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META-ANALYSIS

Cognitive Control in Adolescents and Young Adults with Media Multitasking Experience: a Three-Level Meta-analysis

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Abstract

Media multitasking is an ever-increasing phenomenon whereby different forms of media are used simultaneously. Numerous studies have shown that media multitasking is closely related to an individual's cognitive control abilities. However, existing evidence remains controversial, making it difficult to draw definitive conclusions. Therefore, to increase the understanding of whether and how frequent media multitasking is associated with cognitive control, a three-level meta-analysis, which included 43 studies and 118 effect sizes, was performed to acquire overall differences between heavy and light media multitaskers and to explore potential moderators that may account for the heterogeneity. The results showed a moderate mean negative association between media multitasking and cognitive control, and this association was moderated by the type of cognitive control. Specifically, heavy media multitaskers showed worse inhibitory control and working memory than light media multitaskers, but there was no significant difference in cognitive flexibility. Moreover, the effect was moderated by the measurement type of the dependent variable. The results of this study enhance our understanding of this issue and pave the way for a more nuanced view of altering experimental designs to investigate cognitive control in educational settings.

Keywords Media multitasking · Cognitive control · Three-level meta-analysis · Moderators

In today's fast-paced society, media multitasking has become an essential part of our daily lives. Media multitasking is defined as "a phenomenon characterized by simultaneously engaging in the use of different forms of media," such as listening to music while

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also using social media sites (Minear et al., 2013). When young adults or teenagers multitask with media, they constantly switch between multiple activities and may fail to be absorbed in a single activity. A study showed that young people spend an average of 7.5 h per day engaged in online media, and 25–50% of that time is spent on more than one form of media simultaneously (Popławska et al., 2021). Another recent diary study showed that 60% of the respondents admitted to using multiple screens simultaneously at least once (Segijn et al., 2017), and the time spent multitasking with media is increasing year by year (Beuckels et al., 2021b). The dramatic increase in media multitasking has aroused considerable attention for its effects on people's functioning (Wallis, 2006). For example, it is possible that heavy media multitaskers perform poorly in some cognitive control abilities (Ophir et al., 2009), academic achievements (Ophir et al., 2009; van der Schuur et al., 2015), and social functioning, such as depression and social anxiety (e.g., Becker et al., 2013; van der Schuur et al., 2015). Cognitive control, an important component of people's cognitive functioning, is closely linked to the frequency of media multitasking (e.g., Cain et al., 2016; Ophir et al., 2009). However, there still exists some uncertainty about the strength and direction because of discrepancies in study design and inconsistencies in findings on this topic. In the present study, we provided a synthesis of the results of previous studies examining associations between media multitasking and cognitive control.

Notably, cognitive control involves three components related to one another, namely, inhibitory control, working memory, and cognitive flexibility in cognitive control research (Davidson et al., 2006; Spiegel et al., 2021). Consistent with previous meta-analyses on cognitive control (e.g., Mauger et al., 2018; Spaniol & Danielsson, 2022), this study first aimed to quantify the relationship between media multitasking and overall cognitive control. Second, we further aimed to test the moderating role of three components of cognitive control to explore accurately whether media multitasking is differentially associated with inhibitory control, working memory, and cognitive flexibility, specifically if the relationship between media multitasking and overall cognitive control is significant, and in which component this significant relationship is mainly reflected.

Additionally, as more than one task is required to assess cognitive control in several studies, it is important to note that effect sizes extracted from the same sample groups would be included multiple times. Therefore, dependence between data may exist in conventional meta-analyses. The coping strategy for conventional meta-analyses involves averaging effect sizes or selecting only one effect size per study, which may lead to lower statistical power and a limit in the research questions (Assink & Wibbelink, 2016). A three-level meta-analysis was used in our study to deal with this limitation. Furthermore, we intended to examine potential moderators of the relationship between media multitasking and overall cognitive control, such as gender, age, and other demographic characteristics and methodological factors.

Association Between Media Multitasking and Cognitive Control

Media multitasking has long been a research topic of great interest in the educational domain. Ophir et al., (2009) first defined media multitasking as simultaneously engaging in two or more types of media. The most commonly used tool for examining media multitasking frequency is the Media Multitasking Index (MMI; Ophir et al., 2009). The original MMI devised by Ophir et al., (2009) involves 12 different media categories, such as print media and computer-based video. In subsequent studies exploring media multitasking, some scholars applied this original instrument, and others used a modified version of the MMI (Mod MMI; Cain & Mitroff, 2011). The adapted versions generally reduce or change the media forms of the measure Ophir et al., (2009) used. For instance, Baumgartner et al., (2014) reduced the categories of media used to nine, Seddon et al., (2018) modified several media activities on the basis of the current technological and network environment, and other researchers made other adaptations. For each participant, researchers used the index to define two groups: light and heavy media multitaskers (LMMs vs. HMMs). Moreover, some researchers have adopted several other approaches to explore media multitasking, such as observations, diary studies, and lab experiments (Kazakova et al., 2016; Rideout et al., 2010; Rosen et al., 2013; Seddon et al., 2021). For example, in a naturalistic experimental study, media multitasking was manipulated by a media multitasking scenario. Participants were randomly allocated into two different groups, namely the between-device media multitasking group and the within-device media multitasking group. In the between-device group, participants were required to watch the video on the left side of the screen, while the instant messages would appear on the right side of the screen, and to read the piece of text on the tablet PC, whereas in the within-device group, the video would be on the top left half of the screen, the messages would appear in the bottom left half of the screen, and the text would be presented on the right side of the screen. The instructions for participants in the two groups were the same, paying equal attention to the video, messages, and text (Seddon et al., 2021). The results showed a significant positive correlation between media multitasking and cognitive flexibility but no significant associations between media multitasking and performances on inhibition and working memory. A review by Zhou and Deng (2022) observed that majority (81.9%) of studies on media multitasking behaviors have employed self-report or laboratory experiment methods, while diary analysis and qualitative methods have been rarely used. However, the differences between self-reported measures and laboratory methods may reflect the differences between trait and state levels in media multitasking (Ralph et al., 2020). The dominant measure of media multitasking experience in daily life (trait level) is the self-reported questionnaire. Research showed no significant relationship between self-reported multitasking experience and laboratory multitasking performance (Lui et al., 2022). Thus, notably, the media multitasking experimental paradigm probably cannot reflect the experience of media multitasking as the self-reported measure. Furthermore, most studies examining the relationship between media multitasking and cognitive functioning have mostly focused on individuals' self-reported frequency of media multitasking (Seddon et al., 2021; Waite et al., 2018; Zhou & Deng, 2022). In the present study, therefore, we are only concerned with media multitasking experience in everyday life, measured by utilizing MMI or Mod MMI.

Cognitive control, which is considered to function through the operation of numerous executive functions, refers to a series of challenging top-down psychological processes (Diamond, 2013). Cognitive control has three primary components: inhibitory control, working memory, and cognitive flexibility (Davidson et al., 2006; Lehto et al., 2003). Inhibitory control is regarded as the ability to respond to the environment or internal states by regulating one's actions or an attempt or attention (Diamond, 2013; Miyake & Friedman, 2012). It entails the capacity to filter out irrelevant information and control automatic responses. One typical example of an inhibitory control task is the Go/No-Go task. Participants are required to identify and respond to the target letter with a certain color or shape (Go trials). For no-Go trials, participants are instructed to withhold responses (Murphy & Creux, 2020). The following tasks are also included: Flanker tasks, Stroop tasks, Stop signal tasks, and AX-continuous performance tasks (e.g., Gorman & Green, 2016; Murphy & Creux, 2020; Ophir et al., 2009). Working memory refers to the capacity to retain, update, and operate information mentally (Baddeley & Hitch, 1994). For instance, the n-back task can be considered a common working memory task. It requires participants to identify whether the current letter is the same as the letter seen *n* items ago (Cain et al., 2016). Other tasks included as measures of working memory are Count, Digit, Operation and Reading span tasks, Digit ordering tasks, and so on (e.g., Baumgartner et al., 2014). Cognitive flexibility (also called cognitive shifting) is regarded as an ability to flexibly think, switch, and adjust (Diamond, 2013; Miyake & Friedman, 2012). For example, the number-letter task is a cognitive flexibility task in which a series of "number" or "letter" stimuli are presented to participants. The different cues randomly appear on the screen; then, participants have to indicate whether the number is odd or even or whether the letter was a vowel or consonant as quickly as possible (Alzahabi & Becker, 2013). Cognitive flexibility can also be measured via the following tasks: Set shifting task, Dots–triangles task, Local global task, Phonetic and Semantic fluency tasks, Wisconsin card sorting task, Trail making task (e.g., Rogobete et al., 2020; Seddon et al., 2021). In addition to the performance-based experimental tasks mentioned above, researchers have also employed several self-report scales to measure cognitive control ability. For instance, three subscales of the Behavior Rating Inventory of Executive Function (both the BRIEF intended for children and adolescents and the BRIEF intended for adults): Inhibition, Shifting, and Working Memory, can be considered as measures of the three components of cognitive control, respectively (Huizinga & Smits, 2011; Roth et al., 2013). The Barratt Impulsiveness Scale (BIS-11) is a widely used self-report questionnaire for inhibitory control (e.g., Minear et al., 2013).

Substantial literature has examined the relationship between media multitasking and cognitive control. Some investigators have found that media multitasking is negatively associated with cognitive control. For example, HMMs demonstrated poorer filter ability, working memory capacity, and higher switch costs (e.g., Cain & Mitroff, 2011; Ophir et al., 2009; Ralph & Smilek, 2017). These findings supported the ''scattered attention hypothesis," which holds that doing media multitasking heavily may enable people accustomed to processing information from various sources simultaneously and more likely to focus on information that is irrelevant to the main task, resulting in distraction, the depletion of attention resources, and poorer performance in the cognitive task (Van der Schuur et al., 2015). Thus, the scattered attention hypothesis suggests that media multitasking may be closely related to cognitive control failure.

Although numerous studies have indicated the negative association between media multitasking and cognitive control, several other studies have demonstrated that media multitasking may have a positive relationship with cognitive control, especially in task switching (Alzahabi & Becker, 2013) or working memory capacity (e.g., Minear et al., 2013). These studies supported the “trained attention hypothesis.” According to this assumption, individuals’ abilities to switch between tasks and filter out and update information can be trained and enhanced through constant media multitasking behaviors (Van der Schuur et al., 2015). Furthermore, some studies revealed no significant relationships between media multitasking and cognitive control performances (e.g., Edwards & Shin, 2017; Seddon et al., 2018).

These empirical findings suggested that the associations between media multitasking and cognitive control were not always consistent. These conflicting results may reduce the accuracy and reliability of estimates of the associations between media multitasking and cognitive control, so it is crucial to obtain the estimations reliably. Furthermore, other moderators, such as age, should be considered to account for such discrepancies in a meta-analytic study. Some reviews have examined the association between media multitasking and cognitive processing, but the current meta-analysis intends to extend previous ones and differs from them. Wiradhany & Nieuwenstein, (2017) collected previous studies using related laboratory tasks to conduct a meta-analysis. A qualitative review by Uncapher & Wagner, (2018) found that, in general, heavier media multitaskers perform worse in some cognitive domains compared to lighter media multitaskers. However, such associations were not always evident. The authors observed a negative relationship between media multitasking and working memory but did not draw a definite conclusion on inhibitory control, which may be partly because of the limited data and non-quantitative evidence. In our study, formal meta-analysis and the accumulation of more data can provide quantitative effect size estimates of the relationship between media multitasking and different domains of cognitive control. Wiradhany & Koerts’s, (2019) meta-analysis focused on individuals’ everyday cognitive functions, which were divided into four aspects: attention regulation, impulsiveness or inhibition, behavior regulation, and memory. Results showed a weak correlation between media multitasking and all four cognitive functions. Moreover, the reviews of Wiradhany & Nieuwenstein, (2017) and Uncapher & Wagner, (2018) focused on cognitive tasks in the laboratory, while self-reported performances were included and examined in Wiradhany & Koerts’s, (2019) meta-analysis. Subsequently, Parry & le Roux, (2021) conducted a comprehensive meta-analysis synthesizing different measurement approaches. They divided studies into two groups according to various measurements of cognitive control: studies adopting self-report approaches and those using laboratory tasks. The results showed significant differences between these studies using two assessments. However, several limitations still exist. First, empirical studies from China were also rarely considered. Second, none of the previous meta-analyses explored the moderating effects of age, gender, and culture on the relationship between media multitasking and cognitive control. Third, in some groups of the study of Parry & le Roux, (2021), the number of studies is small. For instance, only three studies using self-reported measures of working memory were included, leading to limitations in accuracy and understanding of the heterogeneity of outcomes.

Accordingly, the present study aimed to fill the research gap by providing a comprehensive three-level meta-analysis to examine the possible relationship between media multitasking and global cognitive control. First, we employed the comprehensive and delicate method to conduct the literature search in English and Chinese databases. Second, we considered the potential moderators in the relationship between media multitasking and cognitive control. We aimed to examine the moderating roles of cognitive control types and measurement approaches consistent with the review of Parry & le Roux, (2021) and analyze other demographic and methodological variables as moderator variables in the current meta-analysis study. Furthermore, the categories of cognitive control in our meta-analysis are different from previous meta-analysis research (i.e., Parry & le Roux, 2021). Based on the recent findings on the cognitive control (Miyake et al., 2000; Takacs & Kassai, 2019; Valcan et al., 2018), cognitive control is comprised of three core components: inhibition control, working memory, and cognitive flexibility. This study analyzes the association between media multitasking and overall cognitive control and also the associations between media multitasking and the three components of cognitive control by conducting a moderating analysis.

Effect of Moderator Variables

The relationship between media multitasking and cognitive control may be moderated by other factors (i.e., Parry & le Roux, 2021). Several potential moderators will be discussed in the following section.

Age

Age may moderate the association between media multitasking and cognitive control. As reported in previous research, cognitive control capacity increases greatly from childhood to adolescence, which then becomes mature and stable in the mid-to-late-20 s (Crandall et al., 2018). Moreover, across the trajectory of lifespan development, executive functions are different for different age groups, with young adults performing the best across the lifespan (Filippi et al., 2020). Empirical studies also showed that adolescents perform more poorly across some cognitive control capacities than young adults (McKewen et al., 2019). One important reason is that the prefrontal cortex is still immature and vulnerable during adolescence (Best & Miller, 2010; Crone, 2009). Meanwhile, research on media use has shown that there are age differences in the amount of engagement in media multitasking. Adolescents were more frequently involved in media multitasking, possibly because of the growing environment full of media and their lack of self-regulatory skills (Baumgartner et al., 2017; Carrier et al., 2009; Voorveld & van der Goot, 2013). Additionally, during this special developmental period, the rapid physical and psychological changes of adolescence were driving certain cognitive skills development; thus, adolescents may be more vulnerable to this media activity (Baumgartner et al., 2017; Steinberg, 2005; Valkenburg & Peter, 2013). Although the exploration of media multitasking focused on different age groups (12–65 years old), most empirical studies examining the association between media multitasking and cognitive control have only focused on young adults and adolescents, and there are few studies conducted during childhood (6–12 years old) and middle- and older adults (35–65 years old) (e.g., Baumgartner et al., 2014; Rogobete et al., 2020; van der Schuur et al., 2015; Voorveld & van der Goot, 2013). Based on the previous studies (e.g., Ran et al., 2022), studies with adolescents (12–18 years old) and young adults (18–35 years old) were compared in the present meta-analytic study to clarify the discrepancies across different age groups.

Gender

Gender is a potential moderating factor in the relationship between media multitasking and cognitive control (e.g., van der Schuur et al., 2015). Previous research has revealed gender differences in cognitive control (e.g., Spencer & Cutting, 2021; Voyer et al., 2017). Specifically, boys show more executive functioning problems than girls during childhood (Huizinga & Smits, 2011; Spencer & Cutting, 2021). Furthermore, some studies found gender differences in sub-functions of executive functions. For example, women perform better in inhibitory control and shifting tasks, whereas men perform better on measures of working memory (Spencer & Cutting, 2021; Voyer et al., 2017). The gender differences in cognitive control are related to brain functional differences. For example, males and females work with opposite response patterns in the prefrontal cortex when performing some cognitive control tasks (Gaillard et al., 2020; Spencer & Cutting, 2021). Moreover, significant gender differences are reported in media multitasking frequency. Empirical research has found that media multitasking is more prevalent among women than among men (Duff et al., 2014; Lui et al., 2021; Rideout et al., 2010). Other researchers, however, have found that gender is related to self-discipline in that women are better at restraining desires to perform unrelated tasks than men, such as avoiding engaging in media devices (Zhou & Deng, 2022). Consequently, it is noteworthy that the gender effect of media multitasking has been inconclusive (Lepp et al., 2019; Ophir et al., 2009). With these considerations, gender was also included in the moderator analysis to test whether gender moderates the relationship between media multitasking and cognitive control.

Culture

Culture can also be a possible moderating variable. Research on media multitasking was conducted in different countries and regions, involving individuals from different cultural backgrounds. Zhou and Deng (2022) reviewed the studies on media multitasking in educational contexts from 2009 to 2020 and indicated that most studies on this topic were carried out in North America and fewer in Asia and Europe. Relative to Western countries, Eastern countries are considered collectivist. Hall, (1976) suggested that collectivist cultural groups mostly regard time as a cycle, arrange their time more flexibly, and prefer to deal with multiple affairs simultaneously, known as polychronicity. Meanwhile, people from individualist cultural groups mostly regard time as linear, pay attention to planning and punctuality, and are inclined to do one thing at a time, known as monochronicity. Moreover, polychronicity is a crucial predictor of media multitasking (Kononova & Chiang, 2015; Lin, 2019; Robinson & Kalafatis, 2020; Srivastava et al., 2016). Some researchers have found that media multitasking is more prevalent in polychronic cultures across several countries (Gray & Schofield, 2021; Kononova & Chiang, 2015; Voorveld et al., 2014). As the perspective of time across different cultural backgrounds leads to changes in preference for media multitasking, the relationship between media multitasking and cognitive control may vary with culture; thus, the present meta-analysis focused on the moderating effect of culture.

Type of Cognitive Control

Previous studies have demonstrated that cognitive control comprised three correlated yet separable components (Davidson et al., 2006; Spiegel et al., 2021), and their mechanisms and functions may differ (Takacs & Kassai, 2019). Although these three constructs emphasize different cognitive processes, all of them can reflect executive functions. As mentioned above, evidence suggests that the effects of media multitasking on inhibitory control, working memory, and cognitive flexibility are different (Liu, 2019; Uncapher & Wagner, 2018). The specific differences among the three components of the cognitive control still need to be further explored. Thus, we considered the type of cognitive control as a possible moderating factor in the association between media multitasking and cognitive control.

Measurement Type of Cognitive Control

In line with prior meta-analyses (Schoemaker et al., 2013; Takacs & Kassai, 2019; Toplak et al., 2013), the measurement type of cognitive control was also a moderator variable. Performance-based measures are mainly carried out in the laboratory, examining the efficiency of cognitive ability in highly standardized conditions, such as the participant's accuracy or response time, while self-reported scales measure the reflective level of cognitive control abilities in daily life, with a more ecologically valid degree (Toplak et al., 2013). Parry and le Roux (2021) found significant differences between self-report and performance-based assessments across some cognitive domains. The correlation between media multitasking and a few cognitive control domains was larger when studies using self-reports compared to those using laboratory tasks. In some meta-analyses in cognitive control, measurement modality was also used as a moderator variable to explore the difference between objective task performance and subjective reporting (e.g., Valcan et al., 2018). Thus, based on the previous research and characteristics of cognitive control, the current study considered the measurement type of cognitive control as a moderator variable in the relationship between media multitasking and cognitive control.

Publication Year

With the rapid development of Internet technology, media multitasking is growing increasingly widespread in people's daily life (Popławska et al., 2021). Furthermore, how individuals engage with digit media is changing and making innovations (Seddon et al., 2018). Thus, considering the possible changes in people's media multitasking behavior in the past two decades, the effect of media multitasking on individuals may vary with time (Parry & le Roux, 2021; Rogobete et al., 2020). Therefore, consistent with previous three-level meta-analyses, publication year was included as a moderator variable in the present meta-analysis (Cai et al., 2022; Mao et al., 2022; van der Put et al., 2020).

The Current Study

Media multitasking is a common digital technology use behavior closely related to how the human brain works (Alho et al., 2022; Uncapher & Wagner, 2018). However, the differences in cognitive control between heavy and light media multitaskers are uncertain. To increase the comprehension of how media multitasking is associated with cognitive control, the current research updates and extends previous meta-analyses in several important ways. First, a wider range of databases was searched. We expanded the search databases to include Chinese databases (e.g., WanFang Data) in addition to those used in previous meta-analyses such as the Web of Science. Second, gender, age, and other moderating variables were analyzed in our meta-analysis. Third, some quantitative research (e.g., Wiradhany & Koerts, 2019) applied conventional meta-analytic methods, which failed to consider the dependence among the effect sizes within the same study; thus, it could lead to ignorance of important information and biased estimates when a study contains multiple effect sizes (Cai et al., 2022; Cheung, 2014). Although Parry & le Roux, (2021) used robust variance estimation, which was also an alternative approach to account for dependency between effect sizes, this method is less suitable than the multilevel approach when each study includes a small number of effect sizes (Rodgers & Pustejovsky, 2020; Roemer, 2021; Tanner-Smith et al., 2016; Van den Noortgate et al., 2015). Thus, the present meta-analysis used the most appropriate novel analytic technique of three-level meta-analysis (e.g., Assink & Wibbelink, 2016; Cai et al., 2022; Mauger et al., 2018; Ran et al., 2022), which can be considered a three-level model with participants at level 1, within-study variance at level 2, and between-study variance at level 3, to provide an accurate understanding of the association between media multitasking and cognitive control with greater statistical power (Assink & Wibbelink, 2016). Therefore, the current meta-analysis addresses the following questions:

Q1 What is the estimated overall relationship between media multitasking and global cognitive control?
Q2 Does type of cognitive control moderates the relationship? What specific type of cognitive control is significantly related to media multitasking?
Q3 Does the relationship between media multitasking and cognitive control vary due to some study variables, such as age, gender, culture, publication year, and measurement type of cognitive control?

Methods

Data Sources and Literature Search

A primary retrieval of the literature was conducted in congruence with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Page et al., 2021). We used multiple electronic databases to search studies, including the Web of Science, PsycARTICLES, PsycINFO, JSTOR, SAGE, ProQuest Dissertation & Theses Global, Springer, Google Scholar, and other open sources. We also searched for Chinese databases such as China National Knowledge Infrastructure (CNKI), WanFang Data, Chinese Selected Doctoral Dissertations and Master's Theses Full-Text Databases (CDMD), and Chongqing VIP data (CQVIP). Research published until June 2021 was considered. Relevant studies included at least one keyword in the title, abstract, or entire article from each of the following two aspects: (a) media multitasking and (b) executive function. For media multitasking, the primary keywords searched were "multitasking," "media multitasking," or "multitask with media." Similarly, the search terms for cognitive control were "cognitive control," "executive function," "working memory," "updating," "inhibitory control," "cognitive flexibility," "shifting," or "task switch." If necessary, we read the full article texts. Additionally, we read titles and abstracts to assess the retrieved studies (van der Put et al., 2020). Subsequently, we reviewed the literature cited in existing reviews and meta-analyses and checked the reference sections of articles found through our search for supplements.

Inclusion Criteria

Studies were included in our meta-analysis if they (1) were empirical and quantitative studies reporting the relationship between media multitasking and cognitive control (i.e., review, theoretical, and qualitative studies were ineligible for inclusion); (2) investigated multitasking behaviors related only to media use; (3) used quantifiable indices that can reflect media multitasking experience (i.e., the MMI or a modified version, whereas studies only carried out by laboratory tasks were not included; Uncapher & Wagner, 2018). As shown in the sixth column of

Table 1, more than half of the included studies ($n = 63$, 53.39%) used the original MMI devised by Ophir et al., (2009), while 55 (46.61%) measured media multitasking with a modified version. Furthermore, according to the definition of media multitasking, if "media-media multitasking" and "media-nonmedia multitasking" were distinguished in the literature, only the samples of media within media types were included, while samples of media multitasking across media and non-media activities were not included; (4) reported sufficient information to calculate the effect size (correlation coefficients, sample size, *t*, *F*, or *r* values, etc.); (5) were written in Chinese or English; (6) included at least one test of cognitive control or executive functions (cognitive control was defined as inhibitory control, working memory and cognitive flexibility), whereas studies that merely examined the effect of media multitasking on academic or job performance were excluded. Most included studies reported specific components of cognitive control. In addition to studies including tests of all three cognitive control components, some studies only examining one or two components were also included in our meta-analysis, which was consistent with a previous study (Spaniol & Danielsson, 2022). Furthermore, when different cognitive control tasks were used in a paper, the effect sizes of all tasks were included. For each task of cognitive control, one single dependent variable (e.g., reaction time) was chosen as the most pertinent measure, irrespective of whether one or multiple measures were reported. Consistent with previous meta-analyses, the most appropriate outcome metric selected was the one most relevant to the task or most frequently used in previous studies (Mauger et al., 2018; Schoemaker et al., 2013; Spaniol & Danielsson, 2022). Additionally, for self-reported scales, if the outcomes of the scales can be matched to a specific component of cognitive control, they can be considered as an assessment; otherwise, they were excluded (Parry & le Roux, 2021; Uncapher & Wagner, 2018); (7) clearly specified the outcome measure (e.g., reaction time, accuracy, error rate, sensitivity; le Roux & Parry, 2019; Rabi et al., 2020; van der Put et al., 2020). If the same data was applied repeatedly to both journal papers and dissertations, only the journal papers were included. Ultimately, 43 studies yielding 118 effect sizes met the inclusion criteria. A flow chart of the full search procedure is presented in Fig. 1.

Coding

Each independent sample was coded as an effect size. When multiple independent samples were reported in a study, they were coded separately. The first and second authors independently extracted data and coded studies to verify the accuracy of each author. Subsequently, each coding inconsistency was resolved through a discussion between the two coders. Other researchers were consulted when a consensus could not be reached. The inter-rater agreement between two coders was assessed by intraclass correlation coefficients (ICC) or Cohen's kappa. The ICC for different continuous variables were publication year (ICC = 1.0) and gender (ICC = 0.996). The Cohen's kappa for different categorical variables were age (Cohen's kappa = 0.921), culture (Cohen's kappa = 0.931), type of cognitive control (Cohen's kappa = 0.884), measurement type of cognitive control (Cohen's

Table 1 Characteristics of included studies

Author	Publication year	K	N	Type of CC	Measurement of MM	Measurement type	Task of CC	Outcome	Age	Gender	Culture
Alzahabi	2013a	1	80	CF	MMI	LAB	Number Letter	Switch cost	YA	0.294	W
Alzahabi	2013b	1	49	CF	MMI	LAB	Number Letter	Switch cost	YA	0.310	W
Alzahabi	2015	1	187	CF	Mod MMI	LAB	Task Switching	RT	YA	0.374	W
Anderson	2010	1	61	IC	MMI	LAB	Flanker	RT	YA	-	W
Baumgartner	2014	6	523	WM	Mod MMI	SR	BRIEF		AD	0.518	W
			523	WM	Mod MMI	LAB	Digit Span	Acc	AD	0.518	W
			523	CF	Mod MMI	SR	BRIEF		AD	0.518	W
			523	CF	Mod MMI	LAB	Dots–Triangles	Switch cost	AD	0.518	W
			523	IC	Mod MMI	SR	BRIEF		AD	0.518	W
			523	IC	Mod MMI	LAB	Eriksen Flankers	I/C	AD	0.518	W
Cain	2016	3	58	WM	Mod MMI	LAB	N-back	d’	AD	0.507	W
			69	WM	Mod MMI	LAB	Count Span	Acc	AD	0.507	W
			58	WM	Mod MMI	LAB	Change Detection	Acc	AD	0.507	W
Cardoso-Leite	2015	4	32	WM	MMI	LAB	N-back	IES	YA	0.867	W
			32	IC	MMI	LAB	AX-CPT	IES	YA	0.867	W
			32	WM	MMI	LAB	Change Detection	k	YA	0.867	W
			32	CF	MMI	LAB	Number Letter	IES	YA	0.867	W
Edwards	2017	1	32	WM	MMI	LAB	N-back	d’	YA	0.500	W
Elbe	2019	2	51	CF	Mod MMI	LAB	Local global task	Switch cost	YA	0.392	W
			51	CF	Mod MMI	LAB	Number Letter	Switch cost	YA	0.392	W
Gorman	2016	10	42	WM	MMI	LAB	Backwards Digit Span	Acc	YA	0.310	W
			42	WM	MMI	LAB	Backwards Digit Span	Acc	YA	0.310	W
			42	CF	MMI	LAB	Task Switching	Switch cost	YA	0.310	W
			42	CF	MMI	LAB	Task Switching	Switch cost	YA	0.310	W

Table 1 (continued)

Author	Publication year	K	N	Type of CC	Measurement of MM	Measurement type	Task of CC	Outcome	Age	Gender	Culture
			42	WM	MMI	LAB	Change Detection	d’	YA	0.310	W
			42	WM	MMI	LAB	Change Detection	d’	YA	0.310	W
			42	IC	MMI	LAB	Eriksen Flankers	RT	YA	0.310	W
			42	IC	MMI	LAB	Eriksen Flankers	RT	YA	0.310	W
			42	IC	MMI	LAB	Go/No-go	RT	YA	0.310	W
			42	IC	MMI	LAB	Go/No-go	RT	YA	0.310	W
Lui& Wong	2012	1	63	IC	MMI	LAB	Pip-and-Pop task	Acc	-	0.460	E
Luo	2021	6	22	WM	Mod MMI	SR	BRIEF		AD	0.318	E
			22	CF	Mod MMI	SR	BRIEF		AD	0.318	E
			22	IC	Mod MMI	SR	BRIEF		AD	0.318	E
			22	WM	Mod MMI	LAB	N-back	RT	AD	0.318	E
			22	CF	Mod MMI	LAB	Number Letter	RT	AD	0.318	E
			22	IC	Mod MMI	LAB	Stroop	Switch cost	AD	0.318	E
Madore	2020	2	40	WM	Mod MMI	LAB	Goal-directed encoding and retrieval task	d’	YA	0.388	W
			40	WM	Mod MMI	LAB	Grad CPT	RTV	YA	0.388	W
Magen	2017	3	196	WM	MMI	SR	BRIEF		YA	0.260	E
			196	CF	MMI	SR	BRIEF		YA	0.260	E
			196	IC	MMI	SR	BRIEF		YA	0.260	E
Minear	2013a	3	69	WM	MMI	LAB	Reading Span	Acc	YA	0.362	W
			69	CF	MMI	LAB	Task Switching	Switch cost	YA	0.362	W
			221	IC	MMI	SR	BIS-11		YA	0.317	W
Minear	2013b	1	56	IC	MMI	SR	BIS-11		YA	0.281	W

Table 1 (continued)

Author	Publication year	K	N	Type of CC	Measurement of MM	Measurement type	Task of CC	Outcome	Age	Gender	Culture
Minear	2013c	2	53	WM	MMI	LAB	Recent probes item recognition	Acc	YA	0.377	W
			53	CF	MMI	LAB	Task Switching	Switch cost	YA	0.377	W
Moisala	2016	1	149	IC	Mod MMI	LAB	Cross-modal filtering	Acc	-	-	W
Murphy	2017	2	56	IC	Mod MMI	LAB	Eriksen Flankers	IES	YA	0.235	W
			56	IC	Mod MMI	LAB	Go/No-go	Acc	YA	0.235	W
Murphy	2020	4	91	IC	Mod MMI	SR	BIS-11		YA	0.231	W
			91	WM	Mod MMI	LAB	Digit Ordering	Acc	YA	0.231	W
			91	IC	Mod MMI	LAB	Stroop	Acc	YA	0.231	W
			91	IC	Mod MMI	LAB	Go/No-go	Acc	YA	0.231	W
Ophir	2009a	2	41	WM	MMI	LAB	Change Detection	k	YA	-	W
			41	IC	MMI	LAB	Stop Signal	RT	YA	-	W
Ophir	2009b	1	30	WM	MMI	LAB	N-back	d'	YA	-	W
Ophir	2009c	2	30	CF	MMI	LAB	Task Switching	Switch cost	YA	-	W
			30	IC	MMI	LAB	AX-CPT	RT	YA	-	W
Ralph	2015a	1	76	IC	MMI	LAB	SART	RT	YA	0.224	W
Ralph	2015b	1	143	IC	MMI	LAB	Go/No-go	RT	-	0.483	W
Ralph	2017	2	265	WM	MMI	LAB	N-back	FA	-	0.483	W
			265	WM	MMI	LAB	N-back	FA	-	0.483	W
Rogobete	2020	6	296	WM	Mod MMI	SR	BRIEF		AD	0.439	W
			296	IC	Mod MMI	SR	BRIEF		AD	0.439	W
			296	CF	Mod MMI	SR	BRIEF		AD	0.439	W
			179	WM	Mod MMI	LAB	Digit Span	Acc	AD	0.439	W

Table 1 (continued)

Author	Publication year	K	N	Type of CC	Measurement of MM	Measurement type	Task of CC	Outcome	Age	Gender	Culture
			179	IC	Mod MMI	LAB	Eriksen Flankers	I/C	AD	0.439	W
			179	CF	Mod MMI	LAB	Dots-Triangles	Switch cost	AD	0.439	W
Sanbonmatsu	2013	2	277	IC	MMI	SR	BIS-11		YA	0.563	W
			277	WM	MMI	LAB	Operation Span	Acc	YA	0.563	W
Schutten	2017	1	148	IC	MMI	SR	BIS-11		YA	0.168	W
Seddon	2018	10	105	IC	Mod MMI	LAB	Stop Signal	RT	YA	0.321	W
			105	IC	Mod MMI	LAB	Go/No-go	Acc	YA	0.321	W
			105	IC	Mod MMI	LAB	Number Flanker	Congruency conflict	YA	0.321	W
			105	IC	Mod MMI	LAB	Arrow Flanker	Congruency conflict	YA	0.321	W
			105	CF	Mod MMI	LAB	Phonetic Fluency	Acc	YA	0.321	W
			105	CF	Mod MMI	LAB	Semantic Fluency	Acc	YA	0.321	W
			105	CF	Mod MMI	LAB	WCST	Error %	YA	0.321	W
			105	CF	Mod MMI	LAB	TMT	B-A difference	YA	0.321	W
			105	WM	Mod MMI	LAB	Span (Backwards Digit)	Mean span	YA	0.321	W
			105	WM	Mod MMI	LAB	Span (Backwards Corsi)	Block span	YA	0.321	W
Shin	2019	3	144	IC	MMI	LAB	Go/No-go	RT	YA	0.333	W
			144	IC	MMI	LAB	Stop Signal	FA	YA	0.333	W
			144	IC	MMI	LAB	BRIEF		YA	0.333	W
Shin	2020	1	71	WM	Mod MMI	LAB	N-back	d’	YA	0.213	W
Swing	2012	1	234	IC	MMI	LAB	Stroop	RT	YA	0.455	W
Uncapher	2016	3	72	WM	MMI	LAB	Change Detection	k	YA	0.420	W
			72	WM	MMI	LAB	Change Detection	k	YA	0.420	W
			139	IC	MMI	SR	BIS-11		YA	0.420	W

Table 1 (continued)

Author	Publication year	K	N	Type of CC	Measurement of MM	Meas-urement type	Task of CC	Outcome	Age	Gender	Culture
Wilmer	2016	2	91	IC	MMI	LAB	Go/No-go	FA	YA	0.286	-
			91	IC	MMI	SR	BIS-11		YA	0.286	-
Wiradhany	2017a	4	23	WM	MMI	LAB	N-back	FA	YA	-	E
			23	CF	MMI	LAB	Task Switching	Switch cost	YA	-	E
			23	IC	MMI	LAB	AX-CPT	RT	YA	-	E
			22	WM	MMI	LAB	Change Detection	k	YA	-	E
Wiradhany	2017b	4	26	WM	MMI	LAB	N-back	FA	YA	-	W
			30	CF	MMI	LAB	Number Letter	Switch cost	YA	-	W
			20	IC	MMI	LAB	AX-CPT	RT	YA	-	W
			22	WM	MMI	LAB	Change Detection	k	YA	-	W
Wiradhany	2020	1	76	WM	Mod MMI	LAB	Change Detection	k	YA	0.391	W
Yang	2016	1	310	IC	Mod MMI	SR	BIS-11		AD	0.507	E
Liu C	2015	3	40	WM	MMI	LAB	Span task	Mean span	YA	-	E
			40	IC	MMI	LAB	Filter task	RT	YA	-	E
			40	CF	MMI	LAB	Task Switching	RT	YA	-	E
Liu Z	2019	6	63	WM	Mod MMI	LAB	N-back	Acc	YA	0.206	E
			63	CF	Mod MMI	LAB	Task Switching	Switch cost	YA	0.200	E
			63	WM	Mod MMI	LAB	Change Detection	Acc	YA	0.212	E
			403	WM	Mod MMI	SR	BRIEF		YA	0.256	E
			403	CF	Mod MMI	SR	BRIEF		YA	0.256	E
			403	IC	Mod MMI	SR	BRIEF		YA	0.256	E
Xia C	2014	3	61	WM	MMI	LAB	N-back	RT	YA	0.492	E
			47	CF	MMI	LAB	Task Switching	RT	YA	0.532	E

Table 1 (continued)

Author	Publication year	K	N	Type of CC	Measurement of MM	Measurement type	Task of CC	Outcome	Age	Gender	Culture
			52	IC	MMI	LAB	Stroop	RT	YA	0.481	E
Xue T	2020	3	98	IC	Mod MMI	LAB	Go/No-go	RT	YA	-	E
			98	WM	Mod MMI	LAB	N-back	k	YA	-	E
			98	CF	Mod MMI	LAB	Number Letter	Switch cost	YA	-	E

K = number of effect sizes; N = sample size; CC = cognitive control; CF = cognitive flexibility; WM = working memory; IC = inhibitory control; MM = media multitasking; Gender = ratio of male; LAB = laboratory task; SR = self-report task; BRIEF = the behavior rating inventory of executive function; BIS-11 = the 11th version of the barratt impulsivity scale; Acc = accuracy; RT = reaction time; d' = sensitivity (hit rate minus false alarm rate); IES = inverse efficiency score; k = a measure of working memory capacity; I/C = ratio (Incongruent/Congruent); Congruency conflict = difference between mean response time for congruent and incongruent trials; YA = young adult; AD = adolescent; W = western countries; E = eastern countries

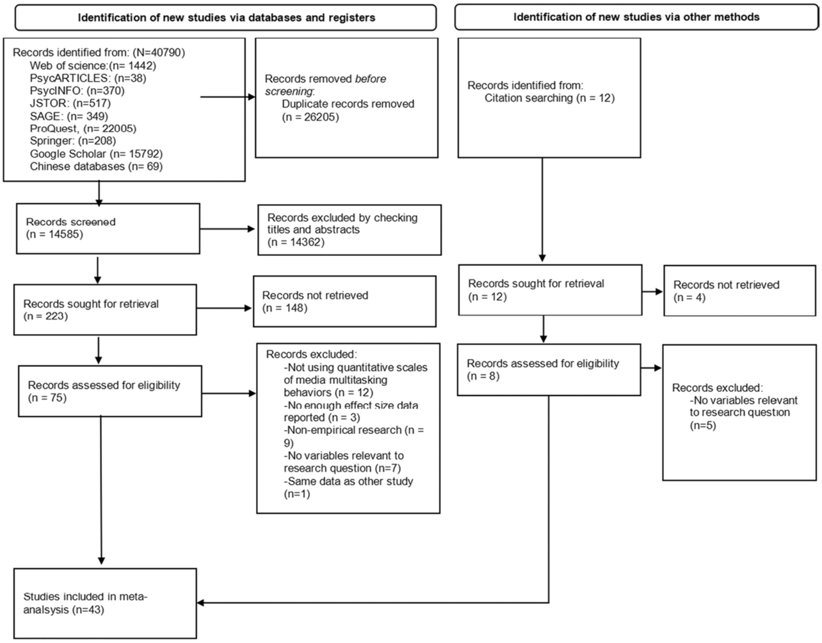

Fig. 1 Flow chart of the search for studies

kappa = 1.0), and measurement of media multitasking (Cohen's kappa = 1.0). These results reflected a high level of inter-rater reliability.

Following the guidelines of Lipsey & Wilson, (2001), studies that met the inclusion criteria were coded for the following study features: author, publication year, sample size, and other demographic and methodological characteristics.

For age, we categorized participants into two groups on the basis of mean age, namely adolescents (12–18 years old) and young adults (18–35 years old). Gender was coded as a continuous variable and represented by the ratio of males in the sample. For culture, we categorized this variable into two categories based on the country participants come from, namely Eastern countries (e.g., China, Indonesia) and Western countries (e.g., the Netherlands, Australia). Concerning different types of cognitive control in studies, we coded them according to both previous considerations in the literature and the author's explanation (e.g., Diamond, 2013; Parry & le Roux, 2021; Takacs & Kassai, 2019). Table 1 demonstrates the outcome variables of the cognitive control tasks.

Furthermore, the measurement type of cognitive control was coded as a categorical variable with two levels: self-report scales and laboratory tasks. Measurement of media multitasking (MMI or Mod MMI) was coded and was listed in Table 1.

Data Analysis

We employed the effect size Cohen's d in the present study for each outcome measured, estimating the standardized mean difference between heavy (HMMs) and light (LMMs) media multitasking groups. On this condition where the outcome variable was continuous, Cohen's d was directly calculated and compared between two groups of participants, using reported z values and p values per group or means and standard deviations (van der Put et al., 2020). In other cases, we transformed the available relevant statistics, such as correlation coefficients, to effect size using the Comprehensive Meta-Analysis (CMA) software or conventional formulas of Ferguson, (1966), Lipsey & Wilson, (2001), and Rosenthal, (1994) (van der Put et al., 2020). Notably, several studies have divided participants into three groups according to their MMI scores, adding intermediate media multitasking groups (IMMs) in addition to heavy and light media multitasking groups (e.g., Shin et al., 2020). However, studies containing IMMs are relatively small (only four studies with eight effect sizes). Furthermore, it is difficult to compare differences between the three groups in a meta-analysis. Therefore, to align with our research goals, we only considered the scores of HMMs and LMMs and explored the association between media multitasking and cognitive control by comparing the differences between the two groups.

Positive effect sizes indicated that HMMs had higher cognitive control ability than LMMs, while negative effect sizes showed that LMMs had higher cognitive control levels than HMMs. The effect sizes were contrary when lower scores denoted better behaviors. Hence, a higher effect size implied higher cognitive control ability across all analyses. Cohen, (1988) has established the criteria that $d=0.2$, $d=0.5$, and $d=0.8$ were regarded as small, moderate, and large effects, respectively.

Because most primary studies included reported effect estimates for multiple outcomes, the key assumption that effect sizes required to be independent in traditional meta-analysis was violated (Assink & Wibbelink, 2016). Hence, the present study applied a three-level random-effects model to calculate a combined effect size and conduct moderator analyses to resolve dependency problems between outcomes. The model of three-level random effects incorporates three sources of variance: random sampling of effect sizes (level 1), differences between effect sizes within studies (level 2), and differences between studies (level 3) (Cheung, 2014). An advantage of this model is that it considers the correlation between effect sizes from the same study. All relevant effect sizes can be extracted from the same study in this approach (Lipsey & Wilson, 2001). Additionally, traditional methods usually average outcomes or select only one outcome from each study, which leads to information loss. In this meta-analysis model, the overall effect was estimated using Cheung's formula (2014). Thereafter, one-tailed log-likelihood ratio tests were conducted to see if the variance distributed at levels 2 and 3 was significant. Subsequently, moderator analyses were performed to find possible variables that can account for within-study and between-study differences. All analyses were performed in the R statistical software using the metafor package (Viechtbauer, 2010). The syntaxes were written in accordance with the manual written by Assink & Wibbelink, (2016).

Moreover, publication bias indicates the phenomenon in which not all published studies that meet the inclusion criteria are included (Kuppens et al., 2013). Publication bias was tested by a direct inspection of the funnel plot. The symmetric funnel plot formed by the data points can confirm that publication bias was non-existent (Cai et al., 2022). Additionally, Egger's linear regression test was employed to evaluate the bias when publication bias was present (Egger et al., 1997). Furthermore, a trim-and-fill analysis was conducted to further evaluate the bias.

Results

Study Characteristics

The meta-analysis of the effect of media multitasking on cognitive control included 118 effect sizes from 43 studies, with a total of 5194 participants. The number of effect sizes in each relevant study ranged from 1 to 12. The number of sample sizes ranged from 20 to 523. The participants' mean age was 20.65 years, with a range of 12.90–35.00 years. The ratio of males ranged from 16.8 to 86.7% ($M = 38.01\%$, $SD = 0.137$). Additional details are provided in Table 1.

Overall Effect and Publication Bias

Overall Effect of Media Multitasking on Cognitive Control

A random-effects model was used to yield the overall effect size of media multitasking on cognitive control. The result demonstrated a statistically significant negative effect, indicating that heavy media multitaskers significantly underperformed compared to light media multitaskers on cognitive control tasks (Cohen'$d = -0.229$, 95% confidence interval (CI) = [−0.338, −0.121], $t(117) = -4.184$, $p < 0.001$). The Q test showed remarkable heterogeneity between all effect sizes ($Q(117) = 376.561$, $p < 0.001$). Additionally, the two separate log-likelihood ratio tests demonstrated statistically significant variance at level 2 ($\sigma^2 = 0.047$, $\chi^2(1) = 49.210$, $p < 0.001$, one-sided), and at level 3 ($\sigma^2 = 0.075$, $\chi^2(1) = 10.701$, $p < 0.001$, one-sided). Of the total effect size variance, 23.008% was the percentage of random sampling variation (level 1), 29.565% was attributed to the variance among effect sizes from the same study (level 2), and 47.427% was accounted for the discrepancies between studies (level 3) using the formula of Cheung, (2014). In our heterogeneous results, there were significant level 2 and level 3 variances. In other words, substantial between-study or within-study variance existed in our study. Therefore, it was necessary to conduct further moderator analyses to investigate whether the strength of the impact of media multitasking on cognitive control was affected by study characteristics.

Moderator Effects

A notable moderating effect was identified for the type of cognitive control [F (2,115) = 4.973, $p < 0.01$]. More specifically, the effects of media multitasking on inhibitory control ($d = -0.307$, $p < 0.001$) and working memory ($d = -0.243$, $p < 0.001$) were significant, while a non-significant effect size was found for cognitive flexibility ($d = -0.053$, $p > 0.1$). Furthermore, the measurement approaches significantly moderated the overall effect (F (1,116) = 17.150, $p < 0.001$). The effect sizes were larger when cognitive control was measured by self-reported approaches ($d = -0.470$, $p < 0.001$) rather than laboratory tasks ($d = -0.161$, $p < 0.01$). No other significant differences were demonstrated in the current moderator analyses (age, gender, culture, and publication year). The results are presented in Table 2.

Publication Bias

As shown in Fig. 2, the asymmetric distribution funnel plot indicated a publication bias tendency. Specifically, the effect sizes were missing at the bottom right side of the plot, indicating potential publication bias. However, publication bias was not detected according to Egger's test. Egger's regression test yielded an unremarkable result ($t = -0.91$, $p = 0.36 > 0.05$), demonstrating no publication bias in our current meta-analysis. Additionally, given the potential for publication bias according to the funnel plot, the trim-and-fill analysis must be further performed to evaluate the bias (Duval & Tweedie, 2000). The result showed that 19 missing studies had to be imputed, and the adjusted average effect size was still significant (Cohen'$d = -0.163$, 95% confidence interval (CI) = [−0.237, −0.090]), which was similar to the non-adjusted overall effect size. In summary, although we cannot entirely exclude the possibility of publication bias, the main findings of the meta-analysis appeared to be robust and still valid, with heavy media multitaskers demonstrating significantly worse performances in cognitive control than light media multitaskers.

Discussion

Association Between Media Multitasking and Global Cognitive Control

The empirical research examining the association between media multitasking and cognitive control has obtained equivocal findings. The current three-level meta-analysis was conducive to a better comprehension of the overall relationship by comparing the cognitive control components between the groups of heavy media multitasking and groups of light media multitasking and assessing possible moderators. A total of 43 studies, including 118 effect sizes, were quantitatively summarized through a literature search. Overall, the result demonstrated a moderate negative association between media multitasking and global cognitive control. Our finding was consistent with prior empirical studies (e.g., Baumgartner et al.,

Table 2 Results of categorical and continuous moderators for the association between media multitasking and cognitive control

# Moderator variables variance	# ES	Intercept/mean d [95% CI]	$\beta 1$ [95% CI]	F (df1,df2)[1]	p[2]	Level 2 variance	Level 3 variance
Overall effect	118	−0.229 [−0.338, −0.121]***				0.047	0.075
Age	113			1.396 (1,111)	0.240	0.047	0.084
Adolescents	22	−0.391 [−0.689, 0.094]*					
College students	91	−0.198 [−0.326, −0.070]**	0.193 [−0.131, 0.517]				
Gender	97	−0.442 [−0.743, −0.142]**	0.009 [−0.890, 0.907]	0.000 (1,95)	0.984	0.041	0.080
Culture	116			0.000 (1,114)	0.995	0.048	0.082
Eastern	30	−0.225 [−0.460, 0.010]					
Western	86	−0.224 [−0.353, −0.095]***	0.001 [−0.268, 0.269]				
Publication year	118	−0.000 [−0.000, −0.000]	−0.006 [−0.042, 0.031]	0.069 (1,116)	0.758	0.047	0.078
Measurement type	118			17.150 (1,116)***	0.001	0.030	0.075
SR	23	−0.470 [−0.626, −0.314]***					
LAB	95	−0.161 [−0.270, −0.051]**	0.309 [0.161, 0.457]***				
Type of cognitive control	118			4.973 (2,115)**	0.008	0.046	0.059
Cognitive flexibility	29	−0.053 [−0.205, 0.100]					
Inhibitory control	46	−0.307 [−0.431, −0.183]***	−0.255 [−0.417, −0.093]**				
Working memory	43	−0.243 [−0.377, −0.109]***	−0.190 [−0.357, −0.024]*				

ES = number of effect sizes; mean d = mean effect size (Cohen's d); CI = confidence interval; $\beta 1$ = estimated regression coefficient; df = degrees of freedom; Level 2 variance = differences among effect sizes within studies; Level 3 = differences among effect sizes between studies; Measurement of CC = measurement of cognitive control

[1] Omnibus test of all regression coefficients in the model

[2] p-value of the omnibus test

$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$

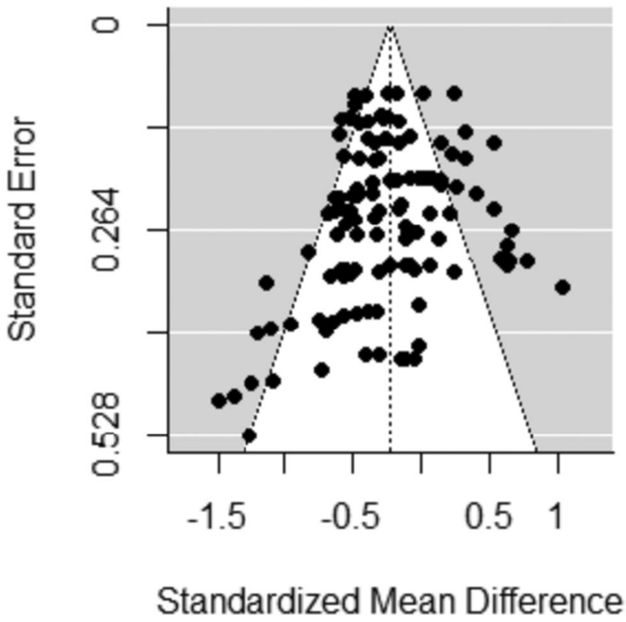

Fig. 2 Funnel plot of effect sizes

2014; Ophir et al., 2009). This relationship indicated that heavy media multitasking might be an effective predictor for damaging individuals' cognitive control abilities. The qualitative review by Uncapher & Wagner, (2018) showed that HMMs could exhibit poorer performances in some cognitive domains. Our study confirmed the general findings from previous meta-analyses (e.g., Parry & le Roux, 2021) and highlighted the negative association between media multitasking and overall cognitive control.

Our finding can be explained by the scattered attention hypothesis, which postulates that heavy media multitaskers tend to adopt a decentralized attention mode and pay attention to multiple stimulus information simultaneously (Yap & Lim, 2013), changing the cognitive processing of HMMs. Specifically, HMMs tend to take on the "breadth-biased" approach and implement a bottom-up attentional processing technique, and thus, they are more easily distracted by irrelevant information and have poorer cognitive control abilities (Cain & Mitroff, 2011; Lin, 2009). This evidence can be found in several behavioral and ERP studies (e.g., Ophir et al., 2009; Zhang et al., 2022).

With the rapid development of online media, individuals live in an environment that is full of multiple media. Individuals who frequently engage in media multitasking behaviors tend to have poor cognitive control abilities in real life, but they might overestimate their ability; thus, they may invest in media multitasking behaviors and further impede their cognitive control abilities (Sanbonmatsu et al., 2013). Given that media multitasking is closely related to cognitive control, media multitasking should be appropriately guided by educators when preventing and intervening in the decline of individuals' cognitive control abilities. Furthermore, it should be noted that another possibility for the association direction is that individuals who perform poorly in cognitive control are more likely to multitask with media, as the self-selection hypothesis suggested (Ralph et al., 2014). This issue deserves further exploration in the longitudinal study design.

Moderator Effects

Type of Cognitive Control

Our results revealed that the type of cognitive control had a significant influence on the effect size heterogeneity. Specifically, media multitasking had a significant negative correlation with individuals' inhibitory control and working memory but had no significant correlation with cognitive flexibility.

Compared to the LMMs, the HMMs exhibited poorer performances in the inhibitory control and working memory tasks. For inhibitory control, our results are consistent with numerous previous studies that have reported poorer filtering skills and poorer performances of responses inhibition for HMMs compared to LMMs (e.g., Cain & Mitroff, 2011; Lui & Wong, 2012; Ralph et al., 2015). Generally, reduced sustained attention can explain why HMMs have poorer inhibitory control than LMMs (e.g., Baumgartner et al., 2014; Madore et al., 2020; Uncapher & Wagner, 2018). Specifically, when people multitask with media, they need to continuously switch attention among multiple information sources or split attention to multiple media streams simultaneously, which can easily lead to deficits in sustained attention (Ralph et al., 2015). Moreover, attentional resources are limited. Different tasks compete for limited attentional resource, and irrelevant tasks attract attention and interfere with the primary task (Ralph et al., 2014). Therefore, increased levels of media multitasking may be associated with poorer performances in ignoring irrelevant distractions and more failure when inhibiting their response (e.g., Baumgartner et al., 2014; Ralph et al., 2015).

With regard to working memory, although a few empirical studies found no correlation or a positive correlation between media multitasking and working memory, our results might be accurate and in line with previous studies which reported poorer working memory performance for HMMs compared to LMMs (e.g., Ralph & Smilek, 2017). Working memory is vulnerable to media multitasking, which, in addition to being explained by attentional differences, may emerge from the increased cognitive load (Luo et al., 2022; Uncapher & Wagner, 2018). Specifically, people's working memory capacities are limited. Engaging in media multitasking more frequently is likely to increase individuals' internal cognitive load and impair their working memory (Luo et al., 2022).

Furthermore, evidence from neurocognitive studies suggested that HMMs showed higher brain activation in prefrontal areas when performing inhibitory control and working memory tasks (Luo et al., 2021; Moisala et al., 2016). These findings implied that media multitasking might be associated with worse efficiency in the brain regions responsible for cognitive control. Specifically, HMMs might need more brain activation to achieve the same cognitive behavioral performance as LMMs (e.g., Luo et al., 2021). This study's findings of inhibitory control and working memory differences between HMMs and LMMs supported the scattered attention hypothesis.

Conversely, the non-significant result in cognitive flexibility tasks did not support either the scattered or the trained attention hypotheses. The findings on the associations between media multitasking and cognitive flexibility in previous empirical studies were mixed, ranging from a positive relationship to a null result to a negative relationship (Uncapher & Wagner, 2018). The complex results imply the possible existence of boundary conditions. For example, Szumowska et al., (2018) suggested that media multitasking frequency is negatively associated with multitasking performance, but only for those participants in the free switching condition and not in the sequential condition. Therefore, although we found that the relationship between media multitasking and cognitive flexibility is non-significant, future studies should focus on the potential boundary conditions. Moreover, the non-significant outcome of cognitive flexibility may also be due to incomprehensive assessment methods and indicators, which do not fully and accurately reveal the true relationship between media multitasking and cognitive flexibility. Most of the research included in our meta-analysis selected the switch cost in the task-switching paradigm as the outcome variable. Nevertheless, some researchers have raised doubts about the measurement index, suggesting that it lacks reliability and cannot accurately reflect individuals' cognitive flexibility (Draheim et al., 2016; Hughes et al., 2014). Additionally, Diamond, (2013) proposed that the capacity to rapidly switch between tasks and mental sets is only one component of cognitive flexibility. Research exploring the relationship between media multitasking and other components of cognitive flexibility is limited to date (Murphy & Shin, 2022). Accordingly, future studies should expand the components and measures of cognitive flexibility.

A recent meta-analysis by Parry & le Roux, (2021) showed small significant negative associations between media multitasking and some cognitive control components ($z_{\text{working memory}} = 0.181$***, $z_{\text{inhibitory control}} = 0.163$***, $z_{\text{sustained attention}} = 0.192$***) and showed non-significant associations between media multitasking and other cognitive control components ($z_{\text{interference management}} = 0.057$, $z_{\text{task management}} = 0.031$). Effect sizes on the three cognitive control components in our study differ slightly from those of Parry & le Roux, (2021). However, their definition of cognitive control differs from the one in our meta-analysis. Notably, different definitions of cognitive control are typically vague, and it is inappropriate to compare meta-analyses based on different classification standards of cognitive control (Spaniol & Danielsson, 2022). Therefore, interpreting conclusions regarding the cognitive control components should be made with caution.

Measurement Type of Cognitive Control

Other potential moderators, such as measurement type of cognitive control, were also analyzed. The present study suggests that the association between media multitasking and cognitive control might differ across outcome measurements. Specifically, the negative correlation between media multitasking and cognitive control is stronger in the self-report methods than in the laboratory tasks. A previous meta-analysis showed differences between self-report and performance-based measures of some cognitive control dimensions (Parry & le Roux, 2021). The self-report methods measure cognitive control at the level of an individual's reflection, reflecting an individual's ability to make rational decisions and take actions to achieve daily goals. The experimental tasks mainly measure generalized cognitive control and require participants to complete the test in a highly standardized condition. The task objectives and requirements are provided by the examiner, which does not require the individuals to do goal-oriented behavior planning (Toplak et al., 2013; Wiradhany & Koerts, 2019). Therefore, media multitasking behavior was negatively associated with generalized cognitive control, but such a negative association appeared to be more effective for the cognitive control ability at the level of reflection. Additionally, there is far more distracting information in everyday life than in the laboratory. Individuals who frequently use media multitasking must make greater efforts to suppress responses to irrelevant information in everyday life. Individuals were exposed to fewer stimuli in the laboratory; therefore, when exploring the relationship between media multitasking and cognitive control in the future, researchers should not limit themselves to laboratory research but must also focus on the association between media multitasking and the outcome variables of cognitive control in daily life, such as academic performance.

Age

Results showed that the negative relationship between media multitasking and cognitive control was similar for adolescents and young adults. The non-significant result with the age moderator may indicate no differences in media multitasking and cognitive control between adolescents and young adults. The media preferences with which they multitask are similar for the age groups of adolescents and young adults, which may lead to a convergence in the impact of media multitasking on adolescents and young adults (Voorveld & van der Goot, 2013). They are both susceptible to the negative effects of media devices. Our finding suggested that educators should pay attention to both adolescents' and young adults' media multitasking behaviors and provide appropriate guidance. Notably, both younger children and older adults are extensive media multitaskers, yet are often overlooked in previous empirical studies (Beuckels et al., 2021a; Valkenburg & Peter, 2013). Considering that the studies we included do not consider all age groups, future research should include more representative samples across a wider age range, from children to older adults.

Publication Years

The association did not differ across publication years. This finding was consistent with that of Parry & le Roux, (2021) which suggested that the overall correlation did not increase for studies that were published more recently since Ophir et al., (2009) first investigated the associations between these two variables. Despite the increasing prevalence and possible change of media multitasking (Rogobete et al., 2020;

Seddon et al., 2018), the strength of the correlation between media multitasking frequency and cognitive control has appeared continuous and stable all the time.

Gender

Moreover, gender was a non-significant moderator in our study. This finding suggested that there were no gender differences in the relationship between media multitasking and cognitive control; that is, from the overall frequency of media multitasking, gender differences in cognitive control could not be explained by the differential effects of media multitasking. Our finding is aligned with previous research that showed few differences in cognitive control between males and females (Grissom & Reyes, 2019). However, studies showed that males and females might prefer different forms of media, with males playing more video/computer games and females preferring social applications (Levine et al., 2007; Ran et al., 2022). Therefore, ignoring the diversity of media multitasking combinations may mask significant gender-related differences. Moreover, the variety of media multitasking behaviors should be considered in subsequent studies to examine the gender differences more accurately.

Culture

Additionally, the analyses showed that culture was not a significant moderator. We expected to find differences between Eastern and Western countries because individuals in different cultures had different orientations toward time (polychronicity vs. monochronicity), which may predict the frequency of media multitasking (Hall, 1976; Srivastava et al., 2016). However, our results demonstrated cross-cultural consistency; that is, whether, in Eastern or Western countries, the relationship between media multitasking and cognitive control was similar and negative. Notably, compared to Western culture, the number of studies in Eastern cultures is relatively small (only 9 studies from three countries), which probably leads to inaccurate parameter estimates (Shi et al., 2021). Additionally, the non-significant result may also be due to the large individual variations within cultures (Eid & Diener, 2001; Shi et al., 2021). Not all Westerners possess monochronic time orientations, and not all Easterners possess polychronic time orientations; that is, people can possess values contrary to their expected cultural context (Kononova & Chiang, 2015; Shi et al., 2021). Thus, our findings should be interpreted with caution, and further empirical research should further explore the relationship between media multitasking and cognitive control across cultures and focus on mono- and poly-chronic differences for elucidation.

Limitations and Future Directions

The current study has several limitations that should be noted. First, the concept of media multitasking is broad, and different methods focus on different aspects of media multitasking. For example, some laboratory-based approaches mainly evaluate participants' media multitasking ability or performance (Seddon et al., 2021; Szumowska et al., 2018). Furthermore, the self-report scales and diary study are mainly used to measure individuals' media multitasking experience (Segijn et al., 2017; Zhou & Deng, 2022). The available studies included in our meta-analysis only used self-report scales, which may lead to an inability to fully describe the content of media multitasking and truly reveal the relationship between media multitasking and cognitive control. Future research should combine multiple methods to explore the relationship comprehensively and systematically.

Second, given that we only calculated the differences between the HMM and LMM groups, the directions of the association between media multitasking and cognitive control could not be derived. Media multitasking may be a predictor of cognitive control failure. Engaging in media multitasking more frequently might lead to poorer cognitive control performance. Media multitasking might also result from existing problems with cognitive control (Ralph et al., 2014; Wiradhany & Koerts, 2019). Furthermore, media multitasking might have a reciprocal relationship with cognitive control. Individuals with a cognitive control defect might have more trouble maintaining attention, need to process multiple target tasks simultaneously to combat distractions, and tend to multitask more (Ralph et al., 2014); this multitasking pattern may further worsen their cognitive control. Additionally, when we examined the differences between different media multitasking groups, only data from heavy and light media multitasking groups were included. Several primary studies have three media multitasking groups, but intermediate groups were not included in the meta-analysis, which may result in important findings being overlooked (e.g., Shin et al., 2020). In summary, future studies should explore the bidirectional dynamic relationship between media multitasking and cognitive control and consider the associations between intermediate media multitasking groups and cognitive control.

Third, age groups only included samples of adolescents and young adults, and children and older adults should be included in future studies. Currently, there is a growing body of evidence that media multitasking behavior is prevalent among all age groups and could be harmful (Beuckels et al., 2021a; Valkenburg & Peter, 2013). For instance, Beuckels et al., (2021a) found that media multitasking could predict more distracting behaviors in children compared to adults. Therefore, it is necessary to conduct relevant studies involving more age groups so that the conclusions can be generalized to individuals across the lifespan.

Fourth, as the current studies were mainly carried out in North America, the number of studies was relatively small for Eastern cultures, which may limit the exploration and extension of the moderating effect of culture. In the future, further comparisons can be made between different cultural contexts after the research at home and abroad becomes abundant. Furthermore, few studies included relevant information on individual differences in polychronicity. In addition to cultural perspectives, personal preferences for time view should be considered and measured. Further research is encouraged on how cultural context and polychronicity of individuals play a role in these related issues.

Finally, the measurement tools which are widely used to measure media multitasking in existing research should be evaluated critically. The MMI and other related measures require participants to estimate the number of hours spent on different types of media, as well as how often they spend on other media at the same time. In the end, a representative overall score is calculated (Ophir et al., 2009). One of the important limitations is that the actual media use time reported by participants is subjective and inaccurate, which may lead to doubts about the reliability of self-reported measures of media multitasking (Murphy & Shin, 2022; Seddon et al., 2018). In addition, since Ophir et al., (2009) developed the MMI, the smartphone technology has made tremendous progress, and various social media and instant messaging applications have emerged. With the advancement of technology, individuals may compulsively use their smartphones, which can also exacerbate the difficulties in their self-reporting the amount of media use time (Lee et al., 2014; Seddon et al., 2018). Therefore, the calculated media multitasking frequency is also subjective and inaccurate. To enhance the reliability and validation of assessment, multiple measurements need to be combined to evaluate the media multitasking experience. For example, self-reporting, recording or tracking the usage of daily media, and observing multitasking tendencies in the laboratory could be included simultaneously in a study and complement each other. Furthermore, it should be noted that the self-reported measures which are represented by MMI and Mod MMI mainly focus on media multitasking in daily life scenarios, while the laboratory paradigms mainly measure the general media multitasking (Lui et al., 2022). Future research should incorporate more everyday life scenarios into the laboratory paradigm to more accurately understand the differences and links between the cognitive processes of the general media multitasking and daily media multitasking. In addition, another limitation about the measure is that the variability between different cognitive and affective characteristics of media combinations is ignored because media multitasking is treated as a unidimensional construct and the mathematical weight on all forms of media multitasking is the same (Baumgartner & Wiradhany, 2022; Seddon et al., 2018; Wilmer et al., 2017). Baumgartner & Wiradhany, (2022) distinguished cognitive and affective characteristics of media combinations and found that media multitasking occurs more frequently among media combinations that do not present information in a transient manner, do not require a behavioral response, and provide instant emotional gratification. These findings indicated that different media multitasking combinations might vary in consequences, and engaging in specific combinations may be detrimental to cognitive control. Therefore, future studies must examine the interaction of media multitasking frequency and different media combinations on cognitive control.

Conclusions

This study involved a quantitative synthesis of previous research on the associations between media multitasking and individuals' cognitive control, employing a three-level meta-analytic model. Two major findings were obtained. The first overall finding was that media multitasking is negatively associated with individuals' cognitive control, consistent with prior studies on this research topic. Notably, the type of cognitive control moderated the strength of the effect. Specifically, heavy media multitaskers performed worse in inhibitory control and working memory tasks than light media multitaskers, but there was no significant difference in cognitive flexibility between these two groups. Second, the effect was markedly moderated by the measurement type of cognitive control. The self-report methods produced a higher mean negative effect than laboratory tasks. This finding pointed out more directions for future research to explore specific differences between different measurements. However, age, gender, culture, and publication year were not significant moderators in the present meta-analysis.

In sum, this quantitative summary provides conclusive evidence that heavy media multitaskers perform worse in cognitive control tasks. Such discrepancy in task performance might be caused by specific factors, including the type of cognitive control and measurement type. Understanding media multitasking and its outcomes may encourage us to pay more attention to media use behaviors in daily life and direct us to improve cognitive abilities using multiple approaches.

Author Contribution FK conceptualized and revisited paper. SM collected and analyzed the data, and modified the paper. HD provided constructive suggestions following the reviewer's comment. MW and XS commented on previous versions of the manuscript.

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Data Availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Competing Interests The authors declare no competing interests.

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