Decision Making with a Time Limit: The Effects of Presentation Modality and Structure

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ABSTRACT

In this study, a user experiment was conducted to investigate the effects of information presentation factors (modality and structure) on decision making behavior, using a time-limited task. The time constraint required subjects to develop heuristic strategies to substitute the defined normative strategy. The two presentation factors have been shown to significantly affect the decision making performance, assessed by time efficiency and accuracy. The modality factor mainly influenced the time efficiency, due to its impact on the efficiency of information perception. By analyzing the subjective reports and the error distribution, the structure was shown to influence the selection of heuristic strategies. Consequentially, it affected both the time efficiency and the accuracy of decision making. The interaction between the time constraint and the presentation effects was also observed.

Keywords

information presentation, modality, structure, decision making, time stress

ACM Classification Keywords

H.5.1 [**Information Interfaces and Presentation (e.g., HCI)**] Multimedia Information Systems; H.1.2 [**Models and Principles**] User/Machine Systems – *Human information processing.*

INTRODUCTION

The influence of information presentation formats on decision making processes has been an important research topic in various fields, such as human-computer interaction, user interface design, economics and marketing. Information presentations are neither only input signals to human cognitive processes nor only extensions of human memory. They guide, constrain, and even determine cognitive behavior [17]. It has been shown that decision makers tend to adapt their manner of information acquisition and their decision making strategies to the way the task is presented, such as the use of modalities and the spatial layout (structure) of the presentation. The adaptation is believed to be guided by a cost-benefit analysis, compromising between the desire to minimize cognitive effort (cost) and the desire to maximize the accuracy (benefit) [5, 8].

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Comparing the presentation of a dataset using tables and graphs, Speier [12] showed that graphs could better assist the acquisition or evaluation of precise data values, as well as the holistic analysis of data relationships and trends. This effect was especially strong when the task was complex. Schkade et al. [10] used numbers and words to present equivalent numerical information, and found that words required more processing effort than numbers. In addition, when words were used, subjects conducted more compensatory and arithmetic activities and less information search activities. Stone et al. [13, 14] investigated the effects of modality on risk-taking decisions. The risk of using a cheaper but less safe tire and a safer but more expensive tire were presented with different modalities. Results show that presenting risk information graphically (with images or graphs) as opposed to numerically (with numbers) increases risk-avoiding decisions, because images and graphs highlight the number of people harmed, thus enhancing the perception of risk.

The spatial structure of the presentation also has been shown to influence decision making [2, 5, 10, 15]. A commonly investigated task is the multi-attribute choice task, which is to select one alternative from several, where each alternative has several attributes. Information can be presented by alternatives or by attributes, using a table or a list. Most studies consistently found that when information was organized by alternatives, subjects tended to process an alternative before considering the next alternatives; when information was organized by attributes, subjects tended to compare all alternatives on a single attribute before considering the next attribute. Schkade [10] shows that the decisions were made faster with the by-attribute structure, and the accuracy was not affected. In contrast, the by-alternative led to more accurate and time efficient decisions in [15].

Previous findings were commonly obtained under a condition where no time limitation was set to the decision making task. However, decision making is very often time-limited in real-life situations. Studies on time-limited decision making behavior suggest that decision makers tend to focus on the general outline of the problem instead of in-depth analysis when time stress sets in [3]. Using the multi-attribute choice task in particular, a strategy switch was observed from being more alternative-based (depth-first) to more attribute-based (breadth first) [8]. In addition, decision makers are also prone to selectively use subsets of the information, adopt simpler modes of information processing and base their decisions on certain important 'cues' [4, 6].

In this study, a user experiment was conducted to investigate the impact of information presentation on time-limited decision making, when information can only be partially processed and heuristic rather than normative decision making strategies[4] are applied. We used a multi-attribute choice task with a clearly defined normative strategy and outcome. On the one hand, the time limitation made the application of heuristic strategies necessary; on the other hand, the selection of heuristic strategies was constrained by the requirement of reaching the same outcome as the normative strategy. The task was embedded into a crisis medical rescue scenario in order to create a context motivating the time limitation. However, it was not our intention to have a realistic medical rescue setup, nor did we expect subjects to have knowledge about medical treatment. We intended to observe the effect of presentation modality and structure on the decision making performance, assessed in terms of time efficiency and accuracy. In addition, we were also interested in subjective perceptions of the different presentation formats, and the influence of information presentation on the subjects' choice of decision making strategy. Finally, we looked into the effect of information presentation format on tasks with different levels of difficulty, where time constraints play a bigger or smaller role.

PRESENTATION AND TASK

The decision making task was set up using an earthquake crisis scenario where the number of wounded people exceeded the capacity of medical resources (equipment and staff). Therefore, the order of treatment needed to be determined as fast as possible, based on the evaluation of the patients' injuries.

Presentation Materials

A pair of patients was presented at a time. The injury condition of a patient was described by five injury categories (derived from [9]): heart failure, respiration obstruction, blood loss, brain damage and fracture. The first three categories were described as more threatening, and thus more important than the last two. The severity of each injury category was described at one of four levels (derived from [11]): severe, moderate, mild or none.

The two presentation factors were *modality* (text or image) and *structure* (by-injury or by-severity), resulting in four different presentation conditions. In the two text conditions, the injury categories and severity levels were presented with English text. In the two image conditions, injury categories were presented by icon images of the affected organs (e.g. an icon image of a brain referred to the 'brain damage' item), and severity levels were presented by color rectangles (red for 'severe', orange for 'moderate', yellow for 'mild' and green for 'none').[5] The injury information of two patients was organized in a table. The table could be structured by the injury categories or by the severity levels. When using the by-injury structure, the more important three injury categories were located on top of the less important two. The injury column was fixed for all tasks and the severity values varied. When using the by-severity structure, the four severity levels were ranked from high to low. A higher severity level was located more on top of the table. The severity column was fixed for all tasks and the locations of injury categories varied. Figures 1–4 demonstrate the four presentations of an identical patient pair.

Injury	Patient 1	Patient 2
Heart failure	mild	severe
Blood loss	severe	mild
Respiration obstruction	none	moderate
Brain damage	none	none
fracture	severe	none

Figure 1. A patient pair presented in the text modality and the by-injury structure.

Severity	Patient 1	Patient 2
Severe	Blood loss fracture	Heart failure
Moderate		Respiration obstruction
Mild	Heart failure	Blood loss
None	Respiration obstruction Brain damage	Brain damage fracture

Figure 2. A patient pair presented in the text modality and the by-severity structure.

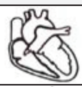
Injury	Patient 1	Patient 2
	Yellow	Red
	Red	Yellow
	Green	Orange
	Green	Green
	Red	Green

Figure 3. A patient pair presented in the image modality and the by-injury structure. The text of colors was added here to ensure the readability in a grayscale printing.

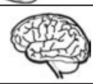
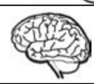
Severity	Patient 1	Patient 2
Red	 	
Orange		
Yellow		
Green	 	 

Figure 4. A patient pair presented in the image modality and the by-severity structure. The text of colors was added here to ensure the readability in a grayscale printing.

[4] Normative strategies apply a careful and reasoned examination of all alternatives and attributes. Heuristic strategies are simple and fast rules of thumb [8].

[5] Strictly speaking, color rectangles are not images. However, in this experiment, we use "image" to generally refer to non-verbal visual modalities.

Task

The subjects played the role of a medical manager in the emergency medical treatment center. The task was to compare the injuries of pairs of patients and select the more seriously injured patients to be treated first. Based on a pilot study, the time limit for each decision was set to 20 seconds. A speech reminder was given after 15 seconds. The information was removed from the screen when time was up so that a decision was forced to be made even if the analysis was not yet completed.

The Normative Strategy

The normative strategy evaluates the overall injury level of a patient by a linear utility function. The attributes of the function are severity values of the five injury categories. The severity level *severe* was described as three times as important as *mild*, and *moderate* twice as important as *mild*. Therefore, the severity values can be considered as 3, 2, 1 and 0 for *severe*, *moderate*, *mild* and *none*, respectively. Moreover, the attributes have different weights, because the more important three injury categories (heart failure, blood loss and respiration obstruction) were considered to be twice as important as the other two. Finally, the over-all injury evaluation of a patient was quantified as equation 1, where 'Se' refers to severity value:

$$Injury_{Norm} = 2 \times Se_{heart} + 2 \times Se_{blood} + 2 \times Se_{respiration} + Se_{brain} + Se_{fracture} \quad (1)$$

When comparing two patients, the one with the highest injury value should be treated first. For the patient pair in Figure 1, the injury value is 11 (2 × (1 + 3 + 0) + 0 + 3) for patient 1 and 12 (2 × (3 + 1 + 2) + 0 + 0) for patient 2. Therefore, the correct decision is to treat patient 2 first. To quantify the processing load of this strategy, the number of elementary information processing operations (EIPs, described in [8]) was calculated. This strategy requires 10 read EIPs (acquiring the values), 8 addition EIPs (summing up the values), 6 product EIPs (weighting operations) and 1 comparison EIP (identifying the larger value between two).

Heuristic Strategies

The 20 seconds time limitation requires subjects to be fully engaged in the task. In most cases there will be insufficient time to apply the normative strategy (equation 1). All intermediate outcomes of the calculation should be kept in the short-term memory which also increases the cognitive load of the normative strategy. Therefore, simpler heuristic strategies are likely to be applied. Various heuristic strategies with different levels of accuracy could be developed for this task. Unbiased heuristic strategies always lead to the correct outcomes, and thus are efficient and accurate decision making "shortcuts". However, biased heuristic strategies might enhance the time efficiency but lead to wrong decisions.

Figure 5 shows an example of an unbiased heuristic strategy which uses compensatory eliminations to reduce the amount of calculation needed. The method is to identify two injury items that 1) are from different patients; 2) have the same severity level; and 3) belong to the same priority group. Such two items have the same contribution to the comparison of the two injury values, and thus can be eliminated from the calculation. When all possible eliminations are done, the remaining items are calculated for a final choice. Note that "none" items have a value of 0 and can be ignored as well. In this example, the moderate respiration obstruction of patient 2 has a value of 4 (2 × 2) and the severe fracture of patient 1 has a value of 3. Therefore, patient 2 is the correct choice. In total, there are 10 read EIPs, 1 product EIP and 3 comparison EIPs (two eliminations and one final choice). The total number of EIPs (14) is only 56% of using the normative strategy (25). The unbiased heuristic strategy was introduced to the subjects in the introduction session as an inspiration. They were informed that they could freely apply their own strategies to reach the correct decisions in time.

Biased strategies might be developed for this task as well. For example, one might ignore the injury categories with the lower priority and only consider the most important three injury categories. One could also ignore the priority rules and treat all five injury categories equally. These biased strategies can reduce the calculation load but cannot guarantee a correct outcome.

Injury	Patient 1	Patient 2	
Heart failure	~~mild~~	~~severe~~	×2
Blood loss	~~severe~~	~~mild~~	×2
Respiration obstruction	~~none~~	moderate	×2
Brain damage	~~none~~	~~none~~	
fracture	severe	~~none~~	

Figure 5. An example of an unbiased heuristic strategy.

EXPERIMENT

Experimental Design

We used a within-subject 2×2 design. The two independent factors were *modality* at two levels (text or image) and *structure* at two levels (by-injury or by-severity). Therefore, all subjects performed four experimental trials, namely the 'text & by- injury', 'image & by-injury', 'text & by-severity' and 'image & by-severity' trial. The trial order was counterbalanced with a size 4 Latin Square. Each trial contained 12 tasks which were identical for all four trials but randomly ordered.

Dependent Measurements

The decision making performance was measured by two dependent variables, namely *time efficiency* and *accuracy*. The *time efficiency* of a decision refers to the time interval between the moment when a task is presented and the moment when the decision is made (in seconds). A decision is *accurate* if it is identical to the outcome from the normative strategy. These two measurements can be retrieved from the log files of subjects' mouse clicks.

Subjective experience was obtained by questionnaires. The questionnaire consisted of two parts. The first part asked subjects to perform four binary comparisons on the cognitive demand of the task as shown in Table 1. A sample of the four presentation conditions (Figures 1–4) was provided as a reference to the questions. The question was for example: "Comparing condition 1 and 3, in which condition did the task require less cognitive effort (was easier)?"

Table 1. The four binary comparisons on the cognitive demand of the decision making task.

Comparisons		Reference
Between modalities (Text vs. Image)	structure = by-injury	Fig. 1 vs. 3
	structure = by-severity	Fig. 2 vs. 4
Between structures (By-injury vs. By-severity)	modality = text	Fig. 1 vs. 2
	modality = image	Fig. 3 vs. 4

In addition, the subjects were also asked to indicate which presentation conditions they found the easiest and the most difficult. The second part of the questionnaire is related to the decision making strategies. Subjects were asked to orally describe the strategies they had used in each presentation condition. Those were written down by the experimenter during the description.

Subject and Procedure

32 university students (graduate students and PhD students) volunteered to participate in the experiment. All of them were fluent English speakers and none of them had a medical background.

The experiment contained three sessions: an introduction session, a training session and the experimental session. The introduction described the rescue scenario, the task and the four presentation styles, the normative decision making strategy and the unbiased heuristic strategy. In the training session, subjects practiced 20 tasks, 5 tasks for each presentation style. No time limit was used. Feedback on the decision accuracy was given after each decision was made, via speech. After training, subjects were required to perform four experimental trials of totally 48 tasks (4×12). A performance summary was given after each trial, announcing how many correct decisions had been made. After the four trials were all finished, subjects were required to complete the questionnaire. The time duration of the experiment was about 40 minutes.

Hypotheses

According to the cognitive fit theory [16], presentation manners that provide a better cognitive fit to the nature of the task can better assist the making of more accurate and less effortful decisions. The modality factor certainly has an impact on the information perception effort and quality. Regarding the representative strength, text is suitable for conveying abstract information, such as the relationships between events; while images are suitable for describing concrete concepts and information of a highly specific nature, such as concrete objects [1]. Therefore, the images of organs were expected to be more suitable than text for presenting the injury categories. Furthermore, shapes and colors have great salience to human information processors due to the sharp contrast they are able to create [7]. Compared to text, the color coding was expected to be better able to reflect the difference in the severity levels and assist comparisons.

One key step of this task is to separate the two priority groups. Only when this separation is clear, the weight and the elimination method (Section: “Heuristic Strategies”) can be applied. When information is presented with the by-injury structure, this separation does not require any effort since the more important three injury categories are located above the other two. In contrast, the by-severity structure does not particularly support this priority separation, which consequentially complicates the application of weights and eliminations. Therefore, we expected the by-injury structure to be more cognitively compatible with the task than the by-severity structure.

We assumed that the cognitive advantage of a certain modality/structure over another is particularly pronounced when the decision making task is time-limited. Accordingly, the following two hypotheses were built:

1. The modality factor has an effect on the decision making performance. The time efficiency and accuracy are both higher in the image conditions than in the text conditions.
2. The structure factor has an effect on the decision making performance. The time efficiency and accuracy are both higher in the by-injury conditions than in the by-severity conditions.

RESULTS

Due to the within-subject design, we applied repeated ANOVAs with *modality* and *structure* as two nested independent factors, on the *time efficiency* and the *accuracy* variable, respectively. The trial order was treated as a between-subject variable and was shown to have no significant effect on either of the two dependent variables.

Decision Making Performance

Time Efficiency

The average time spent on one task (in seconds) in each condition is shown in Figure 6. Subject performed the fastest in the ‘image & by-injury’ condition, and the slowest in the ‘text & by-severity’ condition. Repeated ANOVA results showed that 1) there was no significant interaction between the two factors, F (1, 31) = 0.38, $p > 0.5$. This indicates that the effects of these two factors on the time efficiency are independent from each other; 2) the modality factor had a significant effect on the time efficiency, F (1, 31) = 48.31, $p < 0.001$. Subjects performed significantly faster in the image conditions than in the text conditions, regardless of how the information was structured; and 3) the structure factor also has a significant effect on the time measurement, F (1, 31) = 27.84, $p < 0.001$. Subjects performed significantly faster when the information was sorted by injury categories than by severity levels, regardless of which modality was used. Thus, for both modality and structure our hypotheses regarding time efficiency were confirmed.

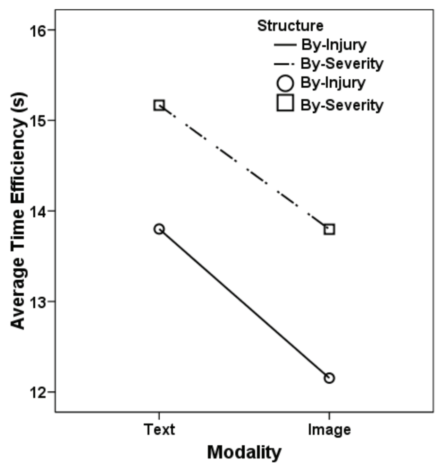


Figure 6. The average time efficiency of four conditions.

A post-hoc test (Bonferroni test) further revealed five significant pair-wise effects, as shown in Table 2. Significant differences in the time efficiency variable occurred between all pairs of conditions, except between the ‘text & by-injury’ condition and the ‘image & by-severity’ condition. One of them has the more suitable modality (allows faster performance) but the less suitable structure; the other one has the more suitable structure but the less suitable modality. For each of the two conditions, the disadvantage counteracts the advantage, leading to a comparable average time efficiency (see Figure 6).

Table 2. Pair-wise comparisons on the time efficiency measurement by Bonferroni test (only significant results).

Pair-wise effects	Sig.	Factor involved
Lower: Text & By-Severity Higher: Image & By-Severity	$p < 0.001$	modality
Lower: Text & By-Injury Higher: Image & By-Injury	$p < 0.001$	modality
Lower: Text & By-Severity Higher: Text & By-Injury	$p < 0.001$	structure
Lower: Image & By-Severity Higher: Image & By-Injury	$p < 0.01$	structure
Lower: Text & By-Severity Higher: Image & By-Injury	$p < 0.001$	modality & structure

Accuracy

The average number of correct decisions made in each trial is shown in Figure 7. Subjects made the most correct decisions in the 'image & by-injury' condition, and the least correct decisions in the 'text & by-severity' condition. ANOVA results show that 1) there was no significant interaction between the two factors, $F\ (1, 31) = 0.07$, $p > 0.5$, indicating that the effects of modality and structure on the decision accuracy were independent from each other; 2) the modality factor did not have an effect on the accuracy measurement, $F\ (1, 31) = 2.26$, $p > 0.1$; and 3) the structure factor had a significant effect on the decision accuracy, $F\ (1, 31) = 4.16$, $p < 0.05$. Subjects made significantly more correct decisions when the information was structured by injury categories than by severity levels, regardless of which modality was used. Thus, our hypotheses regarding accuracy were only confirmed for the structure factor, but not for the modality factor.

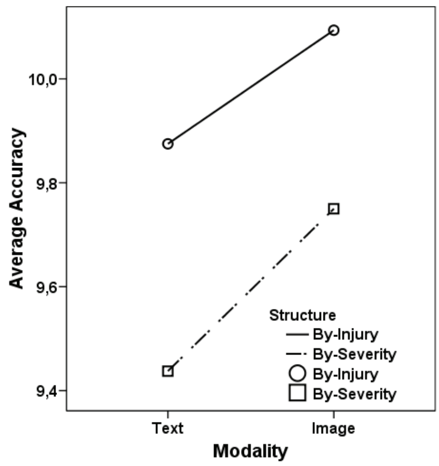


Figure 7. The average decision accuracy of four conditions.

One significant pair-wise effect was found in the post-hoc test. Significantly more correct decisions were made in the 'image & by-injury' condition than in the 'text & by-severity' condition. This indicates that when the more suitable modality and the more suitable structure were combined, subjects performed significantly more accurately than when the less suitable modality and the less suitable structure were combined.

In summary, the two performance measurements reveal a significant modality effect as well as a significant structure effect. The modality factor influences the time efficiency. Image allows faster performance than text. The structure factor affects both time efficiency and accuracy. The by-injury structure allows faster and more accurate performance than the by-severity structure. There is no interaction between these two presentation factors.

Subjective Comparisons

The results of subjective comparisons of the cognitive demand of the task under different presentation conditions are summarized in Figures 8–10. Generally speaking, these subjective judgments are consistent with the results of the performance measurements. The 'text & by-severity' condition was considered as the most difficult condition by 19 (59.4%) subjects and the 'image & by-injury' condition was considered as the easiest condition by 21 (65.6%) subjects (Figure 8). Twenty-six (81.3%) subjects found the task less demanding in the image conditions than in the text conditions, regardless of the structure factor (Figure 9). Twenty-two (68.8%) subjects preferred the by-injury structure to the by-severity structure, regardless of the modality factor (Figure 10).

Apart from the majority preferences, 4 subjects preferred text to image (Figure 9) and also pointed out one of the text conditions to be the easiest one (Figure 8). Further looking into their performance, we found that their decision accuracy was indeed higher in the text condition than in the image conditions (with the same structure). We noticed that three people out of these four have a daily research topic that is clearly text or speech oriented. Although lacking of solid experimental evidence, this observation still suggests that in addition to the generally applicable guidelines (such as 'images are more suitable than text to present concrete information'), the professional background might also be a useful reference for the usage of modality, especially when the interface is designed for a specific user group.

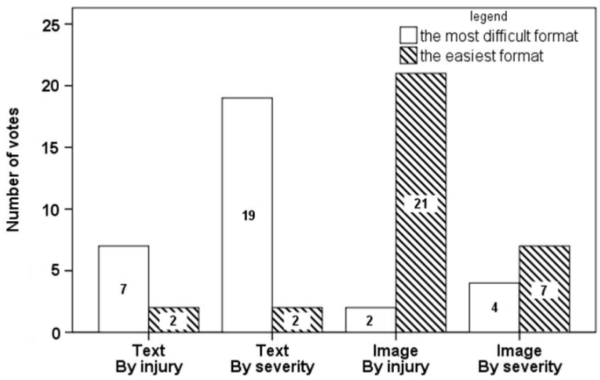


Figure 8. Subjective reports of the easiest and the most difficult presentation conditions.

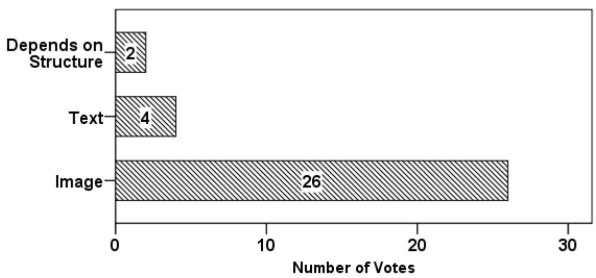


Figure 9. Voting results of the cognitive load comparisons between a text condition and an image condition.

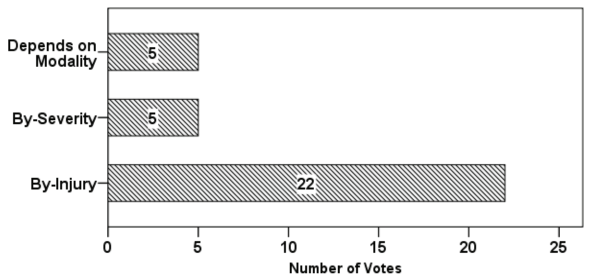


Figure 10. Voting results of the cognitive load comparisons between a by-injury condition and a by-severity condition.

Figure 10 also shows that there are 5 subjects who preferred the by-severity structure instead of the by-injury structure. Again, their performance data shows that they indeed made more correct decisions in their favored structure than in the other (when modality was the same). Therefore, it seems that the subjective preference can very well reflect the decision making accuracy. As a part of the future work, we need to compare all subjective judgments with the associated performance data, aiming at identifying the correlations between them. On the one hand, we have generally applicable guidelines which can lead to a standardized optimal design for a majority of users. On the other hand, in cases where the task performance of every single user is critical (such as when crisis managers work with a realistic crisis support system), additional customized references might be needed in order to enhance the general guidelines. The individual subjective preferences seem like a promising direction to look into.

Strategy Analysis

Subjective Reports

Most of the subjects were able to clearly describe how they processed the information to reach the final decision. Two general trends could be easily recognized from these subjective strategy descriptions. First, the normative calculation model was never applied, meaning that subjects all tried to apply heuristic methods to solve the tasks. Second, the unbiased heuristic strategy introduced to the subjects was generally accepted and applied. However, if the remaining time was perceived to be insufficient, subjects sometimes turned to biased strategies in order to reach a real quick decision. The development of biased strategies was influenced by the structure factor rather than the modality factor.

In the by-injury structure, since the separation of priority group was clear, subjects commonly mentioned that they carried out a careful analysis of the high-priority group, and only if there was still some time left, then they also had a quick glance at the low-priority group. But in most cases, this quick processing didn't change the decision. Basically, this biased strategy (BS1) bases the decision on the more important three injury categories only, as shown in equation 2. Since these three categories do contribute more to the overall injury value, the outcome has a good chance to be correct, but not always.

$$Injury_{BS1} = Se_{heart} + Se_{blood} + Se_{respiration} \qquad (2)$$

In the by-severity structure, realizing the complication to separate the priority groups and apply elimination method, subjects mentioned that they first had a look at the distribution of the injury items and compared which patient's injuries were located more towards the top side of the table (the more severe side). Then started to carefully identify the priorities and apply eliminations. However, very often they could not completely finish so that the primary decision remained. This biased strategy (BS2) ignores the priority definition and treats all injury categories equally, as shown in equation 3.

$$Injury_{BS2} = Se_{heart} + Se_{blood} + Se_{respiration} + Se_{brain} + Se_{fracture} \qquad (3)$$

Quantitative Analysis

Based on the analysis of subjective report, we took one step further to look for quantitative evidence of these two biased strategies being applied. The attempt was also to further confirm the influence of the strategy factor on the development of strategies. First of all, we applied these two strategies to all 12 tasks. Results showed that each of them could reach 8 correct decisions out of the 12. Accordingly, we defined the following four task groups:

1. BS1-Correct group: 8 tasks
2. BS1-Wrong group: 4 tasks
3. BS2-Correct group: 8 tasks
4. BS2-Wrong group: 4 tasks.

Second, for each presentation condition, we calculated how many correct decisions were actually made by the subjects within each group (in percentage). The average from all subjects is presented in Table 3.

Table 3. The average percentage of correct decisions made within each group under each presentation condition.

Presentation Condition	Percentage of correct decisions (%)			
	BS1 Correct	BS1 Wrong	BS2 Correct	BS2 Wrong
Text & By-Injury	**91.4**	**64.1**	80.8	85.2
Image & By-Injury	**92.4**	**63.5**	84.4	83.6
Text & By-Severity	82.4	71.1	**87.9**	**63.9**
Image & By-Severity	83.2	77.3	**86.7**	**69.3**

Next, we compare the results between the BS1-Correct group and the BS1-Wrong group. According to the average values in Table 3, we can see that the difference is larger in the two by-injury conditions than in the two by-severity conditions. Results of T-tests further confirmed that when the by-injury structure was used, significantly more correct results were made within the BS1-Correct group than the BS1-wrong group (Table 4). However, no such effect was found when the by-severity structure was used.

When applying the same comparison between the BS2-Correct and the BS2-Wrong group, reversed results were obtained (Table 4), indicating that significantly more correct decisions were made within the BS2-Correct group when the by-severity structure was used, but no effect was found in the by-injury conditions.

A tentative conclusion that can be drawn from these results is that the decision accuracy was influenced by the application of BS1 when the by-injury structure was used and the application of BS2 when the by-severity structure was used. This in turn means that the structure factor indeed to some extent influenced the development of decision making strategies.

Table 4. T-tests result for identifying the application of BS1 and BS2 in all presentation conditions.

Presentation Condition	T-test pairs	
	BS1-Correct vs. BS1-Wrong	**BS2-Correct vs. BS2-Wrong**
Text & By-Injury	$\boldsymbol{p < 0.001}$	$p > 0.1$
Image & By-Injury	$\boldsymbol{p < 0.001}$	$p > 0.5$
Text & By-Severity	$p > 0.1$	$\boldsymbol{p < 0.05}$
Image & By-Severity	$p > 0.1$	$\boldsymbol{p < 0.05}$

Time Constraint: Low vs. High

The results presented so far have already shown that the presentation factors, modality and structure in particular, had an effect on the time-limited decision making performance. However, we were interested in further exploring the interaction between different levels of time constraint and the presentation effects. Since our experiment setup did not include multiple levels of time limitation, this interaction cannot be directly investigated. However, the 12 decision making tasks were not identically difficult. The difficulty level of a task was assessed by the difference in the overall injury values of a patient pair (calculated by equation 1). The larger the difference is, the easier/quicker it is to identify which patient has more severe injuries. Therefore, the time constraint could be considered as weaker for easier tasks and stronger for more difficult tasks. In this case, if the time efficiency and accuracy are analyzed separately for tasks at different difficulty levels, we might be able to indirectly observe the interaction between the time limit and the presentation effects.

The 12 tasks were assigned into two groups. For the 8 tasks in the more difficult group, the difference between the two overall injury values is below 3. In the relatively easier group, the difference is between 5 and 10 for the 4 tasks. The time efficiency and accuracy were re-calculated respectively for the two groups (Figure 11).

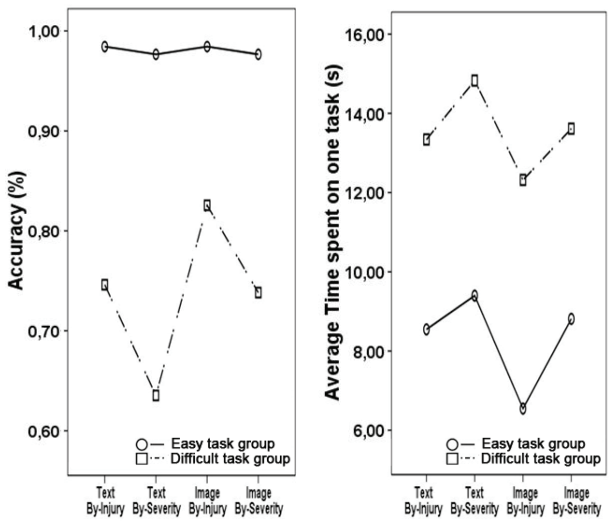


Figure 11. The accuracy (left) and time efficiency (right) calculated respectively for the easy and difficult task group.

As expected, in the relatively easy task group the performance was both more accurate and faster. There were only about 2% of errors among the easy tasks, and most of them occurred in the by-severity conditions. There was no significant modality or structure effect on accuracy. ANOVA on the time efficiency measurement did show a modality effect (F (1, 31) = 22.5, $p < 0.001$) and a structure effect (F (1, 31) = 16.2, $p < 0.001$). This indicates that when the time constraint was relatively weak, the decision accuracy was almost unaffected by the quality of presentation, since the subjects could take their time to make the correct decisions. However, the cognitive benefit of good presentations was still reflected by the time efficiency of decision making.

When the tasks were more difficult, the time allowed to make a decision was no longer sufficient to complete the unbiased but more demanding decision making processes, resulting in a general decrease of accuracy in all presentation conditions. In such a situation, the presentation factors showed an even stronger impact on the decision making performance, since they influenced both the accuracy and the time efficiency. When the presentation manner is more cognitively compatible with the task, the decisions are made faster and more accurate. In addition, it can be observed from Figure 11 (left) that the accuracy showed different levels of tolerance towards the increase of the task difficulty. The better the presentation condition is, the less the accuracy drops between the easy and difficult task groups.

CONCLUSIONS AND FUTURE WORK

In this study, we investigated the effects of information presentation on time-limited decision making, focusing on the modality and the structure factors. The decision making performance was assessed in term of time efficiency and accuracy. The subjective judgments of various presentation formats were also obtained. In addition, we also investigated the influence of presentation factors on the subject's choice of decision making strategy. Finally, we looked into the interaction between presentation effects and the time constraint, by analyzing the performance of tasks at different levels of difficulty, where time constraints play a bigger or smaller role.

Regarding the modality factor, our result is in line with the previous studies and confirms that modality has an impact on the decision making performance. Additionally, we suggest that the modality factor influences the time efficiency more than the accuracy. A suitable modality accelerates the decision making process by decreasing the effort and increasing the quality of information perception. However, this does not necessarily lead to a higher accuracy, because the selection of decision making strategies is not determined by the usage of modality. Generally, modality selection should aim at providing a cognitive fit to the perception task. When visual search among different types of objects is required, images are usually more suitable than text for presenting those objects. When different levels of severity (or urgency, importance etc.) need to be perceived, colors can be a very effective presentation option.

The structure factor has been shown to have a significant impact on both the time efficiency and the accuracy of decision making. This is mainly because of its influence on the selection of strategies. When the time constraint does not allow the most accurate but demanding strategy to be used, subjects develop heuristic strategies in order to make a decision in time. When a structure does not provide a good cognitive fit to the task, more cognitive effort is needed to perform the task. Then, less effortful strategies are more likely to be chosen, which are normally also less accurate. Therefore, the presentation structure should assist the application of unbiased decision making strategies. If several information items are required to be considered as a group, they need to be spatially clustered. If a table is used, locate the more critical information items more on the top.

Regardless of the level of time constraint, the presentation factors always have an impact on the cognitive demand of the decision making task. However, this impact is stronger when the time constraint is stronger. In this experiment, for the relatively easier group of tasks, only the time efficiency was influenced by the presentation factors; while the accuracy stayed high. However, for the group of difficult tasks, both time efficiency and accuracy showed a presentation effect. The decrease of accuracy was less when the presentation format was more cognitively compatible to the task.

Our future work involves three aspects. First, as mentioned in Section: "Subjective Comparisons", the relation between performance measurements (especially accuracy) and subjective judgments needs further investigation. Second, in order to directly observe the interaction between the time constraint and the presentation effect, this experiment needs to be replicated without the time limit or a new experiment needs to be carried out with multiple levels of limits. Third, we noticed that subjects commonly didn't make a full use of the 20 seconds that were offered to them. When the '5 seconds remaining' warning was delivered, some subjects appeared very stressful and they made their choices immediately after the warning speech started. It seems that the level of time stress was perceived to be higher than it really was, and this perception was individually different. However, none of our measurements allowed the assessment of stress. Therefore future work is needed to obtain a deeper understanding of the perceived stress induced by the time constraint.

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