THE INFORMATION SEEKING NAVIGATION INTERFACE WITH SPATIAL ICONS FOR CHILDREN

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ABSTRACT: *This study is to develop an Information Seeking Navigation Interface with Spatial Icons for children. Designing a way-finder in Human–computer Interaction (HCI) will make seeking information easier for children. Developing a spatial icon-seeking interface can assist children as they explore digital learning. It is for this reason that we designed a new user interface in 3D which assists the human user in seeking information through the way-finder. The original idea of this study arose from the fact that humans have different spatial abilities, and that means humans should benefit from using a mental map before searching for information on the Web. Children have limited information-searching skills and exhibit different information seeking behavioural patterns through different media-type interfaces. The field testing part of this study was done at Taiwan's National Library of Public Information using its resource database.*

Taking into account the varying spatial abilities in children, this study uses three research impact factors: (1) Spatial Visualization; (2) Associative Memory; and (3) Spatial Memory. With a focus on these three factors, the recording of the experiment data, which was taken from elementary school students ageing from 7 to 11 years old, was conducted. The goal of this study is to assist children in building a mental map from this user interface.

Through usability testing and statistical analysis, we not only can better understand the way children use the spatial iconography seeking interface, but also the underlying cognitive theory, and find out how the way finding behaviour emerges. The spatial information search system can be used as an information base to improve the development of the spatial Interface design.

KEYWORDS: *Information seeking habits of children, child spatial cognition, HCI*

1. INTRODUCTION

Children have difficulty seeking information on the Web, because of their underdeveloped motor skills, difficulties with spelling, as well as their trouble understanding hierarchies, classification schemes, and metadata. The concepts of different search engine interfaces for children include designs with a variety of iconography, metadata, and hierarchies. These designs, such as Boolean Identification and hierarchical memory, aim to cater to the varying abilities of children in order to assist them in their search for information on the Web (Martens, 2012).

This study presents a Virtual Reality (VR) interface to help children search for information on the Web, by engaging the child's cognition ability and creating a three-dimensional experience. Based on the characteristics of the intuitive operation and visual preferences of young children, concepts of way-finding, information visualization and linkage of digital databases were explored in order to create a game-like interface for children searching for information. However, since children possess different kinds of spatial abilities, these varying spatial abilities influence their way-finding strategies and how they search for correct information in the VR interface.

2. CONCEPT AND MODEL

2.1 Information Behavior of the Child

Hutchinson et al. (2007) explained that many interface designs for children are in fact unsuitable for the average child's skill limitations and cognition preferences. Children can use Boolean queries in a category browser, but they have to focus on the assigned topics to navigate Web sites sequentially, in a top-down hierarchy and branching structure. This searching information mode is too complex process for children to grasp without difficulty. As a result, Hutchinson et al. (2007) recommended a plane, multifunctional interface design that

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would help children search and browse for information on the Web.

Hutchinson et al. (2007) designed the International Children's Digital Library (ICDL), and applied many concepts, such as age, color, story role, award record, and book type to help children easily search for digital books. The core idea of the ICDL interface design was to combine queries of metadata interpretations. Wu (2012) suggested to have information nodes arranged in an extended 2D VR interface for digital databases so that children may search for information in a less-hyperlink intensive, less memory burdening environment. The effect of children using the 2D VR interface was better than that of the text-line interface of the National Public Library of Information in Taiwan. However, there is still an opportunity to explore the information seeking behaviour of children in this VR interface, which extends the interface from 2D into a 3D virtual environment.

2.2 Path finding Strategy and Mental Map

Downs and Stea (1973) noted that a pathfinder, in the route searching process, instead of just taking into account the distance between its present location and destination in a single route searching operation, it will take into account the changes in its surrounding environment and resulting mental thought process will result in a revision of the searching strategy.

Passini (1995) identified the three mental operations of the way-finding process as obtaining information, processing information, and correcting behaviour. These operations combine with the linear tree-hierarchy concept to define the way-finding mental map.

Spence (1999) noted that the navigation cognition includes browsing, formation of the model, interpretation of the model, and formation of the browsing strategy. Chase and Chi (1985) suggested that the way-finding process requires spatial knowledge (a mental map), which consists of two categories: route spatial knowledge and survey spatial knowledge. Route spatial knowledge was defined as a subject's ability to execute a mission with correct event order, as well as the memory recalled as knowledge needed for the event's execution. Survey spatial knowledge was defined as a subject's organizing activities for the event's execution, and the subject's mental cognition of the whole network frame in a task. The survey-oriented subject executed a way-finding mission with strategies based in a cartesian-coordinate setting, while the route-oriented subject executed one based in a relation-coordinate setting (Lawton, 1994, 1996; Cooper, 1976; Janzen, Kitchin,1997；Chang, 2008；Schade, & Herrmann, 2001).

Lawton (1996) suggested that the two kinds of way-finding knowledge, spatial location and the searching strategy, are not entirely independent of each other. One possible reason could be that the individual subject was not solely reliant on a single form of way-finding knowledge, but switched between two forms of knowledge according to the actual situation or needs of the subject (Kyllonen, Lohman,&Woltz,1984). Sadeghian, Kantardzic, Lozitskiy, & Sheta, (2006) pointed out that way-finders, even with overview support, still search based on their route knowledge.

Diverting from the way-finding idea, Kim (1999) in his information seeking study, suggested to combine the topological structures of the hyperlink and the navigation-aided concepts in order to improve the disorienting nature of the interface design. Richard Anderson (2002) argued an information schema should include a structure concept and navigation concept in order to design a system that matches the content with the human-computer interaction.

Therefore, the order of doing things (routing strategy-hierarchy) and organizational ability (mental map-network) affect the way-finder's behaviour. Although the subject may apply the survey spatial knowledge to deal with many functional units in a jumping and non-linear operating manner, too many functional units also contribute to an information overload condition. While the subjects can easily apply the route spatial knowledge approach to navigate the web, with its simple functions and lower information load, they may face breakdown problems with its incomplete informational structure.

2.3 Spatial Capacity – Child Sample Ability Definition

A child's exploratory behaviour using the VR interface to find desired information will be influenced by his or her survey and route spatial knowledge, as well as his or her ability to apply the knowledge. Garden, Cornoldi, and Logie (2002) suggested that the basic cognitive load for way-finding is not working memory, but a special kind of memory, known as Virtual-Spatial Working Memory (VSWM).

Spatial capability refers to a person's ability to produce, retain, extract and transform a visual image into a functional format (Lohman, 1988). Spatial capability is not an isolated skill, but includes a number of factors (Linn & Peterson, 1985; McGee, 1979). McGee (1979) suggested that spatial capability includes two major components: spatial visualization and spatial orientation. Carroll (1993) suggested five factors influencing spatial capability, namely, space imagination, spatial relation, vision-spatial perceptual speed, closure speed, and closure flexibility.

Miyake, Friedman, Rettinger, Shah and Hegatry (2001) developed a way to measure spatial capability. They took into consideration the research of Carrol and used the three most frequently cited factors – spatial imagination, spatial association, and speed of visual-spatial perception – as the indicators of spatial capability.

S.J. Westerman (2005) suggested that cognitive ability influences how a spatial interface is used and made reference to the cognition scale developed by Ekstrom et al. (1976). The spatial visualization, the spatial memory, and the associative memory for graphics were set as the measurement scales. Spatial visualization (VZ) tests, include the VZ-Form Board Test, VZ-Paper Folding Test, and VZ-Surface Development Test. Spatial memory (MV) tests include the MV-Building Memory Test, MV-Map Memory Test, and MV-Shape Memory Test. Associative memory (MA) tests includes the MA-First & Last Name Test, MA-Object-Number Test, and MA-Picture-Number Test.

However, when a child subject operates a VR interface to seek information, he or she does not need to engage in physical movement and has no hyposthenia limitation. Thus, the research model was set by applying the VZ, MV, and MA scales to measure the child's reactions in the VR interface as he or she searched for information. The VZ scale was used to measure the child's cognition speed; the MV scale was used to measure the child's mental map and ability in location repositioning. The MA scale was used to measure the child's memory of icons (information nodes) and the associated recognition of the digital database. Thus, the child's interaction with the different VR interfaces, their mental mapping abilities, and information seeking behaviour can be measured by this investigation as outlined in Figure 1 below.

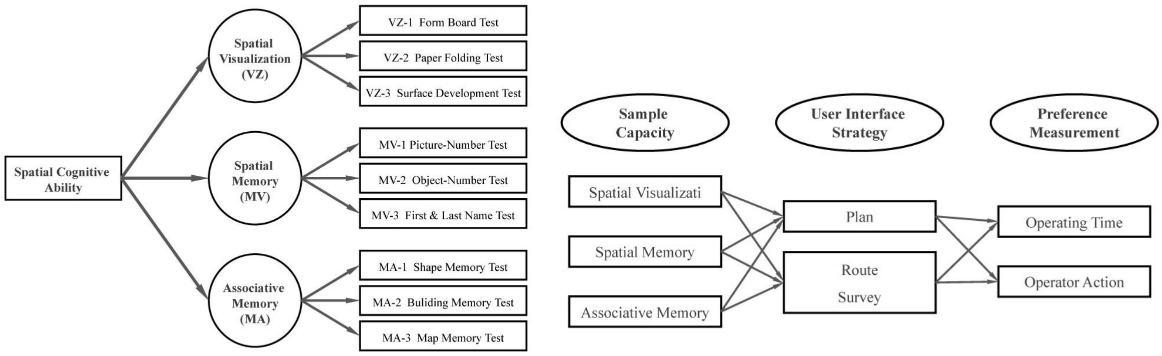

Fig. 1: Spatial ability factors and the use of measurement tools.

3. METHOD

3.1 ANOVA Analysis

The measurement groupings were put in place to distinguish between the differences in spatial abilities of the student subjects. How well they were able to replicate pictures is an example of one such spatial ability that was taken into consideration. An ANOVA (or independent sample T-test) was used to detect if the subjects with their different levels of spatial ability behaved differently as they operated the three different interfaces. This user behaviour was measured for its performance efficiency and effectiveness. Performance Efficiency measured the time used by the subject student to operate the interface and retrieve the information they sought from the database. Effectiveness measured the amount of movement, rotating and mouse clicks that was required to the retrieve information in a ratio with the total amount of those actions that took place (See Table 1).

$$F = \frac{2}{\frac{1}{r} + \frac{1}{p}}$$

The formula is defined as follows:

Effectiveness (EFT) was assessed using an F statistic (harmonic mean) that incorporates variables for recall and precision, where r = recall and p = precision.

Table 1: Interface strategies using the performance parameter design

Time Taken	Time (seconds) spent in the retrieval process per single task
Distance Traveled	In the process of adding 'noise' to create 80% and 60% solutions, some unwanted variation in average inter-document distance was introduced. Therefore, measures of distance travelled were scaled by an appropriate value.
Amount of Rotations	A special feature of the virtual reality spatial environment. Calculated the number of times when the right button of the mouse was clicked by the user to make a rotation.
Total Number of Nodes Visited	Recorded the total number of right or wrong mouse clicks (nodes).
Number of Different Nodes Visited	Recorded the total number of times the wrong number was clicked (node errors).
Lost State	The ratio of the number of nodes visited to the number of unique nodes visited.
Recall	Number of relevant documents retrieved expressed as a proportion of the total number of relevant documents.
Precision	Ratio of relevant documents retrieved to irrelevant documents retrieved.
Effectiveness	Effectiveness (EFT) was assessed using an F statistic (harmonic mean) that combines recall and precision: where r = recall and p = precision.
Performance Efficiency	Performance efficiency (EFY) was assessed by the ratio of (EFT) to time taken.
Self-report	Self-report workload.

Using information from the data about the cognitive ability scale of children, which is an internal factor and navigation design and way-finding, which are external factors, the questionnaire scale design was designed. In this study, a number of definitions were made. Table 2 lists the impact factors of the experiment. There were a total of three search interfaces used. One of them was a navigation-strategy interface: 'GUI-Hyperlink (GH Interface)'. The other two were way-finding strategy interfaces: 'Extended-Survey (the ES interface)' and 'Extended Route (ER interface)'.

Table 2: The search interface nouns classification relational tables

Type	Search interface	Abbreviation	Factor	Interface	Tactics
Graphic User Interface	GUI-Hyperlink	GH	Usability	Navigation	Hyperlink
Spatial User Interface	Extended-Survey	ES	Efficiency	Way finding	Survey
	Extended-Route	ER			Route

In accordance with the data and literature outlining the research issues and impact factors, as shown in Figure 2, the first part of the experimental design was to use a 'flat-image' search interface and a 'spatial-image' search interface in order to do a comparative analysis. This first part also included the spatial interfaces of two different way-finding strategy designs; the second part, which is related to the internal factor of cognitive ability, was to find and understand the cognitive factors that affect the way children use a graphical search interface when way-finding.

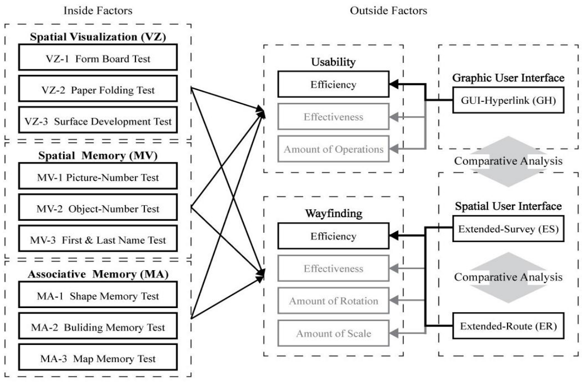

Fig. 2: Structure of Related Factors

3.2 Factor Assumptions

See Table 3 below for the list of experimental design factor assumptions.

Table 3: The factor assumptions of this study.

H1	When children search for information, there is a difference in the efficiency level between those using plane (GH) and spatial (ES, ER) interfaces.
H2	When children search for information, there is a difference in the effectiveness level between those using plane (GH) and spatial (ES, ER) interfaces.
H3	When children search for information, there is a difference in the amount of operations performed between those using plane (GH) and spatial (ES, ER) interfaces.
H4	When children search for information, there is a difference in the amount of operations performed between those using the two kinds of spatial (ES, ER) interfaces.
H5	A child's search efficency when using the plane (GH) and space (ES, ER) interfaces is affected by his or her spatial visualization ability (VZ-1 and VZ-3).
H6	A child's search efficency when using the plane (GH) and space (ES, ER) interfaces is affected by his or her associative memory capacity (MA-1 to MA-3).
H7	A child's search efficency when using the plane (GH) and space (ES, ER) interfaces is affected by his or her spatial memory ability (MV-1 to the MV-3).
H8	A child's search effectiveness when using the plane (GH) and space (ES, ER) interfaces is affected by his or her spatial visualization ability (VZ-1 and VZ-3).
H9	A child's search effectiveness when using the plane (GH) and space (ES, ER) interfaces is affected by his or her associative memory capacity (MA-1 to MA-3).
H10	A child's search effectiveness when using the plane (GH) and space (ES, ER) interfaces is affected by his or her spatial memory capacity (MV-1 to the MV-3).
H11	With children of different spatial visualization abilities (VZ-1 and VZ-3), the efficiency of the use of the plane (GH) and space (ES, ER) interfaces varies.
H12	With children of different associative memory capacities (MA-1 to MA-3), the efficiency of the use of the plane (GH) and space (ES, ER) interfaces varies.
H13	With children of different spatial memory abilities (MV-1 to the MV-3), the efficiency of the use of the plane (GH) and space (ES, ER) interfaces varies.

3.3 Information on the Study Samples

This study involved a sample of 281 subjects, 255 of whom returned valid results – a recovery rate of 91%. As shown in table 4, there were a total of 12 test groups and the subjects were second to fifth grade elementary school students who had an age distribution between 7 and 11 years old. The students were from Zhongzheng Elementary School in New Taipei City, Wanxing Elementary School in Taipei City, and Wenchang Elementary School in Taipei City.

Table 4: Subject distribution according to grade:

Grades	Classes	Number of Classes	Percentage
Second Grade	2	46	18%
Third Grade	3	65	25%
Fourth Grade	3	67	26%
Fifth Grade	4	77	30%
Total	12	255	

The subjects were divided into three groups, each using only one of the three search interfaces. This was done in order to avoid having a learning effect that would influence the performance of the subjects. The number of subjects using each interface and the corresponding proportions are listed in table 5 below.

Table 5: The number of people in the three interface test groups

Searching Interface	Number of Subjects	Percentage
GUI-Hyperlink (GH)	128	50%
Extended- Survey (ES)	64	25%
Extended- Route (ER)	63	24.7%
Total	255	

3.4 Experimental Task Design

During the experiment, the system automatically prompted the test subject with three tasks of collecting information. At the onset of the experiment, the purpose for conducting the experiment was explained to the test subjects. Afterwards, the test subjects were left alone, receiving further guidance from the system itself on the goal of each task and how to operate the interface. The system automatically detected the subjects' output, and recorded the user's operating parameters.

In this study, the main goal was to monitor the performance of the test subjects as they operated the National Taichung Library search interface. As the subjects used the interface, they were tasked to find themed material from the database. After the test subject thought that he or she had found the correct, sought-after information, he or she clicked the 'found' button, the system automatically determined if what was found was actually the target information. During the experiment, those administering the experiment used encouragement to guide the behavior of the subjects. If a subject paused for too long, they would be encouraged with kind's words, like, "It's OK! Don't Worry!" This part of the experiment took into consideration the research of Caicheng You (2011), which suggested that a child's most likely motivating factor for seeking information is 'school work', while the second most likely motivating factor is 'recreation'.

3.5 Experimental Instruments

Task 1: If the subject encountered a problem while searching for the ecological-related information, the teacher responded by telling him or her to search for reference information through the 'ecological notes database'. They then tried to locate the database using the interface.

Task 2: If the subject encountered a problem while searching for the target pictures and images, the teacher responded by telling him or her to browse the 'Tsai Comics animated series database'. They then tried to locate the database using the interface.

Task 3: If the subject encountered a problem while searching for the sports-related information, the teacher responded by telling him or her to locate the 'animated album for international sports competitions'. They then tried to find the album using the interface.

The design process was divided into four parts: the transformation of the flat-screen interface into a virtual reality space; the conversion of the flat-screen navigation design into the spatial navigation, way-finding design; the 'spatial-graphic' search interface design was divided into overview and route navigation in accordance with the development of the functional properties of the two types of interfaces; and the final part was to take the results of the second and third parts, understand them and make them more practical.

Fig. 3: National Taichung Library Children's Digital Resource Portal visual design

For the sake of experimental accuracy, the new version of the spatial icon information interface design (Figure 4) was based on the current children's Digital Resource Portal planar interface (Figure 3). Virtual Reality technology was used to build a 3D world. The color and style used are the same as those of the National Taichung Library interface.

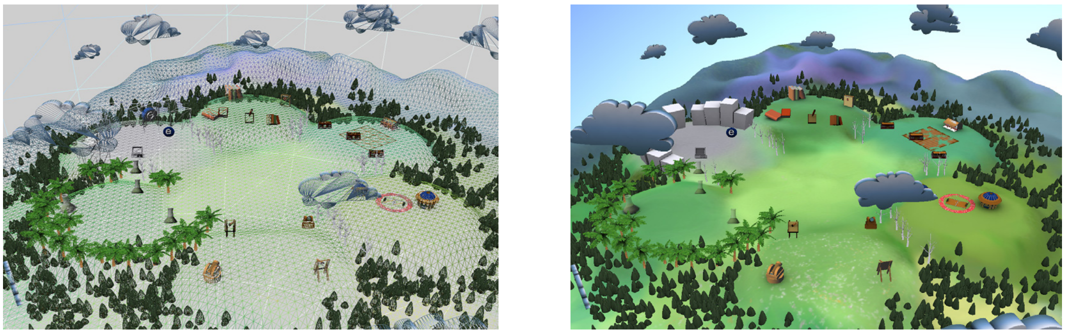

Fig. 4: Spatial icon information' interface, 3D World construction - line composition and the actual scene illustration.

4. DISCUSSION AND ANALYSIS

4.1 Comparison of the GH, ES, ER search interfaces

Table 6, Table 7, and Table 8 show how the three search interfaces (GH, ES, ER) compare in terms of efficiency. The tables list the average time spent to successfully perform a task, as well as the ANOVA, which allows for further insight into the significance of the results. The average time required by a subject to perform each task using the ES interface was less than that of the one using the ER interface. Furthermore, subjects using the GH interface had the shortest task performance time. This is in line with how its hyperlink functions offer quick link ups and shorten the time elements involved. The three tasks have significant differences ($p < .001$), therefore accept H1 assumptions.

Table 6: Task 1 - Efficiency use - comparative analysis (GH)

Interface	Numbers	Average	Standard Deviation	Standard Error	Minimum	Maximum
GH	128	80.16	115.542	10.213	6	827
ES	64	94.88	89.423	11.178	9	493
ER	63	149.63	126.613	15.952	23	567
Significant	p<.001					

Table 7: Task 2 - Efficiency use - comparative analysis (ES)

Interface	Numbers	Average	Standard Deviation	Standard Error	Minimum	Maximum
GH	128	44.05	40.367	3.568	8	264
ES	64	66.06	64.777	8.097	7	296
ER	63	123.70	110.246	13.890	16	505
Significant	p<.001					

Table 8: Task 2 - Efficiency use - comparative analysis (ER)

Interface	Numbers	Average	Standard Deviation	Standard Error	Minimum	Maximum
GH	128	14.64	21.931	1.938	5	203
ES	64	18.44	19.364	2.420	4	117
ER	63	40.19	27.942	3.520	11	172
Significant	p<.001					

4.2 Plane and Spatial Search Interfaces

The result of the experimental data analysis shows that 'plane-image' interface and the 'spatial-extendable' interface of formula" have variation in the outcomes of various performance factors (efficiency & effectiveness). In terms of efficiency, the main cause for the disparity was 'time'. This issue has been identified before by Patrick J. Lynch. Hyperlink based search interfaces create a 'page to page' search process. While way-finding based search interfaces create a 'node to node movement' process. The key advantage to a way-finding based one is that it allows for this movement experience. Whereas, when using a hyperlink based one, there is much allowance for spatial movement.

4.3 Cognitive Ability and User Efficiency

Besides developing a better understanding of how the different graphic and spatial search interfaces are used, statistical analysis of the experimental results was done to determine the different effects a child's cognitive ability has on user efficiency. As shown in Figure 5, a single-factor analysis of the 'flat-image' interface showed variance in results among the children. While, a likewise analysis of the 'spatial-extendable' interface had similar results. Yet, there were differences in the results related to the subject's cognitive ability, such as how the subject's memory capacity (MA & MV) influenced efficient use of the 'flat-image' interface, but not that of the 'spatial-extension' interface. In addition, the 'Map Memory Test (MA-3)' found differences in the efficiency of the use of three search interfaces.

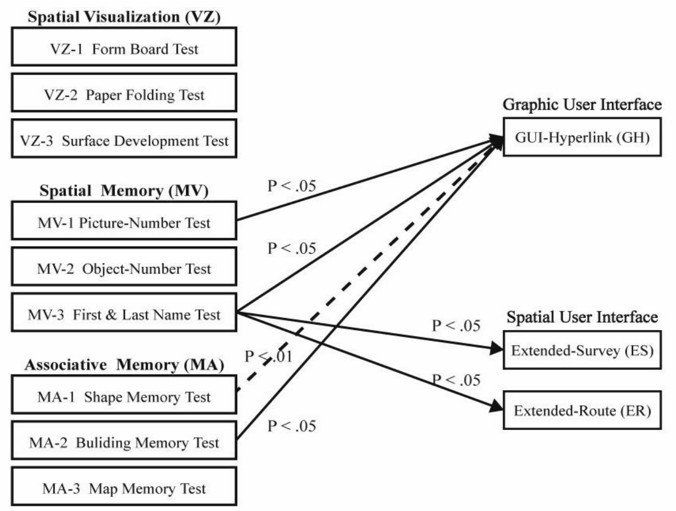

Fig. 5: Significant impact factors that affect the level of efficiency of the interface through the varying cognitive ability of children.

The design attempts to load images and text with different information in the 2D and 3D interfaces, which significantly differ because of their respective spatial capabilities. The grouping of subjects with different spatial capabilities had an impact on the use of the interfaces.

5. CONCLUSION

The first focus point of this study was to incorporate navigation and route functions into a search interface, as they are two different kinds of measuring tools. The second focus point of this study was to measure the spatial ability of the children and classify them according to those abilities. The third focus point of this study was to give children way-finding tasks using an information search interface and measure the performance results.

When comparing the three kinds of search interfaces - 'GUI-Hyperlink (GH Interface)', 'Extended-Survey (the ES interface)' and 'Extended-Route (ER interface)' - pros and cons were found for all. The GH Interface was used the most efficiently. The ES interface was used with the most effectiveness. The Zoom View function was used the best in the ER Interface. The amount of operations performed with each interface was neutral. Comparatively speaking, the spatial- overview and route interfaces have different impacts on the different functions of spatial navigation, rotation, and scaling.

(1) The 'Associative Memory (MA)' capacity will be stimulated more by a 'flat-graphics' interface with more effectiveness and efficiency. (2) 'Mental Rotation (VZ-3)' will be caused more by an 'overview-strategic' interface. (3) The three kinds of Mental Rotation associated with 'Spatial Visual Abilities (VZ)' were not found to have any association with effective and efficient use.

To some extent, cognitive capacity can be associated with effective and efficient use, but the other operations of other performance factors, such as the number of rotations can be influenced by other factors. This study suggests that the 'spatial-rotation' ability is influenced by a different factor. In regards to 'Spatial Navigation', different rotation and scaling technology have been put together. In the present study, no correlation was identified between the scale part number and cognitive ability. There is opportunity for follow-up research to explore this aspect.

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