The Effect of Icon Semantic Distance on Preschool Children's Information Search: Evidence from an Eye-Tracking Study

Jiaqi Yang
Department of Information Management
Peking University
Beijing, China
2100016627@stu.pku.edu.cn

Pianran Wang†
Department of Information Management
Peking University
Beijing, China
pianranw@pku.edu.cn

ABSTRACT

Icons are frequently employed in children-oriented information systems due to children's limited literacy. However, the inherent semantic distances of icons, which may influence their affordance to children, are often overlooked in the development of such systems and related research. In this study, we apply semantic distance to measure the explicitness of icons in children-oriented book search, utilizing self-developed icons tailored for indexing picture books. We first gathered data from children through questionnaires to assess the perceived semantic distance of each icon. Subsequently, we conducted eye-tracking experiments with 50 preschool children, measuring their search accuracy, response time, and eye movement patterns while using icons to locate specific picture books. Our findings indicate that preschool children are easier to use icons with close semantic distance and single icons for searching. Additionally, the ability to use icons with distant semantic distances and combination icons significantly improves with age. These findings may contribute to the development of more effective and children-friendly information search systems.

CCS CONCEPTS

• Human-centered computing~Interaction design • Information systems~Information retrieval~Users and interactive retrieval • Human-centered computing~Human computer interaction (HCI)~Empirical studies in HCI

KEYWORDS

Icons, Semantic distance, Preschool children, Information search system

CIKM '24, October 21-25, 2024, Boise, ID, USA

ACM ISBN 979-8-4007-0436-9/24/10
https://doi.org/10.1145/3627673.3680001

ACM Reference format:

Jiaqi Yang and Pianran Wang. 2024. The Effect of Icon Semantic Distance on Preschool Children's Information Search: Evidence from an Eye-Tracking Study. In *Proceedings of the 33rd ACM International Conference on Information and Knowledge Management (CIKM '24), October 21–25, 2024, Boise, ID, USA.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3627673.3680001

1 INTRODUCTION

Due to children's limited literacy, icons are widely used in children-oriented information systems [1-4]. These systems take children's cognitive characteristics into account, but ignore the impact of icons in the search. Studies have shown that the characteristics of icons can influence the cognitive process when using icons to search. Semantic distance is an important cognitive attribute of icons, denoting the degree of correspondence between the icon and the functional meaning it conveys [5]. And variations in semantic distance, whether close or distant, can yield disparate affordance effects [6-9]. However, this aspect is frequently overlooked in the development of relevant systems. Therefore, this study aims to explore the effect of icon semantic distance on children's information searching, in order to furnish theoretical underpinnings for the design of child-centric information searching systems.

Children have information needs and distinctive search strategies. But children's abilities are too limited to articulate their information needs, let alone to form searching strategies at the level of adult users [10]. To this extent, most information systems are non-child-friendly. Picture books serve as the primary reading material for young children, who frequently search for them. However, the majority of library information searching systems prove too complicated for children to comprehend independently and search effectively [11-17].

Thus, we evaluated our self-developed icon system for preschool children's picture books from the perspective of semantic distance to explore its efficiency in aiding preschool children's searches. Typically, such systems rely on either children's self-reports or researchers' observations to assess and validate usability [15,18,19]. Given the limited expressive ability of preschoolers, we integrate eye-tracking technology to capture the gaze patterns during their book searches, aiming to unveil the underlying cognitive processes.

2 RELATED WORK

Relevant work can be summarized as two issues.

The first is children-centered information search systems. Developing such system need to solve two basic questions: creating metadata that aligns with children's cognitive abilities and establishing controlled vocabularies that are age-appropriate [11]. Based on this, there are many attempts about child-centered book metadata or digital libraries. ICDL (International Children's Digital Library) uses cover color, shape, content, fictional-or-nonfictional, protagonist, recommended reading age and the emotional impact on readers [20]. Metis, a post-Dewey library system, utilizes whole-word labels, child-friendly categories and visually compelling signs, fostering children's optimism in finding desired items and resulting in significant increases in circulation [15]. SearchKids, a digital library interface, offers a graphical interface for querying, browsing and reviewing search results [18]. Additionally, Wang et al. develops a picture book information organization that extracts children' query descriptors and story content entities for metadata and employs colors and icons for visual representation [19].

The second is the effect of icon semantic distance on cognitive load, which manifests in two dimensions. Firstly, it affects attentional resources. When icon semantic distance is close, the working memory in the brain tends to prioritize the most relevant target icon [21,22]. Cherng et al., utilizing EEG data, found that semantically close icons are more likely to evoke memory-related cognition and capture participants' attention effectively [23]. Secondly, it influences cognitive performance, particularly in the efficiency of visual search, measured by response time and accuracy rate [24]. Peng et al. used a visual search experimental paradigm and found that visual search errors decrease when there is semantic-icon alignment through behavioral and eye-tracking data [25]. Additionally, Li et al. investigated the cognitive efficiency and process of military icons under different icon composition-semantic relationships, and found that the accuracy rate is higher when the semantic distance is close [6].

3 HYPOTHESES

Studies investigating the relationship between semantic distance and the efficiency of visual search for icons indicate that when semantic distance is close, search efficiency and cognitive performance improve [6-9]. Four metrics are commonly used to measure search efficiency and cognitive performance in eye movement studies: (1) Time to First Fixation (TFF) indicates the duration from the beginning of the experiment to the first time the subject gazed into the Area of Interest (AOI). The longer the TFF, the longer the time the child spends before directing the gaze to the AOI. (2) Total Fixation Time (TFD) reflects the cumulative time that the subject's gaze remains within the AOI. The longer the TFD, the more attention the child pays to the area of interest. (3) Fixation Count (FC) indicates the number of gaze points observed within the AOI for each subject. A higher FC indicates that the child devotes more attention to information within the region of interest. (4) Visit Count (VC) indicates the number of visual dwells within the AOI for each subject, and it is useful for understanding the degree of attention a subject focuses on when looking at an area. The higher the VC, the more attention the child pays to the area of interest. The following hypotheses are proposed that when children use a single icon to search for certain picture book,

H1.1: The accuracy rate of searching with close-semantic-distance icons is significantly higher than that when using distant-semantic-distance icons.

H1.2: The response time of searching with close-semantic-distance icons is significantly shorter than that when using distant-semantic-distance icons.

H1.3: TFF, FC, TFD and VC of the AOI for close-semantic-distance icons are significantly lower than those for distant-semantic-distance icons.

Combination is a commonly used search logic, and Boolean logic "AND" is also a logic frequently provided by search systems. Therefore, we aim to test children's performance using icons in the context of the AND logic. However, using combination icons for queries requires more reasoning and abstract thinking compared to use single icon. The hypothesis is:

H2: The accuracy rate of using combination icons is significantly lower than using single icon.

According to Jean Piaget's Cognitive Development Theory, preschoolers are in the preoperational stage when their mental reasoning and categorization skills begin to emerge. It comprises two sub-stages: the symbolic function stage (approximately 2~4 years old) and the intuitive thinking stage (approximately 5~7 years old) [26]. This mainly reflects children's transition from concrete experiences to abstract thinking. To distinguish from infants and toddlers, in this study, the definition of preschoolers is from 3 to 6 years old. So we categorized preschoolers into two groups: a 3-to-4-year-old group and a 5-to-6-year-old group. The hypotheses are:

H3.1: The accuracy rate of 3~4 group is significantly lower than the 5~6 group.

H3.2: The response time of 3~4 group is significantly longer than the 5~6 group.

H3.3: The 5~6 group's TFF, FC, TFD and VC for icon AOI are significantly lower than those of the 3~4 group.

H3.4: The 5~6 group's FC, TFD and VC for text AOI are significantly higher than those of the 3~4 group.

4 METHODOLOGY

4.1 Participants and conditions

Researchers recruited preschool children aged three to six through serendipitous sampling. A total of 50 preschoolers (*mean age*=4.5, *SD*=1.15), including 26 girls and 24 boys. The laboratory setup consisted of a Tobii Pro Fusion eye-tracker and a display with a resolution of 1920 x 1080 dpi, controlled by a master computer. The laboratory was set up in a separate room close the children's reading room in a public library.

4.2 Materials

To select representative icons with varying semantic distances, we use questionnaires to collect children's perceptions about the semantic distance of every icon. Every icon was rated on a five-point scale, with 1 indicating very distant and 5 indicating very close. A total of 11 valid samples were obtained (*mean age*=6). There are 60 icons in total, mean score is 3.87 (*SD*=0.86). Based on the results, Figure 1 shows the selected icons for experiments.

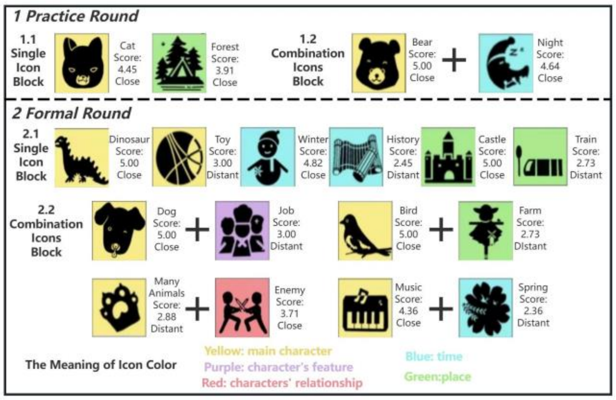

Figure 1: The selected icons for experiments

Figure 2 shows an example of experimental material for searching. Each picture book spine featured for icons arranged in the order of the main character, character's feature, characters' relationship, time and place. To accommodate the literacy level of preschool children, a number was assigned to the top of each book for task completion. Only one picture book was correct for each task. Each task in the formal rounds is corresponded to a different experimental material. To avoid the possibility that children had read experimental materials before, all picture books are fictionalized by researchers. Every experimental material is divided into text AOI and correct icon AOI.

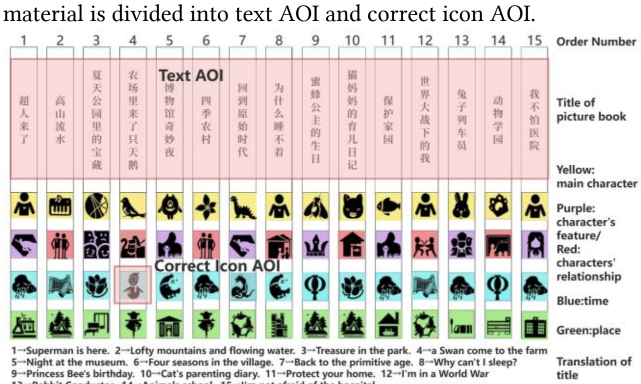

Figure 2: An example of experimental material for searching

4.3 Experiment procedure

Figure 3 shows the experimental procedure and corresponding clarifications.

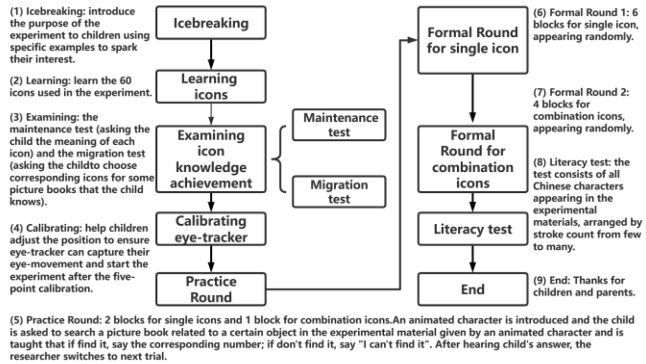

Figure 3: Experimental procedure

4.4 Data analysis

Research data included the accuracy rate, response time and eye movement metrics include TFF, TFD, FC and VC. Due to some children's activities such as moving so dramatically that exceeding eye-tracker's collection range and fingering the screen result in blocking eye-tracker, the data collection rate of 14 subjects for response time and eye movement metrics collected by eye-tracker was too low to use, so the effective sample size was 36 (16 were 3-to-4-year-old and 20 were 5-to-6-year-old). However, the data of their accuracy rate could still be used for analysis. Statistical analysis was conducted using Tobii Pro Lab and SPSS 27.

5 FINDINGS

5.1 Close vs. Distant semantic distance

A t-test comparing the accuracy rates between the close-semantic-distance group and the distant-semantic-distance group in the single icon context shows a significant difference (*p<0.001*) with a mean accuracy rate of 0.67 (*SD=0.05*) for the close group and 0.43 (*SD=0.04*) for the distant. This supports H1.1.

A t-test comparing the response times between the close-semantic-distance group and the distant-semantic-distance group in the single icon context. Although the response time for the close group (*m=64.82, SD=25.15*) is lower than that with the distant group (*m=78.81, SD=37.48*), no significant difference is presented. This contradicts H1.2, indicating that H1.2 is not supported.

Table 1 shows the results of a t-test using eye movement data from the close-semantic-distance group and the distant-semantic-distance group in the single icon context. The t-test reveals no significant differences between the two groups in terms of TFF, FC, TFD, and VC, contradicting H1.3. Therefore, H1.3 is not supported.

Table 1: Eye movement metrics of the close- semantic-distance group and distant-semantic-distance group (Icon AOI)

	TFF		FC		TFD		VC	
	Close	Distant	Close	Distant	Close	Distant	Close	Distant
m	9.58	10.50	2.84	2.36	0.88	0.71	1.74	1.55
(SD)	(6.51)	(8.18)	(1.95)	(1.43	(0.71)	(0.47)	(1.18)	(0.91)
p	0.598		0.237		0.236		0.436	

5.2 Single icon vs. Combination icons

A t-test comparing the accuracy rate between the single icon group and combination icons group shows a significant difference (*$p<0.01$*) with a mean accuracy rate of 0.55 (*$SD=0.26$*) for the single icon group and 0.40 (*$SD=0.27$*) for the combination icons group. This supports H2.

5.3 3~4 years old vs. 5~6 years old

Table 2 shows the t-test results comparing the accuracy rates between the 3-to-4-year-old and 5-to-6-year-old groups. Significant differences are observed in the distant-semantic-distance icon group (*$p<0.001$*), the single icon group (*$p<0.01$*), and the combination icons group (*$p<0.05$*). However, no significant difference is found in the close-semantic-distance icon group. Thus, H3.1 is supported.

Table 2: Effect of age on accuracy rate

		Accuracy rate		Accuracy rate	
		Close	Distant	Single	Combination
m	3~4	0.60(0.33)	0.26(0.20)	0.43(0.21)	0.32(0.25)
(SD)	5~6	0.75(0.31)	0.61(0.31)	0.68(0.25)	0.50(0.26)
p		0.111	0.000***	0.004**	0.014*

Note: significance markers: *p<0.05, **p<0.01, ***p<0.001.; Table3,4,5 is same as Table 2.

Table 3 shows the t-test results for response times between the 3~4 group and 5~6 group. The distant group presents a significant difference (*$p<0.05$*) except for the close group, supporting H3.2.

Table 3: Effect of age on response time

		Close	Distant
m(SD)	3~4	71.39(23.90)	93.10(33.65)
	5~6	59.56(25.47)	67.39(37.21)
p		0.164	0.039*

Table 4 shows the t-test results using eye movement metrics of icon AOI for the 3~4 group and the 5~6 group. Under the distant-semantic-distance icons group, the TFF of 5~6 group (*$m=7.10$, $SD=4.66$*) is smaller than that of the 3~4 group (*$m=14.76$, $SD=9.68$*) and the difference is significant (*$p<0.01$*). The rest do not present significance. This supports H3.3.

Table 4: Effect of age on eye movement metrics (Icon AOI)

		TFF		FC		TFD		VC	
		Close	Distant	Close	Distant	Close	Distant	Close	Distant
m (SD)	3~4	10.84 (8.30)	14.76 (9.68)	2.77 (2.17)	2.04 (1.45)	0.93 (0.91)	0.66 (0.47)	1.64 (1.39)	1.42 (0.90)
	5~6	8.57 (4.62)	7.10 (4.66)	2.90 (1.81)	2.62 (1.39)	0.85 (0.53)	0.76 (0.48)	1.82 (1.01)	1.65 (0.93)
p		0.338	0.004**	0.847	0.233	0.765	0.521	0.672	0.457

Table 5 shows the t-test results using eye movement metrics of text AOI for the 3~4 group and the 5~6 group. For TFD, the 5~6 group (*$m=7.63$, $SD=4.36$*) is greater than that of the 3~4 group (*$m=4.95$, $SD=3.09$*) and the difference presents significant (*$p<0.05$*). The rest do not present significance. This supports H3.4.

Table 5: Effect of age on eye movement metrics (Text AOI)

		FC	TFD	VC
m(SD)	3~4	6.73(4.91)	4.95(3.09)	2.99(1.15)
	5~6	8.40(7.59)	7.63(4.36)	2.63(1.41)
p		0.451	0.046*	0.406

6 DISCUSSION

Preschoolers are easier to use close-semantic-distance icons for searching, which aligns with existing research. When icons closely match semantic information, the working memory in the brain prioritizes the most relevant target icon [21,22].

Preschoolers are easier to use single icon for searching. This can be explained by the cognitive load theory, as the complexity and amount of a task increase, more cognitive resources are consumed. When the task exceeds cognitive system's capacity, cognitive load forms, preventing task completion [27]. Additionally, based on the cognitive development theory, preschool children are in the pre-operational stage and can not apply logical operations to specific problems [26]. Thus, it is difficult for preschoolers to understand the logical meaning conveyed by multiple grouped icons. Consequently, the cognitive load from combining two icons for searching may exceed the capacity of preschool children's cognitive systems. Previous experiments showed no significant difference between single-icon and combination icons groups [19]. This discrepancy may be related to the small sample size of preschoolers in previous study.

The gaze patterns of preschoolers at different ages when using icons to search for picture books show significant changes across metrics. In both metrics on distant-semantic-distance icons test and the combination icons test, 5-to-6-year-old group performs significantly better than 3-to-4-year-old group in terms of accuracy rate and response time. Regarding eye movement metrics, for the correct icon AOI, the TFF of 5~6 group is significantly less than that of 3~ 4 group. Conversely, for the text AOI, the TFD of 5~6 group is significantly greater than that of 3~4 group. This indicates that elder preschoolers pay more attention to textual information.

7 CONCLUSIONS

The above discussion suggests that developers of picture book information search system should: (1) Assign higher weight to close-semantic-distance icons. (2) Make single icon the primary search method. (3) Implement age-graded processing to meet the developing cognitive abilities of children.

The study faces some limitations. The sample size is relatively small which may influence the study's validity. Moreover, the introduction of self-developed icons and the discard of low-data-collection-rate data may lead to potential biases in conclusions. Meanwhile, the experiments focus on single cognitive attribute of icons and a specific set of search tasks that may affect the study's generalizability. At the same time, due to the limitations of display size, eye-tracker 's technical restrictions and only using the spine to identify the correct book, it is difficult to capture the entire process of how children search for picture books. Future research could involve more samples, wider variety of icons and different search tasks, introduce a panel of experts to design icons and review the fairness of icons, and design a prototype of picture book information search system.

ACKNOWLEDGMENTS

This work was supported by the National Social Science Fund of China (Grant No. 23BTQ017). Thanks for the support of Tobii China Innovation Funding.

REFERENCES

[1] Ann Evans, M., & Saint-Aubin, J. 2005. What Children Are Looking at During Shared Storybook Reading: Evidence From Eye Movement Monitoring. *Psychological Science, 16*(11), 913-920. https://doi.org/10.1111/j.1467-9280.2005.01636.x.

[2] Roy-Charland, A., Saint-Aubin, J. & Evans, M.A. 2007. Eye movements in shared book reading with children from kindergarten to Grade 4. *Read Writ* **20**, 909–931. https://doi.org/10.1007/s11145-007-9059-9

[3] Kaefer T, Pinkham AM, Neuman SB. 2017. Seeing and knowing: Attention to illustrations during storybook reading and narrative comprehension in 2-year-olds. *Inf Child Dev,* 26, e2018. https://doi.org/10.1002/icd.2018

[4] Yim, D., Park, W., Kim, S., Han, J., Song, E., & Son, J. 2019. An Eye-Tracking Study of Picture Book Reading in Preschool Children with and without Language Delay. *Communication Sciences & Disorders, 24*(2), 299-316.

[5] Salman, Y.B., Cheng, H., & Patterson, P.E. 2012. Icon and user interface design for emergency medical information systems: A case study. *International journal of medical informatics, 81 1*, 29-35.

[6] Li X, Wang H, Shao J. 2020. Event-related potential study on military icon based on composition -semantic relationship. *International Conference on Intelligent Human Systems Integration*, 248-253.

[7] Wu, X., Yan, H., Niu, J., & Gu, Z. 2021. Study on semantic-entity relevance of industrial icons and generation of metaphor design. *Journal of the Society for Information Display, 30*, 209 - 223.

[8] Zhao, K., Wang, X., Bai, L. 2021. Interface Adaption to Elderly Users: Effects of Icon Styles and Semantic Distance. In: Gao, Q., Zhou, J. (eds) Human Aspects of IT for the Aged Population. Technology Design and Acceptance. HCII 2021. Springer, Cham. https://doi.org/10.1007/978-3-030-78108-8_10

[9] Dosso, C., & Chevalier, A. 2021. How do older adults process icons during a navigation task? Effects of aging, semantic distance, and text label. *Educational Gerontology, 47*(3), 132–147. https://doi.org/10.1080/03601277.2021.1886634

[10] Virginia A. Walter. 1994. The Information Needs of Children. *Advances in librarianship, 18*, 111-129.

[11] Abbas, J. 2005. Creating metadata for children's resources: Issues, research, and current developments. *Library Trends, 54*(2),303-317.

[12] Abbas, J. 2008. Daddy, how do I find a book on purple frogs?: Representation issues for children and youth. https://www.ebsi.umontreal.ca/recherche/colloques-congres-journees-detude/isko2008/documents/abstracts/abbas.pdf

[13] Cooper, L.Z. 2002. A case study of information-seeking behavior in 7-year-old children in a semistructured situation. *Journal of the American Society for Information Science and Technology, 53*(11), 904-922. https://doi.org/10.1002/asi.10130

[14] Hutchinson, Hilary & Druin, Allison & Bederson, Ben & Reuter, Kara & Rose, Anne & Weeks, Ann. 2005. How do I find blue books about dogs? The errors and frustrations of young digital library users. *Proceedings of HCII 2005*, 22-27.

[15] Kaplan, T.B., Dolloff, A. K., Giffard, s., & Still-Schiff, J. 2012. Are Dewey's days numbered: Libraries nationwide are ditching the old classification system. *School Library Journal, 58*(10),24-28.

[16] Ida Kathrine Hammeleff Jørgensen and Toine Bogers. 2020. "Kinda like The Sims... But with ghosts?": A Qualitative Analysis of Video Game Re-finding Requests on Reddit. In *Proceedings of the 15th International Conference on the Foundations of Digital Games (FDG '20).* Association for Computing Machinery, New York, NY, USA, Article 40, 1–4. https://doi.org/10.1145/3402942.3402971

[17] Warren, R.M. 2016. Parents of Young Children Select Picture Books Based on Information Not Found in Bibliographic Records. *Evidence Based Library and Information Practice, 11*, 79-81.

[18] Hourcade, J.P., Druin, A., Sherman, L., Bederson, B.B., Revelle, G., Campbell, D., Ochs, S., & Weinstein, B. 2002. SearchKids: a digital library interface for young children. *CHI '02 Extended Abstracts on Human Factors in Computing Systems.*

[19] Wang, P., Sun, X., & Wang, Y. 2024. An Exploratory Study on a Physical Picture Book Representation System for Preschool Children. *iConference.*

[20] Jin Tao, Niu Yafeng, & Zhou Lei. 2016. Cognitive mechanism of warning icons under different working loads. *Journal of Southeast University (Natural Science Edition), 46*(6), 1204-1208.

[21] Wang, H., Xue, C., Huang, J. & Song, G. 2013. Design and Evaluation of Human-computer Digital Interface Based on Cognitive Load. *Electro-Mechanical Engineering, 29*(5), 57-60.

[22] Chen, X., Xue, C., Wang, H., & Zhang, Q. 2017. A Design Method of Icon Based on Semantic Research of Universal Symbols. *Transdisciplinary Engineering: A Paradigm Shift*, 498-505.

[23] Zhang, Y. & Shao, J. 2022. Research Progress on the Effect of Icon Semantic Distance on Cognitive Load Performance. *Development & innovation of Machinery & Electrical Products, 35(4)*, 174-177.

[24] Peng, N. and Xue, C. 2017. Experimental study on characteristics of icon searching based on feature inference. *Journal of Southeast University (Natural Science Edition), 47(4), 703-709.*

[25] Wang, P., Ma, Y., Xie, H., Wang, H., Lu, J., & Xu, J. 2021. "There is a gorilla holding a key on the book cover": Young children's known picture book search strategies. *Journal of the Association for Information Science and Technology, 73*, 45 - 57.

[26] Robert S. Feldman. 2017. Discovering the Life Span (4th Edition). *Pearson, London.*

[27] Chen, X. & Zhang, J. 2003. The Model of Attentive Capacity Theories and its New Progress. *Psychological Exploration, 4*, 24-28.