income rises (Y), what happens to the sum of public expenditure and business investment (J)?

4. Relations between variables in two different quadrants from an LM perspective

If the interest rate rises (i), what happens to monetary demand for transactions (M_1)?

TABLE 1 Means and standard deviations of correct responses obtained in one quadrant, two quadrants, and four quadrants by participants with high and low scores on the MARMI

	One quadrant		Two quadrants		Four quadrants		Total	
Groups	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
High MARMI	13.20	3.88	12.07	4.09	6.98	2.72	32.25	7.04
Low MARMI	11.92	2.68	10.22	3.91	6.02	2.59	28.16	7.56
Total	12.32	3.64	10.81	4.05	6.32	2.66	29.45	7.60

Abbreviation: MARMI, Measure of the Ability to Rotate Mental Images.

TABLE 2 Means and standard deviations of errors obtained in one quadrant, two quadrants, and four quadrants by participants with high and low scores on the MARMI

	One quadrant		Two quadrants		Four quadrants		Total	
Groups	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
High MARMI	1.75	2.32	2.82	3.66	5.39	2.13	9.95	5.43
Low MARMI	2.55	2.69	2.83	2.77	5.40	2.46	10.78	5.72
Total	2.29	2.60	3.83	3.07	5.40	2.35	10.59	5.66

Abbreviation: MARMI, Measure of the Ability to Rotate Mental Images.

5. Relations between variables in four quadrants from an IS perspective

If there is an increase in public expenditure (that is part of the variable J), what happens to income (Y)?

6. Relations between variables in four quadrants from an LM perspective

If there is an increase in the money supply ($Ms = M_1 + M_2$), what happens to income (Y)?

Examples 1, 3, and 5 interpret the four quadrants from an IS perspective as they refer to variables related to the market for goods and services. Thus, the correct graph for responding to these questions is Figure 2.

In comparison, Examples 2, 4, and 6 interpret the four quadrants from an LM perspective as they refer to monetary variables. Thus, the correct graph for responding to these questions is Figure 3.

In all cases, the correct response to each question could be deduced from the graph for each exercise, and responses were unequivocally restricted to increases or decreases. For example, for Question 2 in the exercise above (*If income falls [Y], what happens to the sum of money disposable for transactions [M1]?*), the correct response is that the sum of money for transactions decreases, given that the function relating to the two variables (represented in the southeast quadrant) shows the direct relationship between both.

Each of the six exercises consisted of eight questions similar to the aforementioned example. The score for each exercise ranged from 0 to 8 points, with 1 point being awarded for each correct response, 1 point for an incorrect response, and 0 points for unanswered questions. According to the total number of right answers on exercises with one, two and four quadrants, a score was calculated for each participant by adding successes in both exercises (one in IS and the other in LM) on variables that are in a quadrant, plus successes in both exercises on variables that are in two quadrants and successes in variables on all four quadrants. An additional score was obtained for each participant corresponding to failures on exercises referring to variables in one, two and four quadrants, respectively.

The investigation was conducted in accordance with ethical rules contained in the Declaration of Helsinki of 2013, and was approved by the Ethics Committee of the University of A Coruña. Written informed consent was obtained from each participant. All of the undergraduates freely volunteered to participate in the study and were not rewarded.

Data analysis

The reliability of the MARMI was determined by the Cronbach's alpha. In order to analyze the influence of the ability to rotate mental imagery and graph complexity on the number of correct responses in interpreting the graphs of the IS-LM models in economics, a two-factor (high or low in the ability to rotate mental imagery, MARMI), and three-factor (number of quadrants [one, two, or four]; i.e., graph complexity) mixed-measures analysis of variance (ANOVA) was performed. The Bonferroni test was used as a post-hoc analysis. The independent variables were the ability to rotate mental imagery and graph complexity (types of quadrants), and the dependent variables were the number of correct responses in one ANOVA, and the number of incorrect responses in the interpretation of the quadrants in the other.

RESULTS

In this study, the MARMI obtained a Cronbach's alpha of .78. The first step was to determine if the ability to rotate mental imagery and the number of quadrants significantly influenced the number of correct responses in the interpretation of the graphs in the IS-LM models in economics. The means and standard deviations for each group are shown in Table 1. The mixed-measures ANOVA found the ability to rotate mental imagery significantly influenced the number of correct graph comprehension responses, $F(1, 137) = 9.21$, $p = .003$, $\eta_p^2 = .06$, power = .85. Participants scoring high in the ability to rotate mental imagery obtained more correct graph-comprehension responses than individuals scoring low in the ability to rotate mental imagery. Moreover, the graph complexity (the number of quadrants: one, two, or four quadrants) significantly influenced the number of correct responses, $F(1, 137) = 252.38$, $p < .001$, $\eta_p^2 = .65$, power = 1. The Bonferroni analysis found significant differences ($p < .001$) between the three graph complexities (one, two, and four quadrants). Thus, more correct responses were obtained with one quadrant than with two or four quadrants, and significantly more correct responses were found with two quadrants than with four quadrants. The interaction between the number of quadrants and the ability to rotate imagery was not significant, $F(1, 137) = 0.19$, $p = .66$, $\eta_p^2 = .01$, power = .19.

The second step was to determine if the ability to rotate mental imagery and the number of quadrants significantly influenced the number of comprehension errors in the interpretation of graphs of the IS-LM model in economics. The means and standard deviations for each group are shown in Table 2. The mixed-model ANOVA found no significant influence of the ability to rotate mental imagery on the number of graph-comprehension errors, $F(1, 137) = 0.65$, $p = .42$, $\eta_p^2 = .01$, power = .13. However, the graph complexity (one, two, and four quadrants) significantly influenced the number of graph-comprehension errors, $F(1, 137) = 108.55$, $p < .001$, $\eta_p^2 = .44$, power = 1. The Bonferroni analysis found significant differences ($p < .05$) for the three graphs (one, two, and four quadrants). Thus, more graph-comprehension errors were observed in four quadrants than in two or one quadrants, and significantly more in two quadrants than in one quadrant. The interaction between the number of quadrants and the ability to rotate imagery was not significant, $F(1, 137) = 0.58$, $p = .45$, $\eta_p^2 = .01$, power = .12.

DISCUSSION

The MARMI obtained a Cronbach's alpha of .78, indicating good test reliability according to the classification of George and Mallery (2003). Moreover, the results of this study indicated that the ability to rotate mental imagery (MARMI) significantly influenced the number of correct graph-comprehension responses. Individuals high in the ability to rotate mental imagery obtained more correct graph-comprehension responses than individuals low in the ability to rotate mental imagery. These results coincided with those obtained in studies analyzing the influence of imagery rotation in complex figures and mathematical problem-solving (Campos & Campos-Juanatey, 2019a; Reingewertz, 2013; Sanchez & Wiley, 2014; Van Garderen, 2006), the interpretation of maps (Campos & Campos-Juanatey, 2019a; Campos-Juanatey & Campos, 2019), and the ability to orient oneself on you-are-here maps. Moreover, the results of this study agreed with other studies analyzing the comprehension of both macroeconomic (Reingewertz, 2013) and microeconomic graphs (Marangos & Alley, 2007). Furthermore, the results on the comprehension of the mathematical graphs were similar to the findings of other authors analyzing mathematical problem-solving (Hegarty & Kozhevnikov, 1999; Sheckels & Eliot, 1983; Van Garderen, 2006; Van Garderen & Montague, 2003).

The analysis of the influence of image rotation on the number of graph-comprehension errors in economics showed the influence was null. In previous studies, Campos-Juanatey et al. (2017) found differences between individuals high or low in the ability to rotate mental imagery and the number of errors made in urban map rotation.

The analysis of the influence of graph complexity (number of quadrants) on the number of correct responses showed the number of quadrants significantly influenced graph comprehension, that is, the simpler the graph, the fewer the errors. Similar results have been obtained by other authors in studies on graph comprehension (Kosslyn, 1994b; Shah et al., 1999), complex figure rotation (Cooper, 1975; Metzler & Shepard, 1974; Piccardi et al., 2011), and the comprehension of you-are-here maps (Campos & Campos-Juanatey, 2019c). Moreover, graph complexity (the number of quadrants in a graph) influenced the number of graph-comprehension errors, a result that agreed with other studies analyzing graph comprehension (Kosslyn, 1994b; Shah et al., 1999), complex figure rotation (Cooper, 1975; Metzler & Shepard, 1974; Piccardi et al., 2011), and the interpretation of you-are-here maps (Campos & Campos-Juanatey, 2019c).

The measures of the abilities in mental rotation (spatial abilities) are part of the constituents of general intelligence (Thurstone & Thurstone, 2002) and significantly correlate ($r = .31$, $p < .01$) with the Domino Test (Anstey, 1944), which is a general intelligence test (Richaud, 1978). It is plausible that participant outcomes may be interpreted according to their brain power. Visual–spatial ability correlates with STEM disciplines, which in turn correlate with high intelligence (Khine, 2017).

This study analyzed only the effects of mental imagery rotation and graph complexity on the understanding of graphs in the learning of economics. However, the effects of image rotation on other types of graphs and visual aids of varying degrees of complexity have not been examined in other university disciplines or other tiers of education. It is to be expected that individuals with a high ability to rotate mental images, be it measured through the test used in this study or through other image-rotation tests, will find it easy to understand other graphic types.

The results of this study reveal that the ability to rotate mental imagery influences the comprehension of graphs in the learning of economics, as in other disciplines, in particular STEM. Since imagery abilities can be trained (Hyde & Lindberg, 2007; Mataix et al., 2014; Mataix et al., 2015;

Uttal et al., 2013), further studies are required to analyze the effects of training on learning in different disciplines and professions.

CONFLICT OF INTEREST

The authors declare there are no conflicts of interest.

ETHICS STATEMENT

We state that we have followed ethical standards in this research.

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