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Information representation in decision making: The impact of cognitive style and depletion effects

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ABSTRACT

Although the literature on information representation in decision support has argued for a long time that the way in which information is presented to decision makers should fit both task characteristics and the cognitive style of decision makers, the latter aspect has received much less attention in empirical research. Most studies that took into account cognitive style used rather general instruments to measure it, which do not focus on the specifics of managerial decision making. In this paper, we describe an experiment that uses an instrument specifically developed for a managerial context to study the relationship between cognitive style and decision performance when using tabular or graphical representations. We also take into account that having to deal with a misfitting information representation depletes cognitive resources, and thus might not only impede the solution of the current problem, but also impact subsequent problems. Our results confirm that a mismatch between information representation and cognitive style indeed has effects that last beyond the solution of the current decision problem.

1. Introduction

The effects that different forms of presenting information might have on decision makers have been an important topic of the DSS literature since its early beginnings (e.g., [1,2]). Presentation of information in information systems is still an important topic. Information visualization, which deals with different methods of presenting data, has developed into a large subfield of computer science [3]. The very early literature on information presentation already emphasized that the form in which information is provided to decision makers has to fit both the characteristics of the problem and of the decision maker, in particular their cognitive style. However, over time, the fit of problem representations to decision maker characteristics received considerably less attention in literature than the fit to task characteristics [4]. This lack of consideration of decision maker characteristics is still evident in recent literature on information visualization. Evaluation of different visualization forms is an important topic in that literature, and various methods are used for this purpose [5]. Although literature sometimes mentions that individual characteristics might play a role in the effectiveness of visual representations [6], empirical studies that actually refer to user characteristics are quite rare. According to a survey by Isenberg et al. [7], <5% of the evaluation studies surveyed involved some forms of user performance experiments at all, and that survey does not even mention experiments considering individual user characteristics or decision making styles.

This prolonged disinterest of researchers in the relationship between individual characteristics of decision makers and the suitability of information presentation formats is surprising. It is a well established fact in research on managerial decision making [8] that individuals approach decision problems in different ways, and many instruments for measuring decision making styles have been developed (e.g., [9,10]; for a comparison of different instruments, see [11]). The argument raised in early literature against considering decision making styles [12], that the concept lacks conceptual clarity and empirical validity, is thus no longer valid. In our opinion, it is therefore necessary to reconsider the relationship between decision making styles and information presentation. Since computer based information is often used for decision making in a business context, we specifically focus on an instrument that was developed to measure cognitive style of managers in an organizational setting, the Cognitive Style Index CSI developed by Allinson and Hayes [9], and analyze whether different forms of information representation are suitable for decision makers having different decision making styles according to that classification. To the best of our knowledge, this instrument was not used in information system research before,

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but to us it seems to be particularly useful to classify potential users of DSS in a managerial context.

Regardless of how it is measured, the concept of a decision making style refers to a stable personal trait. However, the way in which individuals make decisions is not necessarily constant over time. Decision making requires cognitive effort, and human beings have only limited cognitive resources [13,14], which are depleted by tasks such as decision making. Depletion of cognitive resources negatively influences performance in following tasks that again require cognitive resources. Cognitive resources can be replenished over time by resting or consumption of glucose, but in the short run, depletion leads to a degradation of cognitive processes and has a negative effect on decision quality [15,16]. Having to deal with an inadequate problem representation, which does not fit the decision maker's cognitive style, increases the cognitive load [17,18]. However, given a sufficient stock of cognitive resources, it is possible that this depletion does not yet affect solution quality in the current problem, but will only impede performance in subsequent problems. Therefore, we study the effect of fit or misfit between problem representation and cognitive style not only with respect to one single decision problem, but in the context of a sequence of decision problems to identify such delayed effects.

The emphasis of this study is on information presentation. From the decision maker's perspective, we focus on the acquisition of information needed for decision making, rather than on processing. We therefore use a task in which subjects have to rank a number of alternatives, rather than selecting only one alternative. A ranking task forces decision makers to evaluate every alternative, while in a choice task, decision makers who follow a simple aspiration based strategy could stop their search after finding one satisfactory alternative. We thus ensure that all subjects have to obtain and process the same significant amount of information. At the same time, we kept the necessary calculations at a low level by using very simple lotteries as decision alternatives.

The remainder of the paper is structured as follows. Section 2 provides the theoretical basis of our research by giving a literature review on cognitive fit of presentation formats and decision making. Section 3 formulates our specific hypotheses. Section 4 presents the experiment we have conducted. Section 5 reviews the results and Section 6 concludes the paper with a discussion and an outlook to future research.

2. Literature review and motivation

Information representation constitutes a major research topic for information systems [19]. Multiple studies in the literature show the importance of information representation in different settings, e.g., multi-criteria decision problems [20], electronically supported negotiations [21], process models [22,23], auctions [24], simulation [25], design of supply chain networks [26] and representation of uncertainty in data [27]. It is known that the way decision makers are provided with information influences their decisions from task involvement to potential biases [28], but the mechanics of these effects are not yet completely understood [29]. Kelton et al. [29] provide an exhaustive literature review about the effects of static information representation on individual decision making. Interactive information representation, in which the decision maker can select which information is presented in which form, is reviewed by Dilla et al. [30].

Early literature on information representation, as surveyed e.g. by DeSanctis [2] and Jarvenpaa and Dickson [31] focused on the comparison of direct effects of different presentation forms. Studies which only compared presentation forms, but did not include other factors such as psychometric characteristics of the decision maker, found only mixed evidence concerning performance (e.g. [4,32]). Attempts to resolve these inconclusive results motivated the development of the *cognitive fit model* [33] as a general framework integrating various factors that influence problem solving performance.

According to this model, problem solving operates on a mental representation of the problem in working memory. This mental representation results from the task definition and the external problem representation provided to the decision maker. If processing these elements is within the cognitive capabilities of the person, there is a *match* between the information and the problem-solving elements, resulting in an effective solution process. In case of a *mismatch*, creating the mental representation requires additional processing steps. Hence, an inconsistency between external representation and preferred internal model leads to inefficient problem solving [33]. Later works extended the cognitive fit model by emphasizing aspects of individual cognition and perception [34–36]. Kelton et al. [29] extend the cognitive fit model and argue that this model should serve as a general framework for information representation studies. In particular, Kelton et al. [29], in their extended version of the cognitive fit model, refer to cognitive style. One important property of cognitive style according to Kelton et al. [29, p. 81] is that "*… certain characteristics of the decision maker such as … cognitive style are unlikely to be affected by a single use of a presentation format or task.*", and therefore cognitive style can be considered as a factor that influences decision making performance in a consistent way across several tasks.

Although the extended cognitive fit model indicates that an information representation should fit both the task characteristics and the user's cognitive abilities and style, literature has to a large extent focused on the fit between task characteristics and information presentation (e.g., [37]). In the information visualization literature, the lack of consideration of user characteristics has repeatedly been criticized (e.g. [38–40]). For example Bačić and Fadlalla [41] note that the link between user characteristics and representation form has been ignored by a large body of literature. Similarly, Adnan et al. [42] point out the significance of individual cognitive differences as one of the key determinants of system success and state that the topic has not received enough attention. While evaluation is an important topic in the literature on information visualization, a survey of evaluation studies by Isenberg et al. [7] found that only about 5% of the studies used experiments with users for evaluation. In the comprehensive survey on evaluation of information visualization methods by Liu et al. [3], out of 19 papers using experiments, only one [43] considers individual characteristics of users and distinguishes between users of high and low numeracy.

Although rare, there are some studies in the information visualization literature that take into account user characteristics in various contexts. Some studies (e.g., [44]) consider information retrieval in databases and are therefore less relevant for our work. Several studies compare information acquisition using graphical and tabular formats taking into account individual factors like experience [45] or "spatial ability" [32] of users. Bak and Meyer [46] study the performance of subjects in a data mining task and find that users with stronger analytical orientation are better able to detect relationships using graphical representations. More closely related to decision making are studies that consider the performance of users in Bayesian inference tasks. In that context, Kellen et al. [47] compared various graphical displays for users with high and low spatial abilities, and Micallef et al. [43] textual and visual problem representations taking into account numeracy of users. Adnan et al. [42] explicitly refer to a DSS environment and compare decision times in a planning problem for users with different decision making styles when using visual representations showing different levels of detail.

Beyond this literature, there are also some studies that find differences in preferences for information representation due to cognitive styles (e.g. [48–51]). However, these papers do not actually test the performance of users with different cognitive styles, they only reflect preferences for receiving information in a certain form.

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