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ΕΛΛΗΝΙΚΑ ΓΡΑΜΜΑΤΑ

DEDUCTIVE REASONING ABILITY IN CAUSAL, QUANTITATIVE, AND SPATIAL CONTEXT

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The aim of this study was to investigate the deductive reasoning ability in different contexts. Specifically, the deductive reasoning ability has been tested in the form of six different logical inference types within the quantitative, the causal, and the spatial context.

The study is highly related to the debate, both philosophical and psychological one, regarding the nature of human reasoning; that is, whether inference drawing and human rationality, in general, is affected by abstract logical rules that are applied independently of the context involved (Braine, 1978, 1990; Braine & O'Brien, 1991; Rips, 1983, 1990) or by mental models attached to each particular case (Johnson-Laird, 1983; Johnson-Laird & Byrne, 1991), or by the context itself as a framework that provides prior experiences related to new problem-solving situations (Cheng & Holyoak, 1985; Gonida, 1994).

The specific goals of the present study were related to the following:

1. Significance of the *specific context* in reasoning ability.
2. Significance of the *logical type of the argument* in inference formation.
3. Role of other parameters such as the *validity/invalidity* of the argument and the *concrete/abstract* contents.

Our main hypotheses were the following ones:

1. The context within the particular syllogisms were activated was anticipated to highly affect the subjects' performance; that is, subjects were expected not to draw same inferences to arguments of the same logical form when those arguments were quantitative, causal, or spatial.

2. The logical form of the arguments was also anticipated to affect cognitive performance; that is, different scores were expected to different types of syllogisms.
3. In addition, other parameters such as the *validity/invalidity* of the argument and the *concrete/abstract* contents were expected to interact both with the logical form and the specialized context.

Method

Subjects

In order to test the above hypotheses, a sample of 63 subjects was tested. The subjects were college students drawn from both genders and aged from 17,4 to 25,75 years (mean age = 20,7).

Tasks and Procedure

The test battery consisted of 36 logical arguments which in sets of 6 represented six different logical inferences. The logical inferences involved in the study were the following:

1. modus tollens (MT)
2. modus ponens & modus tollens & conditional proof (MP&MT&CP)
3. elementary complex constructive dilemma (CCD)
4. fallacy of affirming the consequent (AC)
5. fallacy of denying the antecedent (DA)
6. fallacy of undistributed middle (UM).

Examples of the arguments used in the study are provided in Appendix 1.

Three contexts were represented in each set of logical relations in pairs of two arguments, namely the quantitative (Quant), the causal (Caus), and the spatial (Spat) domain. Moreover, the abstract/concrete contents of the arguments were systematically handled. Table 1 presents the experimental design of the study.

Table 1. The experimental design of the study

		Quantitative		Causal		Spatial	
		Abstract	Concrete	Abstract	Concrete	Abstract	Concrete
V	modus tollens	✓	✓	✓	✓	✓	✓
	mp & mt & cp	✓	✓	✓	✓	✓	✓
	mini dilemma	✓	✓	✓	✓	✓	✓
NV	affirming the consequent	✓	✓	✓	✓	✓	✓
	denying the antecedent	✓	✓	✓	✓	✓	✓
	undistributed middle	✓	✓	✓	✓	✓	✓

The arguments were given to the subjects in a multiple-choice format with four alternative conclusions. The subjects' answers were scored on the basis of a 4-point scale which corresponded one-to-one to the alternative conclusions. That is, each given conclusion was gradually approaching to the correct answer. Specifically, in all the valid inferences the subjects were given a choice of four conclusions that ranged from the correct conclusion (evaluated as 3) to conclusions that are consistent with the premises (more likely: 2 / less likely: 1) to conclusions that are inconsistent with the premises, i.e. the negation of the correct conclusion, (evaluated as 0). Similarly, in the fallacies the conclusion «possibly p» was the correct (3), with «probably p» as the second best choice (2), «certainly p» as the third choice (1), and «certainly not p» as the last choice (0).

Results

The first step was to confirm the dimensions according to which the tasks had been constructed. Confirmatory factor analysis is considered to be the appropriate method for this aim. Due to the limited number of subjects (valid cases, N=54) and to the great number of both variables and dimensions underlying performance on the tasks, confirmatory factor analysis was applied separately on the valid and invalid arguments. Specifically, the nested factor method was first used in order to test if each of the dimensions built into the tasks was statistically reliable. In this study, by construction, all the tasks-arguments involved (a) a logical inference type which could be either valid or invalid, (b) a specific context (quantitative, causal, or spatial), and (c) concrete or abstract contents. Besides, we can assume that the tasks make use of general processing and control mechanisms. Thus, at the first step, a general factor G was first introduced into the model to which all 18 valid tasks were related. At the second step, two factors were introduced: the general one and the factor that corresponded to the abstract content. This factor was prescribed to be related to those nine tasks which were designed to employ abstract contents. At the third step, the concrete factor was added to the previous two factors. This factor was prescribed to be related to all nine tasks which were designed to have concrete contents. Next, in the order in which they were introduced, the quantitative, the causal, and the spatial factors were added to the model in successive runs. Each of these factors was prescribed to be related to tasks addressed to the corresponding context. Finally, the three valid logical inferences were added into the model in successive runs; modus tollens, modus tollens & modus ponens & conditional proof, and elementary complex constructive dilemma were prescribed to be related to the corresponding pairs of arguments. The summary statistics to the nine models are shown in Table 2. Table 3 shows the complete model.

Table 2. Application of a nested factor model on the Valid Arguments

Factors	x^2	df	CFI	p	Δx^2	Δdf	Δp
General Factor (G)	236.371	135	.429	<.001			
+ Abstract	197.916	126	.595	<.001	38.46	9	<.005
+ Concrete	183.320	117	.626	<.001	14.60	9	<.10
+ Spatial	170.128	111	.667	<.001	13.19	6	<.05
+ Causal	154.329	105	.722	<.001	15.8	6	<.05
+ Quantitative	161.670	99	.647	<.001	7.34	6	<.10
+ MT	142.155	93	.723	<.001	12.17	6	<.05
+ MP&MT&CP	121.327	87	.807	<.01	20.83	6	<.005
+ CCD	76.188	76	.999	.472	45.14	11	<.005

Table 3. Variables' loadings onto the factors in the successive runs (Valid Arguments)

	G	Abst	Conc	Spat	Caus	Quant	MT	MP&..	CCD
MT1	.667*	.308*				.192	.331*		
MT2	.072		.301*			.101	.109		
MT3	.192	.095			.167		.133		
MT4	.504*		.839*		.032		.201		
MT5	.017	.033		.185			.982*		
MT6	.206		.288	.787*			.061		
MP&..1	.523*	.380*				.138		.689*	
MP&..2	.070		.136			.283		.407*	
MP&..3	.274	.031			.947*			.165	
MP&..4	.763*		.136		.078			.006	
MP&..5	.438*	.249		.447*				.117	
MP&..6	.643*		.189	.041				.291	
CCD1	.132	.068				.320*			.295
CCD2	.114		.129			.947*			.076
CCD3	.232	.765*			.538*				.252
CCD4	.338*		.0002		.165				.230
CCD5	.219	.105		.024					.080
CCD6	.208		.156	.039					.965*

Exactly the same model was tested onto the invalid arguments. Table 4 and Table 5 show the summary statistics and the complete model with the factors loadings.

Table 4. Application of a nested factor model on the Invalid Arguments

Factors	x^2	df	CFI	p	Δx^2	Δdf	Δp
General Factor (G)	230.641	135	.519	<.001			
+ Abstract	211.882	126	.568	<.001	18.76	9	<.05
+ Concrete	185.669	117	.655	<.001	26.21	9	<.005
+ Spatial	181.335	111	.646	<.001	4.33	6	<.10
+ Causal	154.604	105	.756	<.005	27.73	6	<.005
+ Quantitative	147.998	99	.754	<.005	5.61	6	<.10
+ AC	133.705	93	.795	<.005	14.29	6	<.05
+ DA	128.326	87	.792	<.005	5.38	6	<.10
+ UM	94.899	80	.925	.122	33.43	7	<.005

Table 5. Variables' loadings onto the factors in the successive runs (Invalid Arguments)

	G	Abst	Conc	Spat	Caus	Quant	AC	DA	UM
AC1	.554*	.235*				.199	.207		
AC2	.428*		.612*			.197	.599*		
AC3	.660*	.175			.129		.719*		
AC4	.586*		.304*		.835*		.155		
AC5	.331*	.435*		.303*			.164		
AC6	.453*		.219	.078			.097		
DA1	.383*	.221*				.129		.193	
DA2	.411*		.297			.835*		.212	
DA3	.446*	.252			.115			.212	
DA4	.568*		.057		.203			.079	
DA5	.212	.371*		.252				.868*	
DA6	.519*		.128	.239				.026	
UM1	.223	.009				.274			.298
UM2	.008					.231			.375*
UM3	.210	.075*			.101				.885*
UM4	.218*		.270		.360*				.297
UM5	.390*	.517*		.681*					.343*
UM6	.073		.632*	.206					.390*

Having confirmed the reliability of the dimensions involved in the study, we proceeded to test the relationships among them. A 6 (logical relations) x 3 (contexts) x 2 (contents) MANOVA with repeated measures was applied on the scores attained by the subjects. The results are the following:

Main effects

logical inference type: $F(5,265)=28.94$, $p=.000$
context: $F(2,106)=9.30$, $p=.000$
content: $F(1,53)=36.06$, $p=.000$

Interactions

logical inference type x context: $F(10,530)=10.34$, $p=.000$
logical inference type x content: $F(5,265)=10.52$, $p=.000$
context x content: $F(2,106)=3.49$, $p=.034$

The main effect of logical inference type indicated that performance on the arguments of different types was not the same; in the first three types which were the valid ones and the last type which was one of the invalid types performance was higher than the others (Figure 1).

The main effect of the context was found significant. In general, subjects scored higher in the quantitative arguments than in the spatial and in the causal ones. But if we take into account the valid/invalid distinction then we can see that in valid inferences the order of scoring leads from spatial (highest) to causal to quantitative (lowest) while the reverse order is observed in the case of invalid arguments (Figure 2).

However, the two main effects mentioned above were qualified by their significant interaction. That is, neither the logical relation itself nor the context itself is sufficient to explain subjects' performance (Figure 3).

Regarding the content effect, significant interaction was found between the abstract/concrete content of the arguments and their logical inference type (see Figure 4) as well as between the abstract/concrete content of the arguments and the context involved (see Figure 5). However, we can see in these figures that, even though subjects generally scored higher in the concrete arguments rather in the abstract ones, still the difference is not significant in half of the cases (e.g. modus tollens, mp & mt & conditional proof, affirming the consequent). The same holds true for the interaction between contexts and the abstract/concrete contents of the tollens, mp & mt & conditional proof, affirming the consequent). The same holds true for the interaction between contexts and the abstract/concrete contents of the argument (e.g. abstract/concrete in the quantitative context vs abstract/concrete in the causal or spatial context).

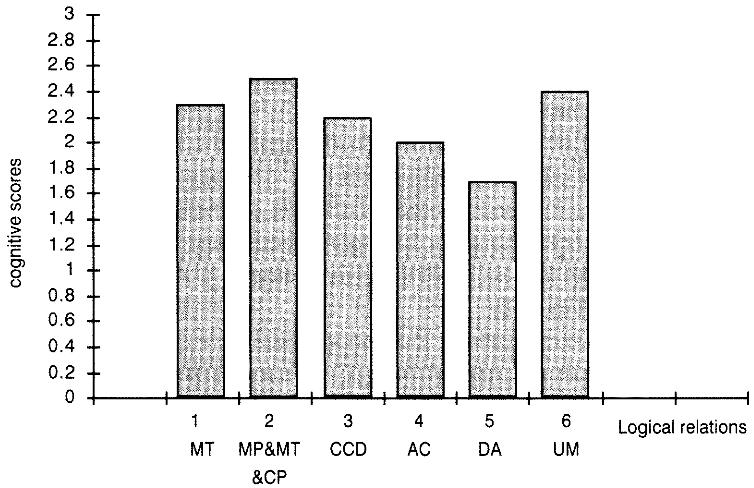

Figure 1. Mean scores attained by the subjects on the arguments of different logical relations

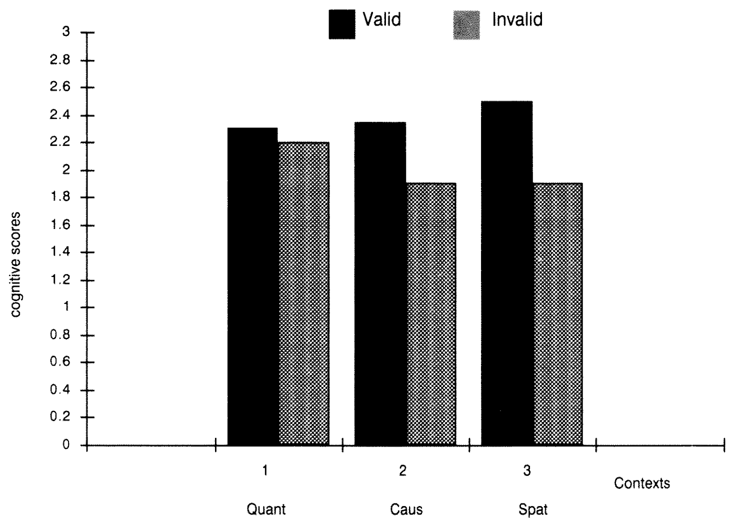

Figure 2. Subjects' performance as a function of the different contexts and the validity/invalidity of the arguments

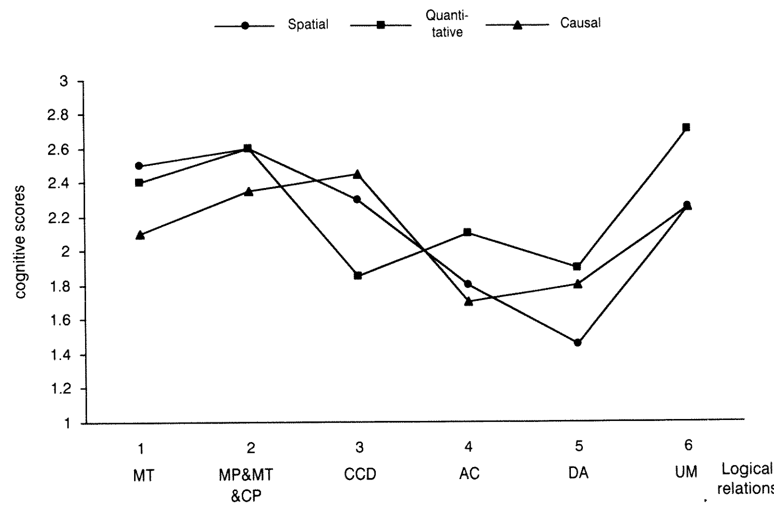

Figure 3. Subjects' scores as a function of the logical relations and the contexts involved in the study

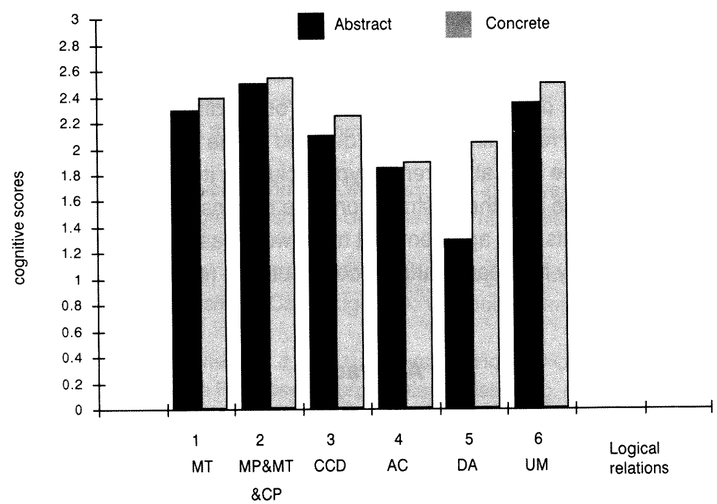

Figure 4. Subjects' performance as a function of the logical relations and the abstract-concrete content of the arguments

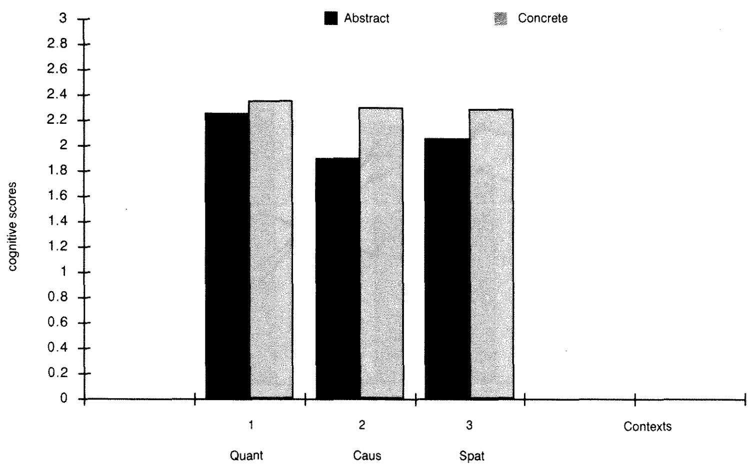

Figure 5. Subjects' performance as a function of the different contexts and the abstract/concrete content of the arguments

Discussion

In conclusion, we can say that according to our findings and in order to explain performance in reasoning tasks we do need all the parameters involved in this study; that is, the logical inference type including its validity/invalidity, the domain of knowledge and the abstract/concrete dimension regarding the contents of the arguments. It is apparent that more work has to be done in order to specify with accuracy how each variable contributes in reasoning performance.

Abstract

The study aimed to investigate deductive reasoning in different domains of thought, namely the causal, the quantitative, and the spatial domain. College students were asked to solve thirty-six syllogisms addressed to six logical relations (i.e., valid/invalid and concrete/abstract across the three domains). Confirmatory factor analyses validated the existence of the above factors. Moreover,

MANOVA indicated the importance of the domain, the validity vs. invalidity and the concrete vs. abstract distinction of type of relations. That is, performance on deductive reasoning tasks seems to be highly influenced both by semantic and syntactic characteristics. On the one hand, the influence of semantics was suggested by the fact that the performance on the quantitative, causal, and spatial arguments was not uniform. Moreover, the concrete/abstract differentiation of the arguments was clearly reflected in the subjects' performance; however, this differentiation did not always favour the concrete syllogisms, indicating the dynamic interaction between the domain of thought and the content of the arguments. On the other hand, syntactic factors also proved important; performance on the valid tasks was systematically better than performance on the invalid ones. That is, the logical relations need the support of the appropriate linguistic schemata in order to yield satisfactory performance.

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APPENDIX

Examples of the arguments used in the study

1. *Modus Tollens*

If p then q
not q

---

not q

Example (Quantitative / Abstract)

If a number divides another number then it must be smaller than it
x is not smaller than y

( ) It is certain that x does not divide y
( ) It is probable that x does not divide y
( ) It is possible that x does not divide y
( ) It is possible that x divides y

2. *Modus Tollens & Modus Ponens & Conditional Proof*

If p then q
If r then not q

If r then not p

Example (Spatial / Concrete)

Punjap is in India
Pamir is not in India

( ) It is certain that Pamir is not in Punjap
( ) It is likely that Pamir is not in Punjap
( ) It is possible that Pamir is not in Punjap
( ) It is certain that Pamir is in Punjap

3. *Elementary Complex Constructive Dilemma*

If p then q
If not p then r

Either q or r

Example (Causal / Concrete)

If the liver is infected, the patient will develop jaundice
If the liver is not infected, the patient will have high whiteblood cell count

---

( ) If the patient has jaundice he will have high whiteblood cell count
( ) The patient will not develop either jauntice or high whiteblood cell count
( ) If the patient develops high whiteblood cell count he will not develop jaundice
( ) The patient will develop either high whiteblood cell count or jaundice

4. *Affirming the Consequent* (fallacy)

If p then q
q

---

p

Example (Quantitative / Concrete)

If Latsis has more boats than Niarchos, he has more boats than Livanos
Latsis has more boats than Livanos

( ) Latsis has more boats than Niarchos
( ) Latsis probably has more boats than Niarchos
( ) Latsis possibly has more boats than Niarchos
( ) Latsis certainly does not have more boats than Niarchos

5. *Denying the Antecedent* (fallacy)

If p then q
not q

---

not p

Example (Spatial / Abstract)

Whatever is inside A, is inside B
X is not in A

( ) X is certainly not in B
( ) X is probably not in B
( ) X is possibly not in B
( ) X is certainly in B

6. *Undistributed middle* (fallacy)

If p then q
If r then q

If r then p

Example (Causal / Abstract)

If A happens, B happens
If C happens, B happens

( ) If C happens then certainly A happens
( ) If C happens then probably A happens
( ) If C happens then possibly A happens
( ) If C happens then it is impossible for A to happen