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THE ASSESSMENT OF TIME PRESSURE EFFECT IN PROBABILISTIC REASONING: EVALUATING PERFORMANCE IN VERBAL-NUMERICAL AND GRAPHICAL-PICTORIAL FORMATS

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Abstract – The purpose of this study was to study the effect of presence versus absence of time pressure on some individual variables in probabilistic reasoning, concerning problems in verbal-numerical and in graphical-pictorial format. Italian undergraduates were assessed to understand these relationships as regards abilities, attitudes, anxiety and confidence. The effect of time pressure on performance has been different in the two formats of problem presentation.

Keywords: Probabilistic reasoning, measurement, performance, time pressure, format of problem presentation

1. INTRODUCTION

The role of probabilistic reasoning in daily and academic contexts is crucial. Its relevance is decisive especially in the study of statistics, a domain in which students always showed big troubles [1]. These difficulties are very strong particularly in some kinds of undergraduates, as Psychology students, for example [2]. In their courses they must deal with many subjects related to statistics, often without appreciating the usefulness of this study in their future career. Moreover, they are not often endowed with the mathematical prerequisites useful to handle these topics [3]. In order to overcome the difficulties in the application of probabilistic reasoning, many researchers have attempted to introduce different ways of problem presentation, for example using graphical devices [4, 5, 6, 7, 8].

However, performances in probabilistic reasoning depend on many individual and contextual dimensions [9, 10, 11]. Among these latter, the timing of problem administration plays a crucial role, especially in scholastic and academic contexts, where tasks usually have a time limit [12].

The relation between timing (presence vs absence of time pressure) and performance has been studied by many authors, especially in relation to anxiety [e.g. 13]. Some researchers highlighted that the presence of time pressure could increase the anxiety [e.g. 14]. Then, in order to reduce the effect of the latter, they claimed that it could be useful to allow an adequate time amount to solve problems. This last caution might reduce the anxiety related to the need for speed in problem solving processes [15]. In this regard Onwuegbuzie and Seaman [14] found that graduate students with high statistics anxiety, carrying out a statistical task under time pressure, might have lower performances than their highly anxious colleagues working in absence of time pressure. On the other hand, the performances of low-anxious undergraduates were similar both in presence and in absence of time pressure. Consequently, the advantage on performance produced by the absence of time pressure was greater for high-anxious learners than for low-anxious subjects [14, 15, 16, 17, 18].

Besides, some researchers discovered that particular learners could take advantage on problem solving when they worked with a time limit [e.g. 13, 19]. For some individuals timing seems to support commitment to the task, and motivation, reducing dysfunctional thinking and improving performance [e.g. 12, 13].

Anyway, the assessment of the effect produced by time pressure is very difficult because these specific outcomes might be interrelated to the emotional features and other individual characteristics, which could influence the solution process [20]. Indeed probabilistic problem solving is undoubtedly related to a number of further individual cognitive and non-cognitive aspects (e.g. abilities, attitudes and confidence) [2, 3, 11, 20].

For example, many researches emphasized the relation between prior curricula and achievement in statistics. Particularly, some authors highlighted the association between statistical and probabilistic reasoning and the specific courses completed in these subjects [21].

Other scholars [22, 2] underlined the influence of the score achieved in University admission examinations on the following academic performance and, subsequently, on the achievement in statistics. Coherently, also other authors [e.g. 2, 3, 23] highlighted that the type of studies carried out in secondary schools (humanistic vs. scientific) could distinguish the students' approach to statistics. Furthermore, strong mathematical skills are decisive for the subsequent success in statistical and probabilistic reasoning, and mathematical ability is a robust predictor of this performance [3, 24].

Moreover, the visuo-spatial ability seems to be essential in probabilistic problem solving. The relation between visuo-spatial and math abilities has been already evidenced [25].

Furthermore, a connection between reduced spatial skills and inadequate math achievement was shown [25, 26]. In this regard, expressly, Kellen et al. [25] claimed that the learners "low-spatial users" could take more advantage from the presentation of text-only displays, rather than from the use of graphical devices. On the other hand, these authors observed that "high-spatial users" subjects could improve their performance when diagrams were used.

Moreover, the attitudes towards statistics exert a strong impact on statistical reasoning [27, 28, 29]. Wise [30] found a significant positive relation between the attitude toward the course and marks in statistics. Similarly other researches [31, 32] evidenced the relation between attitudes and the statistics achievement.

In addition, among the variables that affect performance in problem solving, there is confidence, which showed positive correlations with many cognitive abilities, allowing to consider it as a metacognitive dimension [33, 34]. Stankov [34] specified that "measures of confidence in the accuracy of the just-provided answer are the best non-cognitive predictor of ability/intelligence and achievement" (p. 729).

Indeed, also Kröner et al. [35] highlighted the importance of the correlations between performance and the corresponding confidence in the correctness of solution. Moreover, Morony et al. [36] established that confidence scores improve the prediction of accuracy over and beyond some other non-cognitive dimensions.

2. AIM AND METHOD

This investigation aims at assessing the effect of presence versus absence of time pressure on performances in probabilistic reasoning, in verbal-numerical and graphical pictorial formats, for not evaluative task conditions. Undergraduates in Psychology (without any statistical expertise) were assessed by a battery of questionnaires in order to evaluate (in relation with probabilistic reasoning in both presentation formats) their individual abilities, attitudes, anxiety and confidence in the correctness of response.

We specifically studied the effect of time limits in relation with the factors potentially affecting performances. In particular we supposed that the presence of time pressure should induce some affective change, supporting higher anxiety and therefore reducing performances [e.g. 14].

A new characteristic of this research was the simultaneous measurement of different aspects having an impact on probabilistic reasoning, specifically in the two formats of problem presentation. Indeed, on the base of our knowledge, there are not specific models on probabilistic reasoning, related to the study of the effect of graphical facilitation, including all these dimensions.

2.1. Participants, instruments and procedure

We assessed 549 undergraduates in Psychology, enrolled in the first year of the degree course, without any statistical expertise. Their average age was M = 20 years (SD = 3.67, range 18 to 62); among them there were 147 males (26.8 %).

Participants attended courses at the Italian Universities of Cagliari (n= 28), Chieti (n=144), Genoa (n=58), Milan (n=50), Naples (n=35), Pavia (n=20), Rome (n=173) and Trieste (n= 41).

They belonged to the middle socioeconomic status. Tasks were presented in the form of a practical task of their university course, whose results would be used in order to investigate the human reasoning process. A group of undergraduates (n=173) compiled the questionnaires included within the research protocol with a mild time limit (30'); the remaining participants compiled the questionnaires without any time constraint. In both groups (with and without time pressure) the absence of final assessment was underlined (not evaluative tasks).

We applied a non-probabilistic sampling, based on the availability of participants that voluntarily participated in the research, giving their informed consent. We collected data during the academic year 2013/14.

We submitted all questionnaires to each student in a single work session, in pencil-and-paper form, within a large group in a quiet lecture room.

To assess probabilistic reasoning we presented a short questionnaire, appointed by previous pilot studies [37, 38]. It contained five problems in each of two formats (verbal-numerical – N - and graphical-pictorial - G), presented in different orders (NG vs. GN) and sequences. Each item had a short description and four alternatives of response (of which only one was correct).

Contextually, we presented a question inquiring the level of confidence in the correctness of the answer provided.

To assess the prerequisites of probabilistic reasoning, we presented two scales of the Primary Mental Abilities (PMA) test [39]: the Visuo-Spatial and Numerical Scales.

Moreover, in order to investigate the connections among attitudes, anxiety and performance, we administered the Italian versions of the Survey of Attitudes Towards Statistics (SATS-28) [40] and of Statistical Anxiety Scale (SAS) [41].

In order to evaluate the effect of time pressure in performances in two formats, we applied firstly a MANOVA and then two Structural Equation Models (SEM) [42], using the software LISREL 9.1 [43].

3. RESULTS

Initially the descriptive statistics and the linear correlations (Pearson's *r* Coefficient) were assessed.

Then we used a MANOVA having as a factor the "presence vs absence of time pressure", and the performances in N and G formats as dependent variables. The multivariate tests were significant (Wilks' lambda $_{[2;546]}$ = .965, p<.0001). Concerning between-subjects effects, we observed a significant effect of "time pressure" for the N format ($F_{(1;547)}$ = 16.120, MSE = 33.968, p<.0001, η^2 = .029), but not for the G format ($F_{(1;547)}$ = .086, MSE = .168, p=.769, η^2 = .0001). Specifically, in the N format the subjects under time pressure obtained a higher performance (M=2.277; SD=1.471) than their colleagues that worked without time limits (M=1.742; SD=1.442) (see Figure 1).

But at this point it could be more interesting to consider the effect of time pressure on performance, accounting for the multiple interactions with cognitive and non-cognitive dimensions. More precisely, in order to understand the structure of relationships underlying these results, we applied two SEMs, one in relation to probabilistic reasoning in N format, and the other one for problems in G format [42].

The models are illustrated in Figure 2 (N) and Figure 3 (G). They tested how abilities, previous experiences, timing of administration, anxiety, attitudes and confidence, are related to performance. In each model thirteen measured variables were used as indicators of seven latent variables.

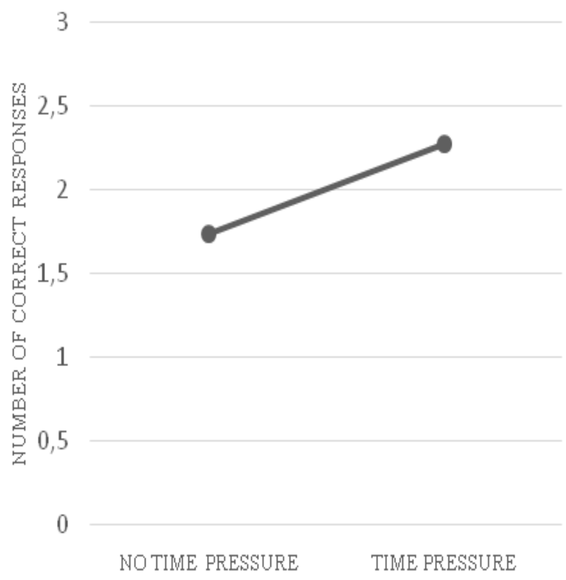


Figure 1. Mean of correct responses for N format in presence vs absence of time pressure

Specifically, three out of the seven latent variables were defined as exogenous (abilities, previous experiences, timing), while the remaining four latent variables were treated as endogenous (anxiety, attitudes, confidence and reasoning). More precisely, the abilities were measured by the two scales of visuo-spatial and numerical PMA [39]. The statistical anxiety was assessed by the three dimensions of SAS (Help, Interpretation and Examination) [41]. The attitudes towards statistics were evaluated by the four dimensions of SATS (Affect, Value, Difficulty and Competence) [40]. The Confidence was measured by the self-assessment in relation to each of five problems. The Previous Experience was estimated by the University admission mark. The timing of administration was evaluated by a dummy variable (the presence of time pressure -“1”- the absence -“0”). The probabilistic reasoning was represented by the performance in five specifically appointed problems [38].

It was hypothesized that abilities would exert both a direct and indirect positive effect on probabilistic reasoning. Moreover it was supposed that the abilities would affect anxiety both negatively and directly, the latter in turn being negatively related to attitudes and confidence, independently from reasoning. We supposed that the presence of time pressure could affect statistical anxiety, and, moreover, could directly affect performance. Attitudes would be directly and positively related to confidence. Finally, reasoning would be directly and positively affected by abilities, previous experiences and by confidence [3, 33]. Similar findings were expected for the two formats, with some specificities related to the role of visuo-spatial abilities in the graphical-pictorial format of problems [25, 26].

The model application showed an acceptable fit for both formats (ratio Chi Square / degree of freedom, Root Mean Square Error of Approximation) [42, 44] (Table 1). The outcomes (see Figure 2 and Figure 3; Table 2) showed as time pressure exerts a dissimilar effect on statistical anxiety and on performance respectively, in relation to the two formats of problems. Precisely the presence of time limits negatively affect statistical anxiety, especially in the G format (Table 2).

Fig. 2. SEM applied in relation to the verbal-numerical format of problems.

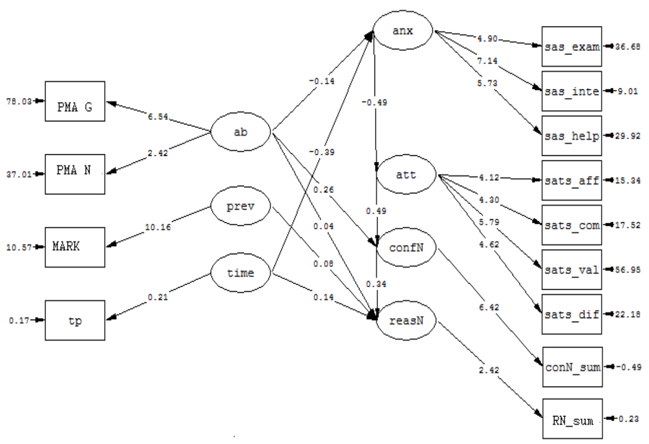
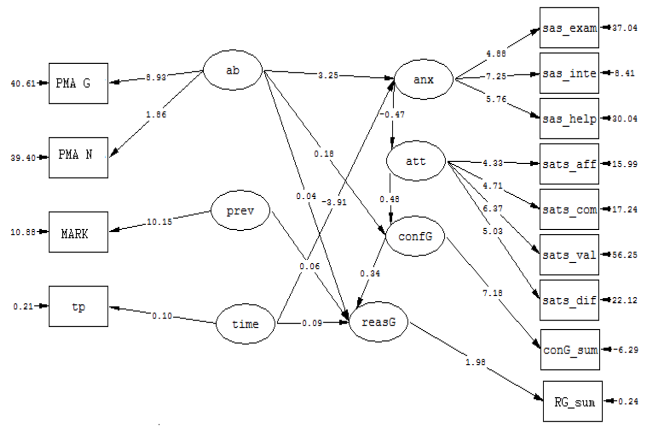


Fig. 3. SEM applied in relation to the graphical-pictorial format of problems.



LEGENDA for Figure 2 and Figure 3	
ab = abilities	Visuo-spatial (PMA G) and numerical (PMA N) scales
prev = Previous experience	University admission mark
tp = timing of administration	Presence vs absence of time pressure
anx = statistical anxiety	SAS (Help, Interpretation and Examination)
att = attitudes	SATS (Affect, Value, Difficulty and Competence)
Conf N = confidence in N format	Confidence in the correctness of responses in N format
Conf G = confidence in G format	Confidence in the correctness of responses in G format
reasN = reasoning in N format	Probabilistic reasoning, sum of correct responses in N format
reasG = reasoning in G format	Probabilistic reasoning, sum of correct responses in G format

Table 1. Indices for Structural Equation Models applied in relation to the N format and to the G format.

	Format N	Format G
Sig.	<.0001	<.0001
χ^2/df	116.449/53=2.197	125.351/53=2.365
RMSEA [90 % CI]	.046 [.035 -.058]	.051 [.038 - .061]
LEGENDA: χ^2/df: Chi Square / degrees of freedom; RMSEA: Root Mean Square Error of Approximation; 90 % CI: 90% Confidence Interval of Root Mean Square Error of Approximation.		

In relation to other paths estimated in the models, we observed that the Gamma coefficient between Timing and Reasoning is positive and significant only in G format. Furthermore, evaluating the total effects, we observed that timing has a negative effect on Anxiety in both formats, while having a positive influence on attitudes, confidence and reasoning, especially in G format of problem presentation (Figure 2 and Figure 3; Table 2). In this study, as each student tried to solve problems in both formats, the differences observed might be related to the interactions between variables in different formats of problems (Table 2).

Table 2. Estimated coefficients in Structural Equation Models applied in relation to the N format and to the G format.

Path	Format N	Format G
Lambda X (Timing - Tp)	.209**	.101**
Beta (Anxiety - Attitudes)	-.492**	-.465**
Gamma (Timing - Anxiety)	-.393*	-3.910**
Gamma (Timing - Reasoning)	-144	.087*
Legenda: * p<.05 ; ** p<.001		

4. DISCUSSION AND CONCLUSIONS

This research aimed at assessing the influence of presence versus absence of time pressure on probabilistic reasoning, applied in not evaluative tasks, in relation to verbal-numerical and graphical pictorial formats, accounting for the influence of different dimensions (metacognitive, cognitive and non-cognitive). Our results did not confirm the hypothesis that time pressure increases anxiety. Indeed it was evidenced a negative relation between the presence of time pressure and anxiety, and, furthermore, a positive relation between timing and probabilistic reasoning performance. This agrees with the fact that the application of a MANOVA emphasized a significant effect of time pressure in the N format, once the students working with time limits obtained better performances.

Generally, we may suppose that facilitation in problem solving might be related to the use of different cognitive processes in the two formats of the tasks. It seems that dissimilarities in formats are important as well as differences in timing conditions. We might suppose that the presentation of problems under time pressure may increase reflective data processing in students who lack expertise in probabilistic problems.

This outcome could be considered coherent with some works, in which students take advantage in problem solving when they work with a time constraint [e.g., 12, 13]. Indeed, these authors supposed that individuals could select different solution strategies on the basis of context and of data, adapting their behaviour to the situation [12, 13].

In the SEM models, differentiated for two formats (N and G), it was detected that the presence of time pressure could affect negatively statistical anxiety, which in turn might negatively affect performance.

Moreover we discovered that the time limit could exert a different influence on performance, in the same participant, in relation to the presentation format (N and G). In particular, the negative effect of time pressure on anxiety is stronger in G format, as well as the positive effect on reasoning performance.

This outcome could be linked to the different cognitive processes implied, as the G format requires a stronger appeal to visuo-spatial processing [25, 26]. Furthermore, these differences could be related to the fact that problems in N format appear to be more similar to classical tasks solved in the academic context (differently from those presented in G format).

It might be suitable to evaluate these findings in agreement with the problem interpretation hypothesis [45], which highlighted that problem structure and format of presentation can recall to mind a particular body of information (e.g., connected to mathematical operators) useful to be applied to specific problem solving [45].

Furthermore, our findings are coherent with the statement that a mild time pressure could support a stronger commitment in the task and improve the application of adequate solution strategies, reducing dysfunctional thinking [46, 47, 48, 49]. Moreover in bibliography it is highlighted that there are specific effects of time pressure on information-processing strategies, defined as "filtration" and "acceleration" [12]. Their application is related to individual differences, which could enhance an adaptive behaviour [e.g. 4, 13]. The time limits could support the awareness that it is necessary to work more than in absence of time constraints [12]. This aspect could give a different connotation to the task, perceived as challenging, characterised by a positive valence and requiring high effort [12]. In our research, giving attention to this fact, specific attention was paid to the instructions given to the participants, emphasizing the absence of assessment in both groups (with and without time pressure). This fact could have affected the anxiety feeling in our students, perceiving the protocol as not evaluative. Furthermore, observing the indirect effect of anxiety on reasoning, we detected in both formats a strongly significant negative effect, as classically depicted in bibliography [14]. This fact might suggest that, nevertheless, anxious subjects experience a negative effect of this feeling on performance [46].

In view of the interactions between all variables, our findings may be understood by resorting to Stanovich's Dual-Process model [50, 51, 52, 53, 54]. This model identifies the relationships between intuitive and reflective cognitive processes. Indeed, we speculate that problems might be solved firstly by the solicitation of Type I processing, wherein non-normative and spontaneous knowledge is used [52]. We suppose that this kind of processing might operate mainly in absence of time pressure. Coherently, the application of Type

II processing should be more strongly implied in the presence of time pressure, where tasks are considered more challenging and there is an increase of commitment.

Furthermore, the impact of metacognitive dimension of confidence on probabilistic reasoning might be understood by considering the outcomes of other researches [54, 55]. Indeed, Thompson et al. [55], taking into account the links between probabilistic reasoning and dual-process approach, suggest that confidence in the preliminary response offers a central key soliciting the Type II of processing [55]. In fact, it seems that when individuals are confident in their primary answer they are less inclined to resort to a deeper handling of data to change their initial reasoning [55].

Moreover, in their recent paper Evans et al. [56] underlined the importance of confidence in conditional reasoning. Indeed they specified that in the new paradigm of probabilistic reasoning we have to overstep the traditional binary deduction paradigm [57], where individuals are required to answer "yes" or "no", correspondingly to valid or invalid claims [56]. They highlighted that probabilistic reasoning in everyday contexts is characterized by specific degrees of confidence that strongly affect the given answers [58, 56, 59, 60]. These considerations are supported by the presence of significant linear correlations between precision and confidence marks recognised on the same items [33].

In summary, the presence of mild time limits in not evaluative tasks for inexperienced undergraduates seemed not to hamper probabilistic reasoning, but rather to support a greater commitment to the assignment. Our outcomes suggest to further investigate the multifaceted effects of time pressure in probabilistic reasoning, considering the interrelations between cognitive, metacognitive and non-cognitive aspects.

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