Future Computer-aided Decision-making Support Systems: Concerning more about the Mechanism of Human Behavior

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***Abstract*—With the development of computer and network technology, more and more areas (such as power system security control, medical diagnosis system, government emergency management, stock invesment strategy anallysis, etc.) have gradually established decision-making support systems, which are mainly responsible for information collection, management and analysis. Studies show that decision-making support systems have greatly enhanced user productivity. So the engineers' interest in designing computerized decision support systems has considerably increased in recent years. The current decision support systems mainly focus on data acquisition and analysis. They are responsible for providing large amounts of data continuously and delivering adaptable models, which can enable people to use these results effectively and then make decisions more quickly and accurately. Then, is there any real-time decision support system in the future that can change human's judgment and decision-making? By behavior science research, this paper will provide some answers by presenting the results of a study that subliminal vision signal may have direct influence on human's advanced cognitive process and finally change human's decision under ambiguity. It will provide key technology and new research ideas for engineers to design more intelligent and more powerful decision-making support systems in the future.**

***Index Terms*—Decision support system(DSS), Subliminal vision signal, Unperceived; Judgment, Decision making, Decision maker(DM), Uncertainty, Ambiguity, Ellsberg paradox**

I. INTRODUCTION

A decision-making support system (DSS) is a computer-based information system that supports human decision-making activities. The systems serve the management and provide help to make decisions, which may be rapidly changing and not easily specified in advance[1]. Scientific analysis of decision problems aims at giving the decision maker (DM) a recommendation concerning a set of objects (also called alternatives, solutions, acts, actions, options, candidates) evaluated from multiple points of view considered relevant for the problem at hand. A properly designed DSS is an interactive software-based system intended to help decision makers compile useful information from a combination of raw data, documents, personal knowledge, or business models to identify and solve problems and make decisions[2].

DSSs may perform selected cognitive decision-making functions by computer technology. However, they can not be studied only from the perspective of computational science or engineering problems. A perfect design of DSS is still largely based on human decision-making mechanism, including human thoughts and behavior. As we all know, People always play a major role in any decision-making process and the brain is human's supercomputer, which may work more like an assembly line when recognizing objects [3]. But we need to note that People are not optimal decision-makers by human nature. There are several factors that hinder the decision-making process, e.g. cognitive biases, accidents, cultural motivations and missing knowledge[4]. So, it is necessary

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to provide favorable technological support for managers to make decisions. And it has been generally acknowledged as a new field of Human-Machine Interaction with the most promising future in 21st century. At present, with the help of conventional decision support systems, people can improve their working efficiency[5]. However, in such situations, the decision maker's final judgment is still based on his or her own inherent disposition. People are usually unreasonable or irrational on some special occasions, especially under stress-related disorders such as depression. They are not able to arrive at well-substantiated policy decisions[6]。The function of additional decision support systems in the future will not limited to providing plenty of data to help decision. The ideal goal is to enhance understanding of human decision-making processes and check if the decision is correct, finally induce them to change their inward decision if necessary. This is a challengeable task, and first of all, it needs the creative work of cognitive science to further explore human's decision-making mechanism.

Decision making is an advanced cognitive process, which is the core component of human intellectual activity. It involves comparing, evaluating alternative solutions and finally making the optimal choice, this process will take a lot of cognitive resources[7].Making a decision implies that there are alternative choices to be considered, and in such a case people want not only to identify as many of these alternatives as possible but to choose the one that has the highest probability of success or effectiveness and best fits with human's goal, desire, lifestyle, value, and so on. People all make decisions of varying importance every day; however, studies have shown that most people are much poorer at decision making than they think[8]. Decision making can be divided into two categories: under certainty or under uncertainty. The former means that all options are pretty sure in the decision-making situation and people may judge or determine based on his individual subjective value; while the latter refers to uncertainty of objective value or probability of each option, even both is uncertain. It should be noted here that very few decisions are made with absolute certainty because complete knowledge about all the alternatives is seldom possible. Decision making under uncertainty can be divided into two kinds, one is ambiguity decision-making and the other is risk decision-making. In the fuzzy situation, people have no way to estimate the probability by experience or reasoning, so they usually have to make decisions in accordance with subjective probability. Economists and psychologists have conducted many studies on ambiguity decision making[9,10], but there is no research on the effect of subliminal perception on it. It is a lively debated issue, whether or not stimuli we are not aware of might influence our behavior. A famous example of such an unconscious effect on behavior that has almost become part of folk psychololgy is the so-called "drink coke/ eat popcorn"-study by James Vicary, an advertising expert, in the late 1950s. He claimed to have inserted the words "drink coke" or "eat popcorn" for about 1/3 ms every 5s into films his participants saw at a movie theater. Allegedly, over the course of 6 weeks a substantial increase in soft drink and popcorn consumption ensued. The "study", howervr, was never reported in a scientific journal and although several attempts were made, the findings could never be replicated. Some years later, Vicary himself confessed in an interview that he had made up the whole story to revise his failing advertising business. Despite this, there was still evidence that subliminal perception really had some impact on human emotion and behavior[11-14]. Here, we investigated whether human's choice changed in the case of uncertainty if they accepted some unrealized guidance information. The purpose of the present study was to contribute to the understanding of human decision and human-computer interaction processes by demonstrating that subliminal information was highly influential for human decision-making.

II. METHOD

A slightly changed paradigm of Ellsberg paradox was used in this research. Participants were seated and received subliminal stimuli from the screen of a computer or the headphones，then they were asked to finish the two-alternative forced-choice task and to response by keyboard as quickly as possible. The whole experiment lasted about 20min, holding in a standard behavior laboratory.

A. Participants

The 34 participants recruited for this experiment are college students and all of them have normal visual acuity (or corrected normal visual acuity) and auditory acuity, between 20 and 26 years old. The age and gender distribution of them is provided in Table I. All the participants were right-handed and denied any history of neurological or mental abnormalities. They were randomly divided into two groups. None of the them was aware of the purpose of the study and none had seen or heard the stimulus material prior to the experiment. Participants were asked to sign an informed consent form before commencing testing, and were paid for their participation.

TABLE I.
CHARACTERIZATION OF PARTICIPANTS

Gender	Number	Average age(years)
male	16	22.94 ± 1.81
female	18	21.83 ± 1.47

B. Apparatus and Stimuli

A DELL desktop computer (Inspiron 560) with a 17-in. LED display was used for stimulus presentation and response sampling. The refresh rate of the monitor was set to 75Hz and the resolution was 1280×1024. There were two kinds of subthreshold stimuli, one was subliminal visual stimuli, presented through the

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computer's LED screen; and the other was subliminal auditory stimuli, presented through the headphones. In previous literature, researchers usually control the presentation time (shorter than 13ms) in order to make people unperceived. While in this paper, a new method was tried. We succeeded in making the visual stimuli unseen by adjusting the color of both the visual stimuli and the LED screen. The background color of LED screen is white (R:255,G:255,B:255）and the color of visual stimuli is very similar to white(R:248,G:248,B:248）. The visual stimuli were presented with the fixation point (+) at the same time, located just below the fixation point for 0.2cm, lasted 1000ms for each trial. All the participants were instructed not to move and to keep their eyes on the fixation. Subliminal auditory signal was achieved through controlling sound intensity of background sound and target signal. In our experiment, the sound intensity difference between them was 30db. The song Spring from Bandari was selected as background sound. The contents of subliminal stimuli were "Choose A" or "Choose B", lasting 1145ms, and the subliminal stimuli repeated by the frequency of 27 times per minute. When the experiment was finished, each participant was asked whether he (or she) had seen or heard the content of subthreshold stimulation during the whole experiment. All the participants answered "no".

C. Experimental material

In the classical Ellsberg's simplest illustration, two urns are filled with red and black balls, Urn A containing an unknown ratio of 100 red and black balls, randomly mixed and Urn B containing 50red and 50 black balls, randomly mixed. A decision maker chooses a color (red or black) and an urn (A or B) from which to make a blind drawing and wins a prize if a ball of the chosen color is drawn. This paper used a slightly changed paradigm of Ellsberg paradox, the main changes were the total number of balls (three levels: 10, 50, 100) and the ratio of red balls in urn A (three levels: 0-100%, 20-80%, 40-60%). Thus, there were a total of 9 ambiguity decision-making scenes, and in previous studies it was proved that the 9 scenes were homogeneous. In each decision-making scene, whether the total number of balls or the ratio of red balls in urn A would be changed. Fig. 1 presents the form of decision-making scene. During the formal experiment, the 9 scenes mentioned above were randomly presented.

D. Experimental design

Firstly, 34 participants were divided into two groups according to the content of subliminal stimuli. And the experiment for each group was relatively independent, but their experiment design was identical, both constructing as a within-subjects design.

1) Independent variables

The experimental design included one within-subjects independent variable. The variable was the kind of subliminal signal. According to the presentation of stimuli, there were three experimental conditions: no subliminal signal, visual subliminal signal and auditory subliminal signal.

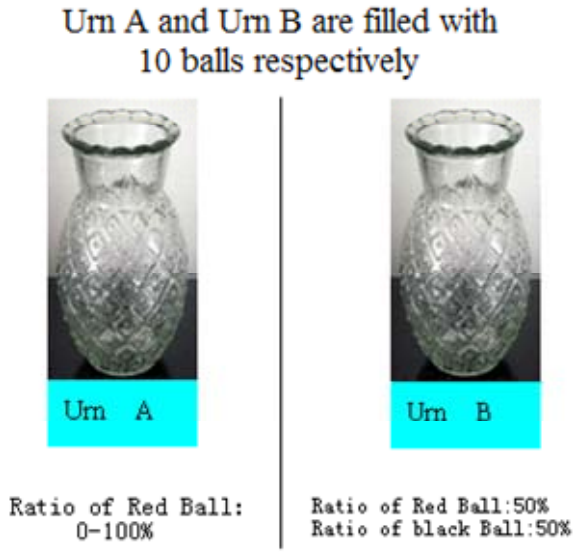

Figure 1. The form of ambiguity decision-making scene

2) Response method

Participants ought to express their preference choice and they were told to response by keyboard as quickly as possible. That is to say, if they want to choose urn A, please hit the keyboard A; and when they want to choose urn B, just hit the keyboard B.

3) Dependent variables

The dependent variables used to measure decision-making were preferred choice (A or B) and response time (defined as the time between the presence of each scene of ambiguity decision mentioned above and the participants hitting the keyboard A or B).These two measures allowed for assessing human's preference and speed of ambiguity decision making.

E. Experimental procedures and order of the trials

A slightly changed paradigm of Ellsberg paradox was used in this research. After signing an informed consent form, participants were taken to individual cubicles and were informed the guidance of the experiment by te famale experimenter. Participants were seated and received stimuli from the screen of a computer or the headphones， then they were asked to finish the two-alternative forced-choice task and to response by keyboard as quickly as possible. Their task was to choose an urn (A or B) to make a blind drawing of red ball. Responses were excuted with the index fingers of both hands and collected with an external keyboard. All the participants were told that they were able to get additional award if they made a blind drawing of red ball in each trial.

The participants were randomly divided into two groups, each group included 17 members. One group received the subliminal signal as "Choose A", and the other group received "Choose B". The experiment was conducted in standard behavior laboratory. Participants received 4 practice trials in order to become familiar with the task and the respond method. 90 trials were conducted

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in the formal test. Each of the nine different decision-making scenes included 10 trials. And the 90 test trials were divided into three blocks, 30 trials in each block. The three blocks corresponded to the following three experimental conditions: no subliminal signa (no SS), visual subliminal signal (visual SS) and auditory subliminal signal (auditory SS). The order of these three experimental conditions was balanced among participants. Participants could take a break between blocks according to their own need.

III. RESULTS

A. Data processing

All data collected in this experiment were valid and the two groups of data were analyzed separately. The SPSS 18.0 statistical package was selected for analysis and one-way ANOVA was used to compare means from the three experimental conditions, then follow-up tests using LSD method were conducted to evaluate pairwise differences among the three treatment groups.

B. Preferred choice

1) The group with subliminal signal as "Choose A"

Participants in this group were provided with subliminal information as "Choose A" either through the vision channel or auditory channel. And in the remaining one-third trials, the participants did not receive any stimulus. A one-way analysis of variance was conducted to explore the impact of sub threshold signal. The results showed that there were significant differences in participants' decision-making preferences（p =0.077） (Table 2).Under the influence of visual subliminal signal, the mean percentage of selecting urn A was higher than the remaining two experimental conditions. Follow-up pairwise comparisons of these three means yielded significant results (p =0.028) only between the condition of no subliminal signal and visual subliminal signal.

2)The group with subliminal signal as "Choose B"

Participants in this group were provided with subliminal information as "Choose B" either through the vision channel or auditory channel. And in the remaining one-third trials, the participants did not receive any stimulus. A one-way analysis of variance was conducted to explore the impact of sub threshold signal. The results showed that there were significant differences in participants' decision-making preferences（p =0.043） (Table 2).Under the influence of visual subliminal signal,

TABLE III.
RATIO OF SELECTING URN A UNDER DIFFERENT CONDITIONS IN "CHOOSE A" GROUP (N=17)

	Percentage of selecting urn A (%)	
	Mean	SD
no SS	46.41	15.53
auditory SS	50.20	17.06
visual SS	58.63	14.34

TABLE II.
RATIO OF SELECTING URN B UNDER DIFFERENT CONDITIONS IN "CHOOSE B" GROUP (N=17)

	Percentage of selecting urn B (%)	
	Mean	SD
no SS	51.39	16.20
auditory SS	53.92	18.11
visual SS	64.11	13.37

the mean percentage of selecting urn B was higher than the remaining two experimental conditions. Follow-up pairwise comparisons of these three means yielded significant results (p =0.016) only between the condition of no subliminal signal and visual subliminal signal.

C. Response time

1) The group with subliminal signal as "Choose A"

This group was provided with subliminal information as "Choose A" either through the vision channel or auditory channel. The mean response time for no subliminal signal, visual subliminal signal, auditory subliminal signal were 2733.32 ms, 2809.18ms, 2791.05 ms, respectively. The main effect on response time was not significant (p>0.10).

2) The group with subliminal signal as "Choose B"

This group was provided with subliminal information as "Choose B" either through the vision channel or auditory channel. The mean response time for no subliminal signal, visual subliminal signal, auditory subliminal signal were 2822.58 ms, 2698.71 ms, 2775.92 ms, respectively. The main effect on response time was not significant (p>0.10). Fig. 2 shows the average response time of the two groups.

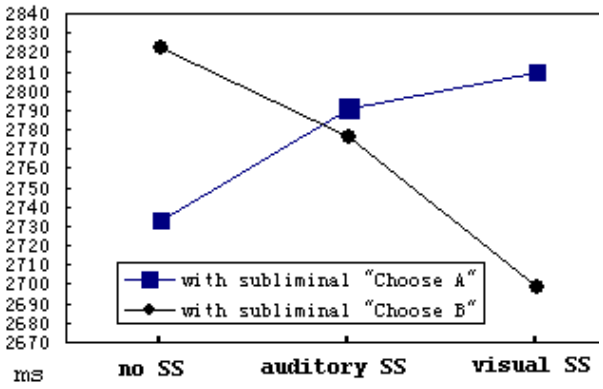

Figure 2. The average response time of the two groups

D. *Summary*

Two main findings emerge from the statistical analysis: (1)In the group with subliminal signal as "Choose A", participants were more likely to choose A, especially when the stimuli were presented through visual channel; (2) In the group with subliminal signal as "Choose B", participants were more likely to choose B,

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especially when the stimuli were presented through visual channel.

IV. DISCUSSION AND CONCLUSIONS

Subliminal perception is a kind of unconscious perception, people can not consciously perceive. In this article, the terms 'conscious' and 'subconscious' are equal to 'supraliminal' and 'subliminal', respectively. Conscious and subconscious processed have been differentiated in past studies by either objective or subjective measures[15].Applying subjective measures, the subject's consciousness is detected by self-reports of experience. In contrast, objective measures are provided by forced-choice or presence-absence tasks, which are based on the subject's discriminative capabilities. One problem of interpreting research on subconscious processing is the possibility that participants are weakly conscious of the stimuli. Previous studies have found that the level of unconscious processing is relatively low. That is to say, with the influence of unconscious stimuli, one can process the physical characteristics of the word, without understanding the meaning[16]. In our experiment, the presentation of subliminal stimuli was different from traditional unconscious stimuli forms, and a new method was tried. We made the visual stimuli unseen by adjusting the color of both the visual stimuli and the LED screen. Based on the results of this study, it was suggested that although all the participants do not see the visual information, but they are significantly affected by those unseen word when making decision. Since Ellsberg's (1961) seminal paper describing choices between options with known and unknown probabilities, behavioral decision scientists use the term ambiguity to define the class of decisions common in everyday life in which at least one of the options is characterized by "uncertainty about uncertainty" (i.e., there is an unknown distribution of outcome probabilities such as the percentage of winning and losing balls in an urn). And ambiguity aversion has been investigated by psychologists since Ellsberg noted that decisions makers tend to prefer taking gambles with known-risk probabilities over equivalent gambles with ambiguous probabilities[17,18]. A large majority of decision makers strictly prefer the known-risk Urn B to the ambiguous Urn A, irrespective of the preferred color. In this study, participants also showed ambiguity aversion and the mean percentage of selecting urn A is 48.90%, which is close to the percentage (46.92%) reported by previous literature[19]. In addition, our experiments extended this finding by showing that unconscious stimuli even affect human's free choices. While the participants received subliminal visual stimuli, their preferred choice changed with the content of those unseen stimuli, showing a clear trend. That is to say, when the participants received the unconscious information of "choose A", they tend to choose urn A; and while they received the unconscious information of "choose B", they tend to choose urn B.

Unfortunately, no significant effect of subliminal auditory stimuli was found in our study. It may be due to the sound intensity, which is probably much too low for human in this experiment. This reminds us of a common problem about subliminal perception. How on earth to define supraliminal and subliminal stimuli? The so-called subliminal perception is largely based on people's subjective experience and the subjective feeling will keep varying due to different persons, different periods or different surroundings. We speculate that the intensity of subliminal stimuli need to be set precisely, which can not be too low. So, in future experiments, we will measure each person's hearing threshold and then try to set the appropriate sound intensity for them.

The results suggest that participants have unconsciously linked the subliminal information to their own decision-making. In summary, this paper indicates that subliminal vision stimuli, which were presented by adjusting the color of both the visual stimuli and the LED screen, provide a promising way to affect human's decision making. This finding has some particular meaning for the development of future decision-making support systems， which will provide the scientific foundation for engineers. The function of current decision-making system is to provide users with large amounts of data to support decision-making. This system mainly consists of human-machine interface and backstage database[20]. The human-machine interface is responsible for providing a platform for users to communicate with the system, and human's operations or commands are accepted by it. The task of backstage database is data acquisition, analysis and information fusion. According to the results of this study, we can imagine that the future decision-making support system is expected to systematically evaluate and change people's decision-making, which is emotional. It only needs engineers to embed a particular decision-making intervention module in the system. In addition, the function of intervention module can be flexibly set according to different intention. Advice for improving decision-making can be derived from the proposed method by identifying possible mechanisms related to each type of decision setting.

The work in this area has just begun. Although experimental studies offer distinct effects, a complete picture of the influence of subliminal information on human's decision-making must be based on data stemming from multiple research strategies. Ecologically valid methods (e.g., observational studies, surveys) in combination with internally valid methods (e.g., experimental simulations) will provide us with the necessary tools for working this ralatively unmined area of decision-making intervention research. And in the future, we may extend this research to brain responses to these stimuli presented outside conscious awareness.

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