PEOPLE: International Journal of Social Sciences
ISSN 2454-5899

Joseph D. Lou, 2018

Volume 4 Issue 3, pp.323-340

Date of Publication: 22nd November 2018

DOI-https://dx.doi.org/10.20319/pijss.2018.43.323340

This paper can be cited as: Lou, J. D. (2018). The Cost of Multitasking: A Computer-Assisted Quantitative Study of Task-Switching Costs in Speed and Accuracy by Age and Gender. PEOPLE: International Journal of Social Sciences, 4(3), 323-340.

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THE COST OF MULTITASKING: A COMPUTER-ASSISTED QUANTITATIVE STUDY OF TASK-SWITCHING COSTS IN SPEED AND ACCURACY BY AGE AND GENDER

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Abstract

*Multitasking is known to have negative impacts on productivity. However, there has been no systematic study on its negative effects comparing age and gender groups at a large scale. Due to limitations in previous methods, this study aimed to develop an original web-based Multitasking Test (MTT) tool and then use it to test a large sample of diverse participants on their task-switching costs (time and accuracy lost when multitasking). MTT allowed participants (*N *= 1,004) to each conduct 6 pattern-matching tasks with playing cards (20 trials per task). Results indicated that (a) high schoolers took 95% more time and made 120% more errors when multitasking than when performing single tasks separately; (b) the 22-25 age group performed the best among all groups, consistent with previous neuroscience findings that the human brain does not reach maturity until 24 years old; and (c) there were significant gender differences (*$p < .001$*) in switching costs in time, potentially explained by gender differences in the structural connectome of human brains. This study presents an innovative, computer-assisted methodological design and demonstrates how multitasking has switching costs across all age and gender groups regardless of prior experiences and education level. In addition to presenting strong empirical data that support the Cognitive Load Theory, it also provides a* *reliable multitasking paradigm for further studies in cognitive science, developmental psychology, and neuroscience.*

Keywords
Multitasking, Task-Switching Cost, Age, Gender, Developmental Psychology

1. Introduction

Multitasking is different from performing multiple actions at once. Chewing gum while reading, for example, does not qualify as multitasking because chewing gum is an "automatic" physical action that the person is familiar with. Rather, multitasking involves performing two or more complex, cognitive tasks simultaneously such as texting friends and playing games while doing homework.

Multitasking has become a frequent occurrence in daily life (Seereekissoon, 2018; Tham & Tham, 2015). Many people are reported to check their emails 30-40 times an hour on a regular workday while working (Walsh, 2011). Teenagers also spend an exorbitant portion of time on media – as much as 9 hours on average every day, according to a survey by Common Sense Media (2015). Half of 2,658 children (aged 8-18) who participated in the survey reported that they performed one or more tasks (such as watching TV, listening to music, texting, or using the Internet) while doing homework (Common Sense Media, 2015). About two-thirds of teens who were asked did not think that multitasking while doing homework "makes any difference to their ability to study and learn" (Lien, 2015).

However, based on cognitive research on how the human brain works, efficient multitasking is a myth. In actuality, research finds that multitasking has performance costs (American Psychological Association, 2006; Koch, Poljac, Müller, & Kiesel, 2018; Strobach, Liepelt, Schubert, & Kiesel, 2012). When the human brain processes visual and verbal information, it uses an information processing system called the "working memory," also known as the short-term memory (Turner, 1989). According to the Cognitive Load Theory, the working memory is limited in both duration (holding information for only a few seconds) and capacity (holding only 5 to 7 items at a time) (Kirschner, 2002; Paas, van Gog, & Sweller, 2010). Therefore, research shows that our brain cannot do two mental tasks at a time (Rogers & Monsell, 1995). While "multitasking," the brain actually subconsciously switches back and forth between tasks so that it handles only one task in its working memory at a time.

According to Rogers and Monsell (1995), it wastes time to force the brain to "juggle" between tasks and thus decreases performance. This juggling between tasks results in switching costs (Rogers & Monsell, 1995; Strobach et al., 2012) or task-switching costs (Wong et al., 2018). Switching costs are defined as the time and accuracy lost to task switching during multitasking (e.g., task switching in the form of ABABAB) when compared to completing single tasks separately (e.g., AAAA for one single task and BBBB for another single task). Switching costs may seem small, taking only a few tenths of a second per switch, but in actuality make a substantial difference when accumulated through repeatedly switching back and forth between tasks (Rubinstein, Meyer, & Evans, 2001). Meyer, a well-known cognitive psychology researcher, suggests that the productivity of completing a task can be reduced by as much as 40 percent when one multitasks (American Psychological Association, 2006).

Even though it is a widely accepted notion that multitasking has negative impacts on productivity, there has been no systematic, quantitative study on the negative effects of multitasking across age and gender groups at a large scale. Previous research on switching costs has often been limited to a few dozen subjects in their 20s or 60s (e.g., N = 14: Czerwinski, Cutrell, & Horvitz, 2000; N = 69: Fox, Rosen, & Crawford, 2009; N = 12: Rubinstein et al., 2001; N = 16: Strobach et al., 2012); empirical studies are lacking for other age groups and gender differences (Stoet, O'Connor, Conner, & Laws, 2013). With a shortage of research findings and convincing data for their own age groups, many students, especially teenagers, do not comprehend that multitasking is a risk to safety and efficiency. Notably, when people multitask, their brain releases a reward chemical called dopamine, a neurotransmitter that makes them feel good about multitasking even when they are actually doing worse (Grattan & Akopian, 2016). There is a need for systematic assessments and data analyses on multitasking costs across all groups in order to understand how the human brain functions and how it changes with age, gender, and other demographic information.

Another limitation that prevents a complete and systematic study on multitasking across age and gender groups is the limited psychological methodologies available for measuring switching costs. Previous multitasking evaluation methods, such as taking standardized tests while texting, do not work with the author's objective of testing a wide range of subjects both young and old. Rubinstein et al. (2001) developed an innovative method of using handmade paper patterns to manually measure switching costs in reaction time and accuracy. However, in a pilot study (N = 13) of using the same method, the author noticed the following problems: (a) manual time measurement was inaccurate; (b) pattern differentiation on geometry shapes was vague, causing random error; and (c) only a few subjects (e.g., N = 12 in Rubinstein et al.'s experiment) could be tested with the existing method due to the time consuming act of data collection. Developing a new approach for both accurate and efficient measurements of multitasking switching costs was needed to meet the objectives of this study.

2. Objectives of the Study

This study aimed to test a large number of diverse participants on the effects of multitasking and investigate the age and gender differences in task-switching costs in speed and accuracy. The objectives of the study were as follows:

- To create an original web-based tool and develop an innovative approach to quantitatively measure participants' task switching costs across age and gender groups.
- To investigate how the Switching Cost in Time (SC^T, i.e., the extra time lost to task switching during multitasking) and the Switching Cost in Error (SC^E, i.e., the extra errors made due to multitasking) change with age group, gender, and complexity of tasks.

3. Hypotheses

Aligning with survey results reporting that high schoolers multitask the most compared to all other age groups (Gaither, 2006), the author hypothesized that the high-school age group (aged 14-17 years) would perform the best and have the lowest switching costs. Media multitasking is especially prevalent with this group due to increasingly available mobile devices and social networking sites (Walsh, 2011). Furthermore, the author predicted that women would have lower switching costs compared to men because women were reported to be involved in more multitasking. Consistent with Rubinstein et al. (2001), the author also hypothesized that complex tasks would increase switching costs for multitasking compared to simple tasks.

4. Method

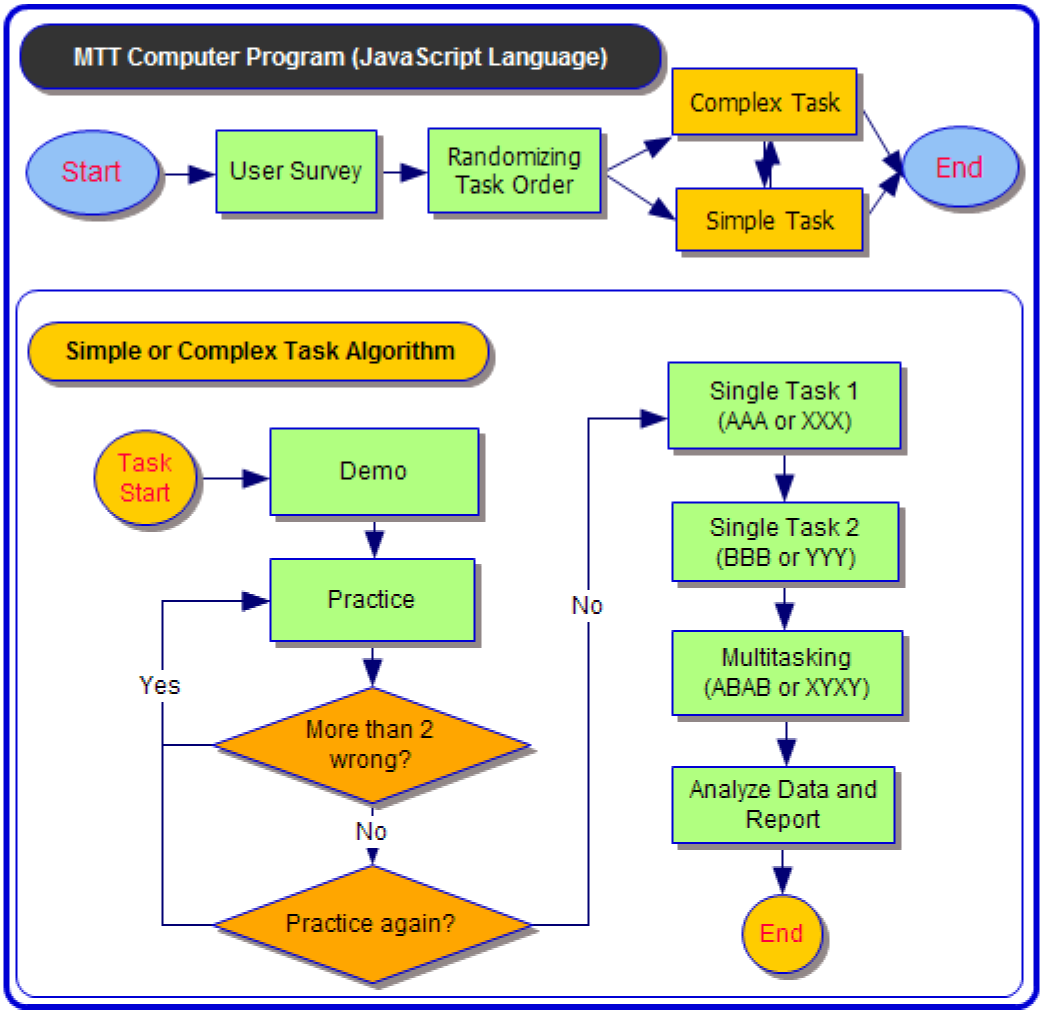
To investigate the age and gender differences in switching costs, the author created an original web-based Multitasking Test (MTT) computer program using JavaScript and a data analysis program using Python (see Figure 1 for program algorithms). The program prompted the subject to conduct six pattern-matching tasks with playing cards. It also asked the subject to take a demographic survey on age, gender, education level, and how much they multitask in their daily lives.

The six pattern-matching tasks included three simple tasks (repetitive-task block AAAA, repetitive-task block BBBB, and alternating-task or multitasking block ABAB) and three complex tasks (repetitive-task block XXXX, repetitive-task block YYYY, and alternating-task or multitasking block XYXY) (see Figure 2 for illustration). Each task took about three minutes to complete and included the practice session and the real test. The real test for each task contained 20 trials (four warm-up trials and 16 test trials) in order to get accurate results. The outlier trials that fell out of the mean ±2 SD were eliminated before the mean scores were calculated. The testing order of simple and complex tasks was counterbalanced for different subjects, following Kray, Eber, and Karbach (2008). The time used for completing each task and the error data were recorded while the subject performed each task on the website. The switching costs were then calculated and reported as feedback to the subject.

The MTT tool was promoted to the public and participants were recruited through personal contacts, emails, and social network sites. A total of 1,004 participants from 29 states in the United States and 10 foreign countries took the online MTT, completing 1,004 (participants) × 6 (tasks/participant) × 20 (trials/task) = 120,480 trials with a multitude of switching cost data. For the present study, only the age groups with a statistically large enough sample size were selected for data analyses, resulting in 607 subjects between the ages of six and 45 (283 males and 324 females) (see Table 2). The test data was calculated with the Python data analysis program and analyzed by using polynomial regression analyses and statistical significance tests, including independent samples *t*-tests and one-way ANOVA tests.

In this study, the constant factors were the set of target cards, the set of test cards to match the target cards, and the procedure in which completion time and error data during the trials were recorded. There were three independent variables: (a) age group, (b) gender, and (c) complexity of tasks.

(a) MTT Computer Program



(b) Data Analysis Program

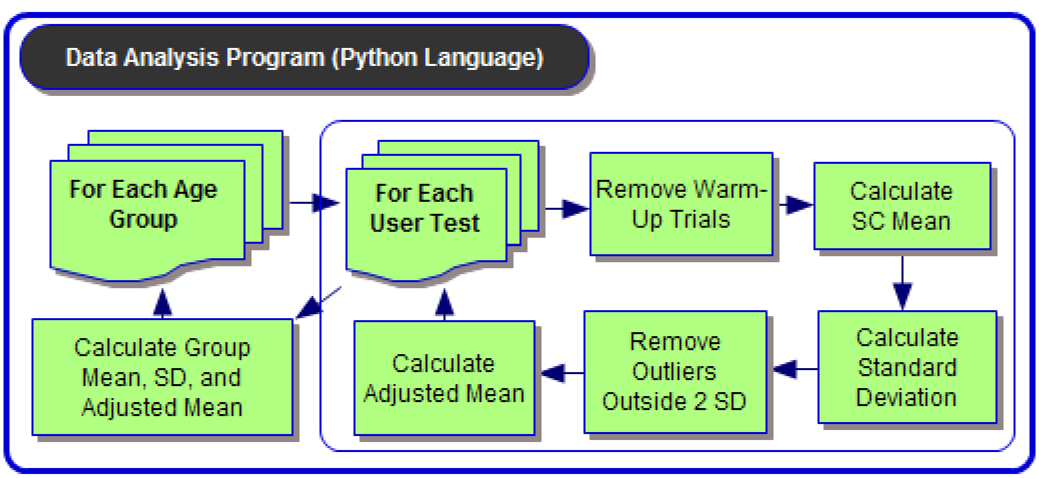


Figure 1: *Algorithm flowcharts for (a) the MTT computer program (using JavaScript) and (b) the data analysis program (using Python)*

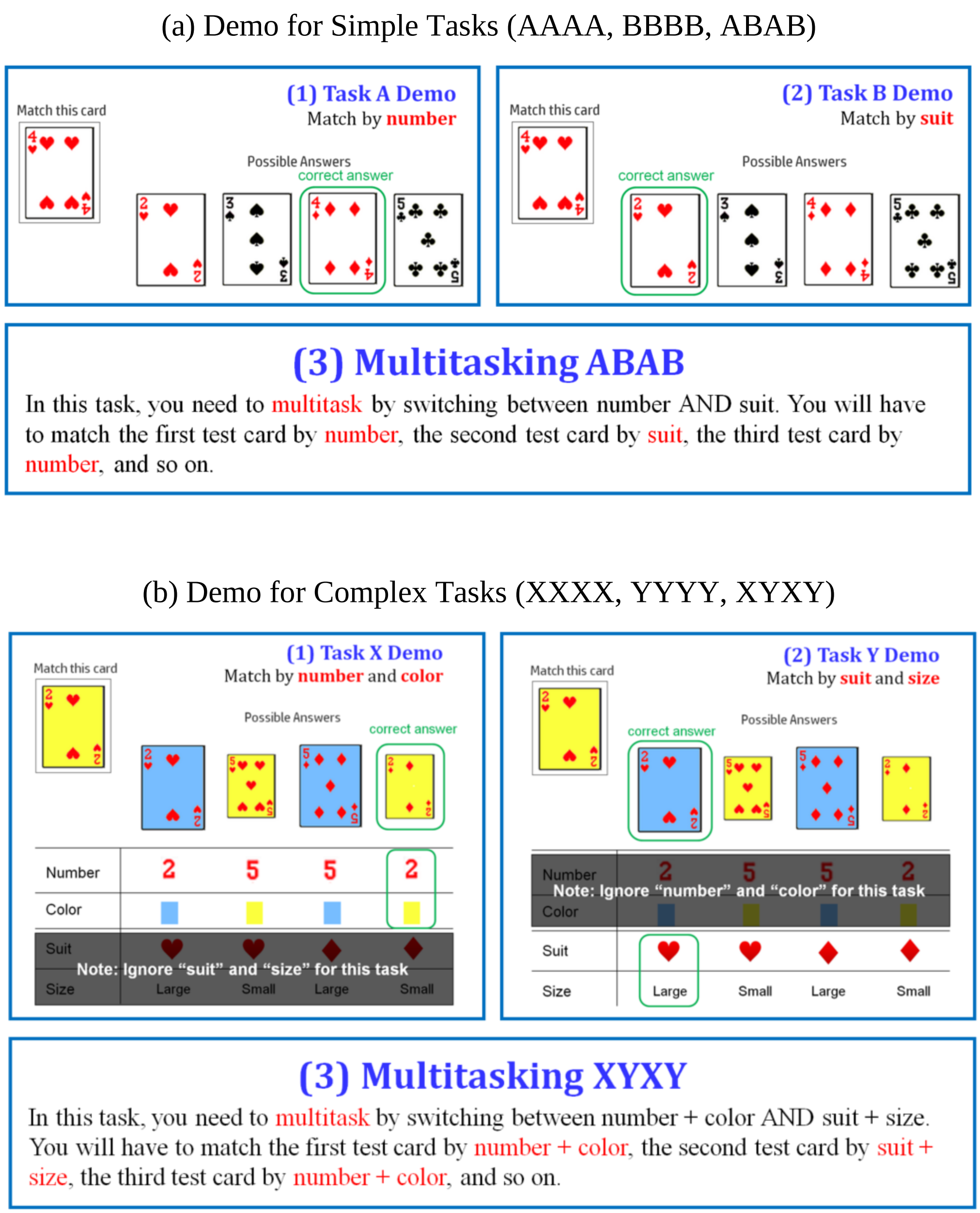


Figure 2: *Screenshots of the MTT demo videos for (a) simple tasks and (b) complex tasks.*

5. Results

The Switching Cost in Time (SC^T) was calculated as the difference between the mean completion time per task-switch (T_{AB} or T_{XY}) spent in an alternating-task or multitasking test ABAB or XYXY and the average of the mean completion times per task-switch (T_A and T_B or T_X and T_Y) spent in performing two single tasks separately, as shown in the formulas (1) and (2).

$$SC_{AB}^{T} = T_{AB} - (T_A + T_B)/2 \qquad (1)$$

$$SC_{XY}^{T} = T_{XY} - (T_X + T_Y)/2 \qquad (2)$$

The Switching Cost in Error (SC^E) was defined and calculated as the number of extra errors made due to task switching out of 16 multitasking trials and calculated as shown in the formulas (3) and (4).

$$SC_{AB}^{E} = E_{AB} - (E_A + E_B)/2 \qquad (3)$$

$$SC_{XY}^{E} = E_{XY} - (E_X + E_Y)/2 \qquad (4)$$

For example, Table 1 presents a set of completion time, in milliseconds (ms), of a 21-year-old male in performing simple tasks (AAAA, BBBB, and multitasking ABAB) for 20 trials (4 warm-up trials plus 16 test trials). Data from his first 4 warm-up trials were not used for analysis. The Switching Cost in Time (SC_{AB}^{T}) was calculated using Formula (1) above. The mean completion time per task-switch (T_{AB}) spent in the multitasking test ABAB (i.e. doing tasks A and B *together* by switching between them) was 1304 ms, as shown in Table 1. The average of the mean completion times per task-switch (T_A and T_B) spent to complete two single tasks *separately* was (883 + 1022) / 2 = 952.5 ms. Therefore, SC_{AB}^{T} was calculated as 1304 – 952.5 = 351.5 ms, indicating that it took the subject an average of 351.5 ms to switch between tasks A and B each time. In other words, the subject's Switching Cost in Time was 351.5 ms for this specific test.

5.1 Age Differences in Switching Costs

Table 2 presents descriptive data and calculated mean scores of switching costs for each age group. Results indicated that high schoolers (the 14-17 age group), with a mean SC^T of 1,600 ms and a mean SC^E of 1.55 errors, took 95% more time and made 120% more errors in average when multitasking with complex tasks than when performing two single tasks separately.

Table 1: *Sample data of completion time from a 21-year-old male in performing simple tasks (AAAA, BBBB, and multitasking ABAB) for 20 trials (4 warm-up trials plus 16 test trials)*

Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	*Mean*
AAAA	-	-	-	-	1014	874	780	1030	1138	874	858	764	952	842	1014	765	702	780	889	858	883
BBBB	-	-	-	-	1284	1061	1076	1201	1030	874	1560	1022	1217	1045	858	718	593	951	874	983	1022
ABAB	-	-	-	-	1201	889	1435	843	1435	1747	1701	1341	1201	1108	1310	1358	1528	1046	1341	1373	1304

Note. Completion time was recorded in milliseconds (ms).

Table 2: *Descriptive data for each age group and mean switching costs as function of group for simple tasks AB and complex tasks XY*

Group	*N*	SC_{AB}^{T}		SC_{XY}^{T}		SC_{AB}^{E}		SC_{XY}^{E}	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age									
6-9	26	1026	522	2067	1068	1.46	1.73	1.33	2.08
10-13	71	710	306	1730	847	1.07	1.33	1.52	1.81
14-17	73	563	252	1600	935	0.67	1.11	1.55	1.96
18-21	132	510	237	1458	746	0.50	1.00	1.22	1.54
22-25	117	428	197	1319	607	0.28	0.75	0.76	1.45
26-29	54	464	216	1442	818	0.40	0.85	0.93	1.81
30-33	37	541	280	1419	668	0.43	0.83	0.99	1.41
34-37	31	528	192	1640	765	0.35	0.77	1.11	1.61
38-41	38	568	303	1629	690	0.36	0.93	1.20	1.38
42-45	28	579	249	1627	710	0.46	0.70	1.19	1.65
Gender									
Male	283	556	267	1642	819	0.57	1.10	1.28	1.79
Female	324	553	284	1427	721	0.61	1.05	1.20	1.94

Note. SC_{AB}^{T} = Switching Cost in Time (ms per switch) for simple tasks AB; SC_{XY}^{T}= Switching Cost in Time (ms per switch) for complex tasks XY; SC_{AB}^{E} = Switching Cost in Error (# errors out of 16 test trials) for simple tasks AB; SC_{XY}^{E} = Switching Cost in Error (# errors out of 16 test trials) for complex tasks XY.

Among the 10 age groups in the 40-year age range (six to 45 years old), the 22-25 age group appeared to have the lowest mean switching costs in both simple tasks (428 ms per switch and 0.28 errors out of 16 trials) and complex tasks (1,319 ms and 0.76 errors). This finding was further confirmed through polynomial regression analyses. As shown in Figure 3, the R^2 values (0.9404 and 0.9830) for the regression curves were very close to 1, suggesting that the fit was good and reliable. The regression equations were then used to calculate the exact value of the minimum point at which the derivative of the equation equaled zero. Age Group #5 (aged 22-25), having the lowest SC^T (451 ms for simple tasks and 1400 ms for complex tasks) among all age groups, was determined to be the best-performing age group.

The regression curves in Figure 3 also display the SC^T trend by age group. Results indicated that young children have the highest switching costs and that switching costs decrease with age until 22 to 25 years old and then increase slightly to a plateau (mid-30s to mid-40s).

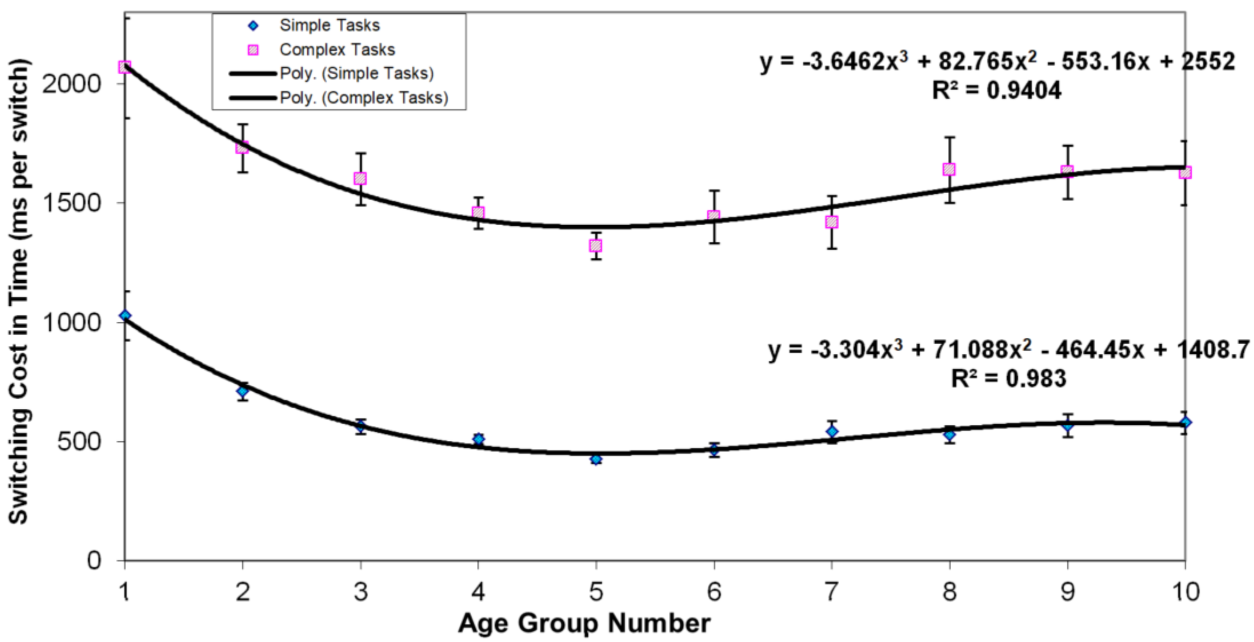


Figure 3: *Change of Switching Cost in Time as function of age group for simple and complex tasks. The third order polynomial regression curve fitting was conducted using Excel. The age group numbers were assigned as follows. #1: 6-9 years old; #2: 10-13; #3: 14-17; #4: 18-21; #5: 22-25; #6: 26-29; #7: 30-33; #8: 34-37; #9: 38-41; #10: 42-45. The error bars represent standard errors of the mean.*

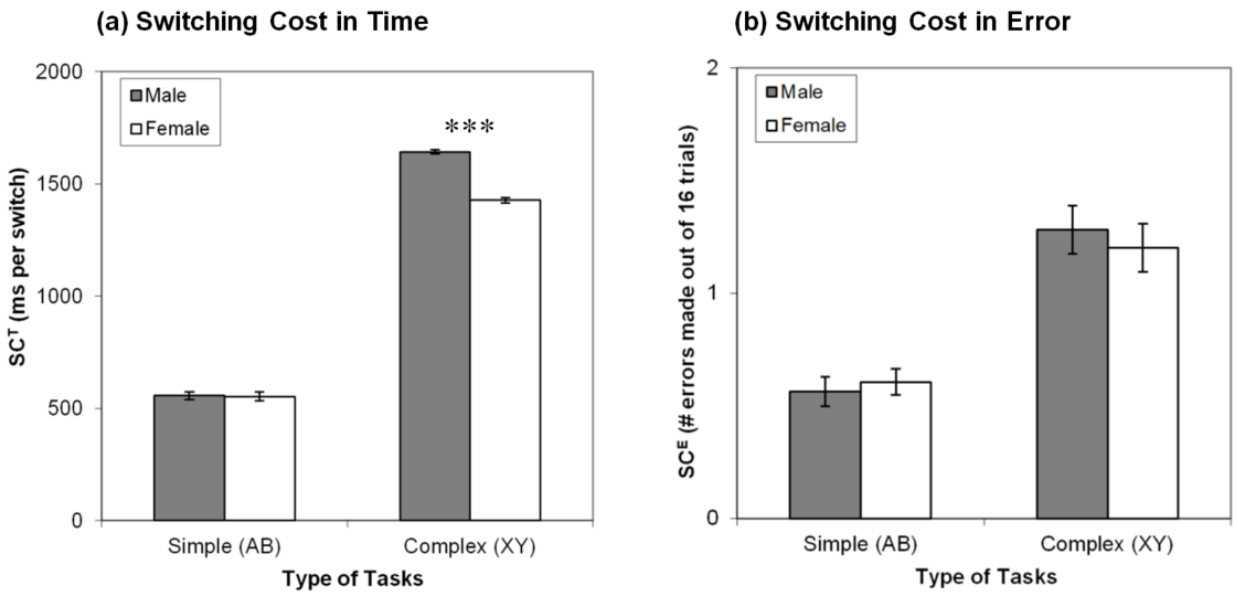


Figure 4: *Gender differences in switching costs for simple tasks and complex tasks. The error bars represent standard errors of the mean. *** indicates significance for* p *< .001.*

5.2 Gender Differences in Switching Costs

Figure 4 presents gender differences in switching costs. Independent samples *t*-tests were conducted. There was a statistically significant difference ($t(605) = 3.44$, $p < .001$, Cohen's $d = 0.26$) between males ($N = 283$, $M = 1642$ ms, $SD = 819$ ms) and females ($N = 324$, $M = 1427$ ms, $SD = 721$ ms) in terms of Switching Cost in Time for complex tasks (SC_{XY}^{T}). Other *t*-tests suggested that there was no significant difference ($p > .05$) between males and females in terms of SC_{AB}^{T}, SC_{AB}^{E}, or SC_{XY}^{E}.

5.3 Effect of Complexity of Tasks on Switching Costs

As indicated in Table 2 and Figures 3 and 4, complex tasks significantly increased switching costs in both time and error when compared with simple tasks. Even though SC^T may seem small (1,528 ms per switch in average), it can make a substantial difference when accumulated through recurring task switches.

5.4 Demographic Analyses

Based on the demographic survey data collected from the present study, further one-way ANOVA and independent samples *t*-tests were conducted. As presented in Table 3, results indicated that factors such as ethnicity, prior experiences with playing cards or musical instruments, prior multitasking experiences, and education level did not have any significant effect ($p > .05$) on switching costs.

Table 3: *Statistical significance tests on the effects of the survey items on switching costs*

Survey item	Level	Statistical test	Simple tasks	Complex tasks
Ethnicity	White, Hispanic, Black, Asian, Others	ANOVA	p = .594 (ns)	p = .270 (ns)
How familiar are you with the playing cards?	Never played them before, Played a few times, Played a lot	ANOVA	p = .132 (ns)	p = .442 (ns)
How often do you multitask when you do homework/work?	Always, Often, Sometimes, Barely	ANOVA	p = .374 (ns)	p = .379 (ns)
Do you play musical instruments?	Yes, No	t-test	p = .250 (ns)	p = .437 (ns)
Education level	Elementary, JH, HS, Associate, Bachelor, Masters, Doctorate	ANOVA	p = .975 (ns)	p = .382 (ns)

Note. ns = not statistically significant

6. Discussion

In this study, the author developed an original web-based Multitasking Test (MTT) tool that was able to reach a large number of participants domestically and around the world. A quantitative study was conducted to investigate how multitasking switching costs changed with age (encompassing a wide age range of 40 years), gender, and complexity of tasks.

Results refute the first hypothesis that the high-school age group (aged 14-17) would have the best multitasking performance among all age groups. Instead, the age group appears as to be one of the worst performing groups despite being reported to multitask the most. This finding on teenage multitasking helps dismiss the common myth among teenagers that multitasking is harmless. Notably, results are consistent with previous neuroscience and developmental psychology findings that the human brain does not reach maturity until 24 years old (Arain et al., 2013), explaining why the 22-25 age group performed the best among all groups in the MTT experiment.

Results support the second hypothesis and demonstrate that women have significantly lower switching costs compared to men, which can be potentially explained by gender differences in the structural connectome of human brains (Ingalhalikar et al., 2014). Said to have conducted the biggest investigation of its kind, Ingalhalikar et al. (2014) scanned the brains of nearly 1,000 subjects and mapped out the brain connection differences by gender using MRI imaging. As illustrated in Figure 5, males' brains (top) display significantly increased brain networks within hemispheres, whereas females' brains (bottom) display far better connections between the left and right sides of the brain. Therefore, researchers propose that the different "designs" of their respective brains account for the findings that males are better at carrying out single tasks while females are better at carrying out multiple tasks simultaneously (Ingalhalikar et al., 2014). Results from the present study not only support the above explanation but also provide further empirical data to demonstrate that the statistical difference between females and males in switching costs in speed is significant even on a level of $p < .001$.

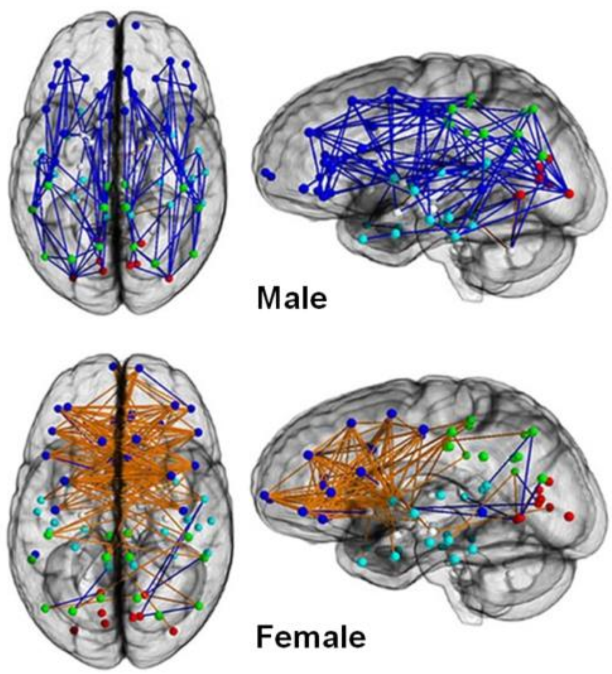


Figure 5: *Images were adapted from Ingalhalikar et al. (2014) and were mapped using the Magnetic Resonance Imaging (MRI) of the brains of 949 subjects (428 males and 521 females), illustrating gender differences in the structural connectome of human brains.*

Results support the third hypothesis that complex tasks would significantly increase switching costs for multitasking compared to simple tasks, which is consistent with the Cognitive Load Theory (Kirschner, 2002; Paas et al., 2010). According to the Cognitive Load Theory, when tasks become more complex and involve more pieces of information, it takes a significantly longer time to switch tasks because of the limitations of working memory resources (Paas et al., 2010). Results from the side experiment also suggest that, even though they differ across age and gender groups, switching costs do not differ significantly for other factors such as experience with multitasking or education level. Results indicate that people should be cautious about multitasking, especially in complex situations that demand safety and efficiency.

7. Conclusions and Implications

Inspired by Rubinstein et al. (2001), the author developed an innovative, computer-assisted switching cost assessment paradigm by creating a web-based Multitasking Test (MTT) tool that allows for better pattern matching, accurate data recording, and greater sampling. A quantitative study on the effects of multitasking was then conducted using the MTT tool.

Results support the Cognitive Load Theory (Kirschner, 2002; Paas, van Gog, & Sweller, 2010) and demonstrate that multitasking has switching costs in speed and accuracy across all age and gender groups regardless of prior experiences and education level. Multitasking may seem efficient on the surface, but it actually takes more time and involves more errors (e.g., taking 95% more time and causing 120% more errors by high schoolers in the present study). Furthermore, people are not necessarily good at multitasking simply because they multitask frequently. Although teenagers have been reported to multitask the most, the present study reveals that they exhibit low multitasking performance. Results from polynomial regression analyses on switching costs across all age groups are also consistent with previous findings in neuroscience and developmental psychology that the human brain does not reach maturity until 24 years old (Arain et al., 2013). Evidence strongly suggests that students, especially teenagers, should reduce multitasking when doing homework in order to increase their productivity. The results regarding the switching costs of complex tasks also suggest that as a task becomes more complex, individuals require a greater amount of focus to perform not only efficiently but also accurately.

The present study is innovative and meaningful for the following reasons. First, it conducts a systematic, quantitative study by analyzing data from a large number of participants across 40 years of age range (from six to 45 years old) and of both genders, while many other studies have only tested a few dozen college students or elderly subjects (Czerwinski, utrell, & Horvitz, 2000; Fox, Rosen, & Crawford, 2009; Rubinstein et al., 2001). Because of the substantial sample size, this study is able to provide strong empirical evidence suggesting that people of all age groups perform significantly worse in speed and accuracy when multitasking, even though they may feel good about multitasking due to dopamine released by their brain's reward center (Grattan & Akopian, 2016).

Importantly, this study also responds to Stoet et al.'s (2013) concern for "the near lack of empirical studies on gender differences in multitasking" (p. 1). Results elaborate Stoet et al.'s (2013) findings on a much larger scale, leading to robust conclusions that females have statistically significantly lower switching costs compared to males on a level of $p < .001$. Interestingly, results about gender difference in the present study can be potentially explained by gender differences in the structural connectome of human brains uncovered from mappings of approximately 1,000 brain MRI images (Ingalhalikar et al., 2014). The combined results from Ingalhalikar et al. (2014) and the present study suggest that the better connections between hemispheres in females' brains appear to have given them a biological advantage over males for significantly faster task-switching during multitasking. Overall, this large-scale quantitative study on age and gender differences in multitasking has revealed interesting facts for further studies in cognitive science, developmental psychology, and neuroscience.

Second, instead of having participants use paper cards for manual pattern matching tasks, the author created a computer-assisted test method and an original web-based computer MTT tool with many advantages. In contrast to the manual time-measurement method used in Rubinstein et al. (2001), MTT allows for accurate data recording on completion time and accuracy due to its precise computing power and capacity. Furthermore, the web-based tool allows greater sampling from over one thousand people in the U.S. and other countries. Fine-tuned data collection by trial that is only possible with a computer program also allows removal of outlier trials caused by unexpected incidents (such as sneezing during testing).

Third, the use of playing cards with existing features (e.g., number, suit, and color) for pattern matching tasks in the MTT experiment is novel and more accurate than using paper cards with vague pattern differentiations (Rubinstein et al., 2001). The number and suit features of the playing cards are familiar for potential subjects of all ages and require no learning curve for completing required tasks. Furthermore, matching by two features at the same time on the playing cards (e.g., matching by both number and color or matching by both suit and size) provides a much more difficult complex task design, thus simulating more realistic tasks and situations for drawing meaningful conclusions.

The MTT tool has received many positive reviews from online participants, such as the following:

- "Very interesting test and a very smart design! Looking forward to more tests like this."
- "This was really fun and great! This is a great way to show kids (like me) not to multitask during homework time."
- "This was very fun and challenging!"
- "Very interesting! I tend to multitask a lot as a college student but this made me think twice about the activities I do when I'm trying to learn something. Thanks!"

To conclude, this quantitative study presents a creative computer-assisted methodological design and develops an innovative MTT tool, which allows for testing over a thousand participants worldwide. In effect, the large sample results in robust conclusions with strong empirical data. Future research should recruit more participants above 45 years old to obtain a statistically large enough sample size for each older age group to complete the present data. Furthermore, it is important to investigate the effects of various interventions, such as practice, on reducing task-switching costs to resolve the ever-increasing conflicts between the cost of multitasking and the demand for efficiency in society. The new MTT tool developed in this study can be used as a reliable multitasking paradigm for further studies in psychology and cognitive sciences to improve safety and productivity in life and at work.

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