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Sex-related differences in attention and memory

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ABSTRACT

Background and objectives: The sex differences and similarities in cognitive abilities is a continuing topic of major interest. Besides, the influences of trends over time and possible effects of sex steroid and assessment time on cognition have expanded the necessity to re-evaluate differences between men and women. Therefore, the aim of this study was to compare cognitive performance between men and women in a strongly controlled experiment.

Materials and methods: In total, 28 men and 25 women were investigated. Variables of body temperature and heart rate were assessed. A cognitive test battery was used to assess attention (visual search, unpredictable task switching as well as complex visual search and predictable task switching tests) and memory (forced visual memory, forward digit span and free recall test).

Results: The differences in heart rate and body temperatures between men and women were not significant. There were no differences in the mean values of attention and memory abilities between men and women. Coefficients of variation of unpredictable task switching response and forward digit span were lower ($P < 0.05$) in men. Coefficients of variation positively correlated ($P < 0.05$) with attention task incorrect response and negatively correlated ($P < 0.05$) with correct answers in the memory task.

Conclusions: Current study showed no sex differences in the mean values of cognition, whereas higher intra-individual variability of short-term memory and attention switching was identified in women, indicating that their performance was lower on these cognitive abilities.

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1. Introduction

Sex differences in cognitive ability have been studied extensively in recent decades [1]. Important issue is if there are any sex-based differences in human cognition [2]. New findings, especially about trends over time (education, new technologies, gender equity, etc.), sex hormones, brain differences, and culture, indicate that earlier conclusions about sex differences and similarities in cognitive abilities need to be re-examined [3].

The different sex brain anatomy is a continuing topic of major interest. Among the observed sex differences, there are larger overall brain dimensions in men, relative increases of global and regional gray matter in women and higher percentage of white matter in men [4,5]. Kanai and Rees [6] highlighted the importance of gray matter in attention. Cognitive function has most commonly been associated with the prefrontal cortex. Recently the crucial role of the basal ganglia has been highlighted, as it interacts with the prefrontal cortex and thalamus via anatomical fronto-striato-thalamic circuits to implement cognitive flexibility. Attention switching performance could be predicted on the basis of individual differences in white matter microstructure in/around the basal ganglia [7]. Rijpkema et al. [8] indicated no differences in basal ganglia morphology between men and women. With reference to the studies mentioned above [5,8], it can be expected that there would be no sex differences in cognitive performance, which includes task switching, whereas attention test without task switching will be different between women and men.

Aging studies have shown that working memory is associated with white and gray matters [9]. Moreover, people with high visual short-term memory capacity have increased gray matter volume [10]. According to sex differences in brain gray and white matter, observed by Luders et al. [5] and Gur et al. [4], it can be expected that women might have advantage in short-term memory task performance, whereas no difference will be observed in working memory tests.

It is noteworthy that sex-related cognitive performance differences observed in previous studies [11–16] do not correspond to previously discussed gray matter and white matter differences in men and women [4,5]. Observed disagreements could be partly attributed to non-controllable experiments. Studies show that both sexes are sensitive to variation in hormonal state, as evidenced in the fluctuations in cognitive performance across diurnal and circadian rhythms, and menstrual cycle in women [3,17,18]. Most neuropsychological studies do not control natural biological rhythms and/or women's menstrual cycles. Measurement of rectal temperature (T_{RE}) is a reliable way of measuring core temperature to study the circadian rhythm [19]. Scheer et al. [20] showed that heart rate (HR) depended on the phase of the day-night cycle and on the intensity of light. The data suggests that circadian rhythm modulates HR. Therefore, the study was performed in the morning and rectal temperate as well as HR were assessed then. Furthermore, it is known that sex hormones can affect neurotransmitter levels responsible for cognition [2,18,21], thus women were tested during the early follicular phase when estradiol and progesterone levels are low. Besides, educational level should be taken into account [3]. Thus, the aim of this study was to compare cognitive performance between men and women in a strongly controlled (assessment timing, women's menstrual cycle and educational level matched groups) experiment.

2. Materials and methods

2.1. Participants

The criteria for participants' inclusion were: (1) the age of 18–25 years; (2) no excessive sport activities, i.e. <3 times per week; (3) non-smoking; (4) no medications that could affect cognitive function; (5) no diseases or disorders that could affect cognitive performance. Seventy-nine participants were assessed for eligibility. In total, 53 volunteers (28 men and 25 women matched by educational level) met the inclusion criteria and agreed to participate in this study. Their physical characteristics are presented in Table 1. Written informed consent was obtained from all subjects after the explanation of all details of the experimental procedures. All procedures were approved by the Human Research Ethics Committee and conducted according to the guidelines of the Declaration of Helsinki. Subjects were in self-reported good health, which was confirmed by medical history and physical examination.

2.2. Familiarization and experimental trials

The study comprised a familiarization trial and an experimental trial. To attain a stable level of performance, one week before the experimental trial, participants attended a familiarization session during which they were introduced to the experimental procedures for cognitive testing. To control for circadian and diurnal rhythm, the experiment began at 8.00 AM. Women were studied during the early follicular phase (days 3–5) of the menstrual cycle. The subjects refrained from consuming any food for at least 12 h, alcohol, heavy exercise and caffeine for at least 24 h before the experiment, and were instructed to sleep at least 8 h the night before the experiment. The experiments were performed at 22 °C and relative humidity of 60%.

On arrival at the laboratory, the subject dressed in a T-shirt, short shorts and socks and self-inserted the rectal probe, and then the strap for recording HR was attached to the chest. The subject was asked to rest in a semi-recumbent posture for 30 min, their HR were recorded during the last 20 min. After the stabilization of the body temperatures, control measurements of T_{RE} and skin temperatures were made. The subject

Table 1 – Physical characteristics of subjects.

Variable	Men (n = 28)	Women (n = 25)
Age, years	20.9 ± 0.8	21.6 ± 2.1
Height, cm	182.5 ± 5.5	169.8 ± 6.5
Mass, kg	78.5 ± 8.4	62.2 ± 9.8
Body mass index, kg/m^2	23.6 ± 2.4	21.7 ± 3.4

Data are presented as mean ± standard deviation.

was then seated at a table, and six cognitive tests were performed.

2.3. Controllable variables of diurnal and circadian rhythms measurements

Temperature measurements. All body temperature measurements were made at rest before cognitive function testing. T_{RE} was measured using a thermocouple (Rectal Probe, Ellab, Hvidovre, Denmark) self-inserted to a minimum of 12 cm past the anal sphincter. Skin temperature was measured with thermistors taped at three sites: back, thigh and forearm (DM852, Ellab), and mean skin temperature (T_{SK}) was calculated by using Burton's [22] equation: $0.5_{Back} + 0.36_{Thigh} + 0.14_{Forearm}$. Furthermore, the mean body temperature (T_B) was calculated as follows [23]: $0.65T_{RE} + 0.35T_{SK}$.

Heart rate measurement. HR was recorded using a HR monitor (S-625X, Polar Electro, Kempele, Finland) and calculated as the average from the last 20 min of the baseline recording.

2.4. Measurement of cognitive abilities

A programmed cognitive test battery was used to assess attention and memory. All tasks were computer-controlled, and the information was presented on the screen of a laptop (HP Compaq 6730b). The same programmed cognitive test battery was used in previous studies [24,25]. The reliability of chosen tests was considered acceptable because the intraclass correlations were $R \geq 0.80$ and the coefficient of variation for repeated tests was <5%. All tests were performed in a quiet and darkened laboratory with a laptop screen ~40 cm in front of the participant. The test battery took ~20 min to perform and included the following tasks:

The visual search test [26], corresponding to a commonly used Schulte's table, assesses attention that involves an active scan of the visual environment for a particular target among other objects. In the middle of the screen there appeared a square table in which the numbers from 1 to 25 were displayed in random order. Participants had to find and click the mouse button on figures in an increasing order from 1 to 25 without omission. After one table was accomplished, the next table appeared on the screen. Participants had to accomplish 5 tables as fast as possible and the mean test duration (in s) was calculated.

The unpredictable odd/even task switching test reflects cognitive flexibility, which is defined as the ability to adjust to changing demands [2]. This test measured mean choice reaction time (in ms) and incorrect response (in percent) to an unpredictable digit-choice protocol. Additionally, reaction time coefficient of variation (in percent) was calculated. Forty randomized single-digit stimuli from 0 to 9 of 180-s duration were displayed with varying inter-stimulus intervals in the middle of the screen. As fast as possible, the subject had to press the button for the even (right button) or odd (left button) digit corresponding to the digit presented.

The complex visual search and predictable task switching test, corresponding to a modified Schulte's table, assessed fourfold-task performance (visual scan and predictable attention switching) according to two different colors and two different sequence orders [2,26]. In the middle of the screen, there appeared a square table which contained random red numbers from 1 to 25 and black numbers from 1 to 24. The subject was asked to mark red numbers in ascending order and black numbers in descending order as fast and as accurately as possible. Besides, every time they had to switch the color and order of numbers in the following sequence: 1 – a red number, 24 – a black number, 2 – a red number, 23 – a black number, etc. The maximum allowed task duration was 5 min. Test duration (in s) and incorrect response (in percent) rate were calculated.

The forward digit-span task test assesses short-term memory [2], which can temporarily hold a limited amount of information in a very accessible state temporarily. The subject was instructed to remember a seven-digit sequence displayed for 3 s in the middle of the screen. The subject then immediately entered the digits using a numeric keyboard in the same consecutive sequence as presented. If the digits were identified correctly, for the next attempt, the sequence was one digit longer; if an error was made, the next sequence was one digit shorter. There were 16 sequences. The mean number and percentage of digit~~s~~ sequences (maximum 16 sequences corresponding to 100%) identified successfully and task duration (in s) were recorded. Additionally answered numbers coefficient of variation (the ratio of the standard deviation to the mean; in percent) was calculated.

The forced-choice recognition memory test [27] assesses visual working memory [2] because during this test participant retained the information in mind and manipulated with it. After looking at nine figures displayed for 15 s in the middle of the screen, the subject was required to recognize them from 28 figures presented in the study list in any order. The number and percentage of correctly identified images (maximum 9 images corresponding to 100%) and time (in s) were recorded.

The free recall test is the most effortful explicit memory test [27] which assesses working memory [2]. Participants were exposed to random and different 10 pairs of digits, each new pair appeared every 1.5-s on the screen, whereas before exposed pair disappeared. Immediately after exposing all pairs, participants were asked to recall as many of the studied digit pairs as they could in any order and enter them in the table which appeared after showing the task. The task was repeated twice, and the number and percentage of correct answers (maximum 20 answers corresponding to 100%) and time (in s) were calculated.

2.5. Statistical analysis

Statistical analysis was performed using SPSS v.21.0 (IBM Corp., Armonk, NY, USA). The data are reported as mean and standard deviation (SD). The univariate ANOVA was used to analyze the differences between men and women in all variables. The level of significance was set at $P < 0.05$ and the statistical power (SP, in percent) was calculated. If a significant difference was found, the bootstrap method was used to confirm the significance of results, and corrected level of significance was presented. The simulated differences were based on 5000 bootstrap samples. Pearson's correlation coefficients were used to identify relationships between variables.

Table 2 – Body temperature variables in men and women.

Variable	Men ($n = 28$)	Women ($n = 25$)	P	SP, %
Rectal temperature, °C	37.1 ± 0.3	37.70 ± 0.2	0.883	5.2
Mean skin temperature, °C	32.3 ± 1.0	32.2 ± 0.6	0.218	7.4
Mean body temperature, °C	34.0 ± 0.6	33.9 ± 0.4	0.557	8.9

Data are presented as mean ± standard deviation. SP, statistical power.

3. Results

3.1. *Evaluation of controlled variables of diurnal and circadian rhythms*

Men and women had similar heart rate (64.5 ± 8.7 bpm and 69.4 ± 10.0 bpm, respectively). Table 2 summarizes the temperature variables for men and women. There were no differences in T_{RE}, T_{SK} and T_B between men and women. There was no significant correlation between HR and body temperature variables.

3.2. *Evaluation of attention abilities in men and women*

Table 3 summarizes the attention test performance in men and women. There were no differences in duration and incorrect responses of the attention tests between men and women. Women had significantly higher ($P < 0.05$) response coefficient of variation than men during the unpredictable odd/even task switching. There was no significant correlation between odd/even switching task responses and coefficient of variation; however, a significant positive correlation was observed between the coefficient of variation and incorrect answers ($r = 0.29$, $P < 0.05$). There was no significant correlation between body temperature variables or HR and attention task performance durations or response time.

3.3. *Evaluation of memory abilities in men and women*

Table 4 summarizes the memory test performance in men and women. There were no differences in the memory test duration and correct answers between men and women. Women had a significantly higher ($P < 0.05$) mean digits

Table 3 – Attention task performance abilities in men and women.

	Men ($n = 28$)	Women ($n = 25$)	P	SP, %
Visual search test				
Mean test time, s	35.0 ± 5.8	34.6 ± 8.9	0.848	5.4
Unpredictable odd/even task switching test				
Mean response time, ms	584.8 ± 63.9	602.4 ± 66.7	0.335	15.9
Coefficient of variation, %	13.2 ± 3.1	15.7 ± 3.1	0.008	79.7
Incorrect response, %	3.6 ± 3.1	3.6 ± 3.6	0.928	5.1
Complex visual search and task switching test				
Test time, s	164.7 ± 31.33	177.4 ± 51.7	0.285	18.5
Incorrect response, %	2.9 ± 4.0	4.5 ± 3.92	0.180	26.6

Data are presented as mean ± standard deviation. SP, statistical power.

Table 4 – Memory task performance abilities in men and women.

Test	Men ($n = 28$)	Women ($n = 25$)	P	SP, %
Forward digit-span test				
Mean digits identified, *n*	6.9 ± 0.6	6.8 ± 0.8	0.426	12.4
Coefficient of variation, %	12.5 ± 2.0	14.0 ± 2.5	0.019	65.9
Correct answers, %	48.6 ± 3.7	49.8 ± 4.2	0.293	18.1
Test time, s	183.7 ± 31.5	173.6 ± 40.0	0.316	16.9
Forced-choice recognition memory test				
Figures identified, *n*	7.7 ± 0.8	7.9 ± 1.0	0.482	10.7
Correct answers, %	85.6 ± 9.1	87.6 ± 10.8	0.482	10.7
Test time, s	67.7 ± 17.6	63.2 ± 18.4	0.371	14.4
Free recall test				
Digit pairs identified, *n*	11.8 ± 2.2	11.9 ± 2.7	0.879	5.3
Correct answers, %	59.1 ± 11.0	59.6 ± 13.7	0.879	5.3
Test time, s	177.9 ± 42.1	202.6 ± 68.0	0.118	34.6

Data are presented as mean ± standard deviation. SP, statistical power.

coefficient of variation than men during the forward digit-span task. Furthermore there was a significant negative correlation between memorized forward digit span and coefficient of variation ($r = -0.59$, $P < 0.001$) and between coefficient of variation and correct answers ($r = -0.45$, $P < 0.001$). There was no significant correlation between body temperature variables or HR and memory span.

4. Discussion

The main aim of this study was to compare cognitive abilities between men and women in a strongly controlled experiment. Although we did not observe differences in the mean values of attention and memory between men and women, higher intra-individual variability of short-term memory and attention switching in women was identified, which correlated with lower cognitive abilities.

The data showed no differences in HR and body temperature variables between men and women, which corresponds to comparable cognitive pattern of functioning of both sexes. We assumed that higher gray matter percentage in women's brain [4,5] would be advantageous in visual search and complex visual search as well as predictable task switching tests, whereas unpredictable task switching would not be affected by sex due to the same basal ganglia morphology [8]. In a previous study by Stoet [15] was observed men's advantage in visual search. Thus, contrary to our expectations and previous study [15], we did not observe any sex advantage in visual search and complex visual search and predictable task switching tests. In contrast to the study by Tun and Lachman [14], we did not observe that increased task complexity was associated with slower responses in women compared to men. However, there can be some discrepancies due to mean measures restrictions to explore intra-individual differences [6,28] or uncontrollable previous experiments. Furthermore, available literature shows contradictory results of task switching paradigm between men and women, arguing about men's [11] or women's [16] advantage in multi-tasking. Our results coincide with the results of the study by Reimers and Maylor [11], which showed that men had advantage in task-switching. We observed that unpredictable task switching mean values were not affected, whereas performance variability was affected by sex, lower coefficient of variation in men was associated with greater cognitive functioning.

We hypothesized that during controlled study women would have advantage in short-term memory task performance, whereas no difference would be observed in working memory tests due to differences in brain morphology [4,5]. Our hypothesis was confirmed partly. In accordance with our expectations and previous studies [29,30] we found no working memory differences between men and women. By contrast, the findings of Harness et al. [12] showed women's advantage in visual working memory. Discrepancies between studies may exist due to the differences in experimental protocols including different controllable factors and different tests to assess cognitive abilities. In the current study we used forced-choice visual working memory recognition task, while in the previous study a free recall task was used. In contrast to our hypothesis, short-term memory task was affected by sex. According to available literature [13,31], our results support findings about men's advantage in digit span task, where we observed differences in coefficients of variation, but not in mean values. Lower coefficient of variation was observed in men, which was negatively related to forward digit span and correct answers, corresponding to inferior cognitive abilities in women.

Some limitations of the study should be noted. First, we did not evaluate the effect of other factors that may influence cognitive performance, such as self-rated health, physical activity level or marital status [1,32]. Second, as we showed in a few tasks, the mean value could be insensitive during cognitive testing. Thus, in accordance with Kanai and Rees [6], we propose that averaging results can lead to incorrect conclusions and must be interpreted with caution. It is of great importance to include intra-individual variability evaluation in cognitive function assessment, as it can show more specific sex differences. It is noteworthy that our results showed that sex difference in cognitive performance cannot be attributed to known brain morphology differences in men and women. It can be expected that there could be changes in brain morphology in line with changes of cognitive abilities over time [1,3]. Moreover, it is known that there exist sex-specific patterns of cortical activation [33–35], which affect cognition and should be included in future investigations explaining morphological differences, brain activation patterns and cognitive function relationships in men and women.

5. Conclusions

In summary, the main findings of our study are as follows: (i) no sex differences were observed in the mean values of memory and attention task performance; (ii) sex differences were observed in short-term memory and unpredictable attention switching task performance variability, which was higher in women compared to men; (iii) higher performance variability was related to inferior performance on these cognitive abilities.

Conflict of interest

The authors state no conflict of interest.

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