Experimental Research on Team Dynamic Function Allocation Strategy Optimization

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Abstract. This paper mainly focused on the dynamic function allocation strategy proposed by the team, and carries out relevant experimental research. The underwater vehicle consists of three workstations, including Operating Officer (OO), Vehicle Officer (VO) and Leader, was designed and built. Twelve healthy male college-age students were recruited to investigate the effects of two allocation strategies on their mental workload and task performance. Although the result showed that the improvement of Operating Officer's task performance was less at human-machine allocation strategies than at human-human allocation strategies, the Vehicle Officer's task performance decreased significantly at human-human allocation strategies. Hence, human-machine collaboration strategy is still the primary scheme at dynamic function allocation based on the convenience of intelligent systems. If the mental workload level and job performance level of Operating Officer are underperforming after the human-machine allocation strategy is completed, part of the Operating Officer's fault task processing function is assigned to Vehicle Officer.

Keywords: Function · Allocation strategy · Team · Underwater vehicle

1 Introduction

Automation and intelligent systems are widespread in the field of transportation, factory manufacturing, nuclear power plants, aerospace, navigation and other fields by the continuous development and progress of industrial level [1, 2]. Automation can improve system performance without increasing manpower demand by delegating routine tasks to automated assistive equipment. The use of automated monitoring assistive equipment can not only improve security, but also increase the productivity of the system to reduce the total cost of the system [3].

However, in the design and functional allocation of automated systems, ignoring human factors can bring many challenges, such as loss of situational awareness, unbalanced workloads, vigilance and skill degradation, which can lead to disastrous results [4]. Therefore, Fitts proposed the concept of man-machine functional allocation, which

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refers to the process of assigning functions or tasks in a system to a person or machine [5]. The primary purpose of dynamic function allocation is to keep operator situational awareness and load levels at acceptable levels. According to the Yerkes-Dodson law, it keeps the worker's cognitive load at a moderate level, i.e., optimal performance [6].

The emergence of automation and intelligent systems has replaced the work of operators and reduced the need for human resources. As time goes on, a lot of new jobs have come up. The nature of human work has shifted from manual to primarily cognitive tasks such as monitoring, diagnosing and solving problems. Even in advanced human-machine systems, humans are still one of the most influential actors. It is worth noting that the failure of human-machine partnership in recent years is mostly caused by human factors, such as loss of professional knowledge, excessive reliance on automation and complacency, people's trust in machines, etc. Then, human-centered human-machine system should be guaranteed in human-machine design [7].

In recent years, people-oriented system development methods have been developed [8]. Task analysis is an important part of many human-centered development methods. In task analysis, what computers and humans do should be distinguished [9]. The 1951 Fitts list marked the beginning of the distribution of man-machine functions. Fitts lists (or variants of them) are still the most widely used feature allocation technique, although they have been questioned and criticized by some scholars [10]. Therefore, in order to ensure rational task allocation, Fitts list is main basis in the allocation strategy of this study.

At present, most literatures about man-machine function assignment mainly involve single-person positions, but this paper mainly focuses on the dynamic function allocation strategy proposed by the team, and carries out relevant experimental research.

2 Methods

2.1 Task Scenario

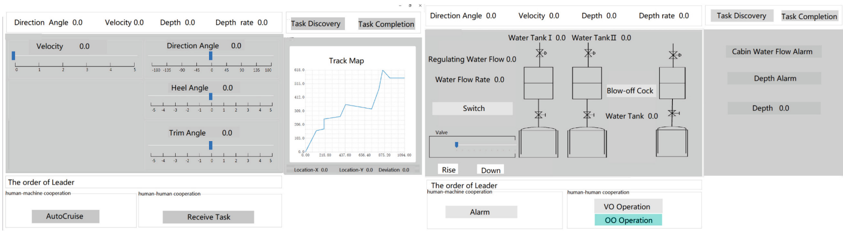
This paper designed and built the underwater vehicle, which consists of three workstations, including Operating Officer (OO), Vehicle Officer (VO) and Leader. Three participants in the experiment work together in their respective positions to complete the tasks prescribed by the simulator. Figure 1 show the task interface diagrams of all positions. The key responsibilities of each position are shown in Table 1.

2.2 Allocation Strategy

It can be known that the workload of operators is high, while the workload of navigators is low through the actual field investigation. Human and machine have different advantages according to the Fitts list. The machine can respond quickly to find the fault, but the personnel are good at judgment processing. Then, based on the difference in the ability of machines and personnel, there are two allocation strategies when adjusting the task amount of each position for the purpose of the balance of cognitive load of team members. One is human-machine function allocation: the Operating Officer's search function for fault task is assigned to the machine; the other is human-human function allocation: the Operating Officer's processing function for fault task is assigned to the Vehicle Officer. Table 2 show the detail description of team function allocation strategy.

Table 1. Team position and responsibility description

Character	Duty description
Operating Officer (OO)	Check the internal parameters of the ship to ensure the normal operation of the cabin and balance the change of the water quantity in the ship
Vehicle Officer (VO)	Monitors changes in the ship's course, speed and depth
Leader	The commanding decision-maker of the entire cabin gives instructions to other station personnel



(a) Operating Officer (b) Vehicle Officer

Fig. 1. The interface chart of the underwater vehicle system

Table 2. The detail description of team function allocation strategy

Allocation strategy		Describe
The human-machine function allocation	Strategy0-1 (S0-1)	The initial state
	Strategy1-1 (S1-1)	The part of the Operating Officer's search function for fault task is assigned to the machine
	Strategy1-2 (S1-2)	The whole of the Operating Officer's search function for fault task is assigned to the machine
The human-human function allocation	Strategy0-2 (S0-2)	The initial state
	Strategy2-1 (S2-1)	The part of the Operating Officer's processing function for fault task is assigned to the Vehicle Officer
	Strategy2-2 (S2-2)	The whole of the Operating Officer's processing function for fault task is assigned to the Vehicle Officer

2.3 Participants

Twelve male students (age 23.250 ± 2.314 years) with good science and engineering background were recruited for this experiment. The subjects were healthy, right-handed and had normal or corrected visual acuity. Before and during the experiment, the subjects had adequate sleep and a good mental state, and did not drink stimulant substances such as caffeine and alcohol, and did not take any drugs. Participants received sufficient training before the experiment proper starts. Since the experiment ended, each participant accepted a monetary reward.

2.4 Study Design

Six team of twelve Subjects were divided into two groups: there were three teams in each group. Each team was exposed to two strategies every day. One group of teams tested the human-machine collaboration strategies at 9:0–11:00, and the human-human collaboration strategies were tested at15:00–17:00. The other group of teams did the opposite. In addition, every allocation strategy with three different workloads were performed in the order designed by the Latin square method.

2.5 Experimental Procedure

The test under each allocation strategy lasted for more than seventy minutes. There were 5 min for preparation before the formal experiment. And then the 1 h was used for test. The formal test includes resting test, the team tasks with three workloads and filling in the NASA-TLX scale. The experimental scene were displayed in Fig. 2.

Fig. 2. Experimental scene of the formal test

2.6 Statistical Analysis

Generalized additive mixed effect model (GAMM) analyses were performed using the open-source statistical package R version 3.6.1 (R Project for Statistical Computing, Vienna, Austria) to test the fixed effect estimates of potential influencing factors on human task performance and NASA-TLX, treating the subject as a random effect.

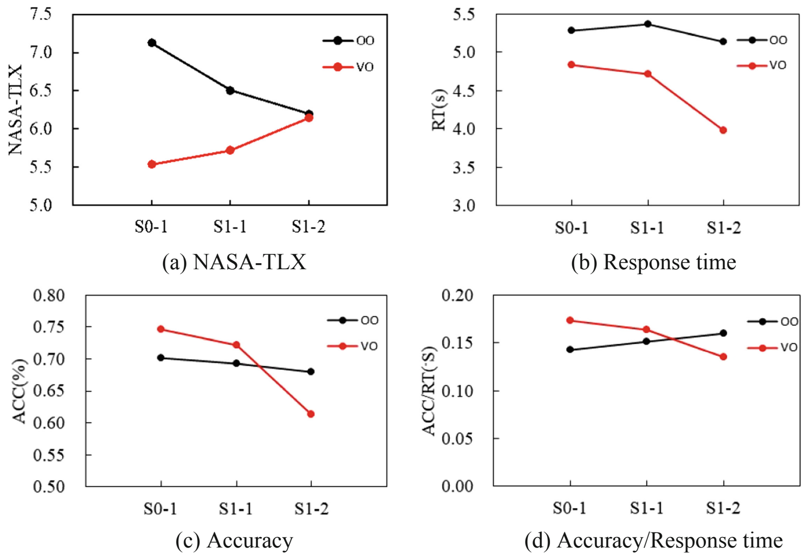


Fig. 3. The mental workload and task performance of team in the human-machine function allocation strategies

3 Result

3.1 The Human-Machine Function Allocation

As shown in Fig. 3(a), the mental workload of Operating Officer gradually decreases along with the increase of workload assigned to machines. Meanwhile, the Operating Officer's performance improved, in Fig. 3(b), (c) and (d). Vehicle Officer's workload did not change. Then, the mental workload and performance of Vehicle Officer remained unchanged.

3.2 The Human-Human Function Allocation

Figure 4(a) showed that along with the increase of the Operating Officer's workload assigned to Vehicle Officer, the Operating Officer's mental workload decreased significantly, however, the Vehicle Officer's mental workload increased significantly. The variation of the Operating Officer's performance was different with the Operating Officer's mental workload. The response time and accuracy of Operating Officer at S2-1 were better than at S0-2 and S2-2, as shown in Fig. 4(b) and (c). Nevertheless, the variation of the Vehicle Officer's performance decreased significantly along with the increase of workload.

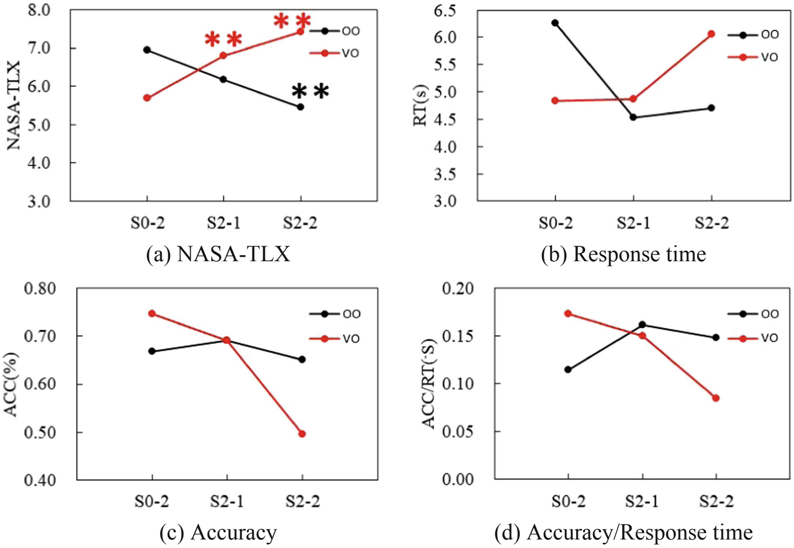


Fig. 4. The mental workload and task performance of team in the human-human function allocation strategies

4 Conclusion

Human-machine collaboration strategy could improve Operating Officer's mental workload and job performance appropriately, but not significantly, which may be related to the small quantity of participants in this experiment. Although there is a significant improvement about Operating Officer's mental workload and job performance at human-human collaboration strategy, the Operating Officer's mental workload and job performance could be optimal, only when the workload was kept at a moderate level, which was proposed by the previous researches, and the performance was the best at moderate mental workload [11]. Meanwhile, the overmuch workloads lead to increase Vehicle Officer's mental workload and decrease Vehicle Officer's mental workload performance, significantly. Therefore, in order to guarantee that the overall mental workload and job performance of the team are optimal, part of the Operating Officer's workload should be allocated to Vehicle Officer.

In summary, Human-machine collaboration strategy is still the primary scheme at dynamic function allocation based on the convenience of intelligent systems. If the mental workload level and job performance level of Operating Officer are underperforming after the human-machine allocation strategy is completed, part of the Operating Officer's fault task processing function is assigned to Vehicle Officer.

Compliance with Ethical Standards. The study was approved by the Logistics Department for Civilian Ethics Committee of School of Aeronautical Science and engineering, Beijing University of Aeronautics and Astronautics.

All subjects who participated in the experiment were provided with and signed an informed consent form.

All relevant ethical safeguards have been met with regard to subject protection.

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