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Effects of Time Pressure on Behavioural Decision Making in Natural Disasters: Based on an Online Experimental System

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Abstract

This paper aims to examine the effects of time pressure on the behavioral decision-making process and outcome to responding a natural disaster, via an online experimental system with simulated typhoon disaster scenario. As decision strategies determine the cognitive processing of decision, we set up a simple approach to recognize them according to previous researches. After investigating with emergency personnel, we develop the disaster decision making system and conduct experiments. Sixty participants (by two groups) make an emergency relief decision via the system with/without time pressure. Based on process tracing technology of Information Display Board, decision strategies and cognitive load are measured to make comparisons between different conditions. The results show that time pressure has a bad impact on decision performance and makes participants use more decision strategies by attribute-based rule to avoid conflicts between attributes of each alternative. With comparisons of variation for cognitive load, we find that time pressure occupies the cognitive resource of emergency decision makers, who are forced to monitor and cope with it. Therefore, they have to reduce cognitive effort on decision-making process, leading to dissatisfactory decision results. Besides, the effects of time pressure on different decision strategies are also discussed in this paper.

Keywords: Natural disaster response; Time pressure; Behavioral decision making; Information display board; Cognitive load; Decision strategy

Introduction

Time is one of crucial resources in decision making; it is also one of the external stimuli that impact on the cognitive process of decision making. Decision makers experience the pressure that is positively correlated with time constraints, which means high-rated time constraints generated intense time pressure. They also need to balance the expectation to optimal results and the tolerance to cognitive stress of the targeted decision task [1]. Accordingly, researchers identify time as a major constraint on decision makers' behavior [2], time pressure also affect the decision making capacity of the individual [3]. In decision making, external information put in the working-memory temporarily, and the capacity of working memory is limited, about "seven plus-or-minus two" chunks [4], but time pressure mainly decreases that amount of information from engaging in elaborate processing [5].

In disaster relief, the effect of time pressure seems to be magnified. A natural disaster is destructive, hard to control totally, and overwhelmed to respond in the early period after it happened. Generally, preparedness plans and task lists are the most effective guideline but perfect ones. In fact, humans are familiar with disasters which happened inevitably, facilities and skills of emergency personnel are professional contemporary. However, the response process is dynamic and unclear, in which some incidents happened unexpectedly, scheduled task plans were invalidated by unpredictable contingency, also worsen the disaster situation and the consequence, even leading to response failures directly. Under the circumstances, response to the disaster relied on heuristics and adaptive decisions made by emergency personnel [6]. With dynamic and unclear environments, correct decisions required more cognitive capacity to process available information and less distraction from time pressure. This paper works on the inclinations of information processing behavior in natural disaster scenarios by emergency personnel, and the time pressure effects on cognitive process of their decisions, using a self-developed online experimental system.

Cognitive Load and Decision Strategies

Identifying decision strategy types and information search features is an effective way to understanding emergency personnel's cognitive processes during decision making. That requires a series of elementary information processing, involved with READ, COMPARE, DIFFERENCE, ADD, PRODUCT, ELIMINATE, MOVE and CHOOSE [7], which is determined by the task difficulty, decision strategies and environments [8]. Disasters are extreme decision environments with dynamic, uncertainty, situational constraints, needed to deal with consistently in a time manner [9,10]. This part will review theories on cognitive load and strategies in decision making, then discuss the relationship between cognitive load and decision making in disasters.

Cognitive load in disaster decision making

Cognitive information processing of decision making works in the limited working memory, with partly independent processing units for visual and audio information, which interacts with an unlimited long-term memory [11]. That means human cannot process information as fast as computers, the maximum of input is about seven chunks of information once [4]. If dealing information with more complex processes, like compare, difference, add, product, eliminate and choose, it may just process two or three items of information once, as opposed to merely holding it [12]. Unlimited long-term memory provides stored knowledge to instruct the information processing, but the expertise one can grasp is limited [13]. So processing resource is limited over a period of time (no new expertise learned), like one decision task. To

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measure the cognitive effort to process information, cognitive load is defined as the cognitive resource consume by processing certain information during cognitive tasks. In natural disasters, decisions made by emergency personnel require heavy cognitive load to cope with changing environments, non-routine tasks and intense time pressure, When it exceeds the capacity of working memory, cognitive overload occurs leading to poor decision making results and dysfunctional performance [10,14,15].

Decision strategies of information processing

Decision strategy is defined as "a sequence of mental and effector (actions on the environment) operations used to transform an initial state of knowledge into a final goal state of knowledge where the decision maker views the particular decision problem as solved" [7]. It says that a decision strategy is actually a process of decision making, dealing with information. An accounting to this research, here we just review the decision strategies with multidimensional alternatives. Previous researches defined most types of decision strategies, like strategies of the equal weight [16], the weighted additive [17], the additive difference [18], the lexicographic [18], elimination-by-aspects [19], the majority of confirming dimensions [20], conjunctive [21]. For decades, researches on heuristic decision strategy across 20 environments, mentioned health care [22], business [23], sports [24], politics [25], finance [26], public security [27] and so on. This research focuses on decision strategies in the environment of natural disaster response and relief.

Based on information processing theories, the way of information search which focus on explicit comparisons across alternatives form the decision rule on information search directions, alternative-based or attribute-based, the former tends to moderate conflicts between attributes, whereas the latter tries to avoid them. Another type of decision rule require the consideration of weighing the attribute differences, whereas others permit arriving at a choice without making such tradeoffs, makes distinguishes between compensatory and non-compensatory information processing. Kirschner combined the two category of decision rules and set up a two-by-two matrix [11]. With the combination of characteristics of the rules, this matrix recognized four types of main decision strategies: linear additive, additive difference, lexicographic, and conjunctive. The linear additive rule involves compensatory, alternative-based processing. The additive difference involves compensatory, attribute-based processing. The lexicographic rule is attribute-based and non-compensatory while the conjunctive rule is alternative-based and non-compensatory [17].

Interactions between cognitive load and decision rules

It is obvious that different decision strategies require different amounts of cognitive resource to execute [28]. Decision strategies consist of different sequences of elementary information processes, so consumption of cognitive resource are varying with these strategies [29]. However, working memory and processing resource are limited within a certain period of time, when a difficult decision task or time pressure caused a heavy cognitive load, even overload, the decision maker may adopt a strategy with less cognitive effort to complete the decision task [30]. Many researches and literatures indicate that compensatory rule needs more cognitive efforts than non-compensatory rule, so as to alternative-based rule versus attribute-based rule [31-33].

Specifically, additive Linear strategy needs most cognitive effort to process information of all attributes for all alternatives with alternative-based search, weight and trade off values, then sum up to final outcomes [34]. While additive difference strategy follows compensatory rule by calculating differences in payoffs and probabilities, but asks for less effort on the attribute-based rule. However, lexicographic strategy costs much less processing resource by ignoring much relevant information; only seek the alternative of best value on the most important attribute with attribute-based search [33]. Relatively, conjunctive strategy is also a noncompensatory one, but it needs more effort to process alternatives in order, making comparisons of attribute values but tradeoffs. In general, when an individual conducts a same decision task with same information, the order of cognitive load of these strategies would be Linear additive>Additive difference>Conjunctive>Lexicographic.

In the other hand, the effects of cognitive load on decision strategies seem controversial. Some researches argued that cognitive overload make decision makers change decision rules and strategies into easier and quicker ones with less cognitive effort. They indicate that heavy cognitive load of processing information makes individuals adapt accelerating and filtrating strategies [35,36], then moving toward a more attribute-based strategies like elimination by aspects and lexicographic [37]. However, the research by Bröder turns out working memory load had no additional effects on strategy selection, even cognitive efforts vary with current situation, which made the strategy not adaptive any more, individuals would be less likely to change strategy [38].

Time Pressure Effects

In disaster relief, time constraint is a significant stressor which generates time pressure. It makes emergency personnel hyper vigilance that leads to impulsive, disorganized decision making [39]. Time pressure may result in premature closure, non-systematic searching, or temporal narrowing of available alternatives in the process of decision making [40], even physical problems like breathing difficulty, rapid heart rate and dizziness to interrupt decision making in extreme disaster situation with severely intense deadline [41]. Other researches indicate that time pressure reduces creative problem solving and information exchange [42], as well as lowers cognitive complexity and flexibility, also the quality of performance [43,44]. Therefore, when emergency workers respond to a disaster, time pressure affects the process and outcome of their decision, disturbs their cognitive information processing.

Many researches work on the effects of time pressure on decision making, it is widely believed that time pressure speeds up of information processing [45,46] and makes individuals change their decision rules from compensatory to non-compensatory, from alternative-based to attribute-based [35,47-49]. Specifically, lexicographic strategy is best predicted to be adopted under high time pressure whereas linear additive strategy seems popular under low time pressure [50]. Another view is that time pressure influences cognitive efforts in the process of decision making [51]. Cognitive overload occurs when there is too much information and too little time to respond [52]. Some studies reveal that time pressure makes individuals acquire more information than in no time pressure circumstance, select to process more important information, and thus use a more attribute-based search [53]. That means time pressure causes more cognitive resource which is contributed to information search, whereas less cognitive effort works on other functions of processing, like judge, compare, calculate, choose and so on, leading to bad decision results. Besides, individuals under time pressure are less likely to revise inaccurate pre-existing cognitive structures during decision making [42].

Online Experimental System and Measurements

To achieve the study goals of the processing of decision making and the effect of time pressure in disaster scenario, we developed an online experimental system to operate the experiments. The website is: http://kangfu101.com/question/rand. (This is participant page, English version please check the studyer page http://kangfu101.com/question.) The consideration of conducting online experiments was that: (1) the participants in this study were real emergency respondents, experiments conducting online can break the boundaries of space and time, considering the nature of their job and convenience; (2) online system applied to processing tracing technology (Information Display Board, details described in the following section) for recording data of every move, it also accessed to data base in real time at any location, which help to enhance the efficiency of the conduction, and reduce subjective bias; (3)experimental system integrates different technology implements according to the aims and needs of this study, like random unique ID generation, multimedia, automatic countdown timer, process tracing and so on, it simplified the procedure and saved the experiment operation time.

Online experimental system design based on information display board

The design of this online experimental system represents in Figure 1 below. This system includes three parts: function design, technology implementation and outcome list.

Function design consists of 3 modules. The function of module 1 is instruction of the experiment and teaching participants to make decisions using information display board (IDB). Module 2 is the experiment part, also the core of the system, including natural disaster scenario presented by a video episode and descriptions, time pressure manipulation by an automatic countdown timer, information display board to trace information search by participants, and decision result and relevant outcome recording. Module 3 is self-report scales part, it helps to provide evidence for validity of relevant design and mutual verification.

Technology implementation is consistent with function design (details see Figure 1). Here it is necessary to explain about IDB technology. IDB was invented by Payne in a psychological experiment [17], and they developed IDB software named Mouselab [54], and recently the improved online version Mouselab web was released in 2008 [55]. It records information checking time, steps and other relevant information by a matrix, where decision cue informations are hidden behind each cell at first, then displayed with mouse clicks by decision makers. The IDB in this study was developed by referring to Mouselab web, however, we made some modifications fitting to this study, Time recording needed to keep pressing down the mouse on the cell to remain it open, then one finished checking the information by releasing the press to close the cell and moved on to the next. The modification aims to reduce errors of participants' misoperations and drive them focus on the decision making by IDB. The structure of data recording is different from Mouselab web as well, to meet the demands of the study. Besides, to verify the judgments of decision strategy by IDB recording data, we developed an online "dynamic information search process demonstration" at the website: http://kangfu101.com/question/drawPointResult (details see the latter Section 6.3).

Cognitive load measurement

Cognitive load measurement is difficult because it is in "black box operation", though individuals have perception of it, but it's hard to distinguish clearly of specific elementary cognitive functions and test their quantification. Studyers have worked on this topic about two decades, in the early time Bettman et al. measure the cognitive effort with a model elementary information processes (EIP), by dividing a decision process into read, compare, product, eliminate and other elementary processes, and measure the cognitive effort for each required [28]. After that, methods of cognitive load measurement come into many dimensions as analytical versus empirical, direct versus indirect, subjective versus objective [56,57]. The techniques

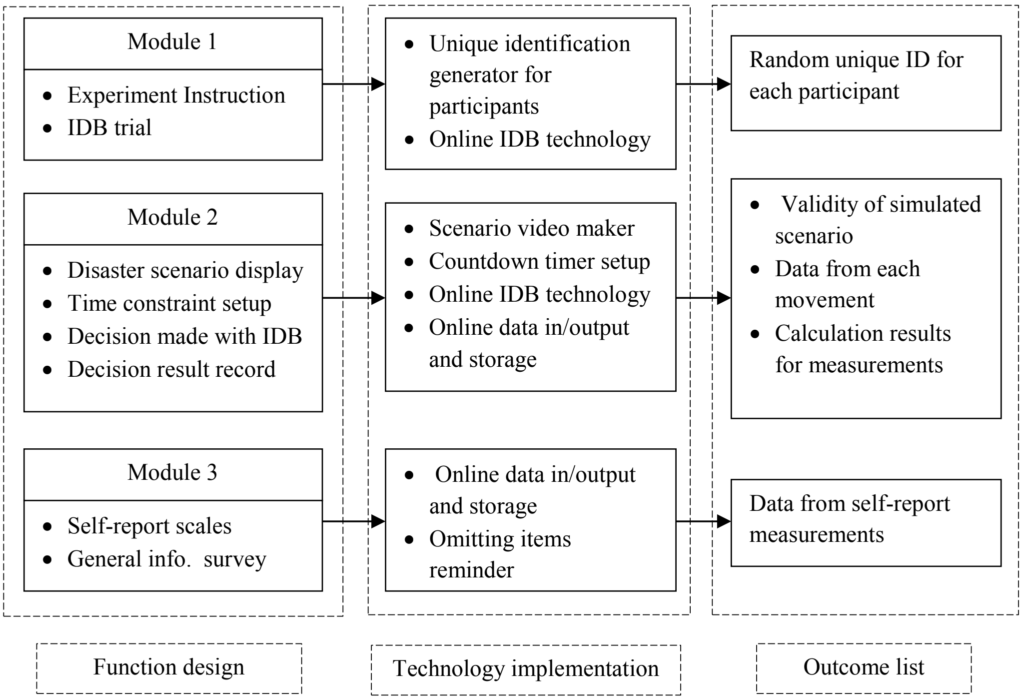

Figure 1: Online experimental system design of disaster decision.

used includes self-rating scale, performance measurement [56], physiological measurements like heart rate, brain activity and eye responses [58], dual-task approach [59,60] and so on.

Based on the previous measurements and the characteristics of this study, we adopted combined measurements of cognitive load, which include self-report, performance measurements and information processing time recorded by IDB. Note that, there are two assumptions of this study. First, information processing time is the external representation of cognitive load occupied, for the capacity of working memory is limited, complex information processes (like compare, calculate and choose) need more cognitive efforts than simple ones (like read and input), so they require more time to processing information. The assumption is supported by the study of Payne et al. in which time of each elementary information process was estimated [35]. Second, decision result is positive correlated with one's mental effort on it, which means more cognitive efforts on decision making come out better outcomes. Though we cannot tell which elementary information process individuals adopt to deal with one item by using IDB, the recorded time can reveal the cognitive load of processing information.

Measurement indicators and discriminance of decision strategies

With information processing theories and IDB technology, decision rules and strategies can be determined by measurement indicators and discriminance [54,61]. Below is the statistics measurements of indicators and discriminance mentioned (Tables 1 and 2). As mentioned above, decision strategies could be determined by indicators to tell difference decision rules explicitly [11] that were VSA to distinguish compensatory or noncompensatory rule, while DS for attribute-based or alternative-based rule. Therefore, the discriminance of decision strategies was represented in Table 2.

(1) Latency of search (LS): it is the amount of time the individual spent on the task to make a choice, as a surrogate measure of cognitive effort or attention [62].

(2) Proportion of information search (PIS): It indicates the degree of information searched by each individual [62].

PIS=the number of boxes examined/total number of boxes on the board

(3) Direction of search (DS): It indicates the extent of alternative-based or attribute-based processing that the individual demonstrates during the search sequence [54].

DS=(ALTERN-ATTRIB)/(ALTERN+ATTRIB), -1<DS<1.

(4) Variability of search of alternative (VSA): the percent of information searched per alternative and then computing the standard deviation of these percentages for the alternatives on the board [54].

$$\mathbf{VSA} = \left[\left(\sum x_i^{\,2} - \left(\sum x_i^{\,2}\right)^2 / n(n-1)\right)\right]^{1/2},$$ where n=number of total atrributes and xi=percent of attribute i searched.

(5) Compensation index (CI): it is the measure of the extent of compensatory rule used [63].

CI=PIS (1-2VSA), 0<CI<1.

According to those measurement indicators, decision rules and strategies can be distinguished by the discriminance, by statistical outcome from information display board [64,65].

Methods

Participants

Sixty people (44 men and 16 women) with an average age of 31 years were valid samples in the experiment, which took approximately 10-20 minutes. Most were emergency workers and personnel with experience of emergency response from State Grid Corporation in cities of Shenzhen, Beijing, Harbin, Qitaihe of China. They were random assigned to the different experimental groups with or without time pressure.

Materials and theoretical evaluation criterion for decision outcome

The decision problem and natural disaster scenario design was based on investigations and surveys with fire fighters in Fire Department of Claremont, California, USA and personnel working State Grid Corporation of Shenzhen, China. At first, the issues were investigated with fire fighters, like the format of information display board design, general disaster relief procedure and exceptional cases and influence of time pressure. Then the investigations were repeated in State Grid Corporation of Shenzhen, and with their help was designed a typhoon scenario and decision problem whose information was consistent to the real world and the values of each attribute were set up according to the empirical expertise.

The disaster scenario included a typhoon video episode from movie "Ultra Strong Typhoon" and the description as below. The decision problem was making the order of repairing the damaged devices from the four units. The information of the attributes and alternatives were hidden in Information Display Board (Figure 2). Their values were shown in the Table 3.

Scenario description: "After a strong typhoon, it is found that the outdoor power supply devices of 4 units are damaged separately in an area, but there is only one access to the 4 units. Suppose you are the captain of the emergency repair team, your mission is getting the damaged devices fixed as more as possible before the storm (usually following a typhoon, and the weather forecast says it would happened

Index	Compensatory	Noncompensatory	Attribute-based	Alternative-based
PIS	Bigger PIS value	Smaller PIS value	—	—
DS	—	—	DS<0	DS>0
VSA	VSA=0	VSA>0	—	—
CI	Bigger CI value	Smaller CI value	—	—

Table 1: Discriminance of decision rules.

Rules	Attribute-based	Alternative-based
Compensatory	VSA=0, DS<0, AD	VSA=0, DS>0, LA
Noncompensatory	VSA>0, DS<0, LEX	VSA>0, DS>0, CONJ

Table 2: Discriminance of decision strategies.

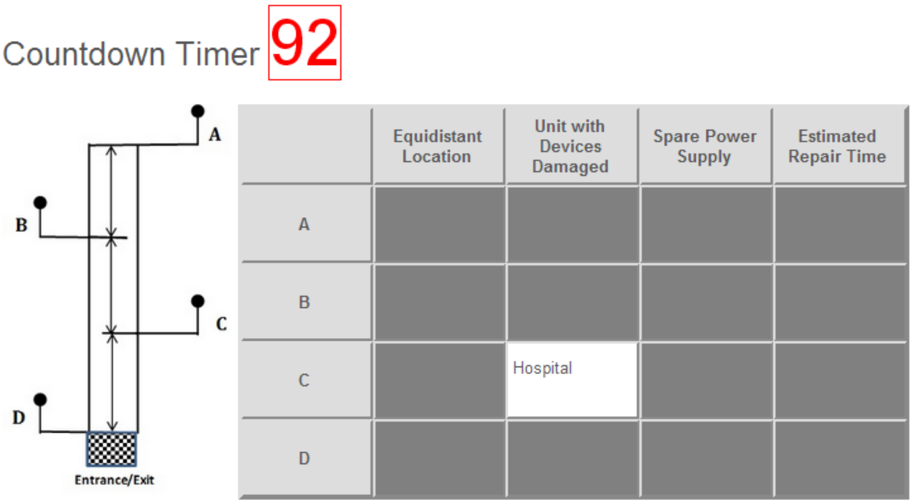

Figure 2: Decision information display board.

	Equidistant Location	Unit with Devices Damaged	Spare Power Supply	Estimated Repair Time
A	3 h to Entrance/Exit	Television Station	Yes, extra supply for 8 h	3 h
B	2 h to Entrance/Exit	Elementary School	No	5 h
C	1 h to Entrance/Exit	Hospital	Yes, extra supply	5 h
D	At Entrance/Exit	High-rise Residential Building	No	10 h

Table 3: Information of units with power supply facilities damage.

in the following 24 to 48 hours this time). Now you only have one team with one set of tools and ancillary devices, that means your team cannot work on more than one unit simultaneously; you have to finish one unit then get start on another. The heavy storm would force your team to stop repair work; also a danger of landslide is hidden in the area, it is better to leave this area once your team finish repairing or the storm is too heavy, the nearer to the entrance/exit, the safer of your team. We know the distance among the 4 units is even; their locations and other necessary information are in the Information Display Board."

Given the decision problem and conditions above, we needed criteria to evaluate decision outcomes. Therefore we used theoretical decision outcomes as criteria, which could be calculated by mathematical models and calculated with the methods of Bellman iteration.

Technically, this decision is a discrete dynamic programming problem; from Figure 2b we can see there are six decision nodes, Start entrance, A, B, C, D, Terminal exit. Each decision maker needs to undergo five phases of pathway selections to access to all the nodes. Decision objectives are: (1) minimize the total time cost; (2) minimize the possible loss by power cut offs.

So set six decision nodes={*S, A, B, C, D, T*}, the repair time cost in phase is RT_{ix} (repair), ∈ {*S, A, B, C, D, T*}; set traffic time cost is DT (distance), represents the time spending from

Phase to phase, $0 \le i \ne j \le 5$.

The least time cost equation is: $\gamma(s,t) = \min \sum_{i=0,j=1}^{5} \left(DT_{ij} + RT_{jx}\right)$ (1)

Set decision value in phase is $q^{(i)}$, BO represents the blackout time of unit before it get repaired in phase, and SP represents the time of spare power supply.

Therefore, $BO_x=(\gamma\ (s,q^{(1)})+\cdots+\gamma(q^{(i-1)}, q^{(i)})) - SP_x$.

Besides, with the help of emergency personnel, who collaborated in this study, the economic influence weighs of four units was determined, that is $k_A=7 \times 10$, $k_B=5$, $k_C=10 \times 10$, $k_D=10$.

The loss function is $\varphi(s,t) = \min \sum_{i=0,j=1}^{5} \left(k_x \bullet B0_x\right)$

$$= \min \sum_{i=0,j=1}^{5} \left(k_x \bullet \left[\gamma\left(S,q^{(1)}\right) + \ldots + \gamma\left(q^{(i-1)}\right) - SP_x\right]\right) \quad (2)$$

The results were calculated by Bellman iteration, and they formed a decision outcome evaluation system in Table 4. The satisfactory decision outcomes, at least acceptable ones are required that Unit A (television station) and Unit C (hospital) can't be blackout in the same time. To simplify the outcomes, we design a decision score system to evaluate them. This system is 10-point scale, from 1 to 10 by isometric measure with the metric tensor of 0.5 point. Higher score means better quality of decision. Scores above 6 point (including 6) are acceptable outcomes or successful decisions, whereas those below 6 point are unacceptable outcomes or failed decisions.

Procedure

Participants were recruited by our partners from State Grid Corporations from the four cities in China, and available samples were counted on when they completed all parts of the study. They were given a brief introduction to explain how the experimental system working. Participants were randomly allocated to one of two conditions, no time pressure (control group) and time pressure (time pressure group). In the pre-experiment session, only no time pressure experiment was conducted to find out any flaws and the trend of outcomes. It was also the basis of time pressure setup.

In the formal experiments, participants followed the instructions

Decision Outcome	Loss of Blackout	Time Cost	Decision Score
(S, A, C, B, D, T)	424 (A、C 0 h)	31	10
(S, A, C, D, B, T)	426 (A、C 0 h)	33	9.5
(S, A, B, C, D, T)	562 (A 0 h，C 2 h)	29	9
(S, C, A, B, D, T)	602 (A 3 h，C 0 h)	29	9
(S, C, A, D, B, T)	736 (A 3 h，C 0 h)	33	8
(S, B, A, C, D, T)	742 (A 3 h，C 2 h)	29	8
(S, C, B, A, D, T)	922 (A 8 h，C 0 h)	29	7
(S, B, C, A, D, T)	1052 (A 10 h，C 0 h)	31	6.5
(S, D, C, A, B, T)	1172 (A 13 h，C 0 h)	29	6
(S, A, D, C, B, T)	1276 (A 0 h，C 9 h)	33	5.5
(S, C, D, A, B, T)	1394	31	5
(S, D, C, B, A, T)	1492	29	5
(S, D, A, C, B, T)	1534	31	5
(S, A, B, D, C, T)	1712	31	4.5
(S, C, D, B, A, T)	1714	31	4.5
(S, B, C, D, A, T)	1822	33	4
(S, C, B, D, A, T)	1852	33	4
(S, B, A, D, C, T)	1892	31	4
(S, A, D, B, C, T)	1946	33	3.5
(S, D, A, B, C, T)	1992	29	3.5
(S, D, B, C, A, T)	2370	31	2.5
(S, D, B, A, C, T)	2380	29	2.5
(S, B, D, C, A, T)	2672	33	1.5
(S, B, D, A, C, T)	3022	33	1

Table 4: Theoretical decision outcome evaluation.

and procedure to complete the IDB trial of a cell phone buying selection to learn making decision with IDB. Next, both groups watched the same typhoon scenario video and descriptions, and used IDB to work on the decision problem of repair order for damaged power supply devices. Control group took time freely on it, whereas time pressure group had to finish it within 100s (details discussed later), after the deadline it had no access to hidden information. Then participants reported themselves according to their situations in the process of decision making like their feeling about the scenario, cognitive effort, and task difficulty. After that, time pressure group would finish the time pressure test questionnaire, this questionnaire included 8 items, like "I felt that time past quickly", "I can't stop looking at the time"; and all questions were answered on 5-point Likert scales, from "strongly disagree-1 point" to "strongly agree-5 point". At last, both groups filled out their general information like gender, age and so on.

After participants finished the experiments, we downloaded all the records of data via SQLyog software and made some necessary data cleaning like default data processing and data culling beyond 6σ(that is between mean minus and plus 3 times standard deviation, which included 99.95% of valid values of normal distribution).

Results and Discussion

Validity check of disaster scenario design and time-pressure manipulation

Before decision making, participants came into the disaster context by typhoon video episode and relevant description. To test the validity of this design, they were asked with a question of "To what extent do you feel like facing a disaster via the video episode and emergency scenario", after they solve the decision problem. The answer was designed as 5 point Likert scale, from "no feeling to the disaster-1 point" to "very intense feelings to the disaster- 5 points." Results of the answers showed that, control group had feelings to the disaster between slight to moderate degree (M=2.82, SD=0.945); while time pressure group had moderate feelings to the disaster (M=3.07, SD=1.202). It indicated that the design of disaster scenario was effective, participants were brought into the disaster context to some extent, and the experience was more sensitive in time pressure condition.

Time pressure was set up by a countdown timer showed together with IDB as Figure 3. The time limitation was calculated by the mean of time cost on the decision (M=168.17s) minus its standard deviation (SD=63.95) in the pre-experiment session, it came out as 104.22s, so we set up 100s as time constraint. After decision making session, participants in time pressure group were required to answer the time pressure test questionnaire mentioned before. Since the Cronbach's alpha of the participants' responses to the 8 questions was 0.903, exceeded 0.80, the average score was used as an index of overall relevance. The score was total of the 8 items, ranged [8,40]. The mean of score was 21.43 (SD=8.508), that for each item was 2.68 (SD=1.063). It showed that participants perceived low to moderate degree of time pressure, the setup of countdown timer put time pressure on them indeed.

Outcome analysis of indicators

The experimental system recorded the results of seven indicators totally as dependent variables, including Total Clicks (TC), Decision Time (DT), Proportion of Information Search (PIS), Direction of Search (DS), Variability of Search of Alternative (VSA), Compensation Index (CI) and Outcome Score (OS), as well as self-report variables Cognitive Effort (CE) and Task Difficulty (TD), as Table 5 showed. Then we conducted a multivariate analysis of variance (MANOVA) with the seven dependent variables as indicators for process and outcome of emergency decision making, and time pressure as the source of variation. Result showed a significant difference between control and time pressure groups, F (7, 51)=6.413 $p < 0.001$, so time pressure affect the process and outcomes of decision making in disaster scenario. To be specific, we conducted T test among each dependent variables to see their significances of difference between two groups. The results of T test were in Table 5.

The results showed significant differences of three indicators, they were Decision Time (DT, F (1, 58)=4.569, p=0.037<0.05), Direction of Search (DS, F(1,57)=10.324, p=0.002<0.05), and Outcome Score (OS, F(1, 58)=20.461, p=0.000<0.05). As time pressure was the only source of variation, it indicated that: (1) Time pressure forced decision

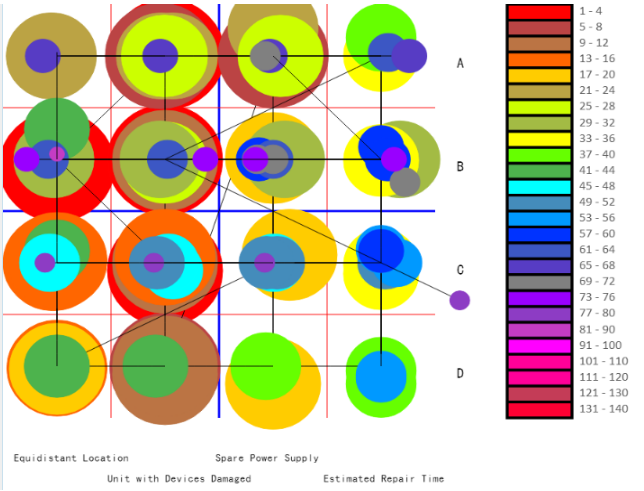

Figure 3: An example of dynamic information search process demonstration.

makers to accelerate the speed of information search and total time cost; (2) Under time pressure, participants were more likely to adopt attribute-based decision rule (Mean of DS=-0.22<0) than alternative-based one, which is more used in no time pressure situation(Mean of DS=0.26>0); (3)Time pressure had a strong impact on the quality of decision outcomes (8.13>5.40), many participants failed to work out an satisfactory or even acceptable solution.

Effects of Time Pressure on Decision rules and strategies

According to this discriminance in Tables 1 and 2, decision strategy each participant used could be recognized, and then we conducted Crosstab Analysis with different decision rules between two groups, as Table 6.

The result above showed that time pressure had little impact on decision rules of Compensatory or Noncompensatory. Compensatory rule was more likely to use in both control group (total 60%) and time pressure group (total 56.7%). However, there were definite differences in decision rules of information search direction, Attribute-based or Alternative-based. In control group, 60% of participants selected alternative-based rule to the emergency make decision, which required to calculate values and mediate conflicts of attributes within one alternative and call for much cognitive effort; whereas under time pressure, the rate of that rule usage was just 23.3%, in other words, 76.7% of participants preferred attribute-based rule to avoid conflicts between attributes, which need less cognitive effort.

As to specific decision strategies, followed compensatory rule, participants used more Additive Linear strategies than Additive Difference ones (AL 33.3%>AD 26.7%) in control group, while under time pressure, more Additive Difference strategies were adopted (AD 40.0%>AL 16.7%). It indicated that time pressure was more likely to drive decision makers avoid mediating conflicts of different attributes, which asked for less processing resource, though participants from both groups preferred compensatory rule. In the other hand, under noncompensatory rule, participants in control group applied more Conjunctive strategies than Lexicographic ones (CONJ 26.7%>LEX 13.3%); relatively, participants in time pressure group preferred Lexicographic strategies (LEX 36.7%>6.7%).

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Different decision strategies revealed different processes of decision making, the results above showed the effects of time pressure on that process, though emergency personnel still made necessary tradeoffs under time pressure (more compensatory rule adopted), they were more likely to avoid conflicts between attributes of each alternative, and put much less cognitive efforts on decision making, leading to bad decision results.

Besides, to improve the validity of the approach to recognize decision strategies, we developed an online "dynamic information search process demonstration" at the website: http://kangfu101.com/question/drawPointResult, we just summited the random unique ID of one participant, the process would be displayed by circles with different colors and sizes. In the way, decision strategy one used could be mutual authentication by the discriminance and this software. Figure 3 was the demonstration result of a participant with ID 8229111, who was judged to apply additive difference (AD) strategy by the discriminance. The picture showed that "8229111" compared the values by attributes at first, then checked attributes by alternatives before making final decision. That search behavior was in accordance with the feature of additive difference strategy, so we judged "8229111" as an additive difference (AD) strategy user.

Effects of time pressure on cognitive load

The combined measurements of cognitive load were used in this study. Wes calculated the self-report cognitive effort, outcome score as well as decision time for each strategy group in different experimental conditions, shown in Table 7.

From the results in Table 7, though time pressure seemed to affect little on the self-report cognitive effort, it had a deep impact

	TC	DT	PIS	DS	VSA	CI	OS	CE	TD
Control Group									
M	65.67	129.07	0.89	0.26	0.06	0.70	8.13	2.82	3.00
SD	27.25	62.66	0.25	0.62	0.14	0.41	1.52	0.95	1.09
Time Pressure Group									
M	47.10	63.50	0.72	-0.22	0.18	0.50	5.40	2.87	2.87
SD	51.97	42.04	0.30	0.32	0.15	0.37	2.92	1.11	1.04
F	1.139	4.569	0.870	10.324	0.070	0.001	20.461	0.028	0.227
p	0.290	0.037	0.355	0.002	0.792	0.976	0.000	0.868	0.635

Table 5: Description and ANOVA analysis for dependent variables.

	Control Group			Time Pressure Group		
	Attribute-based	**Alternative-based**	**Total**	**Attribute-based**	**Alternative-based**	**Total**
Compensatory	AD	LA	60%	AD	LA	56.7%
	26.7% (8)	33.3% (10)		40.0% (12)	16.7% (5)	
Non-compensatory	LEX	CONJ	40%	LEX	CONJ	43.3%
	13.3% (4)	26.7% (8)		36.7% (11)	6.7% (2)	
Total	40%	60%	—	76.7%	23.3%	—

Table 6: Comparison of decision rules and strategies in different time conditions.

Strategies	LA		AD		CONJ		LEX	
	M	SD	M	SD	M	SD	M	SD
Control Group								
Cognitive effort	2.89	0.78	2.63	1.30	2.89	0.93	3.00	0.00
Decision time	122.10	55.81	137.67	23.88	45.10	44.62	59.50	24.75
Outcome score	8.30	1.27	8.69	1.13	7.95	1.61	6.00	2.83
Time Pressure Group								
Cognitive effort	2.60	1.52	3.08	1.08	2.50	0.71	2.82	1.08
Decision time	84.60	28.95	70.43	35.65	60.50	20.98	53.27	44.66
Outcome score	6.80	1.44	4.92	2.84	5.25	3.01	5.32	3.23

Table 7: Total decision time and outcome score in different strategy groups.

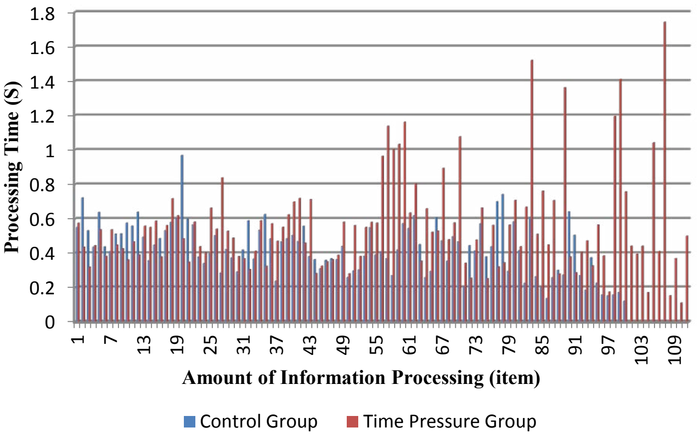

Figure 4: Cognitive load of information processing in different experiment groups.

on Decision Time and Outcome Score of strategies following Compensatory Rule, it made emergency personnel reduced decision time on strategies adoption of LA and AD which obey Compensatory Rule, along with dissatisfactory decision results. Especially in AD strategy groups, Decision Time decreased from 137.67s (SD=23.88) to 70.43s (SD=35.65); while Outcome Score dropped from 8.69 (SD=1.13), which was the best in control group, to 4.92 (SD=2.84), the worst in time pressure group, implying that AD strategy seemed not a good approach to making decision under time pressure; and for LA strategy usage,

Decision Time fell from 122.10s (SD=55.81) in control group to 54.60s (SD=28.95) in time pressure group, and Outcome Score, from 8.30 (SD=1.27) fell to 6.80 (SD=1.44). It indicated that emergency workers kept considering tradeoffs among attributes under time pressure, but it made them put much less cognitive efforts than that in control group, resulting in bad decision performance. However, time pressure seemed to have much less impact on Decision Time of Noncompensatory rule groups, including strategy groups of CONJ(45.10s versus 60.50s) and LEX (59.50s versus 43.27s), it also caused a worse decision quality (CONJ:7.95 versus 5.25; LEX: 6.00 versus 5.32).

Another method to measure cognitive load by information processing time with IDB, to reveal the cognitive resource consumed in each processing, also say it as cognitive effort. So we integrated a sequence of process time for all participants, worked out the fitting histograms for the two experiment groups in Figure 4. Furthermore, we used the same approach on the four decision strategy groups of different experiments, as Figure 5 showed. Noted that, each processing time in charts was its mean value of all participants by the same sequence in one group or the same decision strategy.

In Figure 4, blue straights represented cognitive load measured by processing time in control group, and the red ones for time pressure group. We can see more cognitive resource was consumed in time pressure group(more areas of red straights exceeding), especially when it was near the deadline of 100s; cognitive loads from two groups almost kept in the equal level, of which the control group (blue straights) was slightly higher during first 35 seconds. However, after 57th second, an increasing trend of cognitive load was observed, fluctuant rising to end. It was inferred that emergency personnel perceived time pressure increasing rapidly to the deadline, they had to divide some cognitive resource to monitor it; and they were more likely to need more effort to focus on the decision task, as well as fight against the interruptions of time pressure.

However, though more cognitive resource was used under time pressure, the decision performances of emergency workers were poor, the mean of outcome score was 5.40 (SD=2.92), ranking as unacceptable result. It implied that less cognitive resource was assigned to decision making, while time pressure occupied much cognitive resource with monitoring and coping with.

To be specific, we made comparisons of cognitive load for decision strategies between two experiment groups in Figure 5 with four small histograms. We can see the variations of cognitive load were varying from decision strategies and experimental groups. Strategies of Linear Additive (LA) and Additive Difference (AD) cost more cognitive resource definitely than Conjunctive (CONJ) and Lexicographic (LEX) in both control and time pressure groups.

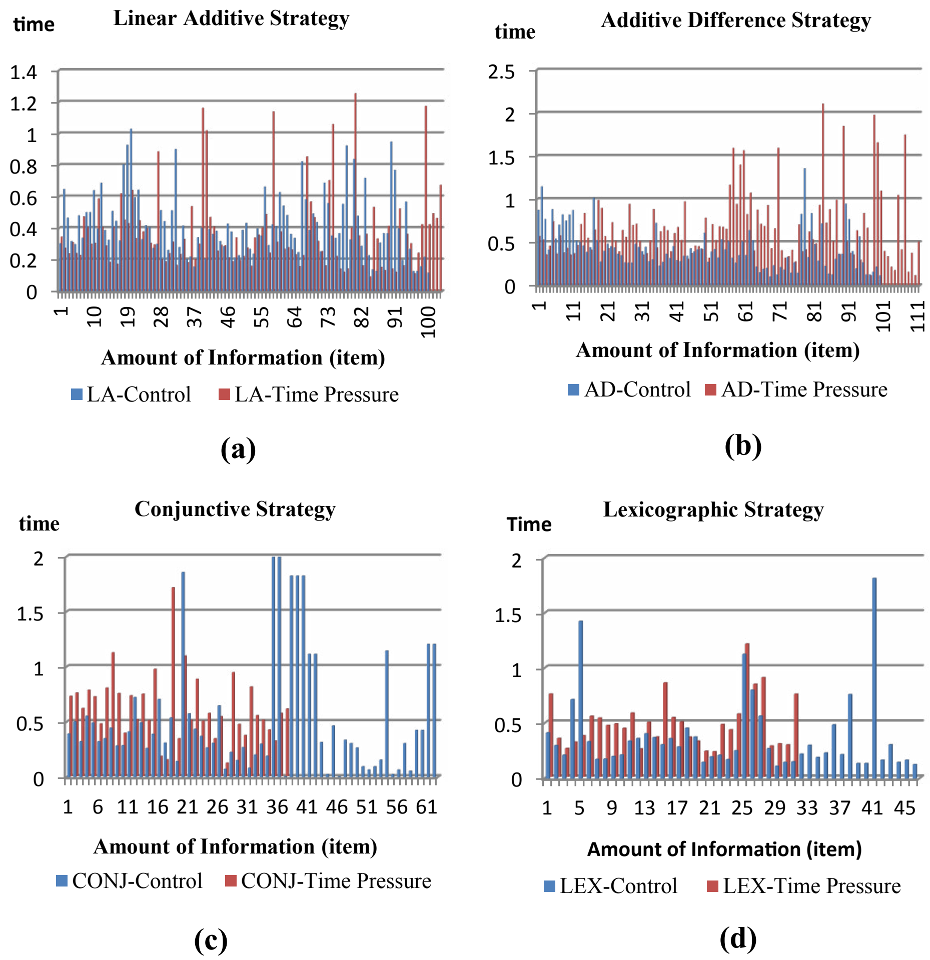

Figure 5: Cognitive load of decision strategies in different experiment groups.

In LA groups, it seemed cognitive loads in control group were consistently higher than that in time pressure group of the whole decision-making process (blue straights exceeding red ones), though couples of peaks from time pressure group were outstanding when the process was closing to the deadline, also more amount of information checked with less time. It indicated LA strategy users had a faster but less deliberate decision process under time pressure. Less cognitive efforts input resulted in the outcome score fell from 8.30 (SD=1.27) in control group to 6.80 (SD=1.44) in time pressure group. Whereas, cognitive loads in AD strategy of time pressure group were obviously higher, though they were under that from control group within the first 11 seconds, as well as more amount of information processing. Also an uptrend of cognitive loads was observed in time pressure group after 55th second. Unfortunately, AD strategy users in time pressure group got the lowest average decision score of 4.92 (SD=2.84), though the highest score was from the same strategy users in control group (8.69, SD=1.13). It indicated that time pressure had much effect on AD strategy, which was conducted in different directions by making comparisons among attributes and calculations within alternatives.

As to CONJ strategy, time pressure made its users cut down the decision time and cognitive effort to solve decision problem, resulting in worse decision performance, the mean score decreased from 7.95 (SD=1.61) in control group to 5.25 (SD=3.01) in time pressure group. Similar situation happened in LEX strategy as well, though in both strategies, every single cognitive load from time pressure group was higher (red straights exceeding blue ones). That means time pressure interrupted the decision-making process, it might make emergency workers more deliberate, but it pushed them to make decision prematurely. Therefore, the decision performance by using LEX strategy also had a small decline, from 6.00 (SD=2.83) in control group to 5.32 (SD=3.23) in time pressure group.

Conclusion

In this paper the effect of time pressure on decision-making process in natural disaster scenario was discussed, we combined cognitive load and decision making strategies to examine the effects of time pressure on the information processing and decision outcomes, which were varying by different decision strategies used by emergency personnel.

At first, based on process tracing technology of information display Board and previous theories, we set up a simple approach to recognize four decision strategies with indicators of direction of search (DS) and variability of search of alternative (VSA). Besides, we developed an online dynamic information search process demonstration to example the validity of the approach.

Then, accounting to investigations real emergency personnel, we designed an emergency decision making experiments in a typhoon scenario, also developed an online experimental system to conduct the experiments with multimedia and networking technology. Besides, a decision outcome we Mathematical decision models were also set up for the decision problem to evaluate the quality of decision by emergency workers.

The experiment results indicated that: (1) time pressure had a bad impact on emergency decision performance; (2) under time pressure, emergency personnel tend to use attribute-based information search rule to avoid conflicts among attributes within an alternative; (3) time pressure occupied emergency decision makers' cognitive resource, forcing them to monitor and cope with it; as the capacity of working memory is limited, the cognitive efforts on decision making had to be reduced, which leading to a bad decision results.

Besides, though time pressure had a bad impact on decision outcomes from all the four strategies, the effects were varying on the decision process and behavior of emergency respondents. Time pressure made linear additive (LA) users to speed up but think less deliberately in decision making, while its disturbances consumed much mental effort of additive difference (AD) users to cope with, and they were forced to distract from deliberate information processing like comparison and calculation, resulted in the worst outcomes. As to strategy users of conjunctive (CONJ) and lexicographic (LEX), similarly, time pressure made them put more efforts on finding the values of most important attribute, once they confirmed, they made a quick decision to complete the task. The uniqueness of this study, from other researches in decision making process, was its research field of emergency decision making to respond disaster. Disaster is an exceptive decision environment, which is often complicated and changing, and individuals may generate physical perceptions or mental sensations to interrupt decision-making process. However, this paper didn't mention that because it focused on the effect of time pressure, which was the variation between two experiment groups. Time pressure was the only part changed, so we believe that all the variations were due to time pressure. Besides, the investigations and experiments were both conducted with real emergency respondents, getting close to real disaster decision making.

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