Study on the Correlation and Inhibition of Visual Marking and Industrial Icons

Xiaoli Wu[a,c,1], Ke Zhang[b,d,2], Zexi Fang[a,3,*] ,Duncan P. Brumby [c,4] , Xiaoyang Mao [a,5], Xiaoyan Wang[b,5] , Qian Li[a,7]

a. School of Design Art and Media, Nanjing University of Science and Technology, China

b. College of Mechanical and Electronic, Hohai University, China

c. UCL Interaction Centre, University College London, United Kingdom

d Wuxi Little Swan Electric Co., Ltd, China

1 Dr Xiaoli Wu is currently a professor in School of Design Art & Media, Nanjing University of Science & Technology. She is currently academic research visitor of UCL Interaction Centre, University College London. She received her Ph. D degree of Mechanical Engineering in Southeast University. She mainly engages in Information displays and design cognition.

2 Mr Ke Zhang is currently an engineer in Little Swan. He received his master degree from Hohai University. He mainly engages in Human factors in design.

3 Miss Zexi Fang is currently a postgraduate in School of Design Art & Media, Nanjing University of Science & Technology. Her mainly engages in Human computer interaction.

4 Dr Duncan Brumby is currently a professor in Human-Computer Interaction at University College London (UCL). His research is in the field of Human-Computer Interaction and is concerned with understanding how people manage digital distractions.

5 Miss Qian Li is currently a postgraduate in School of Design Art & Media, Nanjing University of Science & Technology. Her mainly engages in Human computer interaction.

6 Dr Xiaoyang Mao graduated from Florida Institute of Technology. He is assistant professor in design science at Nanjing University of Science and Technology, and mainly focus on design theory and methodology, design automation, design cognition and design ideation.

7 Dr Xiaoyan Wang is currently an accociate professor in School of Mechanical Engineering, Hohai University. She received her Ph. D degree from Suzhou University. She mainly engages in Industrial design.

Study on the Correlation and Inhibition of Visual Marking and Industrial Icons

As a carrier of complex information, industrial icons play an important role in intelligent manufacturing systems, and the superiority of its visual presentation affects the visual search efficiency of operators. This paper applied the theoretical knowledge of visual marking to the study of industrial icons, and the relationship between the inhibitory mechanism of visual marking and the information characteristic, semantic categories and spatial layout of industrial icons is explored from the inhibition of location, feature, category and spatial structure in visual marking. The experimental results show that: in the aspect of feature inhibition, the 2.5D style inhibits the flat style and the complex icon inhibits the simple icon. In the aspect of category inhibition, the inhibitory degree of four different categories are warning, monitoring, equipment and production in order from high to low. In the aspect of spatial layout inhibition, the regular layout inhibits the chaotic layout and the orderly arrangement inhibits the disorderly arrangement. It is concluded that there is a certain correlation among the industrial icons' inhibition of feature, category and spatial layout, and the priority of category is higher than that of feature, the spatial layout inhibition is jointly influenced by the inhibition of feature and category, among which category inhibition takes the lead role.

Keywords: Industrial Icons; Visual Marking; Correlation; Inhibitory Mechanisms

Subject classification codes: Human-Computer Interaction Innovations in China

1. Introduction

The visual system prioritizes items that are relevant to the current visual search target, and this phenomenon of visual preference has been the research focus of visual search. Waston et al. (1997) proposed the visual marking theory that the visual system would mark the locations of the items that appear first, thus a prior search for the items that appear later. Hao and Fang et al. (2006) conducted an analysis of visual preferential selection mechanism and systematically examined the inhibitory mechanism in visual marking from two perspectives based on the inhibition of location and feature.

In the research of visual marking, scholars have pioneered several experimental paradigms. Watson (2003) created a classical preview search paradigm, including single-feature search, joint search, and preview search. In the follow-up study, Watson et al. (2012) introduced a probe detection task paradigm to study location inhibition in visual marking; Humphreys et al. (2004) introduced an attention-allocated time-paced task model to study the mechanism of location inhibition; Olivers et al. (2002) introduced a dual-task experimental model to investigate whether the inhibitory effect on the original item in the preview search experiment required allocation of attentional resources. Theeuwes et al. (1998) used an independently manipulated preview search experiment paradigm to investigate the mechanism of preferential selection of new items in a multi-target preview search experiment. Donk et al. (2001) set the number of new and old items as a single variable to test the preview effect. Xuemin Zhang et al. (2011) used multi-target tracking and dot probe detection stimuli to explore the selective inhibitory effect of multi-target visual search. Jiang et al. (2002) proposed two preview search experimental paradigms, i.e, effective preview search and ineffective preview search, to investigate the inhibitory effect of visual marking.

In the field of research on the inhibitory mechanisms of visual marking, scholars have focused on the following four perspectives.

(1) Inhibition based on‘location’. Watson et al. (1997) proposed that visual marking is to mark the locations of first-appearing items, which will be inhibited later so that the later-appearing items are preferred. Waston et al. (2000) found that the experimental performance at the locations of first-appearing items was lower than that of later-appearing items through dot probe detection experiments.

(2) Inhibition based on‘Feature’. Watson et al. (2002) argued that during visual search, the features of the first-appearing items will be marked, resulting in feature-based inhibition. Humphreys et al. (2004) experimentally found that the efficiency of visual search decreased when the target color was the same as the interferent’s color, demonstrating that color-based interferent’s inhibition occurs in visual search. Agter et al. (2005) conducted experiments using color as a variable and demonstrated the possible existence of color-based inhibition by adjusting the same and different colors of old and new items. Xiangyu Cui et al. (2007) combined a preview

search task with a detection task and demonstrated the existence of color-based inhibitory mechanism in the preview search by two experiments. Atchley et al. (2003) argued that marking the position, color, shape, and motion of old items could be preferred to new items. Juli Cui et al. (2010) chose regular pentagon and regular hexagon shapes as experimental materials and used a preview search experimental paradigm to find that there is visual preference in graphical searching and it is determined by position and color inhibition of old items together.

(3) Inhibition based on‘spatial structure’. Hodsoll et al. (2005) used a preview search experimental paradigm to verify the spatial structure inhibition, and the results showed that when the old item and the target had a specific spatial structure, the preview effect appeared when the old item was repeated. Ming Zhang et al. (2007) used a dual-task interference paradigm to explore the effect of working memory on object-based returning inhibition in a dynamic paradigm. Jing Zhao et al. (2010) found that the spatial return inhibitory effect is influenced by visual attention based on spatial working memory when the return inhibition task target is matched with working memory content. Aijun Wang et al. (2015) used virtual reality technology to apply the cueing paradigm in the two-dimensional plane to three-dimensional space and experimentally examined the late inhibitory effect resulting from attention being directed or redirected at three-dimensional spatial depth locations.

(4) Inhibition based on‘category’. Xuejun Lei et al. (2006) investigated the effect of category relationship between new and old items on visual search under equal luminous conditions by using numbers and letters as experimental materials. Using Chinese and Arabic numerals as experimental materials, they investigated the effect of category mixing and anticipation of target category on preview search, and suggested that anticipation of target category could improve search efficiency, and the anticipation effect would be weakened when the target was

in the same category as the old item, and be strengthened when the target was in a different category as the old items.

To sum up, in the field of visual marking, scholars have investigated whether there are other unknown inhibitory units based on location, feature, spatial structure and category, besides color and shape in terms of feature inhibition. In terms of experimental material choosing, the research materials are mostly simple figures such as numbers, letters, and basic geometric figures(i.e. circles, pentagons, rectangles), and rarely involve experimental materials with relatively complex graphic expressions. The use of geometric shapes allows for a purer examination of the effects of changes in features such as shape on the preview effect, while the use of more figurative and complex graphical symbols might allow for an examination of the correlation between different inhibitory effects. Research on visual marking has mostly focused on experimental areas and less on application area, especially in the field of industrial icons, so the research and discussion of visual marking mechanisms in new areas should continue in depth.

2. Method

2.1. Experimental paradigm of visual marking

Waston et al. (1997) proposed the preview search experimental paradigm, which is one of the most important experimental paradigms for visual marking, as shown in figure 1-a. In this experimental paradigm, a number of interferents are presented first, and then after 1000 ms, a number of interferents are presented with the target, keeping the original interferent's position unchanged, which has gradually formed the classical preview search paradigm (Watson et al., 2003), the independent manipulation preview search paradigm (Theeuwes et al., 1998) and two preview search paradigms(Jiang et al., 2002). Waston (2003) then proposed visual marking as marking the positions of the first-appearing items again, which are inhibited so that the later-appearing items get preference, the experimental paradigm is shown in figure 1-b.

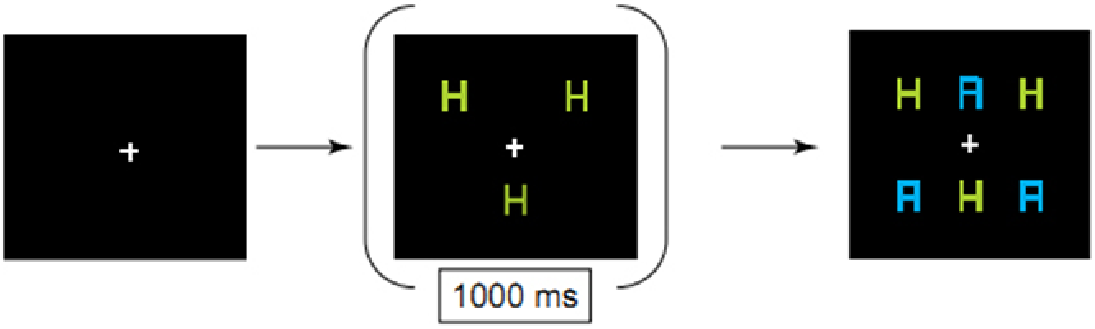


Figure 1-a. Preview search paradigm.

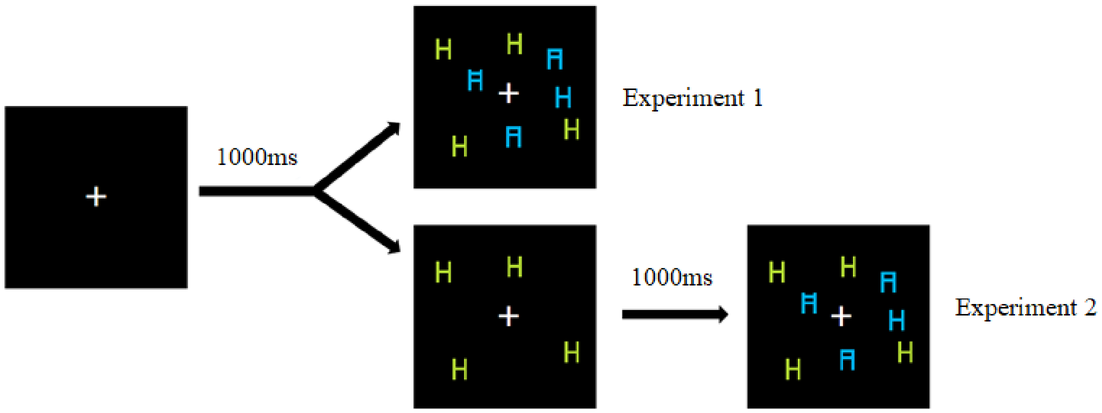


Figure 1-b. Conjunction and preview search.

2.2. Visual marking-related inhibition of industrial icons

Industrial icons are one of the most important visual elements of intelligent manufacturing system, compared with the presentation of text, industrial icons have relatively larger information carrying capacity and higher information integration, so it can present information more quickly and efficiently, mostly expressed in the three following aspects: information characteristics, semantic category, and spatial layout. Wu et al. (2019) conducted a visual search experiment with information characteristic and presentation as variables, and the results showed that both icon form and information presentation both have significant effects on visual search, and the fixation/saccade time and path can reflect the complexity of icon form and the difficulty of information presentation. Yan, Wu, and Zhang (2020) conducted a semantic study on industrial icons of its indicative, security and color characteristic within domestic and abroad studies, and analyzed the specific correlation between the semantics of industrial icon symbols and entities. NingYue Peng et al. (2017) used a visual search experimental paradigm to compare the effects of different feature inference conditions on each measure, then concluded that the semantic word-guided target search had the highest accuracy.

Visual marking mainly embodied four inhibitory mechanisms, including location, feature, spatial structure and category. In the selection of experimental materials, the research materials are mostly simple symbols such as numbers, letters, basic geometric figures(i.e. circles, pentagons, rectangles), while there are fewer studies in the experimental analysis of complex material, and there is no experimental investigation on the location, feature, category, and spatial layout of industrial icons at all. Hence this paper adopts the combination of the inhibitory mechanisms of visual marking and the expression form of industrial icons, correspond the information characteristics of industrial icons to the feature inhibition, the semantic categories to the category inhibition, and the spatial layouts to the location inhibition, in order to explore the internal correlation and inhibitory effect of the four inhibitory mechanisms of visual marking and the three main forms of industrial icons.

Focusing on the related experimental paradigm of visual marking(preview search paradigm), this paper carry out a series of experiments on visual search of industrial icons with information features, semantic categories, and spatial layout as visual marking to explore whether the inhibition of feature, category, spatial layout, and the effects of different information characteristics, semantic categories, and spatial layouts on operators' visual search efficiency.

3. Experiment 1: Industrial icon search with information characteristics as visual marking

3.1. Experiment design

Experimental 1 selected information characteristics as experimental variables and applied a target searching task to investigate the effect of feature inhibition on the search efficiency of industrial icons.

Twenty-four industrial manufacturing-related icons were selected, as shown in table 1. The icons were divided into flat icons and 2.5D icons according to the style, and simple icons and complex icons according to the complexity. The color is designed as one of the important elements to stimulate, considering that the experimental material is from PV manufacturing system, while the color blue(RBG 29/44/101) is selected as the main color scheme of the icons, orange(RGB 212/94/23) as the secondary color, and white as the background color.

Table 1. Industrial icon style classification.

Icon Style	Simple	Complex
Flat		

The independent variables(stimulus variables) of experiment 1 were divided into 3 groups, including icon style(flat, 2.5D), complexity(simple, complex), and task difficulty(6,9,12 levels). Flat icons have the characteristics of simplicity and are divided into linear icons, plane icons and line-plane combined icons; 2.5D icons are in between of flat icons and 3D icons, with the simplicity of flat icons and the spatiality of 3D icons. Simple icons are composed of fewer elements, indicating simple equipment and process, complex icons are composed of more elements, indicating complex equipment and process. The difficulty of the task is determined by the total number of icons appearing on the searching interface.

The dependent variable(response variable) of experiment 1 was the subject's reaction time, and a 2x2x3 mixed factorials experimental design was used. To ensure the validity of the behavioral experimental data, additional repeat groups were set up, for a total of 24 experimental groups, and the arrangement is shown in table 2. The experimental procedure is shown in figure 2.

Table 2. Experimental arrangements.

Experimental Group	Targets	Interferents	Presentations	Task Difficulty	Repeat Group
01	2.5D and simple	Flat and simple	2.5D and simple、flat and simple	Level 6、9、12	2 times
02	2.5D and complex	2.5D and simple	2.5D and complex、2.5D and simple	Level 6、9、12	2 times
03	Flat and simple	Flat and complex	Flat and simple、flat and complex	Level 6、9、12	2 times
04	Flat and complex	2.5D and complex	Flat and complex、2.5D and complex	Level 6、9、12	2 times

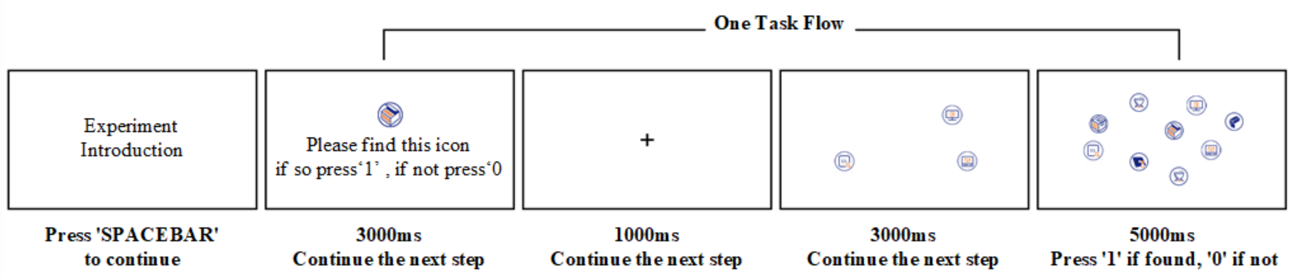


Figure 2. Experimental procedure.

3.2. Experimental equipment and subjects

This experiment was conducted in the Interactive Laboratory of Human Factors and Information Systems of Hohai University, using a computer with a screen solution of 1366(px) *768(px) and 64-bit color quality, and the experimental program was written by E-Prime. Twenty students from university with engineering backgrounds were selected as subjects, aged between 20 and 26 years old, with an average age of 22 years old, and none of the subjects were color blindness or color weakness, the corrected visual acuity of them were all above 1.0.

3.3. Experimental results and data analysis

First, the data of reaction time over 5000ms and the data of target not founded were removed, and then the data beyond 3 standard deviations were removed using the response time's mean value as a reference, for a total of 1.2% of the data.

(1) Levene test of equality of error variance. The significance of the response time's mean value in the Levene test for response time's mean value data(P=0.593, p>0.05) proved that the null hypothesis of equal variance in the errors of the dependent variables in each group stands, satisfying the homogeneity of variance and allowing further ANOVA to be carried out, as shown in table 3.

Table 3. Levene test of equality of error variance.

Time	F	df 1	df 2	p
Based on the Mean	0.672	3	8	0.593
Based on the Median	0.164	3	8	0.918
Based on the Median with Adjusted Degrees of Freedom	0.164	3	6.582	0.917
Based on the Truncated Mean	0.614	3	8	0.625

Note: The original hypothesis:'dependent variable error variances are equal across groups' is tested;

a. Dependent Variable: Time;

b. Design: Intercept + Icon Style + Complicity + Task Difficulty + Icon Style * Complicity+Icon Style * Task Difficulty + Complicity * Task Difficulty + Icon Style * Complicity * Task difficulty

(2) Main effect test. The main effect test on response time for the three experimental variables of icon category, complexity, and task difficulty is shown in table 4. The significance of icon category(P=0.003, p<0.05) indicates that the difference in icon style has a significant effect on response time; the significance of complexity(P=0.001, p<0.05) indicates that the difference in complexity has a significant effect on response time; the significance of task difficulty(P=0.000, p<0.05) indicates that the difference in complexity has a significant effect on response time; three variables interact in pairs(icon style interacted with complexity: P=0.125, p>0.05; icon style interacted with task difficulty: P=0.616, p>0.05; complexity and task difficulty interaction:

P=0136, p>0.05) and in three-way(icon style, complexity, task difficulty interaction: p=0.161, p>0.05), the effects on response duration were not significant.

Table 4. Main effect test.

Dependent Variable: Time	Test of Between-subjects Effects				
Source	Type III sum of squares	df	Mean square	F	p
Correction Model	7262564.72a	11	660233.157	25.629	0.000
Intercept	133238780.1	1	133238780.1	5171.982	0.000
Icon Style	65019.781	1	65019.781	2.524	0.003
Complicity	6652.334	1	6652.334	0.258	0.001
Task Difficulty	6084161.269	2	3042080.634	118.086	0.000
Icon Style * Complicity	287057.514	1	287057.514	11.143	0.125
Icon Style * Task Difficulty	520158.987	2	260079.494	10.096	0.616
Complicity * Task Difficulty	697758.6	2	398879.3	13.838	0.136
Icon Style*Complicity*Task Difficulty	101756.239	2	50878.119	1.975	0.161
Error	618279.52	24	25761.647		
Total	141119624.3	36			
Total Adjusted	7880844.244	35			
a. R^2*= .992（adjusted* R^2*= .886）*					

(3) Data analysis. The experimental results show that, under the condition of ensuring the consistency of other variables, the response time of all 2.5D style icons is lower than that of flat style icons, which indicates that in visual task search, flat icons are inhibited more strongly than 2.5D icons; the response time of all complex icons is lower than that of simple icons, which indicates that in visual task search, simple icons are inhibited more strongly than complex icons; the higher the quantity level, the higher the difficulty of the task, the longer response time, which indicates that there is an upper limit to the number of visual marking, and the higher the quantity level, the greater the ratio of old and new items , and the lower the efficiency of visual search, as shown in figure 3.

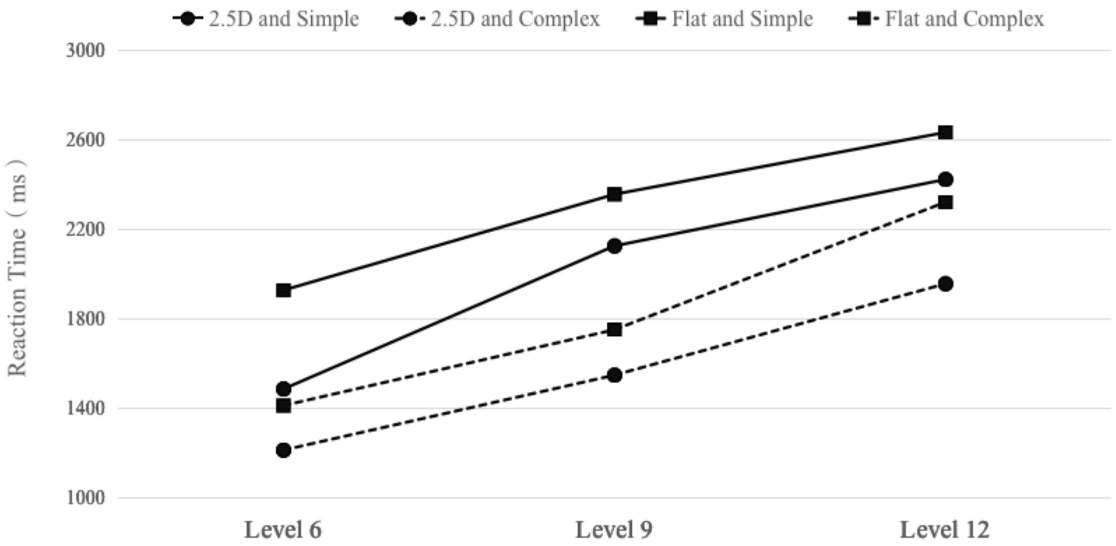


Figure 3. Reaction times of different information characteristics between different task difficulties.

3.4. The inhibitory effect of visual marking in information characteristics of industrial icons

In order to investigate the inhibitory effect of visual marking in the information characteristics of industrial icons, the data from the repeat groups and the task difficulty groups were combined, and only focus on the icon style and complexity through four sets of experiments, as shown in table 5.

Table 5. Comparison of groups.

Experimental Groups	Targets	Interferents
01	2.5D and simple	Flat and simple
02	2.5D and complex	2.5D and simple
03	Flat and simple	Flat and complex
04	Flat and complex	2.5D and complex

The comparison of the experimental groups shows that 2.5D icons are more efficient than flat icons in visual search, so that flat icons are inhibited stronger than 2.5D icons; complex icons are more efficient for visual search than simple icons icons, so that simple icons are inhibited stronger than complex icons. Therefore, in the industrial system, flat icons have abstract characteristics and obvious plane characteristics, 2.5D icons have concrete characteristics and obvious three-dimensional characteristics, When the operator performs a visual search, the characteristics with a stronger sense of space will inhibit the characteristics with a weaker sense of space. In the same task interface, the 2.5D icon has a stronger sense of space, and the visual search efficiency is high. Simple icons are composed of fewer elements, which mean the characteristics of simplicity and fewer memory points, while complex icons are composed of more icons, which imply complicated characteristics and more memory points. When operator performs visual search, the characteristics with more memory points will inhibit the characteristics with few memory points. In the same task interface, the memory points of complex icons are more, which brings higher visual search efficiency. The difficulty of the task is determined by the total number of icons on the target interface, the higher the number, the bigger the ratio of old and new items, and the higher the difficulty of the task, then the less obvious the inhibitory mechanism of icon features and locations, the shorter the response time of the operator in visual search, the longer it is, the less efficient it is.

4. Experiment 2: Industrial icon search with semantic categories as visual marking

4.1. Experiment design

Experiment 2 selects 70 icons of industrial manufacturing system, as shown in table 6, and classifies the icons into production, equipment, monitoring and warning categories from the semantic perspective, and the color setting of stimulus material is the same as experiment 1.

Table 6. Category classification of solar industrial icon.

Category	Industrial Icons								
Production Icons	Before Cleaning	Diffusion	After Cleaning	Coating	Screen Printing	Power Test	Small Package	Big Package	Sorting and Packaging
	Warehousing	Preparation	Charging	Ingot	Demolition	Truncation	Ground	Chamfer	Production Warehousing
	Slicing	Sticky Stick	Ingot Inspection	Square Bar Test	Square Bar Storage	Square Bar Material	Pre-cleaning	Insert Cleaning	Confirm Warehousing
Equipment Icons	EVA(FCE)	Backplane	Profile	Grass	Profile Glue	Glue A	Glue B	Interconnect Bar	Bus Bar
	Cell	Junction Box	Wire Box Base Glue						
Monitoring Icons	ERP Integration	Hierarchical Monitoring	Video Live	Production Display	Equipment Process	Device Monitoring	Workshop Data	Factory Data	Transparent Factory
	Machine Status	Configuration Parameters	Return Rate	Running Numbers	Downtime Numbers	Standby Numbers	Smart Application	Image Query	3D Factory
	EL Image Recognition	Welding Machine Display on Eest	Welding Machine Display on West	East Floor Laminator Display	Connections Number	String Production	Real-time Temperature	Industrial interconnection	
Warning Icons	Abnormal Alarm	Current Alarm	History Alarm	Normal Communication	Exceptional Communication				

The independent variables(stimulus variables) of this experiment were divided into 2 groups, the semantic categories of icons(production, equipment, monitoring, and warning), and the number of targets(1, 2, and 3). The experimental dependent variable(response variable) was the reaction time of the subjects. This experiment used a 4x3 mixed factorials experimental design , and to ensure the validity of the behavioral experimental data, additional repeat groups were set, for a total of 24 experimental groups. The experimental procedure is shown in figure 4.

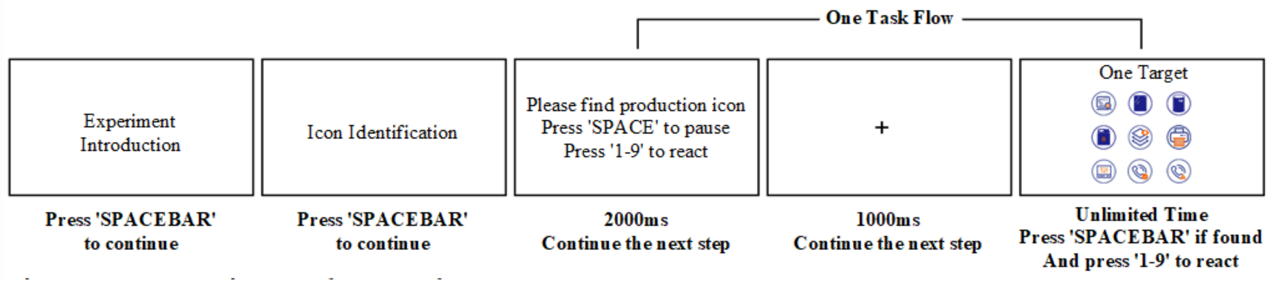


Figure 4. Experimental procedure.

4.2. Experimental equipment and subjects

The experimental equipment and subjects were selected as in Experiment 1, and 25 college students with engineering background were selected as subjects.

4.3. Experimental results and data analysis

First, the data of incorrect responses from the subjects were removed, and the data beyond 3 standard deviations were removed using the response time’s mean value as a reference, for a total of 1.6% of the data.

(1) Levene test of equality of error variance. The significance of response time’s mean value in the Levene test for response time’s mean value data($P=0.281$, $p>0.05$) proved the null hypothesis that the error variances of the dependent variables are equal in each group holds, satisfying the homogeneity of variance and allowing further ANOVA to be carried out, as shown in Table 7.

Table 7. Levene test of equality of error variance.

Time	F	df 1	df 2	p
Based on the Mean	1.305	11	24	0.281
Based on the Median	0.406	11	24	0.939
Based on the Median with Adjusted Degrees of Freedom	0.406	11	12.920	0.929
Based on the Truncated Mean	1.220	11	24	0.327

(2) Main effect test. The main effect test on the response time of two experimental variables, including icon category and target quantity, is shown in Table 8. The significance of icon category (P=0.000, p<0.05) indicates that the difference in icon category has a significant effect on the response time; the significance of target number(P=0.000, p<0.05) indicates that the difference in target quantity has a significant effect on response time; two variables interact in pairs, when icon category and target quantity interact with each other(P=0.127, p>0.05), it did not have a significant effect on response time.

Table 8. Main effect test.

Dependent Variable: Time	Test of Between-subjects Effects				
Source	Type III Sum of Squares	df	Mean Square	F	p
Modified model	150222505a	11	13656591.36	10.654	0.000
Intercept	1642937600	1	1642937600	1281.661	0.000
Overall Layout	101521470.3	3	33840490.10	26.399	0.000
Partial Layout	34278788.72	2	17139394.36	13.370	0.000
Overall Layout*Partial Layout	14422245.94	6	2403707.657	1.875	0.127
Error	30765164.00	24	1281881.833		
Total	182392569	36			
Corrected Total	180987669.0	35			
a. R^2= .830（adjusted R^2= .752）					

(3) Data analysis. The experimental results showed that the search time of warning icons was the shortest and that of production icons was the longest under the condition that other variables were consistent; there was a mutual inhibitory relationship between icons in different semantics, and the inhibition between icons in four different categories was from strong to weak in the order of warning, monitoring, equipment and production. With the increase of targets quantity, the increase of time spent by subjects in visual search slowed down indicating that with the increase of the targets quantity, the correlation between the objects increased, the ratio of the target to the interferent increased, the visual center of gravity occupied by the target is enhanced, and the increase in the time spent by the subjects for target searching slowed down, as shown in figure 5.

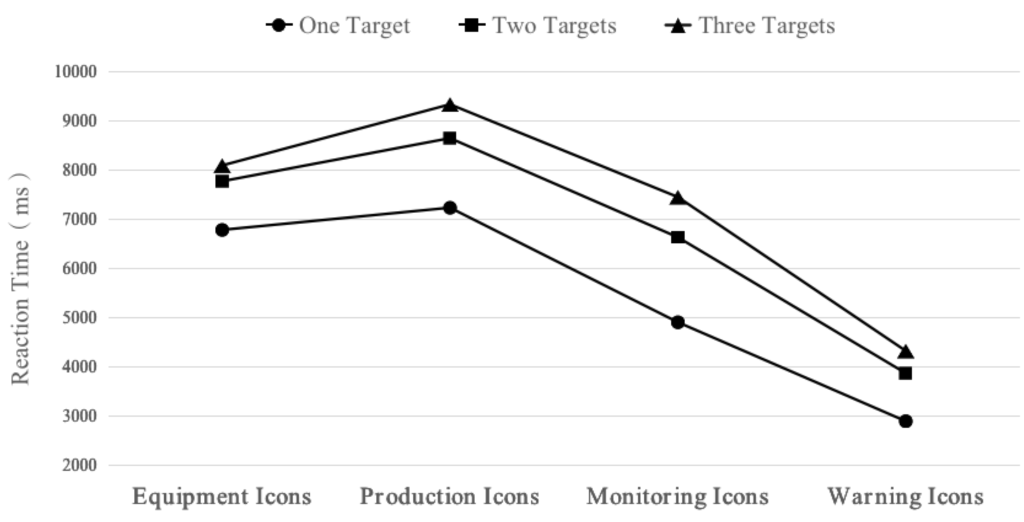


Figure 5. Response times for different semantic category icons.

4.4. The inhibitory effect of semantic categories as visual marking in industrial icons

In order to investigate the inhibitory effect of visual marking in the semantic category of industrial icons, the data from the repeat groups and different number of target groups were combined and only focus on the semantic category of icons, with four sets of experiments, as shown in table 9.

Table 9. Comparison of groups.

Experimental Groups	Targets	Interferents
01	Equipment Icons	Production Icons, Monitoring Icons，Warning Icons
02	Production Icons	Equipment Icons，Monitoring Icons，Warning Icons
03	Monitoring Icons	Equipment Icons，Production Icons，Warning Icons
04	Warning Icons	Equipment Icons，Production Icons，Monitoring Icons

The above four types of icons are analyzed from four aspects, including combination, style, color and characteristics, as shown in table 10. The common characteristic of warning icons is the red alarm bell, which is consistent with people's perception, and the color red can also attract people's attention, so the operator will combine with the consistent cognition and read it more efficiently; the common characteristic of monitoring icons is the symbol of the display, and it is strongly associated with the monitoring situation, so the operator will recognize the icon belongs to the monitoring category more quickly when reading it; the equipment icons are mostly consist of visualized tools with strong independence, concise semantics and strong concentration, so operators can recognize them more efficiently; production icons are mostly accompanied by multiple types of action symbols, which have strong visual complexity, causing operators read it more slowly. Different categories of icons have different characteristics that affect the operator’s visual search efficiency, and these characteristics that are closely related to past cognition will reduce the operator’s cognitive load and improve the cognitive performance.

Table 10. Analysis of icons of different categories.

Category	Demonstration	Combination	Style	Color	Characteristics
Production Icons		Multiple-symbol Combination	2.5D	Blue as main color tone, yellow as secondary color tone	Actional Style
Equipment Icons		A Single Symbol	Flat	Blue as main color tone, yellow as secondary color tone	Figurative Style
Monitoring Icons		A Single Symbol	Flat	Blue as main color tone, yellow as secondary color tone	Display as the main part
Warning Icons		A Single Symbol	Flat	Red as main color tone, yellow as secondary color tone	Light or phone as the main part

5. Experiment 3: Industrial icon search with spatial layout as visual marking

5.1. Experiment design

The materials of experiment 3 were also selected from 70 icons, and the icon layout was divided into regular layout and chaotic layout from the perspective of overall spatial layout , and the icon layout was divided into orderly arrangement A, orderly arrangement B, disorderly arrangement C, and disorderly arrangement D from the locally spatial layout. The color setting of stimulus materials was the same as experiment 1.

The independent variables(stimulus variables) of Experiment 3 were divided into 2 groups: overall spatial layout(regular layout, chaotic layout), and locally spatial layout(ordered arrangement A, ordered arrangement B, disordered arrangement C, disordered arrangement D). The experimental dependent variable(response variable) was the reaction time of the subjects. The experiment used a 2×4 mixed factorials experimental design , in order to ensure the validity of the behavioral experimental data, additional repeat groups were set up for a total of 16, and the experimental procedure is shown in figure 6.

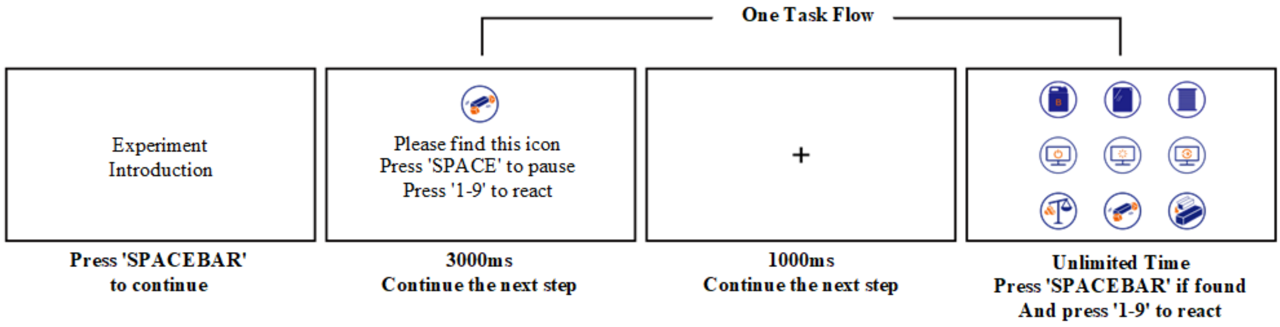


Figure 6. Experimental procedure.

5.2. Experimental equipment and subjects

The experimental equipment and subjects were selected as in experiment 1, and 30 college students with engineering background were selected as subjects.

5.3. Experimental results and data analysis

First, the data of incorrect responses and the data of target not founded from the subjects were removed, and the data beyond 3 standard deviations were removed using the response time's mean value as a reference, for a total of 1.4% of the data.

(1) Levene test of equality of error variance. The significance of the response time's mean value in the Levene test for the response time's mean value data($P=0.082$, $p>0.05$) proved the null hypothesis that the error variances of the dependent variables are equal in each group holds, satisfying the homogeneity of variance and allowing further ANOVA to be carried out, as shown in table 11.

Table 11. Levene test of equality of error variance.

Time	F	df 1	df 2	p
Based on the Mean	3.236	3	8	0.082
Based on the Median	3.214	3	8	0.083
Based on the Median with Adjusted Degrees of Freedom	3.214	3	2.162	0.233
Based on the Truncated Mean	3.235	3	8	0.082

(2) Main effect test. The main effect test on the response time of the two experimental variables of overall layout and partial layout is shown in table 12. The significance of overall layout(P=0.000, $p<0.05$) indicates that the difference in overall layout has a significant effect on the response time; the significance of partial layout(P=0.045, $p<0.05$) indicates that the difference of the partial layout has a significant impact on the response time; two variables interact in pairs and the overall layout interacted with partial layout(P=0.486, $p>0.05$) when the effect on reaction time was not significant.

Table 12. Main effect test.

Dependent Variable: Time	Test of Between-subjects Effects				
Source	Type III Sum of Squares	df	Mean Square	F	p
Modified model	469598.917a	3	156532.972	45.127	0.000
Intercept	49179154.08	1	49179154.08	14177.774	0.000
Overall Layout	448146.750	1	448146.750	129.195	0.000
Partial Layout	19602.083	1	19602.083	5.651	0.045
Overall Layout*Partial Layout	1850.083	1	1850.083	0.533	0.486
Error	27750.000	8	3468.750		
Total	49676503.00	12			
Corrected Total	497348.917	11			

a. R^2= .944（adjusted R^2= .923）

(3) Data analysis. The experimental results show that the search time of regular layout is lower than that of chaotic layout; the search time of orderly arrangement layout is lower than that of disorderly arrangement layout. When the overall spatial layout was regular and the locally spatial layout was orderly arrangement A, the subjects took the shortest time to search for the target, and when the overall spatial layout was chaotic and the locally spatial layout was disorderly arrangement D, the subjects took the longest time to search for the target, as shown in figure 7.

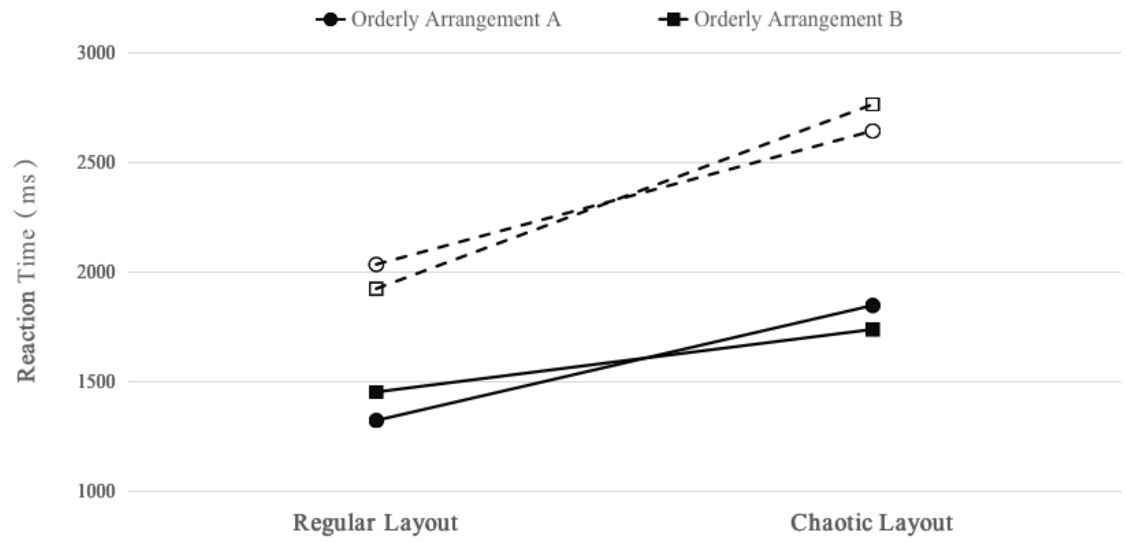
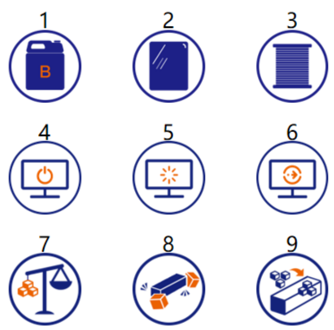


Figure 7. Response times between groups for different spatial layout icons.

5.4. The inhibitory effect of spatial layout as visual marking in industrial icons

In order to investigate the inhibitory effect of visual marking in the spatial layout of industrial icons, the data from the repeat groups were combined and only focus on the spatial layout of icons, with 8 sets of experiments, as shown in table 13.

Table 13. Comparison of groups.

Experimental Groups	Target	Presentations	Spatial Layout
01	 Production Icons		Production icons are orderly arranged as combination A,distributed horizontally and centrally in a regular layout, and their coordinates are 7, 8, and 9；

02

Equipment Icons

Equipment icons are orderly arranged as combination B,distributed vertically and centrally in a regular layout, and their coordinates are1, 4 and 7;

03

Monitoring Icons

Monitoring icons are disorderly arranged as combination C, distributed randomly in a regular layout, and their coordinates are 2, 6 and 7;

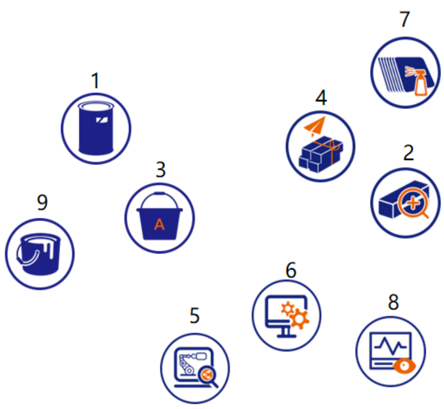
04

Equipment Icons

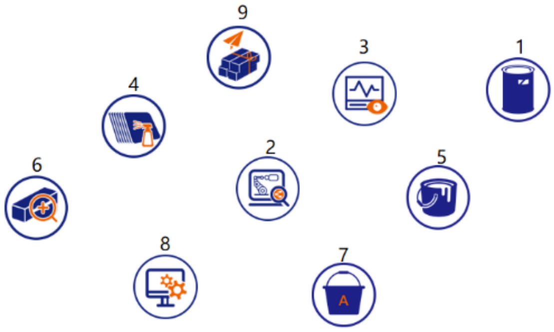
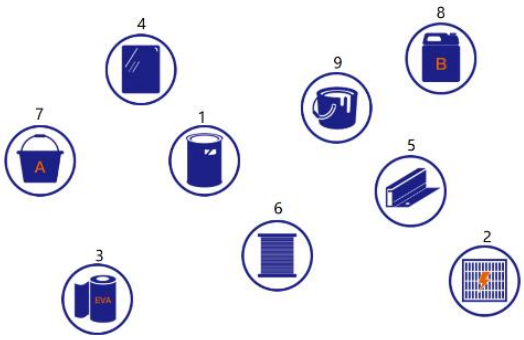
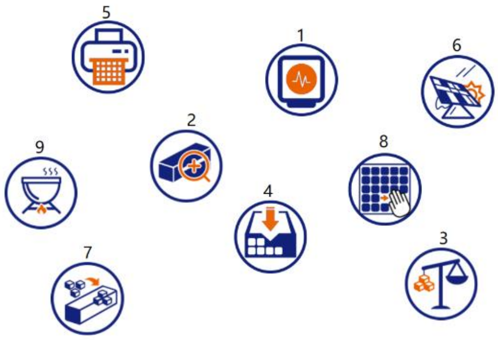
Equipment icons are disorderly arranged as combination D, distributed randomly in a regular layout, and their coordinates are 1, 8 and 9;

05

Production Icons



Production icons are orderly arranged as combination A, planar distributed in a irregular layout, and their coordinates are 2, 4 and 7;

06	 Monitoring Icons		Monitoring icons are orderly arranged as combination B, linearly distributed in a irregular layout, and their coordinates are 3, 2 and 8;
07	 Equipment Icons		Equipment icons are disorderly arranged as combination C, distributed randomly in a regular layout, and the target coordinate is 9;
08	 Production Icons		Production icons are disorderly arranged as combination D, distributed randomly in a irregular layout, and the target coordinate is 3;

According to the experimental results, the overall spatial layout of experimental group 01, 02, 03, 04 should be characterized by 3×3 regular layout, and subjects followed the visual search rule when searching for the target, which is from top to bottom and left to right, until they found the target after one by one searching; the overall spatial layout of experimental group 05, 06, 07, and 08 should be characterized by chaotic layout, the arrangement was not regular, and the subjects appear to repeat the search action,using a rather long time. Therefore, the irregular icon layout will inhibit the subjects' visual search efficiency.

According to the spatial layout of the experimental groups, it is known that when the target has a specific spatial relationship with the presented objects in the same category, such as orderly arrangement A(horizontally and planar concentrated distribution) and orderly arrangement B(vertically and linear concentrated distribution), the subjects' visual search efficiency will be higher than the spatial layout of disorderly arrangement C and disorderly arrangement D.

6. Discussion

6.1. Comparison of characteristics and category inhibition of industrial icons

According to experiment 1, it is concluded that in addition to the location-based kind, the inhibitory mechanism in the visual marking theory also includes the information-based inhibitory mechanism. 2.5D icons have better visual search efficiency than flat icons, and complex icons have better visual search efficiency than simple icons, and the visual search efficiency decreases as the difficulty of the task increases. In the aspect of icon style, 2.5D icons inhibit the expression of flat icons, giving 2.5D icons a higher visual search efficiency; in the aspect of icon complexity, complex icons inhibit the expression of simple icons, giving complex icons a higher visual search efficiency.

According to experiment 2, it is concluded that in addition to the location-based and feature-based kinds, the inhibitory mechanism in the visual marking theory also includes the semantic category-based inhibitory mechanism. When the category of the icon is 'warning', the response time is shorter and the cognitive efficiency is higher compared with other icons. The four different categories in order of inhibition are warning, monitoring, equipment and production. The icons of the same category have the same information characteristics in terms of icon style and icon complexity. Based on the above analysis, the priority ranking of industrial icon category inhibition was conducted in four perspectives of icon style, icon complexity, icon characteristics, and inhibitory strength, as shown in table 14.

Table 14. Priority analysis of category inhibition.

Category	Style	Icon Complicity	Characteristic	Inhibition Intensity Priority Ranking
Production Icons	2.5D	Complex	Accompanied by movements	Level 4
Equipment Icons	Flat	Simple	With tool visualized	Level 3

Monitoring Icons	Flat	Simple	Elements on display	Level 2
Warning Icons	Flat	Simple	With alarm and phone	Level 1

Inhibitions are not consistent with the relevant findings in that of feature-based inhibition. Taking production and warning icons as examples for comparative analysis, the style of production icons is 2.5D and complex, while that of warning icons is flat and simple. In the icon searching experiment, the efficiency of warning icons is much higher than that of production icons, and warning icons will inhibit the expression of production icons, which indicates that the priority of industrial icon category inhibition is higher than that of feature-based inhibition. The icon category is divided from people's habits and cognition, combined with relevant knowledge and experience, and the information characteristics are divided and matched according to the specific information of icons.

6.2. Spatial layout inhibition of industrial icon and the cluster relation

According to experiment 3, it is concluded that in addition to the location-based, feature-based and icon category-based kinds, the inhibitory mechanism in the visual marking theory also includes the spatial layout-based inhibitory mechanism, and the regular layout inhibits the chaotic layout ,while the orderly arrangement inhibits the disorderly arrangement. The different spatial layout to which industrial icons belong has a significant effect on the visual search efficiency of icons. When the overall spatial layout of icons is regular and the locally spatial layout is orderly arrangement A, the subjects' reaction time is shorter and the cognitive efficiency is higher compared with other spatial layouts. The closer the location of icons in the same category, the more obvious the information characteristics and semantic categories, the stronger the correlation between the targets, the more significant the icon cluster relationship, the higher the icon visual search efficiency.

Meanwhile, the main difference between ordered arrangement and disorderly arrangement is whether the target has a cluster relationship with other icons in the task interface. The cluster relationship between icons is determined by the characteristics of location, information and semantic category of icons. When the target has a specific spatial relationship with the interferents of the same category, for example the icons of the same category show horizontal concentrated distribution, vertical concentrated distribution, face concentrated distribution and line concentrated distribution, the cluster relationship between icons will generate and the operator will prioritizes retrieval of this cluster based on the characteristics of the target.

6.3. Correlation of industrial icons and inhibitory mechanisms

There is a certain correlation between the industrial icons' inhibition of feature, category and spatial layout, as shown in figure 8. This correlation is reflected in the fact that the priority of the category inhibition is higher than that of feature, and the inhibition of spatial layout is jointly influenced by feature and category, among which the inhibition of category plays the main role. In the aspects of industrial icon feature inhibition, 2.5D icons inhibit the visual search of flat icons , and complex icons inhibit the visual search of simple icons; In the aspects of industrial icon category inhibition, the inhibition from strong to weak order is warning, monitoring, equipment, production. In the aspects of industrial icon spatial layout inhibition, regular layout will inhibit the visual search of chaotic layout, and orderly arrangement will inhibit the that of disorderly arrangement.

In the comparative analysis of orderly arrangement and disorderly arrangement, it is found that in the orderly arrangement spatial layout, the target has a specific clustering relationship with other icons in the task interface, and this clustering relationship is jointly determined by the location, information characteristics(style, complexity), and category of industrial icons, in which the category plays an important bonding role, and icons of he same category have the same information characteristics(style, complexity), and the closer the icons of the same category are to each other, the more obvious the clustering relationship is, the higher the visual search efficiency is, and the stronger the inhibition of icons with no cluster relationship is.

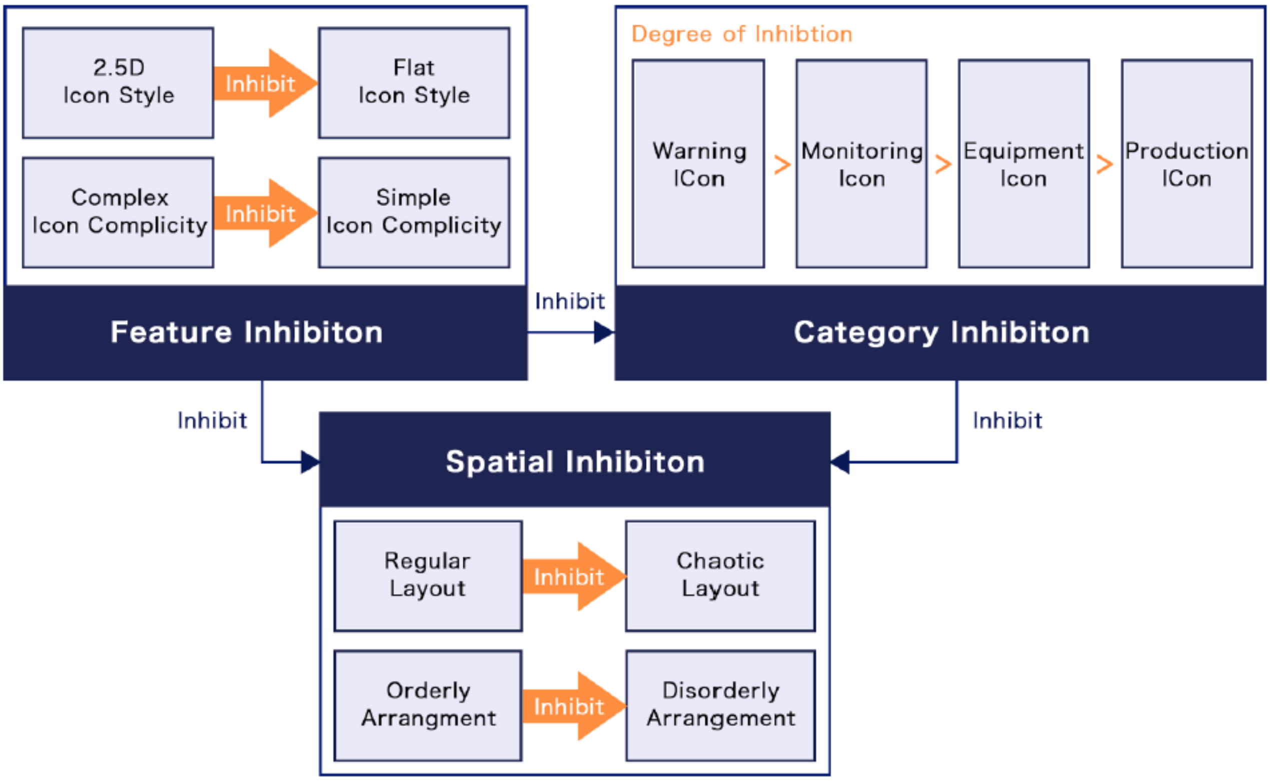


Figure 8. Industrial icons search for experimental inhibitory mechanism relationships.

7. Conclusion

Based on the related theory of visual marking, we explored the concept of visual marking mechanism, experimental paradigm, inhibition mechanism, and the relationship between inhibition mechanism in visual marking and industrial icons in this paper. Using the psychological behavioral response experiments to analysis the relationship between inhibition mechanism of visual marking and information characteristics, semantic category and spatial layout of industrial icons. This paper mainly discussed the influence of the inhibition mechanism of visual marking on the visual search of industrial icons through experiments. However, this article is not quite as comprehensive as the lack of anthropomorphic and 3D icon style, and the polarized division of simple and complex. The future subsequent experimental investigation can be consider for the refinement of industrial icons and the icon complexity of different perspectives to establish a more perfect guideline and specification for the design of intelligent production control system icons.

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