Research on the Interaction Mechanism Between Teenagers' Digital Multitasking and Cognitive Control

Ruoyuan Huang[1]

[1] *Grandview Heights Secondary School, Surrey, V3Z 0Z9British Columbia, Canada*
[1]*Email: 1503792747@qq.com*

ABSTRACT
This study explores the interaction mechanism between Digital Media Multitasking (DMM) and Cognitive Control (CC) in adolescents. Cross-sectional design was used to recruit 130 middle school students aged 12-18. The frequency, inhibition control, attention flexibility, working memory capacity and executive function of DMM were measured by self-rating scale and behavior experiment. The results show that the frequency of DMM is negatively correlated with the ability of inhibition and control (β=0.29), and the working memory capacity plays a partial mediating role (indirect effect 95% CI= [0.006, 0.082]), while the mediating effect of attention flexibility is not significant. Age plays a moderating role in the path of DMM's inhibition and control through working memory. Young adolescents (M-1SD) are more negatively affected by DMM (β=-0.32), and the effect of the elderly is weakened (β=-0.09). Gender did not show significant regulatory effect. This study reveals the negative influence mechanism of DMM on adolescent CC, emphasizes the importance of early intervention, and provides empirical evidence for scientific guidance of digital media use.

Keywords: *Teenagers, Digital media multitasking, Cognitive control, Interaction mechanism.*

1. INTRODUCTION

Today, the digital wave profoundly reshapes daily life. As a group of "digital aborigines", teenagers' media use behavior presents unprecedented multi-tasking characteristics. High-frequency and multi-channel Digital Media Multitasking (DMM) behavior has become a key variable that can't be ignored in the cognitive development environment of contemporary teenagers, and its potential impact on the Cognitive Control (CC) system of teenagers has aroused widespread concern and continuous debate in academic circles.

DMM refers to the behavior mode that individuals contact at the same time or frequently switch between multiple digital media platforms in the same time period [1]. Different from the traditional single-task activities, DMM requires individuals to constantly allocate attention, suppress irrelevant interference and flexibly switch between tasks with limited cognitive resources. This process is considered to pose a continuous challenge to the executive function system. DMM is not homogeneous behavior, which includes active switching type and passive accompanying type. There may be essential differences in their influence paths on cognition, and this distinction is often ignored in previous studies.

CC refers to an individual's advanced cognitive ability to regulate thinking and action in goal-oriented behavior, and its core components include inhibition control, working memory updating and cognitive flexible switching [2]. In the aspect of neural development, these components mainly depend on the prefrontal cortex (PFC) and its functional connection with the parietal lobe, basal ganglia and other brain regions, and the prefrontal cortex is in the critical window of continuous maturity in adolescence [3]. This means that teenagers' CC system may be highly sensitive and plastic to external environment input, including digital media usage patterns, and the impact of DMM on it, whether negative or positive, may leave a far-reaching mark at this stage of development.

Most of the existing studies only stay at the relevant level of DMM and CC, and lack the mechanism exploration of "through what path and under what conditions"; the research on teenagers, a specific development group, is relatively insufficient, especially in the Asian cultural background. The detailed distinction of DMM behavior types has not been included in the analysis framework of CC. In view of this, this study systematically discusses the interaction mechanism between juvenile digital multitasking and CC. Specifically, this study takes the three-component model of executive function as the theoretical framework, and uses the method of combining self-rating scale with behavior experiment to test the following assumptions:

H1: The frequency of adolescent DMM is negatively correlated with the ability of inhibition and control.

H2: Attention flexibility and working memory capacity play an intermediary role between DMM and inhibition control;

H3: Age and gender play a regulatory role in the above path.

This study hopes to provide empirical evidence for the scientific guidance of teenagers' digital media use by revealing the specific channels and boundary conditions of DMM's influence on CC.

2. METHOD

2.1 Participant

In this study, G*Power 3.1 software is used for prior power analysis to determine the sample size. According to the reference of the effect quantity in the existing similar studies [4], this study set the medium effect quantity (f^2 =0.15) as the detection standard. Assuming the statistical test force is 0.80 and the significance level α=0.05 (two-tailed), the minimum sample size is estimated to be 107 under the regression model including three predictive variables: DMM frequency, attention flexibility and working memory capacity.

Considering the invalid data rate of about 15%, this study recruited 130 adolescent participants. The recruitment target is middle school students aged 12-18. Informed consent is issued through school channels, and the written informed consent of the participants and their guardians is obtained at the same time. Participants need to meet the following conditions: (1) No diagnosed neurodevelopmental disorder or mental illness; (2) Normal vision or corrected vision; (3) No color blindness or color weakness.

2.2 Research Design

The study adopts cross-sectional design, combining questionnaire survey and behavior experiment [5]. All participants completed the following two stages in turn:

① In the first stage, the questionnaire was filled out, and all the self-assessment scales were completed in the classroom by group test, which lasted about 25 minutes.

② In the second stage of behavioral experiment, I went to the school computer laboratory or psychology laboratory in batches within one week to complete three computerized CC tasks in a standardized environment, which lasted about 30 minutes.

The order of the two stages is fixed, and the questionnaire is first followed by the experiment, so as to avoid the cognitive load in the behavior experiment from interfering with the quality of the questionnaire.

2.3 Measuring Tool

2.3.1 DMM Frequency

The Media Multitasking Scale (MMS) developed by Luo et al. (2018) was used, which is specifically designed for Chinese adolescents. The scale consists of 14 items and covers three dimensions: cross media multitasking (5 items), media and non-media multitasking (4 items), and level of focus without multitasking (reverse scoring, 5 items) [6]. Use a 5-point Likert scale (1="never", 5="always"). The scale has good reliability and validity, with Cronbach's alpha of 0.95, and has been cross culturally validated in a sample of Portuguese adolescents.

2.3.2 Inhibition Control

Use Color Stroop task to measure inhibitory control ability [7]. Participants need to name the color words presented, ignoring the interference of the meaning itself. Record the reaction time and correct rate. Stroop interference effect is the core index of inhibition control. The smaller the effect is, the stronger the inhibition control ability is.

2.3.3 Pay Attention to Flexibility

Using the Number letter Task to measure attentional flexibility [8]. Participants need to determine the parity or vowel/consonant properties of numbers or letters based on their position on the screen, and the task rules will randomly switch between trials. Record the conversion cost, which is the difference in reaction time between conversion attempts and repeated attempts.

2.3.4 Working Memory Capacity

Using 2-Back task to measure working memory capacity [9]. Participants need to judge whether the current stimulus is the same as the second stimulus counted forward, and complete several trials in succession. Record the correct rate and d' value as indicators of working memory capacity.

2.3.5 Daily Performance of Executing Functions (Self-assessment)

Using the self-assessment version of BRIEF2 (Behavior Rating Inventory of Executive Function, Second Edition) for adolescents [10], measure three dimensions of executive function in daily life: working memory, inhibition, and conversion. Each dimension contains 8 items, using a 3-point Likert scale (1="never", 3="often"). The higher the score is, the more prominent the problem in that aspect of daily life is. The internal consistency Cronbach's alpha values for the three dimensions of the scale are 0.85, 0.77, and 0.82, respectively.

2.4 Procedure

In the preparation stage, researchers communicate with school administrators in advance to obtain school support. Issue informed consent to qualified students and their guardians, detailing the research purpose, procedures, duration, confidentiality measures and voluntary withdrawal rights.

In the testing stage, during class meeting or self-study class, group testing is carried out by class as a unit. The examiners read out standardized instructions, emphasizing that there is no right or wrong answer and asking participants to answer according to the real situation. Questionnaires are treated anonymously and matched only by number. Within one week after the completion of the questionnaire, participants entered the laboratory in batches. In a quiet independent compartment, three cognitive tasks are completed by using a unified computer and headphones. Latin square design is used to balance the sequence effect. There are practice trials before each task to ensure that participants understand the rules. In the observation room next door, the main experimenter checks the progress of the experiment in real time through monitoring software, but does not intervene.

During the data organization stage, questionnaires with short response times (<5 minutes) or obvious regularity in response should be excluded; Exclude trial data in behavioral experiments where the accuracy is below the chance level or the reaction time exceeds the mean ± 3 standard deviations.

2.5 Data Analysis

SPSS 26.0 and PROCESS macro were used for statistical analysis. Firstly, descriptive statistics and correlation analysis are carried out to investigate the correlation between variables. Secondly, step-by-step regression analysis was used to test H1. Subsequently, Bootstrap intermediary effect test is used to test H2. Finally, group regression and interaction test were used to examine H3. All the analyses took α=0.05 as the significance level. Data analysis is completed in R language.

3. RESULTS

3.1 Common Method Deviation Test

Because some variables in this study were collected at the same time point through the self-rating scale, there may be common method deviation. Harman single factor test was used to analyze all the items in the self-rating scale by principal component analysis. The results show that there are four factors with eigenvalues greater than 1, and the variance explained by the first factor is 26.73%, which is lower than the critical standard of 40%. This shows that there is no serious common method deviation in this study.

3.2 Descriptive Statistics and Correlation Analysis

The mean, standard deviation and Pearson product-moment correlation coefficient of each variable are shown in "Table 1". The average frequency of teenagers' DMM is 2.31 (SD=0.68), which is equivalent to the average level of teenagers' media multitasking in existing studies [11]. There is a significant positive correlation

between DMM frequency and Stroop interference effect (r=0.31, p<0.01), indicating that the higher the DMM frequency, the worse the performance of adolescent suppression control. DMM frequency was negatively correlated with the correct rate of 2-Back task (r=-0.22, p<0.05). There is no significant correlation between DMM frequency and the conversion cost of digit-letter tasks (r=0.08, p>0.05), which is consistent with some existing research findings [12]. In addition, age was negatively correlated with DMM frequency (r=-0.19, p<0.05), indicating that younger teenagers reported higher media multitasking frequency. The correlation between gender and DMM frequency did not reach a significant level (r=0.10, p>0.05).

Table 1. Descriptive statistics and correlation matrix of each variable (N = 130)

Variable	M	SD	1	2	3	4	5	6
1. DMM frequency	2.31	0.68	—					
2. Stroop interference effect quantity (ms)	89.47	42.15	0.31**	—				
3. 2-Back accuracy rate (%)	78.62	11.34	-0.22*	-0.18*	—			
4. Conversion cost (ms)	124.38	58.27	0.08	0.12	-0.10	—		
5. Age	15.23	1.87	-0.19*	-0.07	0.15	-0.05	—	
6. Gender (1=male, 2=female)	—	—	0.10	0.06	-0.09	0.04	-0.02	—

a Note: *p<0.05, **p <0.01.

The larger the Stroop interference effect is, the worse the suppression control is. The greater the conversion cost, the worse the attention flexibility.

3.3 Predictive Effect of DMM Frequency on Suppression Control (H1 test)

In order to test H1, taking Stroop interference effect as the dependent variable and DMM frequency as the predictive variable, hierarchical regression analysis was adopted, and the control variables (age, sex) were gradually included. The results are shown in “Table 2”.

Table 2. Hierarchical regression results of DMM frequency predictive suppression control

Predictor variable	Model 1 (only controlling for variables)		Model 2 (with DMM added)	
	β	t	β	t
Age	-0.06	-0.68	-0.01	-0.11
Gender	0.05	0.57	0.03	0.34
DMM frequency			0.29	3.38**
R^2	0.01		0.09	
ΔR^2			0.08**	

a Note: **p < 0.01.

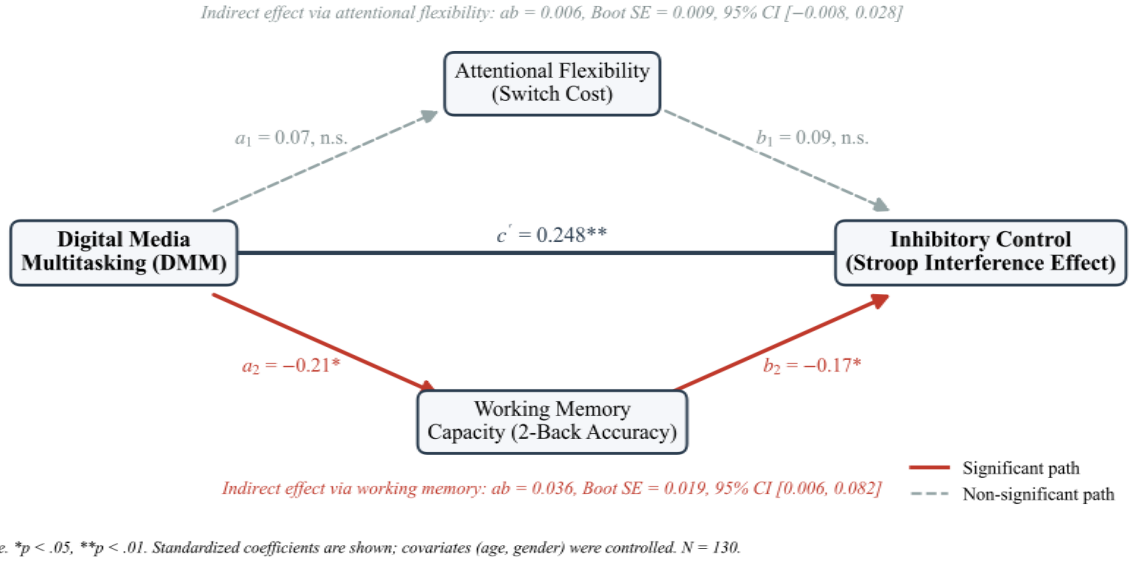
After controlling for age and gender, the predictive effect of DMM frequency on Stroop interference was significant (β=0.29, p<0.01), and the model explanatory power R^2 was 0.09. This result indicates that the higher the frequency of DMM, the poorer the inhibitory control ability of adolescents. H1 received support.

3.4 Paying Attention to the Mediating Effect of Flexibility and Working Memory Capacity (H2 test)

In order to test H2, PROCESS macro (model 4) was used to test Bootstrap mediation effect, and the sampling was repeated for 5000 times, and the 95% confidence interval was calculated. Taking DMM frequency as independent variable, Stroop interference effect as dependent variable, attention flexibility and working memory capacity as parallel intermediate variables, the analysis results are shown in “Figure 1” and “Table 3”.

The results showed that the negative predictive effect of DMM frequency on working memory capacity was significant (β=-0.21, p<0.05), and the negative predictive effect of working memory capacity on inhibitory control was significant (β=-0.17, p<0.05). Bootstrap analysis showed that the indirect effect of working memory capacity was 0.036 (Boot SE=0.019), with a 95%CI of [0.006, 0.082], excluding 0, indicating a significant

mediating effect of working memory capacity. However, the predictive effect of DMM frequency on attentional flexibility was not significant (β=0.07, p>0.05), and the indirect effect of attentional flexibility was 0.006 (Boot SE=0.009), with a 95%CI of [-0.008, 0.028], including 0, indicating no significant mediating effect.



*Note. *p < .05, **p < .01. Standardized coefficients are shown; covariates (age, gender) were controlled. N = 130.*

Figure 1 Path diagram of parallel mediation model.

Table 3. The direct and indirect effects of parallel mediation models

Path	Effect size	BootSE	95%CI
indirect effect			
DMM→Working Memory→Stroop Interference	0.036	0.019	[0.006, 0.082]
DMM→Pay attention to flexibility→Stroop interference	0.006	0.009	[-0.008, 0.028]
direct effect			
DMM→Stroop interference (direct)	0.248	0.085	[0.081, 0.415]

Based on the above results, working memory capacity plays a partial intermediary role between DMM frequency and inhibition control, but the intermediary role of attention flexibility is not significant. H2 is partially supported.

3.5 The Moderating Effect of Age and Sex (H3 test)

In order to test H3, PROCESS macro (Model 7) was used to test the moderating effects of age and gender in the direct path of DMM frequency→working memory capacity and DMM frequency→inhibition control. In the path from DMM frequency to working memory capacity, the interaction term between DMM frequency and age is significant (β=0.18, p<0.05). Simple slope analysis shows that for younger adolescents (M-1SD), DMM frequency has a stronger negative predictive effect on working memory capacity (β=-0.32, p<0.01); For older adolescents (M+1SD), the predictive effect was weakened and not significant (β=-0.09, p>0.05). In the direct path from DMM frequency to inhibitory control, the moderating effect of age was not significant (β=-0.07, p>0.05). The moderating effects of gender on the DMM frequency→working memory capacity path (β=0.06, p>0.05) and the DMM frequency→inhibition control direct path (β=0.04, p>0.05) were not statistically significant. To sum up, age plays a regulatory role in the path of DMM through the influence of working memory capacity, and younger adolescents are more sensitive to the negative cognitive effects of DMM. Gender did not show significant moderating effect in this research model. H3 is partially supported.

4. DISCUSSION

It is confirmed that the frequency of DMM is positively correlated with Stroop interference effect (β=0.29), which indicates that high-frequency

DMM will weaken the inhibition and control ability of teenagers. This result supports the distraction hypothesis, that is, multi-task switching leads to excessive consumption of attention resources, making it difficult for individuals to suppress irrelevant interference. It is worth noting that the differences of DMM behavior types have not been fully discussed, and the neural mechanism differences can be further distinguished by combining eye tracking or behavior coding technology in the future.

Working memory capacity partially mediates between DMM and inhibition control, indicating that DMM may indirectly damage inhibition control performance by reducing the efficiency of working memory resource allocation. This is consistent with the theoretical expectation of the three-component model of executive function, that is, the updating of working memory is the core link of CC. However, the mediating effect of attention flexibility is not significant, suggesting the different paths of different cognitive components affected by DMM.

Age exhibits a significant regulatory effect in the pathway of DMM→working memory→inhibitory control. Younger adolescents (M-1SD) have a stronger negative prediction of working memory with DMM (β=-0.32), while the effect weakens in older adults (β=-0.09). This confirms the theory of the critical window period for the development of the prefrontal cortex before puberty and suggests that early intervention may be more effective. The gender moderation effect did not reach a significant level, which may be related to the current gender balance of the sample (r=0.10). Different from most studies that only focus on the correlation between DMM and CC, this study systematically examines the parallel mediation model and reveals the specific role of working memory capacity. This finding is consistent with Pham et al.'s (2025) study on the damage of digital social multitasking to working memory [13].

The research results support the concept of "hierarchical teaching of digital literacy": for young students, unnecessary multitasking scenarios should be reduced, and cognitive resource management abilities should be improved through working memory training games. Schools can guide students to establish a sense of priority. Parents need to be wary of the "digital companion trap" and avoid using electronic devices as parenting tools. The research results provide scientific basis for the implementation rules of the Regulations on the Protection of Minors' Networks. It is suggested to add the option of "single task focus mode" in campus network construction, such as the dynamic theme generator can automatically switch interface styles according to learning scenarios.

The cross-sectional design cannot confirm the causal relationship, and longitudinal tracking studies need to be conducted in the future. In addition, self-assessment scales may have social expectation bias, and it is recommended to verify them with objective indicators such as electroencephalography (EEG). This study did not include potential confounding variables such as duration of social media use and sleep quality. In the future, AI big model can be introduced for automatic analysis of meeting records to mine finer-grained behavior characteristics. The unique phenomenon of "screen dependence" among teenagers in China may strengthen the cognitive cost of DMM. It is suggested to carry out transnational comparative research and explore the influence mechanism of cultural values on DMM-cognitive relationship.

To sum up, this study not only deepens the theory of cognitive development in the digital age, but also provides an evidence-based basis for building an educational ecology of "science and technology for goodness". Just like the "new quality empowerment" advocated by the Urban Planning Forum, we urgently need innovative technology to feed back the cognitive health of teenagers and promote the transformation of digital tools from "interference source" to "enabler".

5. CONCLUSION

In this study, the interaction mechanism between teenagers' digital multitasking and CC was systematically investigated by means of questionnaire and behavior experiment. The main findings are as follows: (1) DMM frequency significantly negatively predicts the inhibition and control ability of adolescents, which verifies the hypothesis of distraction; (2) Working memory capacity partially mediates the relationship between DMM and inhibition control, revealing an important way for DMM to influence CC; (3) Age plays a moderating role in the path of DMM→ working memory → inhibition control, suggesting that early adolescence may be the key sensitive period for the negative effects of DMM. The above results have important theoretical significance and practical enlightenment for understanding the risk

factors and protective mechanism of adolescent cognitive development in the digital age.

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