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Research article

Influencing factors of novice pilot SA based on DEMATEL-AISM method: From pilots' view

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ABSTRACT

Pilot situation awareness (SA) regulates flight safety, and inexperience may impair novice pilot reliability in SA. This study aims to determine the key influencing factors of novice pilot SA and to analyze the interrelationship and interaction mechanism of the factors. We investigated 55 novice pilots trained at aviation schools and identified the influencing factor index system by the Delphi survey. The method of Decision Making Trial and Evaluation (DEMATEL) combined with Adversarial Interpretive Structure Modeling (AISM) was adopted. The results show that: (1) The influencing factor index system includes 18 factors, divided into four categories: individual factors, team factors, task and human-machine system factors, and cockpit environment factors. (2) Team communication, team cooperation, basic cognitive ability, interface design, occupational age and experience, and authority gradient are the six crucial influencing factors. The former three have the greatest association with other factors, while the latter three are most likely to affect other factors. (3) Team communication, basic cognitive ability, and interface design are root-cause factors, of which team communication is the most fundamental. (4) The results of DEMATEL and AISM are consistent, both disclosing team communication as the fundamental factor with the highest priority, and cockpit environmental factors as the direct influencing factors but most susceptible to other factors. The present study can be viewed as a conducive attempt to extract vital influencing factors of novice pilot SA, and to provide ergonomic insights for determining the priorities to improve novice pilot SA in training and aircraft design for flight safety.

1. Introduction

The annual safety records of the global civil aviation accidents show that human factors in flight have become a bottleneck, restricting civil aviation safety with the increasing air traffic complexity [1–3]. Studies show that it depends largely on pilots' situation awareness (SA) that whether pilots can make correct decisions and conduct appropriate operations in a timely and effective way [4,5]. Statistics show that over 70% of flight accidents and incidents are related to the weakening or loss of pilot SA [6,7]. According to Endsley's three-level model [8–10], pilot SA is both process and product concept that reflects the dynamic interaction between pilot and flight situations, including three progressive levels of perception (level 1), comprehension (level 2), and projection (level 3) [11,

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12]. Therefore, it is of great significance to investigate the influencing factors of pilot SA and their interrelationship for determining pilot SA reinforcement strategies, preventing pilot error, and improving flight safety [13,14].

1.1. Research status of individual, team, and system factors influencing pilot SA

Studies on individual pilot show pilot SA is influenced by multiple factors, which directly or indirectly impact pilot information processing and decision-making. Many experimental studies have verified that pilot SA is significantly affected by pilot's working memory, attention allocation, mental arousal, fatigue, etc. [15–17], and it can be monitored through neurophysiological signals [18]. Pilot SA is also constrained by task characteristics [19]. For example, researches show that with the increase of task complexity or time pressure, the challenges to pilot attention allocation get worse because of multitasking, resulting in distraction under high workload and SA degradation in consequence [20–23]. Besides, pilot SA is also shaped by human-machine interaction system in cockpit, an interaction medium between pilot and external flight situations. For instance, the cockpit interface displays structured information [5, 24,25], the automation and intelligent design provide important help in rapid responding, reducing pilot workload, and assisting decision-making, etc., thus contributing to pilot SA enhancement [26–30].

In recent years, studies on pilot SA have gradually shifted from individual pilot to socio-technical system, which focus on a systematic view of SA in the air transport system, including human agents and non-human agents. Thus, researchers pay more attention to the influence of team factors and environmental factors [31,32]. Relevant experimental studies have shown that it can evidently support aircrew pilots SA that to improve team communication, to assign task dynamically, and to establish good cockpit culture with reasonable authority gradient [33–35]. Stanton, Salmon et al. [36–38] proposed the Distributed Situation Awareness (DSA) model, expounding from the systematic view that flight accidents should be jointly responsible by cockpit aircrew, aircraft, air traffic control, etc. For example, the investigation of Air France Flight 447 crash showed that the aircrew pilots failed to understand each other's

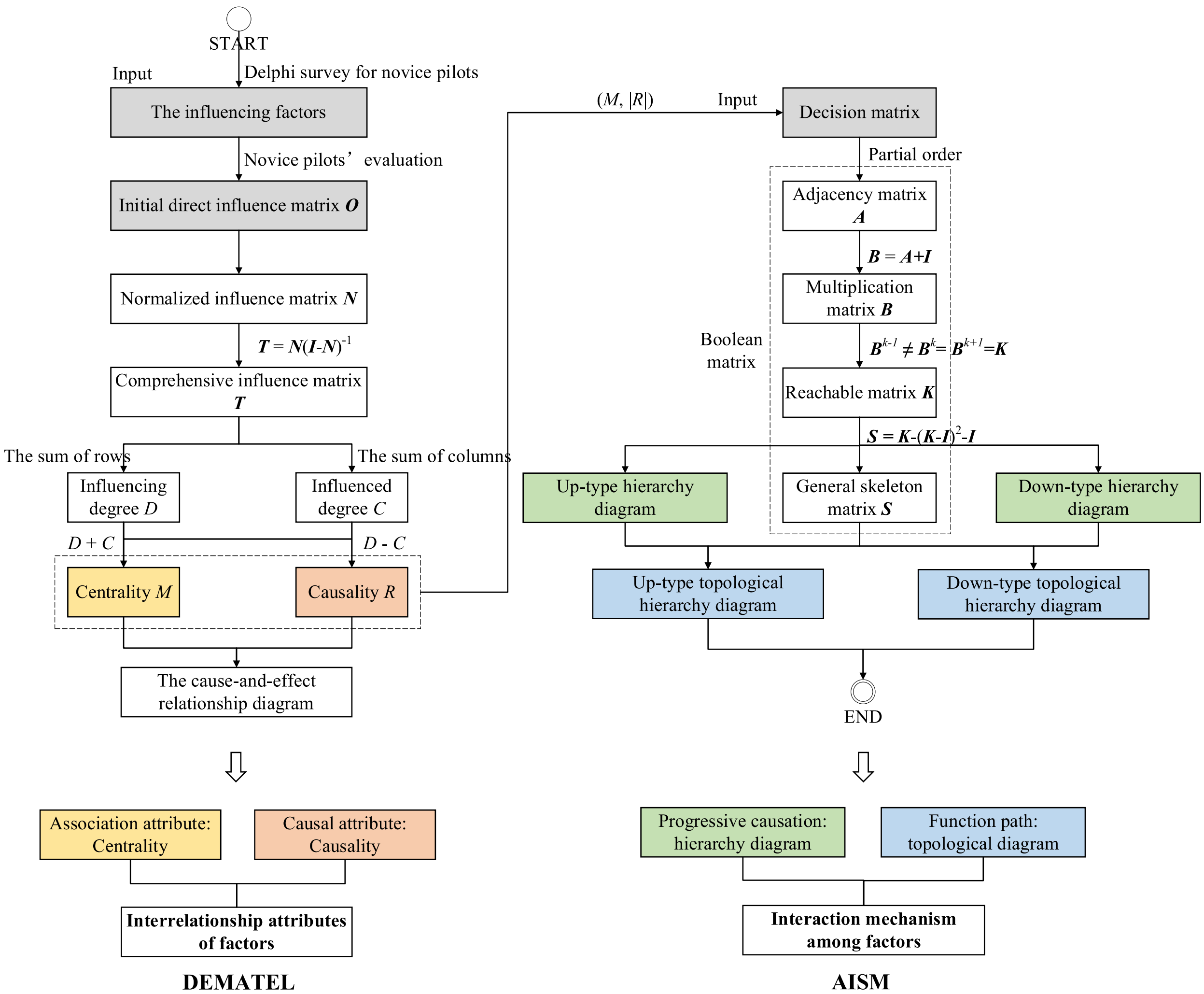


Fig. 1. Framework of DEMATEL-AISM method.

intention and behavior in emergency, meanwhile obstacles appeared in the information exchange between the aircrew and the automatic flight system, which together led to SA failure, and finally caused the disaster [39]. Besides, environmental factors, such as harsh weather, adverse illumination, circadian rhythm, are also confirmed in experimental studies to impact on pilot ability to maintain good SA stably [40–43].

Current studies have widely covered individuals, teams, and systems, and significant progress has been made in disclosing the variation of pilot SA under different conditions. However, general consensus has not been reached yet on the understanding of the comprehensive mechanism of multiple influencing factors on pilot SA [44,45]. In fact, current research is restricted by the dynamics of pilot psychological and physiological state, the complexity of socio-technical system, and the limitations of SA measurement [46]. Hence, methods of experiment analysis and theoretical modeling are mostly used in current studies to reveal the causality relationship between pilot SA and one or a few specific factors [47]. The interaction among various factors and their comprehensive impact on pilot SA are rarely involved, limiting the application potential of current studies. A workable solution is to use the systematic approach [48–50] to establish the influencing factor index system of pilot SA and to further explore the inherent interrelationship and interaction mechanism of these factors. This can be regarded as a direct reference to analyze the causes of pilot SA degradation and propose reasonable strategies for pilot SA improvement.

1.2. Research status of systematic methods about influencing factors of novice pilot SA

A series of experimental studies engaging pilot participants have verified that it is more difficult for inexperienced novice pilots to maintain stable SA in complex and dynamic flight situations than experienced expert pilots [40,51,52]. The increase in task complexity can easily lead to the decline of novice pilots' information perception and rapid response, making novice pilot exposed to SA deterioration and safety risk growth [53,54]. Researchers are trying to develop various training methods [55,56], including optimizing pilot's visual attention mode [57,58], promoting pilot's mental state [59,60], enhancing aircrew communication and cooperation [33], etc. The training methods can help novice pilot to maintain the abilities of efficient perception, appropriate decision-making, and dynamic adaptation stably, thus ensuring optimal performance and flight safety [61,62]. Nonetheless, SA studies of novice pilots are far fewer than the similar of expert pilots or non-pilot participants at present. As an indispensable process, the novice stage is the formative period of pilot ability to establish and maintain good SA. The novice stage has a long-term and profound impact on pilot SA in the subsequent career because of anchoring effect [63,64]. Therefore, the value of novice pilot perspective in pilot SA study is necessary to be reexamined.

The objectives of this study include determining the key influencing factors of novice pilot SA and analyzing the interrelationship of the factors. The influencing factor index system of novice pilot SA was identified by the Delphi survey for novice pilots trained at aviation schools. Based on it, we used an integrated method of Decision Making Trial and Evaluation (DEMATEL) and Adversarial Interpretive Structure Modeling (AISM) (shown in Fig. 1) to analyze the interrelationship and interaction mechanism of the influencing factors quantitatively, which can contribute to pilot SA reinforcement in training, aircraft design, and cockpit resource management, etc. The DEMATEL took the knowledge of novice pilot as input (i.e., the evaluation on the mutual influence degree among the factors), and calculated the centrality (i.e., association attribute) and causality (i.e., causal attribute) based on the influencing degree and influenced degree of the factors. Thus, the DEMATEL provides an approach of quantitative comparison for factor importance [65–67]. Besides, the AISM was combined to further explore the adversarial topological hierarchy diagrams, disclosing the progressive causality (in hierarchy diagram) and function paths (in topological diagram) among factors [68–70]. As a systematic tool, the method of DEMATEL-AISM quantifies and visualizes the interrelationship and interaction mechanism among the influencing factors of novice pilot SA. The findings based on pilot view can provide a direct reference for extracting vital influencing factors and viable decision-making support for determining the priority measures of novice pilot SA improvement [71].

2. Methods

2.1. DEMATEL

DEMATEL method uses graph theory and matrix tools to calculate the influencing degree, influenced degree, centrality, and causality of each SA influencing factor (as shown in Fig. 1 left). The interrelationship attributes of the factors can be ascertained, including the association attribute represented by centrality and the causal attribute represented by causality, and can help uncover the vital factors that deserve priority attention.

(1) Initial direct influence matrix $\boldsymbol{O}$

The mutual influence among all the influencing factors (the number is denoted as n), as the initial input to DEMATEL, were first

Table 1
Five-level scale for the degrees of mutual influence among factors.

Direct influence degree	None	Very low	Low	High	Very high
Numerical scale	0	1	2	3	4

determined by the evaluation for novice pilots in a survey, and thus the initial direct influence matrix $\boldsymbol{O} = (x_{ij})_{n\times n}$ was established. Pair-wise comparison between factors was executed, in which the novice pilots were required to rate the direct influence degree of factor F_i on factor F_j (i.e., x_{ij}) and that of factor F_j on factor F_i (i.e., x_{ji}). The pilots participating in the survey for DEMATEL rated the x_{ij} and x_{ji}, and then the matrix $\boldsymbol{O}$ consisted of the average scores of x_{ij} and x_{ji}. The five-level scale method is usually adopted in this kind of fuzzy evaluation, as shown in Table 1.

(2) Normalized influence matrix $\boldsymbol{N}$

The matrix $\boldsymbol{O}$ was normalized to obtain the normalized influence matrix $\boldsymbol{N}$, in which all the elements range from 0 to 1. This process was to take the maximum value of the row sum of the matrix $\boldsymbol{O}$ (shown in Equation (1)) and multiply its reciprocal by the matrix $\boldsymbol{O}$ (shown in Equation (2)).

$$\overline{a} = \max a_j = \max\left(\sum_{j=1}^{n} x_{ij}\right) \tag{1}$$

$$N = \frac{1}{\overline{a}} O \tag{2}$$

(3) Comprehensive influence matrix $\boldsymbol{T}$

Since the interactions among the factors in the complex factor system, the indirect influence is also necessary to be considered as well as the direct influence. The comprehensive influence matrix $\boldsymbol{T}$ totally reflects the direct and indirect influence, the former reflected in the matrix $\boldsymbol{O}$ and the latter expressed as a multiplication of the matrix $\boldsymbol{N}$. The matrix $\boldsymbol{T}$ were calculated as Equation 3

$$T = \sum_{k=1}^{\infty} N^k = N(I - N)^{-1} \tag{3}$$

where matrix I represents the $n \times n$ identity matrix.

(4) Influencing degree, influenced degree, centrality, and causality

Influencing degree D_i, computed as the sum of elements in row i in matrix $\boldsymbol{T}$, represents the comprehensive influence of the factor F_i on all other factors (shown in Equation (4)). Influenced degree C_j, denoted as the sum of elements in column j in matrix $\boldsymbol{T}$, represents the comprehensive influence of all other factors on the factor F_j (shown in Equation (5)).

$$D_i = \sum_{j=1}^{n} t_{ij} \tag{4}$$

$$C_j = \sum_{i=1}^{n} t_{ij} \tag{5}$$

As shown in Equation (6), the centrality M_i of factor F_i was calculated as the sum of D_i and C_i. As a positive indicator, centrality M_i represents the total interaction relationship between factor F_i and all other factors in the factor system, namely the association attribute in the present study.

$$M_i = D_i + C_i \tag{6}$$

The causality R_i of factor F_i was computed as D_i minus C_i, as shown in Equation (7). Causality R_i reflects the causal attribute of factor F_i relative to all other factors in the factor system. If the causality of a factor is positive, the influence of this factor on other factors exceeds that of other factors on it, hence it can be regarded as a reason factor. Contrarily, if the causality of a factor is negative, this factor can be regarded as a result factor.

$$R_i = D_i - C_i \tag{7}$$

2.2. AISM

DEMATEL method provides an approach to determine the interrelationship attributes of the influencing factors by integrating centrality and causality. However, the interaction mechanism among the factors is not clear yet. Therefore, AISM method can be jointly used (as shown in Fig. 1 right) to provide the adversarial topological hierarchy diagrams, visually presenting the progressive causation and function paths among the factors. Afterwards, the interaction mechanism among the influencing factors of novice pilot SA can be structurally analyzed.

(1) Adjacency matrix $\boldsymbol{A}$

The centrality M and the absolute value of causality $|R|$ of all the factors constitute the decision matrix $\overline{\boldsymbol{D}}_{n\times 2}$. Based on the partial order (PO), the adjacency matrix $\boldsymbol{A} = (a_{ij})_{n\times n}$ can be acquired by (M, $|R|$) pair-wise comparison between the factors (as shown in Equation (8)). The partial order was described as follows: for any two factors F_i and F_j, the fact that $PO_{(i\to j)} = F_j \prec F_i$ occurred only if $M_j < M_i$ and $|R_j| < |R_i|$, meaning the factor F_i was superior in merit to the factor F_j. Thus, the matrix $\boldsymbol{A}$ is a Boolean matrix.

$$a_{ij} = \begin{cases} 1, \text{if } PO_{(i\to j)} \\ 0, \text{if } PO_{(j\to i)} \text{ and there is no comparitive merit between } F_i \text{ and } F_j \end{cases} \tag{8}$$

(2) Reachable matrix $\boldsymbol{K}$ and general skeleton matrix $\boldsymbol{S}$

Adding the adjacency matrix $\boldsymbol{A}$ to the identity matrix $\boldsymbol{I}$ yielded the multiplication matrix $\boldsymbol{B}$ (as shown in Equation (9)). The reachable matrix $\boldsymbol{K}$ was gained by multiplying the matrix $\boldsymbol{B}$ by itself several times until the result does not change (as shown in Equation (10)). In fact, $\boldsymbol{K} = \boldsymbol{B}$ because of Boolean calculation. The general skeleton matrix $\boldsymbol{S}$ was computed as Equation (11). All the above operations are Boolean calculations and all the matrices are Boolean square matrices.

$$B = A + I \tag{9}$$

$$B^{k-1} \neq B^k = B^{k+1} = K \tag{10}$$

$$S = K - (K - I)^2 - I \tag{11}$$

(3) Hierarchy extraction

There was a reachable set R, a prior set Q, and a common set $T = R\cap Q$ for the above Boolean matrices. Taking the reachable matrix $\boldsymbol{K}$ as an example, there were the following situations for the element e_i in it:

a) the reachable set R (e_i) was the set of all elements corresponding to row value 1;
b) the prior set Q (e_i) was the set of all elements corresponding to column value 1;
c) the common set T (e_i) = R (e_i) $\cap Q$ (e_i).

(4) Adversarial topological hierarchy diagrams

The adversarial topological hierarchy diagrams are composed of the up-type and down-type topological hierarchies. The up-type topological hierarchy, also named as result-first hierarchy extraction, followed the extraction rule $T(e_i) = R(e_i)$. The final result factors were extracted firstly and placed on the top layer, and then the factors on the other lower layers can be extracted by analogy. The down-type topological hierarchy, or reason-first hierarchy extraction, followed the extraction rule $T(e_i) = Q(e_i)$. Reversely, the root cause factors were firstly extracted and placed on the bottom layer, and then the factors on the other upper layers can be extracted by analogy. The topological diagrams were extracted hierarchically based on the matrix $\boldsymbol{S} + \boldsymbol{I}$, and the reachability relationship among the factors can be represented by the directed line segments.

The factors on the lower layers in both the up-type and down-type topological hierarchy diagrams represent the reason, while the factors on the upper layers represent the result. Thus, the influencing factors of the novice pilot SA were divided into three sets: the direct-influencing factors (on the top layer), the intermediate-influencing factors (on the middle layers), and the root-influencing factors (on the bottom layer). The direct-influencing factors have the most direct impact on the novice pilot SA. The intermediate-influencing factors are the medium between the direct-influencing factors and the root-influencing factors. The root-influencing factors have the most fundamental and root influence, and they are the Pareto optimal factors that should deserve the highest priority in theory [48].

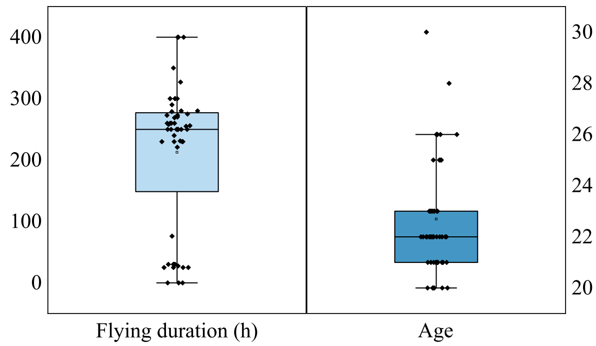


Fig. 2. Flying duration (hour) on planes and age (year) of the novice pilot.

3. Results

3.1. Identification of influencing factors

This study involved a pilot-oriented investigation, which was approved by the Biological and Medical Ethics Committee of Beihang University. We consulted 55 male novice pilots (age: Mean = 22.7, SD = 2.2) trained at aviation schools including National Air College (International) in the United States, Moncton Flight College in Canada, and Air China Limited in China. As shown in Fig. 2, their average flying duration on planes was 212.7 h (SD = 116.7 h), the median and the mode was 250 h. All the novice pilots have obtained private pilot licenses while most of them are pursuing commercial pilot licenses.

The investigation was conducted in two separate and sequential steps, both containing the comparison of SA influencing factors. Delphi survey was used in the first step to accomplish the transformation from an ambiguous and uncertain pool of factors to a definite factor system. The survey for DEMATEL-AISM in the second step was performed to make the influencing factor index system well-presented and well-organized for analyzing and extracting key factors [66]. To avoid the possible conceptual confusion among pilots in the two sequential steps of comparison, two homogeneous groups of pilots were selected as survey samples, and each group participated in only one step. The sample size is regularly recommended to be 10–20 in existing survey studies [67,72,73], however, considering the subjective bias in survey, expanded sample size (when not difficult to implement) can promote the accuracy and authority of survey results. Hence, based on the different questionnaire dimension related to the number of influencing factors (denoted as n) in the two steps, we expanded the samples size to 40 in Delphi survey (with fewer dimensions as n), while set a regular sample size as 15 in the survey for DEMATEL-AISM (with more dimensions as n^2). The consensus was reached after two rounds of the Delphi survey, and the influencing factor index system of novice pilot SA was finally determined, comprising 4 categories and 18 influencing factors. The definitions and explanations are shown in Table 2.

Table 2
The influencing factor index system of novice pilot SA.

Categories	Factors	Definitions and Explanations
Individual factors	F1 Basic cognitive ability	Visual processing, working memory, spatial/speed perception, time planning, decision-making, anti-interference and other foundation skills of individual pilots
	F2 Expertise and skills	The specialized knowledge, expertise, and skills possessed by individual pilots for flight
	F3 Occupational age and experience	Service years (or accumulated flying duration) for individual pilots, and experience in dealing with various flight situations, including conventional and non-conventional
	F4 Psychological state	The emotional state, arousal state, and mental health state of individual pilots before and during flight
	F5 Physiological state	The physiological health state and fatigue state of individual pilots before and during flight
Team factors	F6 Authority gradient	Differences among cockpit aircrew members in seniority, position, decision-making authority, cultural background, etc.
	F7 Mission assignment	The flexibility, coordination and rationality of dynamic mission assignment among cockpit aircrew members
	F8 Team cooperation	The tacit degree to which the cockpit aircrew members work collaboratively to accomplish tasks safely and efficiently
	F9 Team communication	The ability of the cockpit aircrew members to convey information and knowledge to each other for reasonable mission assignment and effective cooperation
Task and human-machine system factors	F10 Task complexity	Time pressure, decision challenge, operation difficulty, fault tolerance degree, etc., affected by different task characteristics (such as conventional task, sudden and unexpected accident, emergency)
	F11 Interface design	The information design in cockpit interface for pilot visual processing, including position, layout, highlighting, dimensions, enhanced visual design, decision support design, etc.
	F12 Control design	The control design for pilot manipulating hardware facilities, including the design of the position, size, and shape of buttons, rods and valves, as well as the design of touch control, voice control, and eye control, etc.
	F13 Automation design	The smoothness and coordination of the interaction between cockpit automation system and pilots, as well as the dynamic adaptability to flight situations
	F14 Intelligent design	The degree of mutual trust and integration between cockpit intelligent systems and pilots, as well as the initiative, timeliness, accuracy and appropriateness of responding to the variations of flight situations
Cockpit environmental factors	F15 Gas environment	Concentration, distribution, and circulation of gases (O_2, CO_2, other gases or pollutant particles) in the cockpit
	F16 Light environment	The pilot's visual comfort with light, and the display effect of cockpit interface (glare, too bright, too dark, etc.) under various environmental conditions, such as sunny and rainy, day and night
	F17 Temperature and humidity environment	The adaptability and support of cockpit temperature and humidity environment to pilot's (physiological and psychological) comfort and health
	F18 Day-and-night environment	Day-and-night shift or cross day-and-night flight that may affect pilots' circadian rhythms, health states, and cognitive abilities

3.2. Influencing degree, influenced degree, centrality, and causality

The initial direct influence matrix $\boldsymbol{O} = (x_{ij})_{n \times n}$ (where $n = 18$) was constructed based on the novice pilots' evaluation of the mutual influence among the factors, as shown in Table 3. The normalized influence matrix $\boldsymbol{N}$ and the comprehensive influence matrix $\boldsymbol{T}$ were computed according to Equation (1)–(3). Then the influencing degree D, the influenced degree C, the centrality M, and the causality R of the 18 factors were calculated, as shown in Table 4 and Fig. 3.

3.3. Adversarial topological hierarchy diagrams

The adjacency matrix $\boldsymbol{A}$ is shown in Table 5. The reachable matrix $\boldsymbol{K} = \boldsymbol{A} + \boldsymbol{I}$, and the general skeleton matrix $\boldsymbol{S}$ is shown in Table 6. Then the up-type and down-type topological hierarchy diagrams by hierarchy extraction, as shown in Fig. 4.

The adversarial topological hierarchy diagrams in Fig. 4 are composed of seven levels, which show the progressive causation and function paths among the factors. The layer L7 is the root-influencing layer, and the layer L1 is the direct-influencing layer, meanwhile the layers L2, L3, L4, L5 and L6 are the intermediate-influencing layers. Considering the large number and the complex interaction of the factors, we mainly focused on and labeled the function paths between the factors in adjacent layers in the present study for simplification, while ignoring the cross-layer function paths.

4. Discussion

Novice pilot SA results from a complex interaction among different influencing factors. The current study is to explore the interrelationship attributes (including association attribute and causal attribute), and interaction mechanism of the influencing factors (including the progressive causation and function path). We expect it to provide decision support for improving novice pilot SA and optimizing novice pilot training strategies. The 18 influencing factors of SA were identified through the Delphi survey facing novice pilots. The centrality, causality, and the adversarial topological hierarchy diagrams were obtained by the DEMATEL-AISM method, and the primary influencing factors for novice pilot SA were extracted through the analysis of factor interrelationship and interaction

Table 3
The initial direct influence matrix $\boldsymbol{O}$.

$O_{18\times18}$	F1	F2	F3	F4	F5	F6	F7	F8	F9
F1	0.000	2.800	2.267	2.400	2.333	2.133	2.000	2.000	2.333
F2	3.067	0.000	2.733	2.267	1.933	2.267	2.400	2.533	2.667
F3	2.667	3.333	0.000	2.533	2.733	2.733	2.467	2.467	2.933
F4	3.067	2.000	2.333	0.000	2.600	1.733	2.067	2.667	2.800
F5	2.800	2.333	2.067	2.200	0.000	1.733	2.000	2.600	2.933
F6	1.933	2.000	2.600	2.267	2.067	0.000	3.000	2.733	3.000
F7	2.200	2.533	2.133	2.400	2.000	2.533	0.000	3.400	3.067
F8	2.533	2.267	2.067	2.867	2.067	2.400	2.600	0.000	2.867
F9	2.533	2.333	2.267	2.733	2.467	2.333	2.733	2.867	0.000
F10	2.200	2.333	2.267	2.733	2.400	2.133	2.733	2.600	2.667
F11	2.733	2.267	2.067	2.267	2.000	1.467	2.267	2.533	2.400
F12	2.400	2.133	1.800	2.133	1.533	1.533	1.867	1.867	2.133
F13	2.133	2.333	2.267	2.400	1.733	1.333	2.133	2.133	2.200
F14	2.600	2.267	2.000	2.067	1.733	1.533	2.333	2.333	2.333
F15	2.067	1.200	1.667	2.067	2.733	1.467	1.667	1.800	1.867
F16	2.133	1.867	2.067	2.133	2.333	1.467	1.467	1.800	1.933
F17	1.667	1.667	1.733	1.867	2.067	1.533	1.600	1.667	1.800
F18	2.133	1.667	2.333	2.200	2.267	1.467	1.933	2.200	2.067
	F10	**F11**	**F12**	**F13**	**F14**	**F15**	**F16**	**F17**	**F18**
F1	2.267	2.133	2.400	2.200	2.067	1.600	1.733	1.400	2.000
F2	2.333	2.067	2.200	2.467	2.400	1.733	1.400	1.800	1.800
F3	2.267	2.067	2.267	2.133	2.133	1.667	1.267	1.867	2.067
F4	2.267	1.600	1.400	2.000	1.533	1.733	1.733	1.667	2.067
F5	2.267	1.867	2.133	1.933	1.933	1.867	1.800	1.733	2.000
F6	2.067	1.467	1.667	1.867	1.467	1.533	1.533	1.667	1.867
F7	2.000	1.667	1.933	1.867	2.467	1.867	1.800	1.600	1.933
F8	2.200	2.000	2.133	2.333	1.800	1.533	1.800	1.933	1.800
F9	2.667	1.867	2.133	2.467	2.200	1.800	1.533	1.867	2.067
F10	0.000	1.733	2.267	2.267	2.000	1.600	2.133	1.600	2.067
F11	2.467	0.000	2.200	2.400	2.533	1.667	1.867	1.533	1.867
F12	2.267	2.067	0.000	2.467	2.733	1.800	1.733	1.400	1.667
F13	2.733	2.733	2.867	0.000	2.533	1.800	1.267	1.667	1.600
F14	2.600	2.067	2.133	2.667	0.000	1.800	2.000	1.733	1.867
F15	2.200	1.267	1.667	1.733	1.533	0.000	1.933	2.000	1.933
F16	2.067	1.800	1.933	1.600	1.933	1.667	0.000	1.667	2.133
F17	2.067	1.267	1.600	1.200	1.867	2.200	1.933	0.000	1.800
F18	2.467	1.667	2.000	1.933	2.200	2.000	2.333	1.933	0.000

Table 4
The influencing degree D, the influenced degree C, the centrality M, and the causality R.

	F1	F2	F3	F4	F5	F6	F7	F8	F9
D_i	9.469	9.977	10.363	9.276	9.490	9.162	9.802	9.736	10.157
C_i	10.670	9.834	9.598	10.339	9.646	8.464	9.793	10.517	10.960
M_i	20.139	19.811	19.961	19.615	19.136	17.626	19.595	20.253	21.117
R_i	−1.201	0.143	0.765	−1.064	−0.157	0.699	0.009	−0.780	−0.803
	F10	**F11**	**F12**	**F13**	**F14**	**F15**	**F16**	**F17**	**F18**
D_i	9.876	9.582	8.815	9.415	9.448	8.073	8.408	7.754	9.097
C_i	10.199	8.289	9.172	9.362	9.240	7.830	7.807	7.646	8.535
M_i	20.075	17.871	17.987	18.777	18.688	15.903	16.215	15.400	17.632
R_i	−0.323	1.294	−0.356	0.053	0.208	0.244	0.601	0.107	0.561

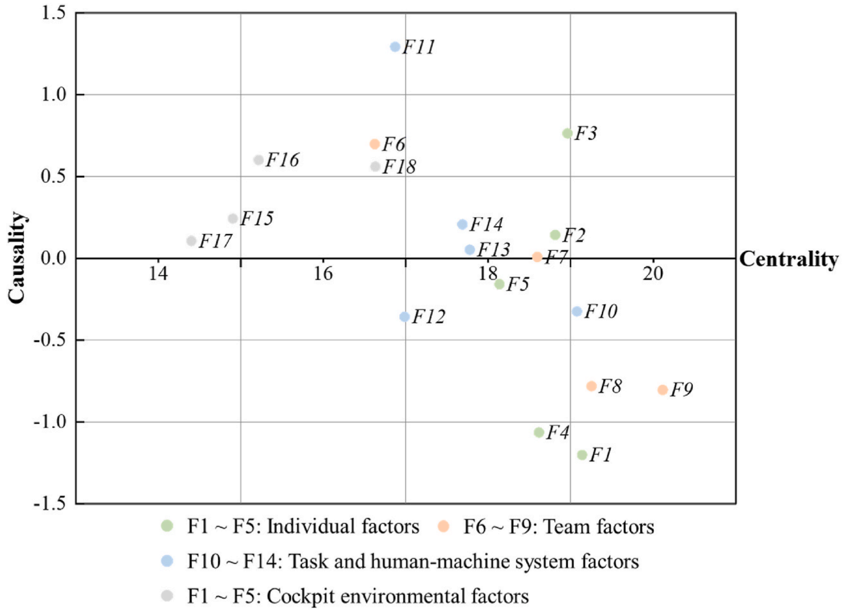


Fig. 3. The cause-and-effect relationship diagram comprising centrality and causality.

Table 5
The adjacency matrix ***A***.

$A_{18\times18}$	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18
F1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	1	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
F3	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
F4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F5	1	0	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0
F6	1	0	1	1	0	0	0	1	1	0	1	0	0	0	0	0	0	0
F7	1	1	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0
F8	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F10	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F12	1	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0
F13	1	1	1	1	1	0	0	1	1	1	0	0	0	0	0	0	0	0
F14	1	0	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0
F15	1	0	1	1	0	1	0	1	1	1	1	1	0	0	0	1	0	1
F16	1	0	1	1	0	1	0	1	1	0	1	0	0	0	0	0	0	0
F17	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	0	1
F18	1	0	1	1	0	0	0	1	1	0	1	0	0	0	0	0	0	0

Table 6
The general skeleton matrix ***S***.

$S_{18\times18}$	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18
F1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
F3	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
F4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F5	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
F6	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
F7	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F8	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F10	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F12	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F13	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
F14	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
F15	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1
F16	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
F17	0	1	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0
F18	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0

mechanism. The DEMATEL-AISM method has been verified to be an effective systematic technique with advantages in uncovering the cause-and-effect interrelationships in complex systems, different from research methods based on SA model theories and multi-dimensional measurement techniques [68]. Compared with methods of subjective survey, the DEMATEL-AISM method can uncover the interactions among the influencing factors of novice pilot SA from systematic view, which is of great significance for multi-criteria decision in improving pilots SA [65,67].

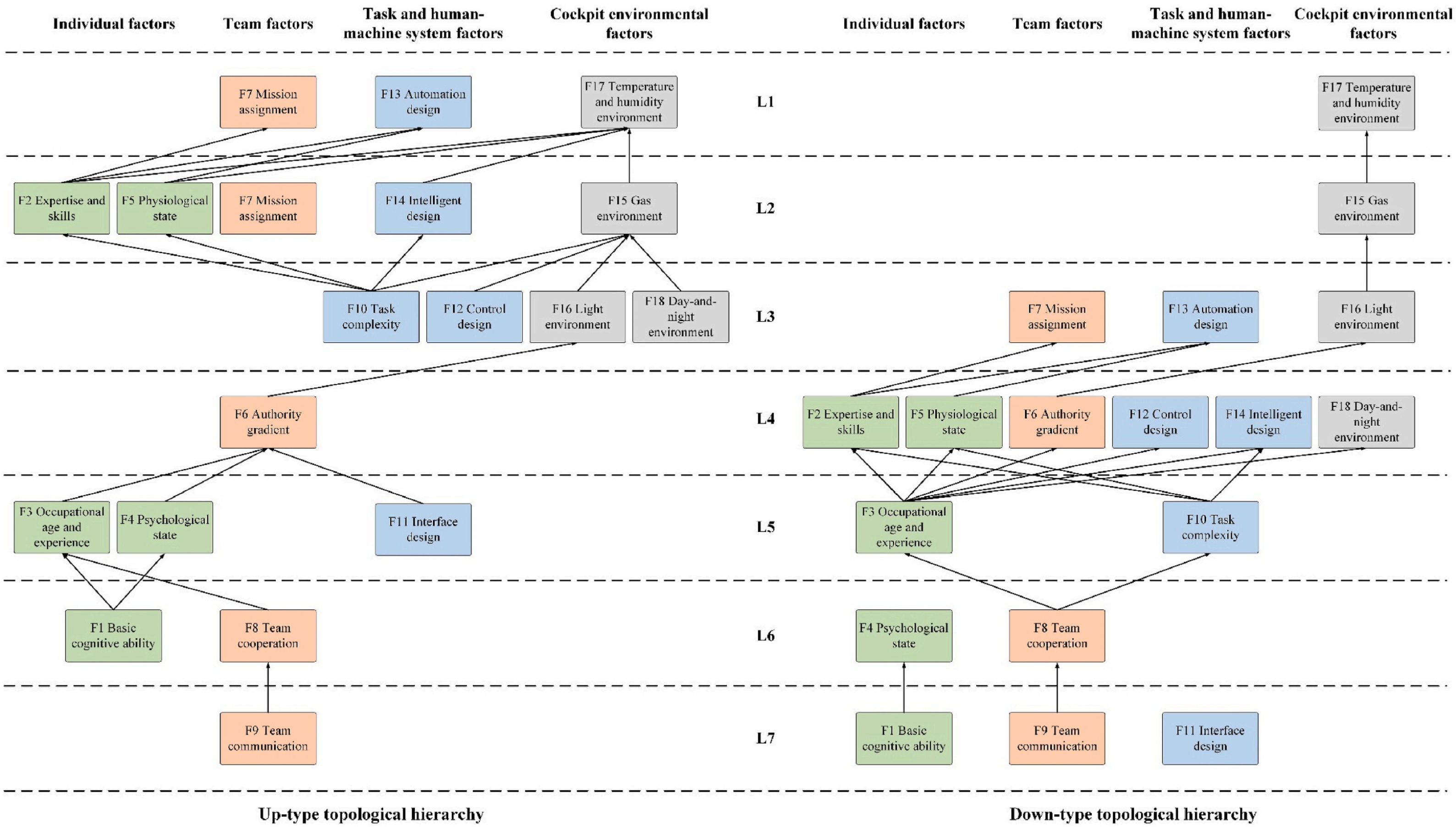
4.1. Interrelationship attributes of SA influencing factors

We argue that the centrality of a certain factor represents its association attribute in the present study, meaning the sum of the mutual influences between the factor and other factors. According to the order of centrality from high to low, the top 20% factors are team communication, team cooperation, and basic cognitive ability. Meanwhile, the bottom 20% factors are light, gas, temperature and humidity environment. The above results indicate that team communication has the most prominent influence on novice pilot SA, followed by team cooperation and basic cognitive ability. Thus, it is of priority to strengthen the communication and cooperation ability of novice pilots in training. The relevant studies show that effective team communication and information sharing are conducive to promoting individual SA and team SA of cockpit pilots and reducing human error in high-risk situation such as emergency [33,35]. Considering that basic cognitive ability reflects individual differences of novice pilots, importance should also be attached to novice pilot selection and individual ability reinforcement [15,74]. Efforts to optimize various environmental factors, by contrast, are likely to have limited effects in improving novice pilot SA.

We take the causality of a certain factor as the measure of its causal attribute, which can divide the SA influencing factors into reason factor (positive causality) and result factor (negative causality). In order of causality from high to low, the top 20% factors are interface design, occupational age and experience, as well as authority gradient (all belong to reason factors). The bottom 20% factors are team communication, psychological state, and basic cognitive ability (all belong to result factors). Studies have shown that investment in reason factors tends to have more comprehensive returns [69]. Therefore, optimizing the interface design can be considered as the most direct technical means to improve novice pilot SA [25]. In fact, as an interactive medium, the cockpit interface provides organized information for pilots, hence, the merit of interface design guides the eye movement and information perception of pilot, influencing pilot SA in consequence [75–77]. Studies suggest several feasible approaches to improve the merit of interface design, such as optimizing visual coding, developing enhanced visual system, and exploiting synthetic visual system [78–80]. Moreover, occupational age and experience, as well as authority gradient, are also crucial for novice pilot SA. This reveals that novice pilots value effective collaboration with expert pilots and expect good cockpit culture to support their SA [81,82]. In addition, team communication, psychological state, and basic cognitive ability are the most easily affected by other factors, reminding that the influence of other factors on them should be taken into special consideration when strengthening these abilities in novice pilot training.

4.2. Interaction mechanism between SA influencing factors

As shown in Fig. 4, the results of up-type and down-type hierarchy diagrams show that the three root-influencing factors include basic cognitive ability, team communication, and interface design, among which the factor of team communication is the most root and fundamental one as the intersection of the two hierarchy diagrams. This is consistent with some previous studies that semantic interaction of information and knowledge in aircrew can effectively promote the formation of pilot SA [33,83,84]. As an important content of cockpit resource management, aircrew communication supports the sharing of information and knowledge among the pilots and improves the aircrew's cognitive process and abilities to deal with complex tasks [35,85,86]. Effective exchange of information and knowledge, involving communication purpose, type, content, quantity, quality, etc. [87–89], has been verified to help the aircrew



Notes: (i) the layer L1 is the set of direct-influencing factors; (ii) the layers L2~L5 is the set of intermediate-influencing factors; (iii) the layer L7 is the set of root-influencing factors.

Fig. 4. The adversarial topological hierarchy diagrams.

conduct reasonable task allocation and adapt to dynamic flight situations, and then benefit flight safety [90,91].

Topological diagrams show the function paths between factors, such as F9 → F8 → F3 → F6 → F16 → F15 → F17, reflecting the complex interaction among factors [48,68]. Although not act directly, these intermediate-influencing factors play intermediary roles in the transmission from the fundamental-influencing factors to novice pilot SA. For example, the factors of psychological state, team cooperation, and task complexity are in the middle layers (L5, L6) adjoining the root-influencing layer L7. It suggests that to promote the support of team communication to novice pilot SA, it is necessary to improve novice pilot psychological health [92,93], team cooperation skills and cockpit culture [94,95], as well as their adaptability to complex tasks (such as engine malfunctions) [23,96–98] in training. In addition, cockpit environmental factors locate on the direct-influencing and intermediate-influencing layers (L1∼L4). It indicates that regulating environmental factors may be a direct means in improving novice pilot SA, whereas the effect of this direct means is likely to be uncertain because the influence of environmental factors on novice pilot SA is susceptible to those factors closer to or on the root-influencing layer.

4.3. Applications and limitations

Based on pilot's view, the index system of novice pilot SA influencing factors was identified by the Delphi survey, and the DEMATEL-AISM method was adopted to illustrate the interrelationship and the interaction mechanism of the influencing factors quantitatively and visually. This study implicates the priority measures to improve aviation pilots SA from systematic view. For example, the results implicate that optimizing team communication characteristics (such as frequency, quality, motivation, and classification) may be the feasible measure in aircrew cooperation training for raising pilot SA [99–101]. Similarly, this study can also indicate the concrete efforts direction for improving pilot SA in terms of pilot's individual cognition ability, human-machine interaction, and pilot's adaptability to flight environment.

Nonetheless, there are some limitations to the current study. First, the perspective of novice pilots was used to determine the influencing factor index system and the mutual influence between factors, while novice pilot training is an interactive process between novice pilots and flight instructors. Therefore, supplementing the insights of flight instructors can provide more references for improving novice pilot SA to in future work [83,102,103]. Second, subjectivity and generality, to some extent, exist in the determination of the influencing factor index system and the mutual influence between factors. The combination with experimental data in previous studies and accident analysis data in flight reports is helpful to strengthen the objectivity and profundity of the research. Finally, the DEMATEL-AISM method is good at visual and intuitive description but is short of statistical verification and the limited interpretability of function paths [68]. In fact, the function paths derived from the DEMATEL-AISM method are the production of the mathematical process, which indicate the potential risk transmissions among the influencing factors and inform multi-criteria decision for enhancing pilot SA. Nevertheless, mathematical results are usually the simplification of real-world. It can enhance the reliability and validity of research conclusions by further efforts for refined influencing factors and more aviation pilots as survey sample, as well as introducing other quantitative methods, such as Fault Tree Analysis (FTA), Bayesian Network (BN), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [66,71,104].

5. Conclusion

The influencing factors of novice pilot SA are identified from the novice pilot view by the Delphi survey, and the interrelationship and interaction mechanism of factors are analyzed through the DEMATEL-AISM method. It can provide a workable reference for quantitatively analyzing and extracting the crucial influencing factors and determining the priority measures to reinforce novice pilot SA. The main conclusions are as follows:

(1) The influencing factor index system of novice pilot SA includes 18 factors, which can be divided into four categories: individual factors, team factors, task and human-machine system factors, and cockpit environment factors.
(2) Team communication, team cooperation, basic cognitive ability, interface design, occupational age and experience, and authority gradient are the six key factors. The former three have the greatest association with other factors, while the latter three are most likely to affect other factors. Besides, team communication, basic cognitive ability, and interface design are the root-cause factors of novice pilot SA, among which team communication is the most fundamental.
(3) The results of DEMATEL and AISM are consistent, and both disclose team communication as the fundamental factor with the highest priority, and cockpit environmental factors as the direct but most susceptible to other factors in improving novice pilot SA.

Author contribution statement

Hao Chen: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Shuang Liu: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data.

Xiaoru Wanyan: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Liping Pang: Conceived and designed the experiments; Analyzed and interpreted the data.

Yuqing Dang; Keyong Zhu: Analyzed and interpreted the data.

Xueguang Yu: Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no competing interests.

References

[1] H. Kharoufah, J. Murray, G. Baxter, G. Wild, A review of human factors causations in commercial air transport accidents and incidents: from to 2000-2016, Prog. Aero. Sci. 99 (2018) 1–13, https://doi.org/10.1016/j.paerosci.2018.03.002.
[2] A.T. Bureau, Effects of Novel Coronavirus (COVID-19) on Civil Aviation: Economic Impact Analysis, International Civil Aviation Organization (ICAO), Montréal, Canada, 2020.
[3] P.A.J.M. de Wit, R. Moraes Cruz, Learning from AF447: human-machine interaction, Saf. Sci. 112 (2019) 48–56, https://doi.org/10.1016/j.ssci.2018.10.009.
[4] S. Parmar, R.P. Thomas, Effects of probabilistic risk situation awareness tool (RSAT) on aeronautical weather-hazard decision making, Front. Psychol. 11 (2020), 566780, https://doi.org/10.3389/fpsyg.2020.566780.
[5] H. Wei, D. Zhuang, X. Wanyan, Q. Wang, An experimental analysis of situation awareness for cockpit display interface evaluation based on flight simulation, Chin. J. Aeronaut. 26 (2013) 884–889, https://doi.org/10.1016/j.cja.2013.04.053.
[6] M.R. Endsley, A taxonomy of situation awareness errors, Hum. Fac. Aviat. Oper. 3 (1995) 287–292.
[7] P.M. Salmon, G.H. Walker, N.A. Stanton, Broken components versus broken systems: why it is systems not people that lose situation awareness, Cognit. Technol. Work 17 (2015) 179–183, https://doi.org/10.1007/s10111-015-0324-4.
[8] M.R. Endsley, Situation awareness and the cognitive management of complex systems, in: Proceedings of the IEEE 1988 National Aerospace and Electronics Conference, IEEE, 1988, pp. 789–795, https://doi.org/10.1109/NAECON.1988.195097.
[9] M.R. Endsley, Situation awareness misconceptions and misunderstandings, J. Cogn. Eng. Dec. Making 9 (2015) 4–32, https://doi.org/10.1177/1555343415572631.
[10] M.R. Endsley, Toward a theory of situation awareness in dynamic systems, in: Situational Awareness, Routledge, 2017, pp. 9–42.
[11] K. Smith, P.A. Hancock, Situation awareness is adaptive, externally directed consciousness, Hum. Factors 37 (1995) 137–148, https://doi.org/10.1518/001872095779049444.
[12] R.M. Taylor, Situational awareness rating technique (SART): the development of a tool for aircrew systems design, in: Situational Awareness, Routledge, 2017, pp. 111–128.
[13] X. Wanyan, D. Zhuang, Y. Lin, X. Xiao, J.-W. Song, Influence of mental workload on detecting information varieties revealed by mismatch negativity during flight simulation, Int. J. Ind. Ergon. 64 (2018) 1–7, https://doi.org/10.1016/j.ergon.2017.08.004.
[14] C.D. Wickens, R.S. Gutzwiller, A. Santamaria, Discrete task switching in overload: a meta-analyses and a model, Int. J. Hum. Comput. Stud. 79 (2015) 79–84, https://doi.org/10.1016/j.ijhcs.2015.01.002.
[15] S. Cak, B. Say, M. Misirlisoy, Effects of working memory, attention, and expertise on pilots' situation awareness, Cognit. Technol. Work 22 (2020) 85–94, https://doi.org/10.1007/s10111-019-00551-w.
[16] E.M. Argyle, J.J. Gourley, Z. Kang, R.L. Shehab, Investigating the relationship between eye movements and situation awareness in weather forecasting, Appl. Ergon. 85 (2020), 103071, https://doi.org/10.1016/j.apergo.2020.103071.
[17] J. Armentrout, D. Holland, K. O'Toole, W. Ercoline, Fatigue and related human factors in the near crash of a large military aircraft, Aviat Space Environ. Med. 77 (2006) 963–970.
[18] C. Deolindo, M. Ribeiro, M. de Aratanha, J. Scarpari, C. Forster, R. da Silva, B. Machado, E. Amaro, T. Konig, E. Kozasa, Microstates in complex and dynamical environments: unraveling situational awareness in critical helicopter landing maneuvers, Hum. Brain Mapp. 42 (2021) 3168–3181, https://doi.org/10.1002/hbm.25426.
[19] D. Lercel, D.H. Andrews, Cognitive task analysis of unmanned aircraft system pilots, Int. J. Aer. Psych. 31 (2021) 319–342, https://doi.org/10.1080/24721840.2021.1895797.
[20] M.J. Taber, Investigating offshore helicopter pilots' cognitive load and physiological responses during simulated in-flight emergencies, Int. J. Aer. Psych. 31 (2021) 56–69, https://doi.org/10.1080/24721840.2020.1842208.
[21] L. Wang, S. Gao, W. Tan, J. Zhang, Pilots' mental workload variation when taking a risk in a flight scenario: a study based on flight simulator experiments, Int. J. Occup. Saf. Ergon. 1 (2022), https://doi.org/10.1080/10803548.2022.2049101.
[22] X. Zhang, X. Qu, H. Xue, D. Tao, T. Li, Effects of time of day and taxi route complexity on navigation errors: an experimental study, Accid. Anal. Prev. 125 (2019) 14–19, https://doi.org/10.1016/j.aap.2019.01.019.
[23] S. Asmayawati, J. Nixon, Modelling and supporting flight crew decision-making during aircraft engine malfunctions: developing design recommendations from cognitive work analysis, Appl. Ergon. 82 (2020), 102953, https://doi.org/10.1016/j.apergo.2019.102953.
[24] W.C. Li, M. Zakarija, C.S. Yu, P. McCarty, Interface design on cabin pressurization system affecting pilot's situation awareness: the comparison between digital displays and pointed displays, Hum. Fac. Ergon. Manuf. Serv. Indus. 30 (2020) 103–113, https://doi.org/10.1002/hfm.20826.
[25] C.D. Wickens, Display Formatting and Situation Awareness Model (DFSAM): an Approach to Aviation Display Design, Aviation Human Factors Division: Moffat Field, CA, USA, 2005.
[26] K.L. Mosier, U. Fischer, D. Morrow, K.M. Feigh, F.T. Durso, K. Sullivan, V. Pop, Automation, task, and context features: impacts on pilots' judgments of human-automation interaction, J. Cogn. Eng. Dec. Making 7 (2013) 377–399, https://doi.org/10.1177/1555343413487178.
[27] C. Roos, Are we flooding pilots with data? - effects of situational awareness automation support concepts on decision-making in modern military air operations, in: R. Boring (Ed.), International Conference on Applied Human Factors and Ergonomics, Springer, 2018, pp. 183–191, https://doi.org/10.1007/978-3-319-60645-3_18.
[28] R.W. Andrews, J.M. Lilly, D. Srivastava, K.M. Feigh, The role of shared mental models in human-AI teams: a theoretical review, Theor. Issues Ergon. Sci. (2022), https://doi.org/10.1080/1463922X.2022.2061080.

[29] M.A. Ramos, K. Sankaran, S. Guarro, A. Mosleh, R. Ramezani, A. Arjounilla, The need for and conceptual design of an AI model-based Integrated Flight Advisory System, Proc. Inst. Mech. Eng. O J. Risk Reliab. (2022), https://doi.org/10.1177/1748006X221083379.
[30] L. Sanneman, J.A. Shah, in: D. Calvaresi, A. Najjar, M. Winikoff, K. Framling (Eds.), A Situation Awareness-Based Framework for Design and Evaluation of Explainable AI, 2020, pp. 94–110, https://doi.org/10.1007/978-3-030-51924-7_6.
[31] P.M. Salmon, K.L, Plant, Distributed situation awareness: from awareness in individuals and teams to the awareness of technologies, sociotechnical systems, and societies, Appl. Ergon. 98 (2022), 103599, https://doi.org/10.1016/j.apergo.2021.103599.
[32] T. Etherington, L. Kramer, L. Le Vie, K. Kennedy, R. Bailey, V. Houston, IEEE, Evaluation of Technology Concepts for Traffic Data Management and Relevant Audio for Datalink in Commercial Airline Flight Decks, 2019.
[33] O.E.D. Hamlet, A. Irwin, M. McGregor, Is it all about the mission? Comparing non-technical skills across offshore transport and search and rescue helicopter pilots, Int. J. Aer. Psych. 30 (2020) 215–235, https://doi.org/10.1080/24721840.2020.1803746.
[34] A.A. Alhaider, N. Lau, P.B. Davenport, M.K. Morris, Distributed situation awareness: a health-system approach to assessing and designing patient flow management, Ergonomics 63 (2020) 682–709, https://doi.org/10.1080/00140139.2020.1755061.
[35] Y. Wang, C. Liu, Study on Flight Crew's Team Situation Awareness Based on Team and Task Process, In2019 5th International Conference on Transportation Information and Safety (ICTIS), IEEE, 2019, pp. 653–658.
[36] N. Stanton, R. Stewart, D. Harris, R. Houghton, C. Baber, R. Mcmaster, P. Salmon, G. Hoyle, G. Walker, M. Young, others, Distributed situation awareness in dynamic systems: theoretical development and application of an ergonomics methodology, in: Situational Awareness, Routledge, 2017, pp. 419–442.
[37] T.J. Neville, P.M. Salmon, Never blame the umpire–a review of Situation Awareness models and methods for examining the performance of officials in sport, Ergonomics 59 (2016) 962–975.
[38] P.M. Salmon, G.H. Walker, N.A. Stanton, Pilot error versus sociotechnical systems failure: a distributed situation awareness analysis of Air France 447, Theor. Issues Ergon. Sci. 17 (2016) 64–79, https://doi.org/10.1080/1463922X.2015.1106618.
[39] L.Z. David, J.M. Schraagen, Analysing communication dynamics at the transaction level: the case of Air France Flight 447, Cognit. Technol. Work 20 (2018) 637–649, https://doi.org/10.1007/s10111-018-0506-y.
[40] B.B. Aherne, C. Zhang, W.S. Chen, D.G. Newman, Pilot decision making in weather-related night fatal helicopter emergency medical service accidents, Aeros. Med. Hum. Perform. 89 (2018) 830–836, https://doi.org/10.3357/AMHP.4991.2018.
[41] D. Agrawal, V. Karar, Fuzzy based decision system for estimation of operator's situation awareness index while surveillance during low ambient lighting conditions, J. Intell. Fuzzy Syst. 37 (2019) 8511–8521, https://doi.org/10.3233/JIFS-172095.
[42] L. Arsintescu, K.H. Kato, C.J. Hilditch, K.B. Gregory, E. Flynn-Evans, Collecting Sleep, Circadian, Fatigue, and Performance Data in Complex Operational Environments, Jove-Journal of Visualized Experiments, 2019, https://doi.org/10.3791/59851.
[43] A. Lamp, D. McCullough, J.M.C. Chen, R.E. Brown, G. Belenky, Pilot sleep in long-range and ultra-long-range commercial flights, Aeros. Med. Hum. Perform. 90 (2019) 109–115, https://doi.org/10.3357/AMHP.5117.2019.
[44] N.A. Stanton, P.M. Salmon, G.H. Walker, E. Salas, P.A. Hancock, State-of-science: situation awareness in individuals, teams and systems, Ergonomics 60 (2017) 449–466, https://doi.org/10.1080/00140139.2017.1278796.
[45] J. Lundberg, Situation awareness systems, states and processes: a holistic framework, Theor. Issues Ergon. Sci. 16 (2015) 447–473, https://doi.org/10.1080/1463922X.2015.1008601.
[46] M.R. Endsley, A systematic review and meta-analysis of direct objective measures of situation awareness: a comparison of sagat and spam, Hum. Factors 63 (2021) 124–150, https://doi.org/10.1177/0018720819875376.
[47] T. Nguyen, C.P. Lim, N.D. Nguyen, L. Gordon-Brown, S. Nahavandi, A review of situation awareness assessment approaches in aviation environments, IEEE Syst. J. 13 (2019) 3590–3603, https://doi.org/10.1109/JSYST.2019.2918283.
[48] B. Meng, N. Lu, C. Lin, Y. Zhang, Q. Si, J. Zhang, Study on the influencing factors of the flight crew's TSA based on DEMATEL–ISM method, Cognit. Technol. Work 24 (2022) 275–289, https://doi.org/10.1007/s10111-021-00688-7.
[49] E. Zio, Challenges in the vulnerability and risk analysis of critical infrastructures, Reliab. Eng. Syst. Saf. 152 (2016) 137–150, https://doi.org/10.1016/j.ress.2016.02.009.
[50] M.R. Endsley, Situation awareness, in: Handbook of Human Factors and Ergonomics, John Wiley & Sons, Ltd, 2021, pp. 434–455, https://doi.org/10.1002/9781119636113.ch17.
[51] V. Socha, L. Socha, L. Hanakova, V. Valenta, S. Kusmirek, A. Lalis, Pilots' performance and workload assessment: transition from analogue to glass-cockpit, Applied Sci. Basel 10 (2020), https://doi.org/10.3390/app10155211.
[52] A.K. Taylor, T.S. Cotter, Do age and experience level affect views of pilots' towards cockpit automation, in: I.L. Nunes (Ed.), Advances in Human Factors and Systems Interaction, Springer International Publishing, Cham, 2018, pp. 303–313, https://doi.org/10.1007/978-3-319-60366-7_29.
[53] Y. Lu, Y. Zheng, Z. Wang, S. Fu, Pilots' visual scanning behaviors during an instrument landing system approach, Aeros. Med. Hum. Perform. 91 (2020) 511–517, https://doi.org/10.3357/AMHP.5501.2020.
[54] X. Zhang, X. Qu, H. Xue, J. Liu, Pilots' fixation patterns during taxiing and the effects of visibility, Aeros. Med. Hum. Perform. 90 (2019) 546–552, https://doi.org/10.3357/AMHP.5206.2019.
[55] N.C. Forrest, R.R. Hill, P.R. Jenkins, An Air Force Pilot Training Recommendation System Using Advanced Analytical Methods, Inf. J. Appl. Analy.. (n.d.). https://doi.org/10.1287/inte.2021.1099.
[56] M. Friedrich, S.Y. Lee, P. Bates, W. Martin, A.K. Faulhaber, The influence of training level on manual flight in connection to performance, scan pattern, and task load, Cognit. Technol. Work 23 (2021) 715–730, https://doi.org/10.1007/s10111-020-00663-8.
[57] N. Ahmadi, M. Romoser, C. Salmon, Improving the tactical scanning of student pilots: a gaze-based training intervention for transition from visual flight into instrument meteorological conditions, Appl. Ergon. 100 (2022), https://doi.org/10.1016/j.apergo.2021.103642.
[58] C.P. Ryffel, C.M. Muehlethaler, S.M. Huber, A. Elfering, Eye tracking as a debriefing tool in upset prevention and recovery training (UPRT) for general aviation pilots, Ergonomics 62 (2019) 319–329, https://doi.org/10.1080/00140139.2018.1501093.
[59] J. Cahill, P. Cullen, K. Gaynor, Interventions to support the management of work-related stress (WRS) and wellbeing/mental health issues for commercial pilots, Cognit. Technol. Work 22 (2020) 517–547, https://doi.org/10.1007/s10111-019-00586-z.
[60] D.Z. Wojcik, C.J.A. Moulin, A. Fernandez, Assessment of metacognition in aviation pilot students during simulated flight training of a demanding maneuver, Appl. Ergon. 95 (2021), https://doi.org/10.1016/j.apergo.2021.103427.
[61] H. Mansikka, K. Virtanen, V. Uggeldahl, D. Harris, Team situation awareness accuracy measurement technique for simulated air combat-Curvilinear relationship between awareness and performance, Appl. Ergon. 96 (2021), 103473, https://doi.org/10.1016/j.apergo.2021.103473.
[62] A. Rowen, M. Grabowski, J.-P. Rancy, Moving and improving in safety-critical systems: impacts of head-mounted displays on operator mobility, performance, and situation awareness, Int. J. Hum. Comput. Stud. 150 (2021), 102606, https://doi.org/10.1016/j.ijhcs.2021.102606.
[63] Š. Bahník, B. Englich, F. Strack, Anchoring effect, in: Cognitive Illusions, Psychology Press, 2016, pp. 223–241.
[64] A. Furnham, H.C. Boo, A literature review of the anchoring effect, J. Soc. Econ. 40 (2011) 35–42, https://doi.org/10.1016/j.socec.2010.10.008.
[65] A. Kumar, G. Dixit, An analysis of barriers affecting the implementation of e-waste management practices in India: a novel ISM-DEMATEL approach, Sustain. Prod. Consum. 14 (2018) 36–52, https://doi.org/10.1016/j.spc.2018.01.002.
[66] F. Li, W. Wang, S. Dubljevic, F. Khan, J. Xu, J. Yi, Analysis on accident-causing factors of urban buried gas pipeline network by combining DEMATEL, ISM and BN methods, J. Loss Prev. Process. Ind. 61 (2019) 49–57, https://doi.org/10.1016/j.jlp.2019.06.001.
[67] I. Mohammadfam, M.M. Aliabadi, A.R. Soltanian, M. Tabibzadeh, M. Mandinia, Investigating interactions among vital variables affecting situation awareness based on Fuzzy DEMATEL method, Int. J. Ind. Ergon. 74 (2019), 102842, https://doi.org/10.1016/j.ergon.2019.102842.
[68] A. Trivedi, S.K. Jakhar, D. Sinha, Analyzing barriers to inland waterways as a sustainable transportation mode in India: a dematel-ISM based approach, J. Clean. Prod. 295 (2021), 126301, https://doi.org/10.1016/j.jclepro.2021.126301.

[69] L. Wang, Q. Cao, L. Zhou, Research on the influencing factors in coal mine production safety based on the combination of DEMATEL and ISM, Saf. Sci. 103 (2018) 51–61, https://doi.org/10.1016/j.ssci.2017.11.007.
[70] Y. Zhang, Y. Huang, X. Zhao, J. Li, F. Yin, L. Wang, Research on the influencing factors of kite culture inheritance based on an adversarial interpretive, Struc. Model. Method 9 (2021) 11.
[71] J. Li, K. Xu, J. Ge, B. Fan, Development of a Quantitative Risk Assessment Method for a Biomass Gasification Unit by Combining DEMATEL-ISM and CM-TOPSIS, Stochastic Environmental Research and Risk Assessment, 2021, https://doi.org/10.1007/s00477-021-02084-z.
[72] Q.N. Hong, P. Pluye, S. Fabregues, G. Bartlett, F. Boardman, M. Cargo, P. Dagenais, M.-P. Gagnon, F. Griffiths, B. Nicolau, A. O'Cathain, M.-C. Rousseau, I. Vedel, Improving the content validity of the mixed methods appraisal tool: a modified e-Delphi study, J. Clin. Epidemiol. 111 (2019) 49–59, https://doi.org/10.1016/j.jclinepi.2019.03.008.
[73] Liu Xie, Factors influencing escalator-related incidents in China: a systematic analysis using ISM-DEMATEL method, IJERPH 16 (2019) 2478, https://doi.org/10.3390/ijerph16142478.
[74] J. Chen, Q. Zhang, L. Cheng, X. Gao, L. Ding, IEEE, A Cognitive Load Assessment Method Considering Individual Differences in Eye Movement Data, 2019, pp. 295–300.
[75] T. Lu, Z. Lou, F. Shao, X. You, M. Tang, Attention allocation in pilots based on climbing and circling mission behavior, Psych. Res.-Psychologische Forschung 85 (2021) 1136–1145, https://doi.org/10.1007/s00426-020-01324-1.
[76] C. Feng, X. Wanyan, S. Liu, H. Chen, D. Zhuang, An approach to situation awareness (SA) assessment in flight simulation: SA dynamic circulation (SADC) model, Hum. Fac. Ergon. Manuf. Serv. Indus. 31 (2021) 559–569, https://doi.org/10.1002/hfm.20903.
[77] W.-C. Li, A. Horn, Z. Sun, J. Zhang, G. Braithwaite, Augmented visualization cues on primary flight display facilitating pilot's monitoring performance, Int. J. Hum. Comput. Stud. 135 (2020), https://doi.org/10.1016/j.ijhcs.2019.102377.
[78] C. Liang, S. Liu, X. Wanyan, C. liu, X. Xiao, Y. Min, Effects of input method and display mode of situation map on early warning aircraft reconnaissance task performance with different information complexities, Chin. J. Aeronaut. (2022), https://doi.org/10.1016/j.cja.2022.06.011.
[79] R. Eklund, A.-L. Osvalder, Optimising aircraft taxi speed: design and evaluation of new means to present information on a head-up display, J. Navig. 74 (2021) 1305–1335, https://doi.org/10.1017/S0373463321000606.
[80] D. Friesen, C. Borst, M.D. Pavel, O. Stroosma, P. Masarati, M. Mulder, Design and evaluation of a constraint-based head-up display for helicopter obstacle avoidance, J. Aero. Inf. Syst. 18 (2021) 80–101, https://doi.org/10.2514/1.I010878.
[81] M.C. Noort, T.W. Reader, A. Gillespie, Safety voice and safety listening during aviation accidents: cockpit voice recordings reveal that speaking-up to power is not enough, Saf. Sci. 139 (2021), https://doi.org/10.1016/j.ssci.2021.105260.
[82] M.J. Taber, N. Taber, Learning beyond "hands and feet" in offshore helicopter operations: integrating the individual with the social in CRM and SA, Theoretical Issues in, Ergon. Sci. 21 (2020) 614–631, https://doi.org/10.1080/1463922X.2020.1729444.
[83] Y. Steinman, M. van den Oord, M. Frings-Dresen, J. Sluiter, Flight performance aspects during military helicopter flights, Aeros. Med. Hum. Perform. 90 (2019) 389–395, https://doi.org/10.3357/AMHP.5226.2019.
[84] R. Dapica, F. Peinado, in: J. Watrobski, W. Salabun, C. Toro, C. Zanni-Merk, R. Howlett, L. Jain (Eds.), Towards a Semantic Knowledge Base for Competency-Based Training of Airline Pilots, 2021, pp. 1208–1217, https://doi.org/10.1016/j.procs.2021.08.124.
[85] M. Demir, C. Johnson, D. Grimm, N.J. McNeese, J.C. Gorman, N.J. Cooke, in: G. Rogova, N. McGeorge, O. Gundersen, K. Rein, M. Freiman (Eds.), Effective Team Interaction for Adaptive Training and Situation Awareness in Human-Autonomy Teaming, 2019, pp. 122–126.
[86] S. Ogawa, T. Kanno, K. Furuta, in: L. Li, K. Hasegawa, S. Tanaka (Eds.), Description and Analysis of Cognitive Processes in Ground Control Using a Mutual Belief-Based Team Cognitive Model, 2018, pp. 306–315, https://doi.org/10.1007/978-981-13-2853-4_24.
[87] V. González-Romá, A. Hernández, Climate uniformity: its influence on team communication quality, task conflict, and team performance, J. Appl. Psychol. 99 (2014) 1042–1058, https://doi.org/10.1037/a0037868.
[88] B.G. Kanki, Communication and crew resource management, in: Crew Resource Management, Elsevier, 2019, pp. 103–137, https://doi.org/10.1016/B978-0-12-812995-1.00004-X.
[89] J. Tiferes, A.M. Bisantz, The impact of team characteristics and context on team communication: an integrative literature review, Appl. Ergon. 68 (2018) 146–159, https://doi.org/10.1016/j.apergo.2017.10.020.
[90] S. Mariano, Y. Awazu, Artifacts in knowledge management research: a systematic literature review and future research directions, JKM 20 (2016) 1333–1352, https://doi.org/10.1108/JKM-05-2016-0199.
[91] K. Leung, J. Wang, Social processes and team creativity in multicultural teams: a socio-technical framework: social Processes and Team Creativity, J. Organ. Behav. 36 (2015) 1008–1025, https://doi.org/10.1002/job.2021.
[92] T. Pasha, P.R.A. Stokes, Reflecting on the germanwings disaster: a systematic review of depression and suicide in commercial airline pilots, Front. Psychiatr. 9 (2018), https://doi.org/10.3389/fpsyt.2018.00086.
[93] A. Vuorio, A. Bekker, A.-S. Suhonen-Malm, R. Bor, Promoting flight crew mental health requires international guidance for down-route quarantine circumstances, Front. Public Health 10 (2022), https://doi.org/10.3389/fpubh.2022.854262.
[94] J.M. Anca Jr., Cultural issues and crew resource management training, in: Crew Resource Management, Elsevier, 2019, pp. 539–552.
[95] R.C. Ginnett, Crews as groups: their formation and their leadership, in: Human Error in Aviation, Routledge, 2017, pp. 289–316.
[96] E. Avril, B. Valéry, J. Navarro, L. Wioland, J. Cegarra, Effect of imperfect information and action automation on attentional allocation, Int. J. Hum. Comput. Interact. 37 (2021) 1063–1073, https://doi.org/10.1080/10447318.2020.1870817.
[97] C. Diaz-Piedra, H. Rieiro, A. Cherino, L.J. Fuentes, A. Catena, L.L. Di Stasi, The effects of flight complexity on gaze entropy: an experimental study with fighter pilots, Appl. Ergon. 77 (2019) 92–99, https://doi.org/10.1016/j.apergo.2019.01.012.
[98] A. Landman, S.H. van Middelaar, E.L. Groen, M.M.(René, van Paassen, A.W. Bronkhorst, M. Mulder, The effectiveness of a mnemonic-type startle and surprise management procedure for pilots, Int. J. Aer. Psych. 30 (2020) 104–118, https://doi.org/10.1080/24721840.2020.1763798.
[99] S.L. Marlow, C.N. Lacerenza, J. Paoletti, C.S. Burke, E. Salas, Does team communication represent a one-size-fits-all approach?: a meta-analysis of team communication and performance, Organ. Behav. Hum. Decis. Process. 144 (2018) 145–170, https://doi.org/10.1016/j.obhdp.2017.08.001.
[100] M. She, Z. Li, L. Ma, User-defined information sharing for team situation awareness and teamwork, Ergonomics 62 (2019) 1098–1112, https://doi.org/10.1080/00140139.2019.1607910.
[101] V.K. Takacs, M. Juhasz, Team communication of nuclear fire brigades during routine and non-routine task phases, Int. J. Ind. Ergon. 90 (2022), 103300, https://doi.org/10.1016/j.ergon.2022.103300.
[102] A. Hattingh, S. Hodge, T. Mavin, Flight instructor perspectives on competency-based education: insights into educator practice within an aviation context, Int. J. Train. Res.. (n.d.). https://doi.org/10.1080/14480220.2022.2063155.
[103] C. Lazure, L. Dumont, S. El Mouderrib, J.-F. Delisle, S. Senecal, P.-M. Leger, Certified flight instructors' performance - review of the literature and exploration of future steps, Int. J. Aer. Psych. 30 (2020) 152–170, https://doi.org/10.1080/24721840.2020.1796487.
[104] M. Yazdi, F. Khan, R. Abbassi, R. Rusli, Improved DEMATEL methodology for effective safety management decision-making, Saf. Sci. 127 (2020), 104705, https://doi.org/10.1016/j.ssci.2020.104705.