

Adolescent user behaviors on short video application, cognitive functioning and academic performance

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Abstract:

Despite the soaring popularity of short video applications (SVA) among adolescents worldwide, little is known about its potential impact on adolescent users. This study aimed to examine whether and how adolescents' user behaviors regarding SVA, including daily usage and reliance on algorithmic recommendations, predict their cognitive functioning and academic performance. A sample of Chinese adolescents from two age cohorts ($M_{\text{age}}=12.25$, $SD=0.02$, $N=454$; $M_{\text{age}}=15.21$, $SD=0.02$, $N=368$) completed the survey on SVA user behavior and cognitive ability test regarding academic delay of gratification (ADOG), working memory and verbal ability. The findings reveal that daily usage of SVA is negatively correlated with users' ADOG and academic performance for both age cohorts. And the dependency on algorithmic personalization negatively predicts the working memory, verbal ability and academic performance of the younger cohort only. Also, their SVA daily usage negatively correlates with working memory and verbal ability, which both simultaneously mediate between their user behavior and poorer academic performance. Considering the age differences in SVA-related effects, the study further points out the higher susceptibility of younger adolescents to SVA use compared to their older counterparts, which should be noted by students, parents, educators and researchers to prevent the potentially negative impact.

Key words: short video application, recommendation algorithm, cognitive functioning, academic performance, age differences

1. Introduction

Short video application (SVA), a newly-rising digital media giant that features real-time shooting and sharing of short videos on social platforms, has been growing dramatically worldwide in the past few years (SocialBeta, 2015). Compared with other Internet-based or smartphone-based social networking sites (SNS) and video-streaming platforms (VSP) in this digital age, SVA distinguishes itself by its attractive contents, diversified communicative forms and powerful recommender system (Schellewald, 2021; Su et al., 2021). Noticeably, adolescents are playing a substantial role among the huge quantities of users of SVA, with a quarter of TikTok users from 10-19 age group in the United States in 2021¹ and 49.3% of adolescent SVA users in China in 2020 (CNNIC, 2020). Though SVA can gratify adolescents' developmental need for identity-creation, social recognition and information-seeking (Bucknell Bossen & Kottasz, 2020), skeptical views on its potential negative impact on users' cognitive development and academic performance are increasing. These factors are important predictors of adolescents' future labor market performance, socioeconomic attainment, and both physical and mental well-being (Batty et al., 2007; Lövdén et al., 2020; Ritchie & Bates, 2013). However, whether and how SVA use may affect adolescents' academic performance haven't been addressed in empirical studies, despite previous evidence on the potential negative impact of adolescents' use of digital media on cognitive development and learning (Orben & Przybylski, 2019; Reid Chassiakos et al., 2016; Warsaw et al., 2021; Wilmer et al., 2017). Given that adolescent SVA users are experiencing a developmental window of cognitive susceptibility to digital media effects (Granic et al., 2020; Romer et al., 2017; Valkenburg & Peter, 2013), which is

¹ <https://www.statista.com/statistics/1095186/tiktok-us-users-age/> (accessed 22 Apr 2022)

crucial to learning (Serpell & Esposito, 2016), this study attempts to reveal the impacts of SVA on adolescents' academic performance via cognitive functioning. Meanwhile, considering the differential levels of development within adolescence (Sawyer et al., 2018), the current study attempts to reveal the age-related differences in the associations among SVA user behavior, cognitive functioning and academic performance between two age groups within adolescence (i.e., 12 to 13-year-olds and 15 to 16-year-olds).

2. Literature review

2.1 Properties of SVA and variables of interest on user behaviors

Short video (SV) is generally defined as user-generated videos that last 15 seconds up to a few minutes spreading via online platforms (SocialBeta, 2015). However, as relevant research is still at its nascent stage, definitions of SVA still diverge in current literature, which are deemed as SNS (Bucknell Bossen & Kottasz, 2020; Omar & Wang, 2020), VSP (Su et al., 2021; Yang et al., 2021), or highly visual social media (Marengo et al., 2022). Despite the divergence, it can be inferred that SVA grows out of both Internet-based, or more often smartphone-based social networking and video-sharing sites, and even develops its unique features (Schellewald, 2021). The similarities and extensions of SVA to the other media forms are displayed in Fig. 1.

Internet/Smartphone-based applications		
Social Networking Sites (e.g. Facebook, WeChat)	Video-streaming platforms (e.g. YouTube, Bilibili)	Short video applications (e.g. TikTok, Kuaishou ...)
• High interactivity	Interactivity	Interaction in deeper and more diverse forms
• AI recommender (ads)	AI recommender (contents)	AI recommender combined with technological hooks (e.g. scrolling up and down)
• Text/image-based	Audiovisual-based	Audiovisual-based
• Permanent or ephemeral availability of contents	Combination of long and short videos	Videos short in length and ephemeral in appearance

Fig. 1. Properties of SVA in relation and comparison to SNS and VSP

Apparently, SVA inherits its interactive nature from both SNS and VSP, yet it allows online participation more than liking, commenting, and sharing (Khan, 2017; Omar & Wang, 2020). In fact, the SVA online community has created distinct communicative forms, encouraging diversified ways of interaction, more meaningful connections among users and more social relationships to form. (Schellewald, 2021). For example, TikTok users can use “duet function” (i.e., integrating other users’ SV into one’s own creation) in video-making in response to the SV uploaded by others, and trends shared by SVA communities emerge continuously to stimulate user contribution using diverse SV-specific visual effects.

Also, like other VSP, SVA is the most media-rich presentation interface combining text, audio and video presentations compared to other text- and image-based SNS (Liu et al., 2009). This audiovisual nature can present more subjective information and create proximity in the social space linking individual activities (Daft & Lengel, 1986), and also satisfy users’ content gratification (Balakrishnan & Griffiths, 2017). Meanwhile, differing from other VSP (e.g., YouTube), SVA provides a wide range of creative SV genres and forms, and the multisensory stimuli of SV are organized at higher time resolution, usually condensed into less one or two minutes. This is connected with another nature of SVA, ephemerality, which is neither aligned with the ephemerality rendered by the temporary availability of content shared via SNS (e.g. Snapchat) (Bayer et al., 2016), nor merely reflected by the limited length of SV (Schellewald, 2021). Always looping by default, SV succeeds in immediately impressing users while fails to sustain the impression and meanings beyond momentary presence, as the next video most likely catering to the user’s need might be just one swipe away (Schellewald, 2021).

The readiness of videos to be replaced by a new one is made possible by another conspicuous property of SVA, its powerful algorithm-driven recommender (Zhao, 2021). Adapting online contents to meet users’ personalized needs and enhance human-media interaction, algorithmic individualization was first applied to web pages and later

to various media forms including SNS and VSP (Bozdag, 2013; Hasan et al., 2018; Tam & Ho, 2006). Meanwhile, users' interaction with the platform provides feedbacks for optimizing the recommendations (Bozdag, 2013). Similarly, the recommender embedded in SVA is intended to take over users' role of initiative searching by feeding video clips that will most likely resonate with users' interest. The scope of contents that can be possibly recommended is further expanded by the collaborative filtering algorithm, which is able to identify users' latent interests based on the similarity of user portrait and content labels (Zhao, 2021).

Furthermore, the intelligent algorithm is complicated by the system of functional and technological hooks embedded in SVA (Wang & Scherr, 2021; Yang et al., 2021). For instance, auto-scrolling of SV and the absence of timestamps can immerse users in the continuous consumption of recommended videos and a simple swipe on the screen makes it easier for them to come straight to their interest or get rid of boredom. Despite the user-friendliness rendered by the algorithm-driven system, heated debate is fueled on its negative influences such as user-control of information received and intrusion on privacy (Zanker et al., 2019).

2.2 Potential impact of SVA user behaviors on cognitive functioning and academic performance

Though SVA turns out to be successful in gratifying adolescents' needs for entertainment, affect, information-seeking and identity-creation (Bucknell Bossen & Kottasz, 2020), growing concerns have arisen over the risk of overuse (Yang et al., 2021; Zhang et al., 2019; Zhao, 2021) and potential negative influence on healthy lifestyle (Wang & Scherr, 2021), cognitive functioning (Sha & Dong, 2021) as well as on learning systems (Su et al., 2021). However, empirical evidence on these issues is still scant, compared to relevant research on the use of SNS, VSP, the Internet and smartphones.

Potentially, SVA use may affect users' cognitive functioning, as the constant intrusion of mobile technology on cognition and the way users adapt themselves to the passive consumption of personalized contents may revolutionize how they obtain and process information (Wilmer & Chein, 2016; Zhao, 2021), especially for adolescents undergoing profound cognitive changes (Sawyer et al., 2018). One of the concerns about SVA is that the readiness and immediacy of information rendered by the technological hooks as well as the instant gratification of various user needs may pose challenge to users' self-regulatory system (Wilmer et al., 2017). A key component of this system is the delay of gratification, the tendency to delay instant but smaller gratification for seeking bigger but more distant goals (Mischel & Ebbesen, 1970). This component, also regarded as an aspect of cognitive functioning (Wilmer et al., 2017), fits the research on media effect better than other self-regulatory concepts because instant gratification has become the innate affordance of the current digital media (Shim et al., 2018). The gratifications obtained from using SNS, including entertainment and social interaction, could raise users' expectations regarding the instant rewards and dispose them to pursue short-term goals rather than long-term ones that require lasting efforts (Du et al., 2019; Schutten et al., 2017). Also, using mobile technology is found to negatively predict the tendency to delay gratification, possibly due to the habitual checking of constant notifications and cues (Wilmer & Chein, 2016). Similarly, SVA, which provides online social interaction and video streaming service via mobile technology, is likely to discourage resisting the temptation of instant rewards. SVA may also immerse users in the exposure to the endless stream of short videos from the algorithmic recommender trained by personal preferences. This will presumably reinforce users' tendency to postpone the efforts needed to achieve long-term goals in favor of immediate gratifications, even in real-life work or study scenarios. Particularly, adolescent users are at a higher risk at the critical developmental stage of impulse control and reward sensitivity (Atchley & Warden, 2012; Tibber & Silver, 2022), both closely related to the delay of gratification (McClure et al., 2004). Moreover, since the

major role of adolescents is student, adolescent SVA users are often confronted with the distraction of mobile technology while studying. Hence, the preference to delay gratification in the academic settings, indexed by academic delay of gratification (ADOG), is more influential to them, which can facilitate their information processing and predict their learning performance (Bembenutty & Karabenick, 1998).

A second concern regarding cognitive functioning is that watching highly-personalized short videos distributed by the AI-powered recommender may dispose SVA users towards passive consumption that does not require much cognitive control or inner reflections taking place in working memory. Though the algorithm frees users from dealing with a large amount of information and making decisions, their autonomy of initiative selection or search may be taken over by passive consumption of the personalized feed, and the information search scope becomes limited to the cognizable memory zone of users (Hasan et al., 2018; Zhao, 2021). This coincides with the finding that users exposed to relevant web content tend to seek or spend fewer resources on decision-making than when exposed to irrelevant contents (Tam & Ho, 2006). Thus, indulgence in algorithmic recommendation may fundamentally alter users' way of perceiving, obtaining and storing information, as evidenced by the negative relationship between TikTok use disorder and short-term memory loss (Sha & Dong, 2021). Also, heavy use of mobile media makes frequent media multitasking inevitable (i.e., attention constantly switched among different media forms and non-media activities). Media multitaskers are found to have worse working memory performance, as they are more sensitive to both internal and external distractions when completing tasks (Minear et al., 2013; Uncapher et al., 2016). Previous studies have proved that media exposure, smartphone use, and media multitasking are negatively associated with the working memory of adolescents and adults, yet the sample size of the previous studies is relatively small (less than 110) and the effects remain conflicting with each other due to the various working memory tasks adopted in the studies (Bhosale & Minchekar, 2016; Cain et al., 2016; Fabio & Suriano, 2021; Liebherr et al., 2020; Murphy & Creux,

2021). Still, the relationship between adolescents' SVA use and decline in working memory needs to be testified.

A third aspect of cognitive functioning crucial to adolescent development and susceptible to media effects is verbal ability. As media messages can primarily trigger and influence the meaning-construction process in which information is transformed into knowledge, users' ability to read, understand and process language may be affected (Potter, 2012). Digital media is, to a considerable extent, shaping the culture based on alphabets, characters and written words, which may gradually make people maladjusted to the "written culture" and habituate people to the new extended form of digital communication (McLuhan, 1994). Previous studies suggest that higher frequency of Internet use is directly or indirectly associated with the decline in children's verbal intelligence in the long run (Park et al., 2011; Takeuchi et al., 2018), but it is also found that the impact of media use is determined by the way of using it. For instance, unlike SNS (e.g. Facebook), VSP (e.g. YouTube) facilitates more passive consumption than verbal interactions, and thus is found to have no positive training effect on users' verbal ability (Alloway et al., 2013). Thus, the immersive and inactive use of SVA may not help enhance verbal skills. Furthermore, digital media like SVA has created a visual-based communication form, which is powered by platform-specific trends, icons and unplanned speech, most often grammatically simple and even incorrect (Rettberg, 2017; Subrahmanyam & Smahel, 2011). Though this may compensate for the absence of non-verbal communication in traditional text- or image-based SNS, it is likely to shape users' way to understand and express themselves (Literat & Kligler-Vilenchik, 2019). This may exert a negative impact on adolescent users' meaning-making practices in a purely verbal context, as the dichotomy may take shape between traditional text-based media in the educational context and the multimodal SV media. Another possible explanation for the decline of users' verbal ability is that adolescents spending a great deal of time on digital media may have fewer opportunities to develop reading skills and participate in offline social interaction (Takeuchi et al., 2018).

Apart from the subjectivity of cognitive functioning to SVA use, another key concern for adolescent SVA users is academic performance. Though digital media is increasingly playing a supportive role in educational contexts due to its interactivity, it is still under debate whether students' learning benefits from the interactive engagement (Punch & Vanderbeck, 2017). Born and bred in the era of digital media, it is assumed that digital technologies have disaggregated human body from the nature experience of learning process, changing the feedback mechanisms for learning in terms of connecting physicality, brain, learning, and memory (Albright, 2019; McLuhan, 1994). Moreover, in reference to theoretical assumptions of mobile technology use, adolescents who spend more time on SVA may invest less time in study, and reliance on the recommended videos may cause multitasking and distraction from learning activities (Amez & Baert, 2020). Also, as SVA becomes increasingly popular among adolescents, they are more reliant on this technology as a source of information, and thus become potentially less exposed to those learning experiences that take place in rich conversations and less interested in other information sources such as school lessons and other learning activities (Kucirkova & Sakr, 2016). Hence, adolescent SVA user may perform worse in terms of schooling. This is related to previous findings on adolescents that poorer academic performance is linked to more exposure to Internet (non-academic use) and electronic games (Islam et al., 2020; Kubey et al., 2006), mobile technology (Amez & Baert, 2020; Beland & Murphy, 2016), SNS (non-academic use) (Giunchiglia et al., 2018; Hameed et al., 2022; Junco, 2012; Kirschner & Karpinski, 2010) and media multitasking (Kokoç, 2021; le Roux et al., 2021; May & Elder, 2018). However, inconsistent results remain in this literature (Alloway et al., 2013; Rostaminezhad et al., 2019), and whether SVA use is negatively correlated with adolescents' academic performance has not been explored so far.

2.3 The mediating role of cognitive functioning between SVA user behaviors and academic performance

Media use not only directly influences adolescents' academic performance, but also has an additional indirect impact through cognitive functioning, addictive use, physical and mental health indicators (Amez & Baert, 2020; Bai et al., 2020; Jiang, 2014; Kokoç, 2021; Yan et al., 2019).

Cognitive functioning is closely related to adolescents' learning performance. ADOG reflects students' use of strategies related to self-regulated learning in order to sustain motivation and academic goals (Bembenutty & Karabenick, 1998, 2004), and predicts better academic performance among adolescents (Herndon & Bembenutty, 2017; Herndon et al., 2015). A recent study also reveals that deficient self-regulation mediates between social media overload and academic performance (Kokoç, 2021). Moreover, working memory capacity is crucial to the processing of both verbal and spatial information (Just & Carpenter, 1992), which are at the core of learning tasks for students. Thus, it can strongly predict adolescent students' academic performance on various subjects (Best et al., 2011; Gathercole et al., 2004; Lehto, 1995). Also, verbal ability, involving understanding words and context as well as drawing logical conclusions based on language input, is a strong predictor of academic performance (Swartwout et al., 2010; Vera & Cortés, 2021).

Considering the role of cognitive function predicting academic performance and being subjected to media effects, it is likely that these three aspects of cognitive functioning mediate between adolescents' SVA user behaviors and their academic performance in a parallel fashion.

2.4 Age differences in the potential effect of SVA use

Today's adolescents are born as "digital natives" growing up with constant exposure to digital media, which may fundamentally change their behaviors, cognitive

abilities, physical and mental health (Albright, 2019; Subrahmanyam & Smahel, 2011). Faced with developmental tasks of constructing self-identity and achieving social recognition, they are more prone to seek need gratification via online social media (Granic et al., 2020). Meanwhile, adolescence is essentially a critical period of rapid brain development, behavioral maturation, and major social role transitions, characterized by immature cognitive control, elevated impulsivity and sensation-seeking (Casey et al., 2008; Sawyer et al., 2018). Thus, adolescence is often proposed as a window of susceptibility to various types of media effects and behavioral addictions (Chambers et al., 2003; Crews et al., 2007). Previous studies manifest that adolescents are identified as more subject to the negative impact of excessive use of the SNS or other Internet-based services on mental illness, cognitive functions and academic attainment (Kumar Swain & Pati, 2021; van den Eijnden et al., 2018; Wang et al., 2020).

A closer examination of media effects on cognitive functioning within adolescence may even reveal age-related differences, according to the hypothesis that the impact of media use is conditional upon differential susceptibility due to different developmental levels (Valkenburg & Peter, 2013). Generally, younger (or early) adolescents (usually defined as 10 to 15-year-olds) and older adolescents (usually defined as 15 to 20-year-olds) are undergoing different developmental stages (Sawyer et al., 2018). In terms of cognitive development, evidence from behavioral studies and neuroscience has proved that mid-adolescence may be a watershed on the developmental trajectories of cognitive functions (Icenogle et al., 2019; Pfeifer & Allen, 2021; Roalf et al., 2014). Neural basis of adolescents' cognitive development suggests that a developmental window of higher sensitivity generally overlaps pubertal processes, which can influence adolescent behaviors through the direct or secondary effects of hormones on brain structures and functions underlying behavior (Berenbaum et al., 2015). Age 10-12 is regarded as a period of higher plasticity of brain structure, function, and connectivity related to cognitive functioning and emotional processing, with mid-adolescence emerging as a

plateau as well as a turning point of sexual maturation and mentalizing abilities (Pfeifer & Allen, 2021). Also, behavioral assessments manifest that adolescents' cognitive capacity usually reaches adult levels around age 16 (Icenogle et al., 2019), and that within-individual variability of neurocognitive performance regarding both speed and accuracy gradually decreases from 8 to 14 years. After 14 years, the variability increases probably due to higher levels of brain maturation and specification for cognitive skills (Roalf et al., 2014). Thus, it can be inferred that younger (12-13 years) and older (15-16 years) adolescents are undergoing different stages of cognitive development, which may lead to differential susceptibility to contextual factors including media use.

Accordingly, empirical evidence on the components of cognitive functioning also suggests differential stages of cognitive development for younger and older adolescents, though these components also show uneven pace of development (Best & Miller, 2010; Crone & Steinbeis, 2017). In terms of working memory, ages between 11 and 13 can be considered as a key stage of expanding working memory capacity, while 15 to 16-year-old youths gradually achieve adult-level performance (Gómez et al., 2018). It has been found that the performance in working-memory-related tasks gradually improves from age 5 until age 15, and the performance of age 12-13 exhibits stronger association between task performance and academic achievement in the previous study (Best et al., 2011). Also, the accuracy of language comprehension continued to develop until age 12-13, whereas the speed of comprehension improves until age 15-16 (Wassenberg et al., 2008). In terms of self-regulation, the cognitive process involving the ability to delay gratification develops steadily from pre-adolescence into early adulthood (Steinberg et al., 2018). The correlation between self-control and academic achievement shows a spike in childhood and remains moderate across adolescence.

Apart from cognitive functioning, early and late adolescents may be confronted with different levels of challenges posed by their transition to schooling, which may in turn affect their academic performance (Simmons & Blyth, 2017). For instance,

younger adolescents tend to show heightened mental instability, stronger desire for autonomy, peer orientation and salience of identity (Simmons & Blyth, 2017). Meanwhile, they are confronted with junior high school transition and the “stage-environment mismatch” between their developmental needs and the limited opportunities offered by home and school, which may lead to negative psychological changes including lack of motivation and decline in attention (Eccles et al., 1993). Thus, early adolescents may particularly struggle with maintaining learning motivation and turn to heavier use of SVA to satisfy psychological needs for recreation, identity-creation and social recognition (Bucknell Bossen & Kottasz, 2020). By contrast, in later years these social and psychological processes may become more complex and obscurer for adolescents due to greater developmental readiness for change and more social processes are involved beyond the early stage (Simmons & Blyth, 2017). This is supported by the recent finding that higher susceptibility to the impact of social media use on adolescents’ mental well-being emerges during early adolescence (Orben et al., 2022). Hence, it is likely that younger and older adolescents may exhibit different levels of susceptibility to the impact of media use on their academic performance.

The above theoretical and empirical findings suggest that there may exist distinct difference in susceptibility between early adolescence and the onset of late adolescence to media effects on cognitive functioning and academic performance. Thus, early adolescents may experience the impact of SVA use different from their elder counterparts on these two aspects.

2.5 The present study

Based on the research gap, this study strives to reveal the possible impact of SVA user behavior on cognitive functioning and academic performance among adolescents. In light of the distinctive properties of SVA, this study examines two aspects of SVA user behavior. One is daily usage of SVA, reflecting users’ exposure to the ephemeral

audiovisual video clips recommended by the algorithm, higher level of interactions and distinct functional hooks of SVA. However, explaining media effects simply by media usage, or “screen time” are recently challenged due to inconsistent units of measurement and the intricacies of adolescent users’ use pattern (Nesi et al., 2020; Odgers & Jensen, 2020). Considering the potential impact of algorithmic personalization in SVA, the other core variable represents whether adolescent users are prone to rely on SVA recommendations or search for the contents on their own.

In order to examine the associations between SVA user behaviors and three key aspects of cognitive functioning which further predict academic performance, a hypothesized mediation model is constructed (Fig. 2). Noticeably, from a developmental perspective, the mediation analysis is conducted upon two age cohorts for group comparison, intended to the differential susceptibility to SVA impact within adolescence.

Therefore, the study is intended to test the following hypotheses:

H1: Both younger and adolescent users’ SVA daily usage and reliance on algorithmic recommendations predict worse ADOG, working memory, verbal ability. The effects differ between the younger cohort and the elder counterpart.

H2: Both younger and elder adolescents’ SVA daily usage and reliance on algorithmic recommendations predict worse academic performance. The effects differ between the younger cohort and the elder counterpart.

H3: For both younger and elder adolescents, ADOG, working memory and verbal ability simultaneously mediate the association between daily usage of SVA and academic performance. Specifically, daily usage negatively predicts users’ academic performance through negatively predicting their cognitive functioning. The mediating effects differ between the younger cohort and the elder counterpart.

H4: For both younger and elder adolescents, ADOG, working memory and verbal ability simultaneously mediate the association between reliance on SVA recommendation algorithm and academic performance. Specifically, reliance on SVA

recommender negatively predicts users' academic performance through negatively predicting their cognitive functioning. The mediating effects differ between the younger cohort and the elder counterpart.

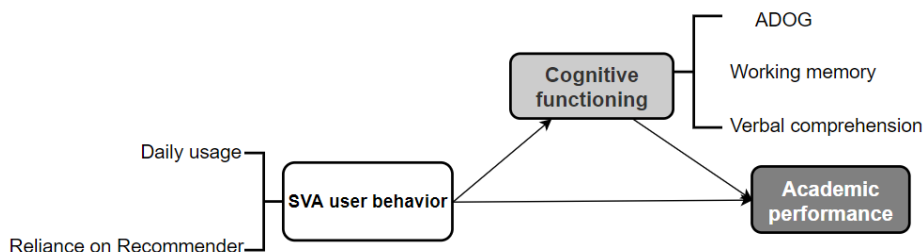


Fig. 2. Conceptual model of the current study

3. Methodology

3.1 Sample and procedure

All the participants of the study were recruited from one ordinary middle school located in the urban area of Beijing, including 498 students from grade 7 (the first year of junior high school; aged 12-13 years) and 390 students from grade 10 (the first year of senior high school; aged 15-16 years). Informed consent was obtained from the participants and their legal guardians before data collection. 464 and 370 students of each cohort completed the survey, and 473 and 377 students of each cohort participated in the cognitive ability test respectively. After merging the two datasets, the final sample consisted of 454 younger adolescents ($M_{\text{age}} = 12.25$ years, $SD = 0.02$; 47.8% girls) and 368 older adolescents ($M_{\text{age}} = 15.21$ years, $SD = 0.02$; 53.3% girls).

This study was carried out during school days under the supervision of trained researchers. Adolescent participants first answered a written questionnaire (including a survey on SVA user behavior and an ADOG scale), followed by an online cognitive ability test administered in a computer room one week later. Final exam scores were provided by the school teachers with consent after that semester. The study protocol was approved by the IRB of the Department of Psychology, Tsinghua University.

3.2 Measures

3.2.1 SVA user behavior

SVA user behaviors are mainly measured by daily usage during the academic semester and users' reliance on algorithmic recommendations. Daily usage (i.e., the average time spent on SVA every day) is assessed on a 6-point scale from less than 15 minutes to over 3 hours. Reliance on recommender is coded as a binary variable. Those who rely more on algorithmic recommendations (i.e., mostly watching the videos popping up on the screen one by one, sometimes scrolling for the next; or watching similar videos filtered out by the app) score 1, while those who tend to explore and search the contents by themselves (i.e., mostly search for the contents of interest on their own or follow the uploaders they like) score 0.

3.2.2 Academic delay of gratification (ADOG)

This study adopts Li's (2005) ADOG scale, a localized version for Chinese middle school students based on Bembenuity & Karabenick's (1998) original scale. The scale consists of 9 context-based items assessed on a 4-point Likert scale. Respondents were asked to choose between "immediate gratification of impulses" and "learning activities leading to more remote academic rewards". Thus, higher score indicates greater tendency towards delayed gratification in academic settings. The internal consistency of the scale is acceptable (Cronbach's $\alpha = 0.76$). CFA verifies good model fit: $\chi^2/df = 2.59$, CFI = 0.97, RMSEA = 0.04.

3.2.3 Working memory, verbal ability and academic performance

Working memory and verbal ability are measured by two computer-based cognitive tasks, each taking 5–8 minutes to complete. Working memory is assessed by an adapted version of the operation span task (Turner & Engle, 1989), as it may better

predict task performance involving higher-order cognitive functioning or general abilities (Bayliss et al., 2003). For each trial, participants must solve a series of arithmetic equations while trying to remember a list of Chinese characters. Individuals are presented with one equation–character string at a time (e.g., $(3 \times 12) - 2 = ?$ “牛”) on the screen, and need to recall the sequence of characters at the end of the series. All the trials are organized in a sequence of increasing difficulty. The participant gains 0, 1, or 2 points for each trial based on the accuracy of recall (in the same order of presentation) and arithmetic until he/she fails the last trial (0 point).

Verbal ability task was adapted from a vocabulary subtest of Wechsler intelligence scales (Kaufman et al., 2006), where participants are asked to choose from 5 definitions of each given word, each of which deserves 0, 1, or 2 points according to its congruency with the correct answer. The task terminates once the respondent earns no more than 6 points from the last 8 trials. Final index score is the sum of the points gained in the past trials for both of the cognitive tasks.

The academic performance is indexed by the average of final examination scores of Chinese and Math.

3.3 Data analysis

The cognitive functioning test scores are standardized across two age cohorts. The academic performance is standardized within each cohort respectively. After that, descriptive statistics were computed in STATA/SE (version 15.1) for Windows and all the further analysis, including correlation and Structural Equation Modeling (SEM), was performed in Mplus 8.3 (Muthén & Muthén, 2017). Considering the missing values of each measurement (missing rates ranging from 1.5% to 11.3%), data missing was handled by full information maximum likelihood (FIML) estimates for multiple imputation (Muthén & Muthén, 2017).

In terms of path analyses of two-group SEM, the standardized coefficients were estimated with 95% confidence interval based on the bias-corrected percentile method

with 5,000 bootstrap samples after controlling for gender. All of the variables including different facets of SVA use, cognitive functioning and academic performance were modelled as observed variables. To examine whether each path differs between the two age cohorts, two-group nested model comparison was conducted. The unconstrained model with all pathways freely estimated, was compared with the constrained models where the coefficient of each path in comparison was constrained to be equal between the two age cohorts. Significant differences in chi-square values between unconstrained and constrained models (i.e., the constrained model fit worse than the unconstrained model fit) suggests that the coefficients of the path being compared are significantly different across the two age cohorts. Bootstrapping method for 5,000 replications was adopted to testify the significance of indirect effects on the unconstrained model.

4. Results

4.1 Preliminary analysis

The descriptive statistics of the SVA use variables are reported in Table 1 by the two cohorts of adolescents. According to Table 1, 90.73% of the younger adolescents reported to be SVA users, and 87.84% for elder adolescents. This is a very large proportion, compared to 73.6% among adults (Su et al., 2021). A majority of respondents reported using SVA for less than 1 hour every day, and nearly three quarters of them reported a preference for algorithmic recommendations over self-searching for both age cohorts, with no significant difference found between groups.

Table 1

Descriptive statistics.

	12 to 13-year-olds (1)	15 to 16-year-olds (2)
N	454	368
SVA users, %	90.73	87.84
Daily usage, %		
<15 mins	41.77	32.62
15-30 mins	26.25	27.69

0.5-1.0 hour	15.99	27.38
1-2 hours	8.59	10.15
2-3 hours	1.67	1.23
>3 hours	5.73	0.92
Reliance on SVA recommender, %		
Low reliance	24.16	25.16
High reliance	75.84	74.84
Cognitive functioning, Mean (S.D)		
ADOG	0.16 (1.05)	-0.20 (0.90) ^{***}
Working memory	-0.34 (1.00)	0.43 (0.81) ^{***}
Verbal ability	-0.27 (1.00)	0.37 (0.87) ^{***}
Academic performance	0.00 (1.00)	0.00 (1.00)

Note. Test scores on cognitive functioning are standardized across two age cohorts. The academic performance is standardized within each cohort respectively. Significant level of t-test between the two cohorts are marked in column (2). *p < 0.05, **p < 0.01, ***p < 0.001.

According to Table 2, ADOG of both age cohorts has a significantly negative relationship with SVA daily usage ($r=-0.45$, $p<0.001$ for the younger cohort and $r=-0.30$, $p<0.001$ for the elder cohort), However, only the younger cohort manifest significantly negative associations of SVA user behaviors with working memory ($r=-0.21$, $p<0.05$ for daily usage and $r=-0.15$, $p<0.01$ for reliance on SVA recommender) and verbal ability ($r=-0.24$, $p<0.001$ for daily usage and $r=-0.11$, $p<0.05$ for reliance on SVA recommender) respectively. In addition, academic performance of both age cohorts manifests negative correlations with SVA daily usage ($r=-0.33$, $p<0.001$ for the younger cohort and $r=-0.11$, $p<0.05$ for the elder cohort), while reliance on recommender is negatively correlated with the younger cohort only ($r=-0.13$, $p<0.01$).

Table 2
Correlation among key variables.

	1	2	3	4	5	6
1. Daily usage	-	0.16 ^{**}	-0.30 ^{***}	-0.04	-0.12	-0.11 [*]
2. Reliance on recommender ^a	0.12 ^{**}	-	-0.07	0.00	-0.08	-0.10
3. Academic delay of gratification	-0.45 ^{***}	-0.10	-	0.01	0.05 [*]	0.13 [*]
4. Working memory	-0.21 [*]	-0.15 ^{**}	0.10 ^{***}	-	0.22 ^{***}	0.12 [*]
5. Verbal ability	-0.24 ^{***}	-0.11 [*]	0.11 ^{***}	0.34 ^{***}	-	0.10
6. Academic performance	-0.33 ^{***}	-0.13 ^{**}	0.22 ^{***}	0.56 ^{***}	0.49 ^{***}	-

Note. Correlations for the elder cohort are displayed above the diagonal and correlations for the younger cohort are displayed beneath the diagonal. *p < 0.05, **p < 0.01, ***p < 0.001.

^a 0=autonomous use pattern, 1=algorithm-driven use pattern.

4.2 Model testing

The hypothesized model (Figure 1) was tested and two-group nested model comparison was conducted to examine between-group differences in the path coefficients. After controlling for gender, the unconstrained models displayed good model fit ($\chi^2(df=4)=5.10$; RMSEA= 0.03; CFI= 1.00; TLI= 0.98). All the significant direct paths are illustrated in Fig. 3 and Fig. 4. ADOG is negatively predicted by daily usage for both cohorts ($\beta=-0.44$, $p<0.001$ for the younger cohort and $\beta=-0.28$, $p<0.001$ for the elder cohort), with the effect of the younger cohort larger than the elder counterpart, $\Delta\chi^2(\Delta df=1) = 3.93$, $p<0.05$. Working memory is negatively predicted by the recommender reliance ($\beta=-0.17$, $p<0.001$) and daily usage ($\beta=-0.19$, $p<0.001$) of the younger cohort only, with significant difference between the two age cohorts, $\Delta\chi^2(\Delta df=1) = 4.09$, $p<0.05$ and $\Delta\chi^2(\Delta df=1) = 8.11$, $p<0.01$ respectively. Similarly, verbal ability is also negatively associated with the recommender reliance ($\beta=-0.12$, $p<0.01$) and daily usage ($\beta=-0.25$, $p<0.001$) of the younger cohort only, with significant between-group difference identified regarding daily usage, $\Delta\chi^2(\Delta df=1) = 3.96$, $p<0.05$. The significant direct path from SVA user behavior to academic performance is identified between daily usage and the final exam score for the younger cohort only ($\beta=-0.12$, $p<0.05$), though no significant between-group difference was identified.

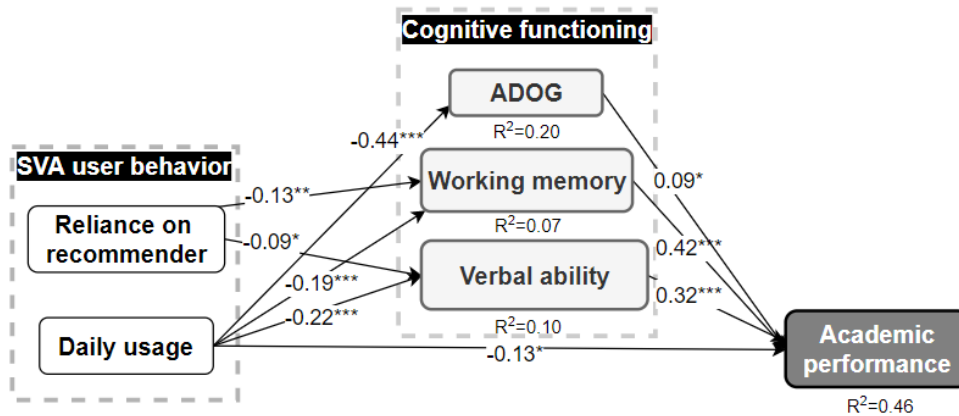


Fig. 3. Mediation model for the younger cohort.

Note. All parameter estimates are standardized. The amounts of variance explained by the model (R^2) are shown below the dependent variables. Only significant direct paths are displayed. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

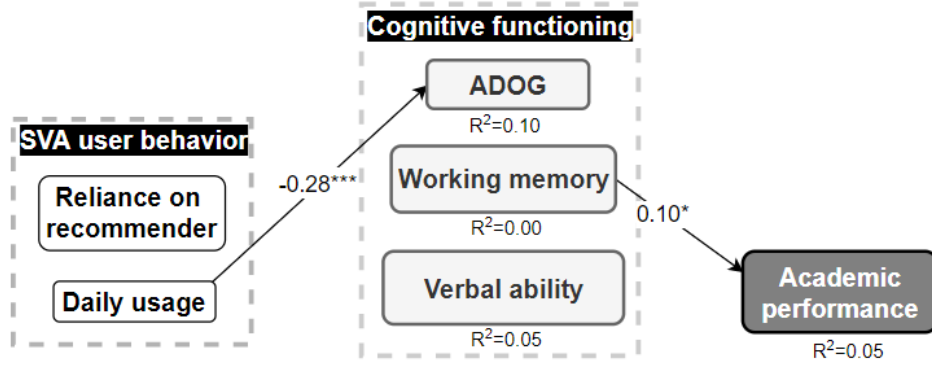


Fig. 4. Mediation model for the elder cohort.

Note. All parameter estimates are standardized. The amounts of variance explained by the model (R^2) are shown below the dependent variables. Only significant direct paths are displayed. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 3

The indirect effect tested in the proposed model for two age cohorts.

Paths	12-13-year-olds				15-16-year-olds			
	Effect	SE	95% LLCI	95% ULCI	Effects	SE	95% LLCI	95% ULCI
DU → AP (total indirect effect)	-0.19***	0.04	-0.27	-0.12	-0.04	0.03	-0.08	0.00
DU → ADOG → AP	-0.04*	0.02	-0.08	0.00	-0.03	0.02	-0.06	0.00
DU → WM → AP	-0.08***	0.02	-0.13	-0.03	-0.01	0.01	-0.02	0.01
DU → VA → AP	-0.07***	0.02	-0.10	-0.04	-0.01	0.01	-0.02	0.01
RR → AP (total indirect effect)	-0.09**	0.03	-0.15	-0.03	-0.01	0.01	-0.03	0.02
RR → ADOG → AP	-0.00	0.01	-0.01	0.01	0.00	0.01	-0.02	0.01
RR → WM → AP	-0.05*	0.02	-0.10	-0.01	0.00	0.01	-0.01	0.01
RR → VA → AP	-0.03	0.02	-0.06	0.00	0.00	0.01	-0.02	0.01

Note. Bootstrap sample size = 5000; Abbreviations: DU = daily usage, RR = reliance on recommender, ADOG = Academic delay of gratification, VA = Verbal ability, WM = Working memory, AP = academic performance, LLCI = lower limit confidence interval, ULCI = upper limit confidence interval; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The mediating role of cognitive functioning between SVA user behaviors and academic performance was tested using the bootstrap method (Table 3). For the younger cohort, the total indirect effects of daily usage and recommender reliance on academic performance are significantly negative ($\beta = -0.19$, 95% CI [-0.27, -0.12] and $\beta = -0.09$, 95% CI [-0.15, -0.03] respectively), with both effects differ between groups, $\Delta\chi^2(\Delta df = 1) = 19.36$, $p < 0.001$ and $\Delta\chi^2(\Delta df = 1) = 9.98$, $p < 0.01$ respectively. More specifically, working memory mediates between daily usage and academic performance ($\beta = -0.08$, 95% CI [-0.13, -0.03], $\Delta\chi^2(\Delta df = 1) = 12.43$, $p < 0.001$ for

between-group difference) as well as between recommender reliance and academic performance ($\beta = -0.05$, 95% CI $[-0.10, -0.01]$, $\Delta\chi^2(\Delta df=1) = 6.63$, $p < 0.01$ for between-group difference). Also, verbal comprehension mediates between daily usage and academic performance ($\beta = -0.07$, 95% CI $[-0.10, -0.04]$, $\Delta\chi^2(\Delta df=1) = 14.29$, $p < 0.001$ for between-group difference) as well as between recommender reliance and academic performance ($\beta = -0.03$, 95% CI $[-0.06, 0.00]$, $\Delta\chi^2(\Delta df=1) = 2.67$, not significant for between-group difference). The mediating effect of academic delay of gratification mediates between daily usage and academic performance was identified as marginally significant for both cohorts ($\beta = -0.04$, 95% CI $[-0.08, 0.00]$ for the younger cohort and $\beta = -0.04$, 95% CI $[-0.08, 0.00]$ for the elder cohort, $\Delta\chi^2(\Delta df=1) = 0.84$, not significant for between-group difference). No other pathways were found significant for the elder cohort. In total, for adolescents' academic performance, this multiple mediation model accounted for 45.6% of variance in the younger cohort and only 4.6% of variance in the elder cohort.

5. Conclusion and Discussion

Concerning the prevalence of SVA among adolescents who are experiencing crucial cognitive development, the present study is aimed to explore the potential impact of SVA use on adolescent users' cognitive functioning and performance. In addition to daily usage as a core variable of interest, the role of algorithm-driven personalization embedded in SVA is unveiled by inquiring into respondents' use pattern in a natural way.

Firstly, this study finds that SVA user behavior can be a negative predictor of adolescent users' cognitive functioning, with results varying between the two cohorts. ADOG, which is closely related to one's self-regulation, is found to be negatively correlated with SVA daily usage for adolescents of both cohorts. It is assumed that instant access to the audiovisual stimuli provided by SVA may generate needs for

immediate gratification, inferred from the potential “rewiring” effect of technology habits on self-control and impulsivity (Wilmer et al., 2017). Similar relation has been found among college students between heavier smartphone use and weaker tendency towards delaying gratification (Wilmer & Chein, 2016). This effect is more influential for the younger cohort than the elder counterpart.

This study also reveals that for the younger cohort only, worse performance in working memory task is predicted by SVA use. This result may add complexity to the previous incongruent results of smartphone-related media effects on working memory (Toh et al., 2021; Ward et al., 2017). Since the current study adopts operation span as the measure of working memory, the result suggests that heavier use of SVA may impair the ability to store and process information simultaneously, as well as a comprehensive and strategic use of inhibition and cognitive flexibility (Murphy & Creux, 2021). Like other mobile technology, SVA use may induce more frequent media multitasking, thus marring adolescents’ ability to forego the temptations and distractions while completing the task. More importantly, SVA exposure is complicated by users’ interaction with algorithmic personalization and various functional hooks (Schellewald, 2021; Zhao, 2021). Thus, it can be inferred that users who are prone to contents “pre-selected” by algorithm may be less likely to search for information autonomously or employing brain resources for information processing. Meanwhile, the immersive nature of SVA may worsen users’ inhibitory control, which in turn correlates with working memory capacity. This possible explanation is inferred from the finding that use of mobile technology may impair users’ working memory via negatively influence their inhibitory control (Liebherr et al., 2020; Schneider et al., 2014).

Another cognitive function negatively correlated with SVA use is verbal ability, which is identified on the younger cohort only. According to McLuhan (1994), digital media as an extension to our central nervous system, is threatening the literacy based on alphabets or characters, favoring the engaging and inclusive spoken word or digital

language over the written one. As for SVA, it has created a unique communicative form composed of platform-specific languages or “memes”, characterized by their audiovisual nature and non-verbal language of pictograms (Rettberg, 2017; Schellewald, 2021). The more embodied and performative facets of the semantic cyberspace tend to prevail over text-based or image-based verbal cues in surroundings if the user is immersed in this new media. Presumably, this may estrange adolescent users from verbal ways of expression and social interaction, and thus impair their verbal comprehension ability.

Second, SVA user behavior negatively predicts adolescent users’ academic performance, with both direct and indirect effects identified. The potential negative impact of SVA use on academic performance might be explained by the detachment of user’s senses from learning experiences once habituated to the exposure to multisensory stimuli delivered by the algorithm-driven and highly interactive SV platforms, according to McLuhan’s (1994) theory of media effects. Also, more exposure to SVA usually means more time investment in digital devices, less devotion to study and insufficient concentration on learning tasks (Amez & Baert, 2020). Meanwhile, the mechanism underlying how SVA user behaviors exert potential negative effect on adolescent users’ academic performance is revealed by the mediating role of cognitive functioning. For the younger cohort, both facets of user behavior addressed in the study are negatively associated with users’ academic performance via working memory and verbal comprehension ability as mediators, while no such effects were found for the elder cohort.

Taking a developmental stance, this study also points out age-related differentiating effects of SVA use. Generally, the younger cohort experience stronger negative influence of SVA on their cognitive functioning and academic performance than their older counterpart, as is testified by the two-group nested model comparison. Particularly, only 12 to 13-year-olds are found subject to the influence of SVA exposure and algorithmic personalization on working memory and verbal comprehension, which

further predict worse academic achievements. The disparity can be explained from two perspectives. On the one hand, the two age cohorts addressed in the study are at distinct stages of cognitive development. According to behavioral and neurophysiological findings on adolescents' cognitive development (Gómez et al., 2018; Linares et al., 2016), working memory capacity steadily matures over adolescence. While 11-13-year-olds are still developing working memory capacity for information transformation and higher demands of retrieval and substitution, 15-16-year-olds have reached nearly adult-level. Also, basic language comprehension develops until 12-14 years (Wassenberg et al., 2008), though verbal fluency develops well into mid-adolescence and language lateralization changes with aging (Lidzba et al., 2011). Thus, it can be inferred that 12-13 (the age of the younger cohort) is a developmental window of higher susceptibility to SVA impact on cognitive functioning. This finding is also aligned with the sensitivity window identified on the effect of social media use on adolescents' mental well-being (Orben et al., 2022). On the other hand, behavioral sensitivity to rewards is found to increase and peak at the age of approximately 14–15 and gradually decline into adulthood (Spear, 2013). This can be explained from a neurobiological perspective, as inclination for novel experiences may increase in compensation for the dopamine reduction in nucleus accumbens coupled with less mature inhibitory capacity during adolescence (Dager et al., 2013). Thus, it is likely that the younger cohort exhibit more compulsive use and heightened sensitivity to the immersive and interactive nature of SVA.

A few limitations of this study are noticed and future studies should make corresponding improvement. Firstly, longitudinal studies are needed on the long-term SVA user behaviors and within-person changes in cognitive functioning and academic performance. Second, a randomized controlled trial should be conducted to examine the causal effects of SVA use on adolescents. Since the present study is cross-sectional, the reverse directions between variables may not be ruled out and causal links cannot be drawn from the present evidence. Furthermore, to explore the mechanism of SVA

impact in depth, it is advisable to introduce physiological measures to record cognitive, emotional and excitative response states while using the media. These are assumed to be important mediators between media use and media effects (Valkenburg & Peter, 2013), which may help to develop a better understanding of how SVA exerts its impact.

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