Friendship Display Medium in Response to Academic Major Influences in Visuospatial Abilities

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Abstract. This study evaluates the effects of display medium (tablet PC, paper-pencil), academic major (design, technology major) and gender on visuospatial ability tests, visuospatial short-term memory test, visual fatigue, subjective preference and mental workload. Sixty university students participated in the study. The results indicate that the display medium had a significant effect on all measurements ($p<0.001$). When using a paper-pencil test, the visuospatial test performance was higher, visual fatigue and mental workload were lower than using the tablet PC test. The interaction effect of display medium and academic major is significant on visuospatial test performance. The design major students performed better on visuospatial ability test but worse on visuospatial short-term memory test than technology major students under the tablet PC test. The gender effect is not significant on all measurements. When assessing visuospatial ability using the tablet PC based test, it should be noticed that the visuospatial ability may be underestimated especial for male testers or design major students.

Keywords: visuospatial ability, visuospatial short-term memory, display, academic major, gender.

1 Introduction

The visuospatial ability, imagining an object's shape while it is rotated and remember the positions of objects and including the cognitive processes of perception, attention, memory, mental imagery, and problem solving [6], is an important ability for some professional tasks, for example, medical students who are learning anatomy [9]. Moreover, the visuospatial ability test has been used for the assessment of cognition ability in neurodegenerative disease patients [1], mental development in children [10] and human intelligence [17]. The "nature" (the biological differences, e.g. gender) and "nurture" (environmental factors which lead to the differences, e.g. education) factors would affect the visuospatial ability performance.

In the early years, males have an advantage on visuospatial ability [16], but the gender differences may be decreasing in recent years [3]. The visuospatial ability can

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be classified into three aspects: mental rotation, spatial perception and spatial visualization [14]. The large gender differences in favor of males were found only on mental rotation [26]. Smaller differences were present on spatial perception [14], whereas for tests in the spatial visualisation, the differences were not significant [26]. Crawford et al. [7] also reported that a decline in gender differences in spatial visualization performance in the past forty years.

Apart from gender effect, Vlachos et al. [24] reported that the effects of educational background was also significant on the visuospatial ability test and the performance was better for technical faculty's students than humanities faculty's students. Moreover, the gender differences on visuospatial ability may be decreasing by academic training. Quaiser-Pohl and Lehmann [19] investigated mental rotation performance in males and females of different academic majors, concluded that the difference of test performance between genders was largest with students majoring in arts, humanities, and social sciences and smallest with those majoring in computational visualistics.

From another point of view, the visuospatial ability is also affected by environmental condition. Chung et al. [6] investigated the effect of 30% and 21% oxygen inhalation on visuospatial cognitive performance, and conclude that more oxygen inhalation enhanced visuospatial performance. Traditionally, visuospatial ability tests were performed with pen and paper [21] due to the ease of administration and existence of well-established normative data [18]. It would be interesting to find out whether the computer-based visuospatial ability test would have a similar outcome as the paper-pencil based test.

The aim of this study is to investigate the possible influences of display medium, academic major and gender factors on visuospatial functioning. The study examined the hypothesis that the pattern of academic major and gender differences in visuospatial tasks may be differential due to display medium factors. Thorough an evaluation of display medium effect would benefit to develop a more refined visuospatial ability test method for different characteristic subjects.

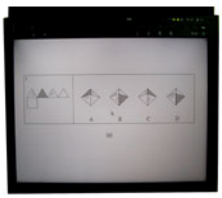
2 Methods

2.1 Subjects

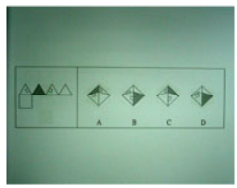
Sixty university students (29 men and 31 women) voluntarily participated in the study. Mean age (S.D.) was 20.4 (1.00) years for the males, and 20.0 (0.78) for the females. Subjects were divided into two groups based on their academic majors. Twenty-seven (13 males, 14 females) subjects who enrolled in the department of industrial design were classified in design group. Another thirty-three (16 males, 17 females) who were science major or technology major students were classified in technology group. They were required to have at least 20/25 corrected vision and without physical or mental problems. They were also requested not to stay up late, take medicine, drink alcohol and any other substance that may possibly affect the test results. All subjects had no previous experience using a tablet PC.

2.2 Experimental Design

Independent variables. This study employed a nested factorial design. The independent variables included gender, academic major (design and technology) and display medium (tablet PC and paper-pencil). The academic major was nested within gender and subject was nested within academic major and gender. Subjects were requested to take both a tablet PC and paper-pencil test. To avoid the differences caused by display medium, all subjects used a touch screen tablet PC for the computer-based tests (IBM ThinkPad, 14 inch screen, visual area 180x245 mm, resolution 1024*768, 16-bit color). The paper-pencil test was prepared in the same format as the computer-based test to minimize the differences between the two. The aspect ratio and the paper size of the paper-pencil test was the same as the tablet PC viewing screen, as shown in Fig. 1.



(A)



(B)

Fig. 1. The illustration of (A) tablet PC test and (B) paper-pencil test in this study

Visuospatial short-term memory test. The visuospatial short-term memory test is the arrow span task [22] (Fig. 2). In each image, a direction is shown by an arrow for one second. After viewing a series of three images, the subject is asked to write down the sequence that the arrows appeared in the boxes. The test score for each task is calculated, with a higher score indicating a better short-term memory. The time required to complete test was also recorded.

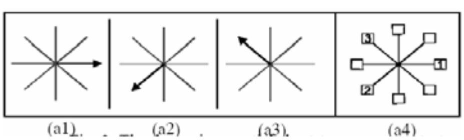


Fig. 2. The three visuospatial short-term memory tests

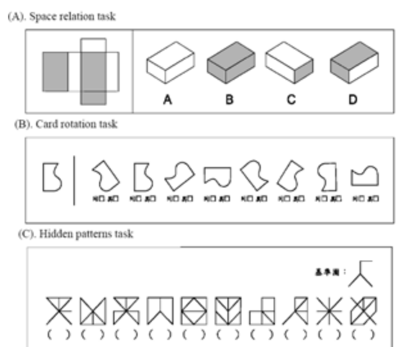


Fig. 3. The three visuospatial ability tests

Visuospatial ability test. The visuospatial test battery includes the space relation test [4], card rotation test and hidden pattern test [8] as shown in Fig. 3. In the space relation test (Fig. 3(A)), each question consists of a two-dimensional image and four three-dimensional images. The subject should envision the shape of the two-dimensional image after it has been folded, and identify the corresponding three-dimensional image being provided. In card rotation test (Fig. 3(B)), an original image will appear on the left side, and there will be an image of the same pattern after rotation on the right-hand side. The subject is asked to choose if the image on the right is the same as the original, or it is a reflection. In hidden pattern test (Fig. 3(C)), a "standard" image is presented to the subject. The subject is asked to identify if the "standard" image is hidden in each of the presented images. A higher score indicates a greater visuospatial ability.

Visual fatigue, subjective preferences and mental workload. To measure visual fatigue, the critical flicker fusion (CFF) frequency and the subjective eye fatigue were evaluated. The CFF is an effective measure of visual fatigue [25]. It measures the minimal number of flashes of light per second at which an intermittent light stimulus no longer stimulates a continuous sensation. A drop in CFF value indicates a drop in the sensory perception function, attributable to a decrease in alertness. As for subjective eye fatigue evaluation, the Borg CR-10 scale [5] was used. The Borg CR-10 scale is a 10-point scale, with 0 denoting 'nothing at all' and 10 denoting 'almost maximal'.

For subjective preference, a five point scale was used with -2 means "dislike it very much" and +2 means "like it very much". The subjective mental workload was assessed by using the NASA Task Load Index (NASA-TLX) [11]. NASA-TLX is a multidimensional mental workload rating which contains six factors: mental demand, physical demand, temporal demand, performance, effort and frustration level. The workload assessment using the NASA-TLX is a two step procedure. First, the subject evaluates the weighting of each of the six factors through pair-wise comparisons. Next, the subject gives numerical ratings to each of the six factors. The rating scale ranged from 'low' to 'high' in linguistic terms for all factors except for the 'performance' factor which is rated from 'poor' to 'good'. The overall workload score is calculated by the weighted average of the ratings ranging from 0 and 100.

2.3 Experiment Procedure

A standard classroom computer desk and chair were used for experimentation. Prior to the experiment, each subject was instructed about the purpose and procedure of the study, and to fill out a written consent form.

At the beginning of each session, the subject's CFF and subjective fatigue were colleted as a baseline measure for making comparison. Two tests, i.e. visuospatial short-term memory test and visuospatial ability test battery were arranged. The visuospatial short-term memory test does not have a time limit, and the subject continues to write until he/she finishes tests. The visuospatial ability tests include three parts, with twelve minutes given for the space relation test, six minutes for the card rotation test, and three minutes for the hidden pattern test.

In paper-pencil tests, each subject completed the tests with a pencil (Fig. 4(A)). In tablet PC tests, each subject used a touch pen on the screen to complete the tests (Fig. 4(B), (C)). After completing the tests, the test scores and answer times were

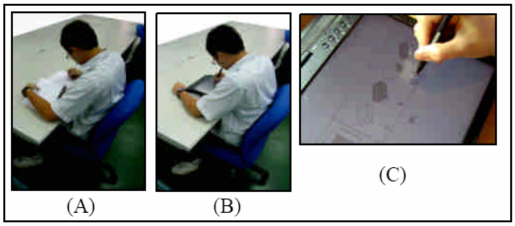


Fig. 4. Subject taking (A) paper-pencil test (B) tablet PC test (C) subject used a touch pen to answer the question on the screen

recorded. In addition, the CFF, the subjective fatigue rating, the subjective preference and subjective mental workload were also taken. After finishing one experiment session, the next one will be scheduled one week later.

3 Results

The summarized ANOVA results are shown in Table 1. The test display medium had a significant effect on all measurements (p<0.05 or better). Table 2 shows the corresponding mean values of all measurements for display media, academic majors and gender. As can be seen in the table, the average arrow span task scores for the paper-pencil test and tablet PC test are 78.43 and 72.47, respectively. In other words, the tablet PC test score is about 8% lower than that for the paper-pencil test. The answer time for the arrow span task for the tablet PC is about 22% longer than those the paper-pencil tests.

Table 1. The ANOVA results (n=60)

Dependent variables			Independent variables				
			Medium,(M)	Academic major,(A(G))	Gender,(G)	M*A(G)	G*M
Visuospatial test	Visuospatial short-term memory test	Scores	***			*	
		Answer time	***			*	
	Visuospatial ability test (scores)	Space relation task	***	**		**	*
		Card rotation task	***				
		Hidden patterns task	***				
Visual fatigue	CFF change		***				*
	Subject eye fatigue		***				
Subjective preference			***				
Subjective mental workload			***			***	

*p<0.05, **p<0.01, ***p<0.001

The average score of the space relation task is 38 for the paper-pencil test and is 24 for the tablet PC test. The test score with the tablet PC test is about 58% lower than for the paper-pencil test. The tendency of test card rotation and hidden patterns task scores are similar to that for the space relation task. The card rotation and hidden patterns task scores for the tablet PC test are about 26% and 33% lower than for the paper-pencil test, respectively.

Table 2. The corresponding mean values of measurements under display medium, academic major and gender effects

	Display medium		Academic major		Gender	
	Paper-pencil test	Tablet PC test	Design	Technology	Female	Male
Visuospatial short-term memory test						
Scores	**78.43**	**72.47**	74.39	76.31	75.02	75.90
Answer time (s)	**166.07**	**203.02**	189.70	180.32	183.74	185.40
Visuospatial ability test (scores)						
Space relation task	**37.47**	**24.42**	**35.57**	**27.16**	32.70	29.06
Card rotation task	**137.33**	**108.85**	127.65	119.36	121.08	125.24
Hidden patterns task	**128.90**	**96.80**	114.35	111.62	106.56	119.57
Visual fatigue						
CFF change (Hz)	**0.98**	**1.74**	1.24	1.46	1.31	1.41
Subject eye fatigue	**1.50**	**2.48**	1.83	2.12	2.02	1.97
Subjective preference	**0.68**	**-0.43**	0.06	0.18	0.05	0.21
Subjective mental workload (scores)	**63.17**	**67.19**	65.22	65.15	64.19	66.24

Bold face indicates significant differences (p<0.05) between levels of a factor for that measure

The increase in CFF change after the tablet PC test is 1.74 Hz which is about 0.98 Hz greater than for the paper-pencil test. Moreover, the subjective eye fatigue rating for the tablet PC test is about 65% higher than that of the paper-pencil test. The mean value for the subjective preference for the tablet PC is negative, which means the subjects do not like to use the tablet PC for performing visuospatial tests. Additional, tablet PC test produces about 6% increase in mental workload than paper-pencil test.

As shown in Table 1, the academic major effect is only significant on space relation task. The test score of design group students is about 33% higher than technology students (Table 2). For two-way interactions, the interaction effect of display medium and academic major is significant on four of the nine response measures as shown in Table 2 and Fig. 5. Changing the display medium from paper-pencil to tablet PC decreases the score of arrow span task by about 4% for technology group and 13% for design group students (Fig. 5(A)). Further, the complete time of arrow span task shows a greater increase in design group as comparing to technology group when the display medium is changed from paper-pencil to tablet PC (Fig. 5(B)). For the test score of space relation task (Fig. 5 (C)), the score decrease caused by changing display medium from paper-pencil to tablet PC for design group is greater than the decrease caused by display medium changed for technology group students. As shown in Fig. 5(D), the subjective mental workload is similar for technology group students under both display media, but the workload increases about 16% for design group students.

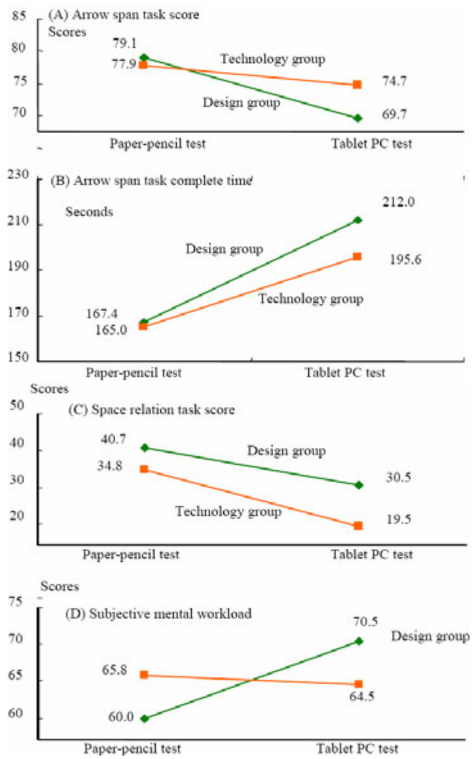


Fig. 5. The effect of medium* academic major interaction on (A) arrow span task score, (B) arrow span task complete time, (C) space relation task score and (D) subjective mental workload

The gender effect is not significant for all measurements. However, the interaction effect of gender and academic major is significant on the test score of space relation task ($p<0.05$) and CFF change ($p<0.05$). Fig. 6(a) shows the gender and academic major interaction on the test score of space relation task. It shows a greater decrease on the space relation task score for males as comparing to females when the test is changed from paper-pencil to tablet PC. On the other hand, Fig. 6(b) shows that the CFF change for female is about 0.3 Hz higher than that of male subjects when using paper-pencil test. The situation is reverse for using tablet PC test that the CFF change for male is 0.5 Hz higher than that of female.

4 Discussion

Present results provided evidence that display medium, apart from gender and academic major, relates to the performance on both visuospatial short-term memory task and visuospatial ability task. The processes of performing visuospatial short-term memory task include perceptual recognition of objects and visual imagery of the reconstruction of objects [2]. In the perceptual recognition phase, the subjects' visual load was greater for the tablet PC tests due to the higher subjective eye fatigue rating and the greater CFF change and resulting in the subjects' visual perceptive sensitivity decreasing more for the tablet PC tests. Besides, in the visual imagery phase, the luminance contrast and the screen resolution were worse for the tablet PC than for paper and pencil, resulting in decreased visual acuity and visual identification performance. It seems that the screen image quality is still not good enough to process visuospatial material, resulting in a decrease in visuospatial short-term memory performance.

In the study, the visuospatial ability test score tended to be significantly higher under paper-pencil than under tablet PC. This is consistent with the previous findings of Kang et al. [13] that comprehension of verbal material was better for reading from paper than reading from a screen. To perform the visuospatial ability test need not only perceptual recognition and visual imagery but also rotations and translations of visual imagery [2]. These results of the study probably result from the attention decreased more while reading from screen than form paper [23] and manipulation differences between these two test material display media. Although adequate controls were taken to ensure that the tablet PC and paper-pencil tests were similar, there are still some differences. For the table PC test, the subject had to click on an icon to go to the next page, whereas in the paper-pencil test the subject only had to turn to the next page. Additional mental resources are needed to manipulate the tablet PC resulting in a visual imagery translation processing delay and visuospatial ability decreasing.

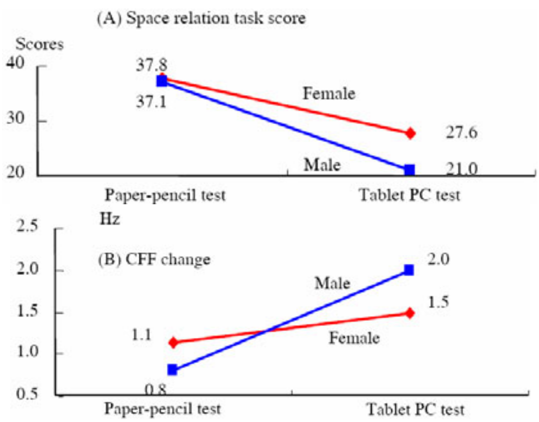


Fig. 6. The effect of medium* gender interaction on (A) space relation task score, (B) CFF change

The industrial design students performed better than the technology major group on the space relation task, where spatial visualization was required [12]. This further supports the notion of undergraduate programs improving specific abilities, such as visuospatial processing, exemplified as perspective taking and looking at mental objects from different angles, which are strategies that are used in the space relation task. Thus, spatial visualization might have been performed well in the design student group. However, the effect of academic major was not significant on card rotation task and hidden patterns task in the study. Compare with space relation task, the card rotation task and hidden patterns task are simpler [17] and the visuospatial ability training is also included in undergraduate programs of technology major [24]. Thus, the performance of card rotation task and hidden patterns task were similar for both academic groups.

Unexpected findings are that the interaction results of display medium and academic major. Under tablet-PC test condition, the performance of visuospatial ability (space relation task) for design group is better than technology group students but tendency is contrary for the visuospatial short-term memory test. In comparison with the technology students, it seems that the visual perceptivity of design students is more sensitive and the efficiency of perceptual recognition and visual imagery (visuospatial short-term memory test was required) decreases more easily due to the negative effect of display medium. However, because of the effect of academic training, the better performance during visual imagery translation phase (visuospatial ability was required) offsets the loss of perceptual recognition and visual imagery phases and results in better visuospatial ability for design students.

For gender effect, the current study found no difference between the performance of males and females on visuospatial ability, which is consistent with the finding reported by Loring-Meier and Halpern [15] and Weiss et al. [26]. It could be explain by the interaction between academic major and gender. Academic training with more visuospatial related task practice, benefited females more than males and, as a result, reduced the original gender differences in performance [20]. More interesting finding was that under tablet-PC test, the space relation task score for male was lower than female, but the CFF change was greater for male students than female students (Fig. 6). Kang et al. [13] also reported that female subjects had less eye fatigue than male subjects while reading the electronic book. Thus, males' eye fatigue increased more easily than females' and resulted in visuospatial ability decreased greatly.

In conclusion, the current findings show that the display medium effect is more significant than academic major and gender effects. The visuospatial ability test was better administered with paper-pencil than with a tablet PC. This would underestimate the visuospatial ability when using the Tablet PC, especial for male or design major students. An improvement in PC display quality is needed to increase performance and preference in the visuospatial ability test.

References

1. Alescio-Lautier, B., Michel, B.F., Herrera, C., Elahmadi, A., Chambon, C., Touzet, C., Paban, V.: Visual and visuospatial short-term memory in mild cognitive impairment and Alzheimer disease: Role of attention. Neuropsychologia 45(8), 1948–1960 (2007)
2. Anastakis, D.J., Hamstra, S.J., Matsumoto, E.D.: Visual-spatial abilities in surgical training. The American Journal of Surgery 179(6), 469–471 (2000)
3. Baenninger, M., Newcombe, N.: Environmental input to the development of sex-related differences in spatial and mathematical ability. Learning and Individual Differences 7(4), 363–379 (1995)

4. Bennet, G.K., Seashore, H.G., Wesman, A.G.: Differential aptitude test: Spatial relations (Form T). Psychology Corporation, New York (1972)
5. Borg, G.: Psychophysical bases of perceived exertion. Medicine & Science in Sports & Exercise 14(5), 377–381 (1982)
6. Chung, S.-C., Lee, B., Tack, G.-R., Yi, J.-H., Lee, H.-W., Kwon, J.-H., Choi, M.-H., Eom, J.-S., Sohn, J.-H.: Physiological mechanism underlying the improvement in visuospatial performance due to 30% oxygen inhalation. Applied Ergonomics 39(2), 166–170 (2008)
7. Crawford, M., Chaffin, R., Fitton, L.: Cognition in social context. Learning and Individual Differences 7(4), 341–362 (1995)
8. Ekstrom, R.B., French, J.W., Harman, H.H., Dermen, D.: Manual for kit of factor-referenced cognitive tests. Educational Testing Service, Princeton (1976)
9. Garg, A.X., Norman, G., Sperotable, L.: How medical students learn spatial anatomy. The Lancet 357(9253), 363–364 (2001)
10. Gathercole, S.E., Alloway, T.P., Willis, C., Adams, A.M.: Working memory in children with reading disabilities. Jour. of Experimental Child Psychology 93(3), 265–281 (2006)
11. Hart, S.G., Staveland, L.E., Peter, A.H.A.N.M.: Development of NASA-TLX (task load index): Results of empirical and theoretical research. Advances in Psychology, 139–183 (1988)
12. Kail, R., Park, Y.-S.: Impact of practice on speed of mental rotation. Journal of Experimental Child Psychology 49, 227–244 (1990)
13. Kang, Y.-Y., Wang, M.-J.J., Lin, R.: Usability evaluation of e-books. Displays 30(2), 49–52 (2009)
14. Linn, M.C., Petersen, A.C.: Emergence and characterization of sex differences in spatial ability: A meta-analysis. Child Development 56(6), 1479–1498 (1985)
15. Loring-Meier, S., Halpern, D.F.: Sex differences in visuospatial working memory: Components of cognitive processing. Psychonomic Bulletin & Review 6(3), 464–471 (1999)
16. Mcgee, M.G.: Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences. Psychological Bulletin 86(5), 889–918 (1979)
17. Miyake, A., Friedman, N.P., Rettinger, D.A., Shah, P., Hegarty, M.: How are visuospatial working memory, executive functioning, and spatial abilities related? A latent-variable analysis. Journal of Experimental Psychology: General 130(4), 621–640 (2001)
18. Perry, R.J., Hodges, J.R.: Attention and executive deficits in Alzheimer's disease: A critical review. Brain 122(3), 383–404 (1999)
19. Quaiser-Pohl, C., Lehmann, W.: Girls Spatial abilities: Charting the contributions of experiences and attitudes in different academic groups. British Journal of Educational Psychology 72, 245–260 (2002)
20. Razumnikova, O.: Role, sex and professional orientation of students as creativity factors. Voprosy Psihologii 1, 111–118 (2002)
21. Rizzo, M., Anderson, S.W., Dawson, J., Myers, R., Ball, K.: Visual attention impairments in Alzheimer's disease. Neurology 54(10), 1954–1959 (2000)
22. Shah, P., Miyake, A.: The separability of working memory resources for spatial thinking and language processing: An individual differences approach. Journal of Experimental Psychology: General 125(1), 4–27 (1996)
23. Shieh, K.K., Chen, M.H., Wang, Y.W.: Effects of display medium and luminance contrast on memory performance and EEG response. International Journal of Industrial Ergonomics 35(9), 797–805 (2005)

24. Vlachos, F., Andreou, G., Andreou, E.: Biological and environmental influences in visuospatial abilities. Learning and Individual Differences 13(4), 339–347 (2003)
25. Wang, M.J.J., Huang, C.L.: Evaluating the eye fatigue problem in wafer inspection. IEEE Transactions on Semiconductor Manufacturing 17(3), 444–447 (2004)
26. Weiss, E.M., Kemmler, G., Deisenhammer, E.A., Fleischhacker, W.W., Delazer, M.: Sex differences in cognitive functions. Personality and Individual Differences 35(4), 863–875 (2003)