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ORIGINAL ARTICLE

# Association Between Gaming Disorder, Action Videogames, Working Memory Capacity and Cognitive Control

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**Abstract**
Previous studies have focused on social, personality, emotional, and environmental factors associated with gaming and gaming disorder (GD) risk. However, little is still known about the relationship between cognitive functioning and GD in the context of playing action videogames. Consequently, the present study examined the association between gaming disorder, time spent playing action videogames, working memory capacity, and cognitive control. The sample comprised 527 active gamers (268 female gamers; M = 22.12 years, SD = 2.84, age range: 18–38 years). Gaming disorder was assessed using the Internet Gaming Disorder Scale Short-Form. The AX-CPT task assessed cognitive control in the Dual Mechanisms of Cognitive Control. The Operation Span Task and Symmetry Span Task assessed working memory capacity. The time spent playing videogames was evaluated using classifications presented in the Video Game Questionnaire. Results showed that gaming disorder was positively associated with time spent playing both action and non-action videogames. Also, action videogames were positively associated with working memory capacity and negatively associated with proactive cognitive control mode. The findings also showed a positive indirect effect of working memory capacity in the relationship between time spent playing action videogames and proactive cognitive control mode. The present study addressed a research gap regarding the relationship between videogame playing, gaming disorder, and gamers' cognitive functioning. The study's results also demonstrated possible oppositional effects between the time spent playing action games and proactive cognitive control mode.

**Keywords** Gaming disorder · Action videogames · Gaming · Cognitive control · Working memory capacity

## Introduction

Videogame playing is an entertainment activity that attracts an increasing number of individuals every year (Statista, 2024a). Videogame playing is "an activity that utilises a digital video screen in some way. It is constrained by a system of rules in which a player combats with another player, or with the game itself, often to achieve a definite desirable outcome" (Khaliq & Purkiss, 2015; p.2). The development of videogames contributed to a broader interest in this phenomenon by researchers and health professionals. While there are many positive effects of playing videogames (e.g., cognitive benefits, affective well-being benefits, educational benefits, health benefits, therapeutic benefits), (Bediou et al., 2018; 2023; Griffiths, 2019; Johannes et al., 2021; Prot et al., 2014), possible negative consequences of excessive videogame playing include gaming disorder (GD) (Männikkö et al., 2020; Prot et al., 2014; Stevens et al., 2021).

In the 11th revision of the *International Classification of Diseases* (ICD-11), GD is "characterised by a pattern of persistent or recurrent gaming behaviors ("digital gaming" or "video-gaming"), which may be online (i.e., over the Internet) or offline, manifested by: (1) impaired control over gaming (e.g., onset, frequency, intensity, duration, termination, context); (2) increasing priority given to gaming to the extent that gaming takes precedence over other life interests and daily activities; and (3) continuation or escalation of gaming despite the occurrence of negative consequences" (World Health Organization, 2018). Additionally, internet gaming disorder (IGD) was also included in the 5th edition of the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5) as a tentative condition requiring further research (American Psychiatric Association, 2013).

In a meta-analysis, the worldwide prevalence rate of GD was estimated to be 1.96% among studies with high quality data. (Stevens et al., 2021). Moreover, a higher prevalence was reported in Asian countries while lower one was reported in Western countries (Stevens et al., 2021). Although most gamers do not manifest GD, gamers with GD pose a challenge to healthcare and society. It is important to understand the mechanisms of GD development to better manage gamers' health. Previous studies have focused on social, personality, emotional, and environmental factors associated with GD risk (e.g., Cudo et al., 2023; 2024; Männikkö et al., 2020; Richard et al., 2020; Schneider et al., 2021; Şalvarlı & Griffiths, 2021). However, little is known about the relationships between cognitive functioning and GD (Billieux et al., 2020; Nuyens et al., 2017).

In the context of cognitive functioning, an important one is cognitive control, which can be characterised as "the collection of processes that are involved in generating and maintaining appropriate task goals and suppressing task goals that are no longer relevant, as well as the way in which current goal representations are used to modify attentional biases to improve task performance" (Gratton et al., 2017; p. 1). Consequently, the aim of the present study was to examine the relationship between GD and cognitive control. It should also be noted that based on previous research findings, the relationship between GD and cognitive control may be associated with other variables. More specifically, previous research has shown relationships between both action videogame use and cognitive functioning (Bediou et al., 2018; 2023) and between GD and the time spent playing videogames (Pontes et al., 2022), especially action videogames (Cudo et al., 2020, 2024; Cudo, Kopiś, et al., 2018; Cudo, Montag & Pontes, 2022). Action videogames are videogames with rapid pace, demanding constant vigilance of peripheral vision and often necessitating simultaneous tracking of numerous targets (Green & Bavelier, 2003, 2007). Consequently, the present study addressed a research gap in the extant literature by examining the relationship between GD and cognitive control by analysing associations with action videogame use and working memory functions.

***Gaming disorder and cognitive functioning***

Previous research has suggested that GD is associated with deficiencies in reward processing, impulse control, and decision-making (Billieux et al., 2020). Moreover, gamers with GD have demonstrated poorer response inhibition compared to non-disordered gamers (Argyriou et al., 2017). They also exhibit decreased sensitivity and increased response bias on tasks assessing inhibitory control (Billieux et al., 2020; Kuss et al., 2018; Nuyens et al., 2019). Additionally, GD has been associated with reward-related decision-making deficits (Yao et al., 2022) and lower working memory task performance (Ngetich et al., 2023). While some studies have suggested deficits in error processing and attention control (Dong, Li et al., 2017; Little et al., 2012) might underlie GD, others have specifically emphasised reduced inhibitory control (Luijten et al., 2015). Additionally, cognitive bias towards gaming-related stimuli has been observed among gamers with GD symptoms (Dong, Wang et al., 2017; Wang et al., 2017). These cognitive impairments may reflect broader deficits in cognitive control mechanisms. In this context, Fathi et al. (2022) reported that gamers with GD symptoms demonstrated difficulties in cognitive processing in the execution stage and in the early stages of inhibition and conflict monitoring compared to gamers without GD.

According to the Interaction of the Person-Affect-Cognition-Execution (I-PACE; Brand et al., 2016; 2019) model, GD development is associated with deficits in self-regulatory mechanisms. More specifically, GD development occurs from gratification associated with gaming to problematic game use. Additionally, an increase in game-related cue reactivity has been observed when GD develops (Dong, Wang et al., 2017; Wang et al., 2017). In this context, gamers may present greater gaming engagement when internal triggers (e.g., thinking about games) and external triggers (e.g., game-related objects) occur. Also, according to the I-PACE model, excessive engagement in the game may contribute to deficits in stimuli-specific reductions in inhibitory control. Previous research has shown positive relationships between both GD and cognitive control deficits research (Argyriou et al., 2017; Billieux et al., 2020; Fathi et al., 2022), and between time spent playing videogames and cognitive control deficits (Bailey et al., 2010; West et al., 2020). However, it remains open as to whether the results of the relationship between time spent playing videogames and cognitive control deficits are driven by excessive game engagement manifesting by GD.

***Gaming disorder, action videogames and cognitive control***

Previous research has shown a positive relationship between GD and the time spent playing videogames (Cudo, Montag & Pontes, 2022; Pontes et al., 2022), especially action videogames (Cudo et al., 2020, 2024; Cudo, Kopiś, et al., 2018). Action videogames are characterised by their rapid pace, demanding constant vigilance of peripheral vision and often necessitating simultaneous tracking of numerous targets. These videogames typically offer a first-person or third-person perspective and commonly fall into genres such as first-person shooter games, action-adventure games, action-RPGs (role-playing games), and action massively multiplayer online role-playing games (Green & Bavelier, 2003, 2007).

Additionally, it should be noted that the effects of action videogames on cognitive function have been studied, with some research suggesting enhancements in various cognitive abilities among gamers who play action videogames (for reviews, see Bediou et al. [2018, 2023]). Previous studies have demonstrated that action videogame gamers tend to exhibit greater visual attention span, enhanced visual-spatial attention, improved visual short-term memory, better visual searching abilities, enhanced visual motor control, and faster processing speed compared to non-action videogame gamers (Bediou et al., 2018; 2023). Moreover, action videogames have also been associated with improvements in cognitive control, including greater cognitive flexibility, faster error correction, and reduced switching costs (Bavelier & Green, 2019; Bediou et al., 2018; 2023; Cardoso-Leite et al., 2016).

However, some studies have failed to replicate the observed enhancements or reported smaller effects than previous studies (Boot et al., 2011; Redick et al., 2017; Sala et al., 2018; Roque & Boot, 2018; Unsworth et al., 2015). West et al. (2020) found that playing action videogames increased visuospatial processing but decreased proactive cognitive control, potentially leading to difficulties in maintaining continuous goals. According to the Dual Mechanisms of Cognitive Control (DMCC) model (Braver, 2012; Braver et al., 2007; 2009), the proactive control mode can be understood as an early selection mechanism, where relevant goals are actively maintained before encountering demanding tasks, to effectively guide attention, perception, and actions toward achieving those goals. It is important to note that cognitive control may operate on a continuum from proactive to reactive control mode, with increased reactive control associated with decreased proactive control (Braver et al., 2007; Chiew & Braver, 2017). In this context, reactive cognitive control mode can be understood as a late corrective function where the detection and removal of interference occur at the time this interference occurs (Braver, 2012).

Based on previous research (Cudo et al., 2020, 2022, 2024; Cudo, Kopiś, et al., 2018; Pontes et al., 2022; Rehbein et al., 2021), it can be concluded that, on the one hand, time spent playing action videogames is associated with GD. On the other hand, GD and the action videogame playing can be associated with cognitive control deficits (Billieux et al., 2020; West et al., 2020). Consequently, it can be assumed that GD can indirectly affect the relationship between time spent playing action videogames and cognitive control deficits. However, a review by Ngetich et al. (2023) noted that gamers with GD presented worse scores in working memory task performance than gamers without GD in some previous studies. In this context, working memory capacity reflects the ability to manipulate information in working memory and maintain and shift attention between memory representations (Engle, 2010; Engle & Kane, 2004; Kane et al., 2007). Low working memory capacity is associated with more attentional failures and worse attentional control, which is reflected in the difficulty of ensuring that memory representations are in an active state in the presence of interference and distractions (Unsworth & Robison, 2017). Moreover, previous research showed strong correlations between working memory capacity and many cognitive abilities (Cowan, 2014; Unsworth & Engle, 2007). Consequently, it should be pointed out that the functioning of working memory has implications for other cognitive functions. In this context, working memory capacity is associated with cognitive control (see Unsworth et al., 2012). Based on the DMCC model (Braver, 2012; Braver et al., 2007; 2009), higher working memory capacity is related to higher proactive cognitive control (Redick, 2014; Wiemers & Redick, 2018). In this context, high working memory capacity manifested in easier maintenance of memory representations in an active state may promote active maintenance of relevant goals before encountering demanding tasks in the presence of various distractors and interference. In contrast, the difficulty of actively maintaining a memory representation and its susceptibility to distraction can lead to losing prior information about the relevant goals before encountering demanding tasks.

Moreover, videogame playing time, especially action videogames, has been associated with better working memory (Blacker et al., 2014; Waris et al., 2019). In this context, videogames can be considered as a form of working memory training (see Bavelier & Green, 2019; Bediou et al., 2018). More precisely, playing action videogames can enhance attentional control associated with a swift shift between attention states based on task demands (Bavelier & Green, 2019). Consequently, this game genre can enhance the ability to actively maintain memory representation. However, excessive gaming can lead to GD. The development of GD contributes to an increasing preoccupation with gaming content. An increased preoccupation with gaming content can lead to attentional bias (Kim et al., 2018) and desire thinking (Dragan & Grajewski, 2021). In the GD context, attentional bias is associated with enhanced attention toward game-related cues and desire thinking reflect voluntary cognitive concentration of the desired game-related target. Desire thinking can proceed at the verbal as well as the imaginary level. Consequently, on the one hand, the attentional bias may contribute to the difficulty of maintaining current memory representations in the presence of game-related stimuli. On the other hand, gamers with GD may occupy memory resources by thinking excessively about gaming and imagining gaming situations. Therefore, it can be assumed that working memory capacity can play an indirect role in GD and cognitive control, as well as in action videogame use and cognitive control.

In this context, it should be noted that time spent playing videogames, especially action videogames, can play a positive and negative role in cognitive control. However, this role has not been described in detail in the previous literature. Based on previous research, working memory capacity (Blacker et al., 2014; Ngetich et al., 2023; Redick, 2014; Wiemers & Redick, 2018; Waris et al., 2019) and gaming disorder (Billieux et al., 2020; Cudo et al., 2020, 2024; Cudo, Kopiś, et al., 2018) may play an indirect role in this relationship between time spent playing videogames and cognitive control in the DMCC model (Braver, 2012; Braver et al., 2007; 2009). More specifically, there may be two competing mechanisms related to the engagement in the videogame. On the one hand, excessive engagement in videogames may lead to GD development, which in turn may lead to cognitive deficits. On the other hand, engagement in videogames, particularly action videogames, may function as training for working memory, which can strengthen cognitive control.

### *The present study*

Based on the aforementioned literature, a model was developed for the relationship between gaming disorder, action videogames, working memory capacity, and cognitive control (see Figure 1), which was tested in the present study. More specifically, considering previous research (Billieux et al., 2020; Cudo et al., 2020, 2024; Cudo, Kopiś et al., 2018; Ngetich et al., 2023) and the I-PACE model (Brand et al., 2016; 2019), it was hypothesised that time spent playing action videogames would be positively associated with GD ($H_1$), GD would be negatively associated with working memory capacity ($H_2$) and cognitive control ($H_3$). Additionally, considering previous research (Blacker et al., 2014; Waris et al., 2019), it was hypothesised that time spent playing action videogames would be positively associated with working memory abilities ($H_4$). Moreover, considering the relationship between working memory capacity and cognitive control in the DMCC model (Redick, 2014; Wiemers & Redick, 2018), it was hypothesised there would be a positive relationship between working memory capacity and cognitive control ($H_5$). Previous research examining the relationship between time spent playing action videogames and cognitive control have been mixed (see Bediou et al., 2018; 2023; West et al., 2020). Consequently, the primary research question (RQ1) was whether there would be a relationship between action videogames and cognitive control. Furthermore, based on the studies mentioned above, it was also hypothesised that working memory capacity ($H_6$) and gaming disorder ($H_7$) would play an indirect role in the relationship between action videogame use and cognitive control in the DMCC model.

Figure 1. The proposed model analysed in the present study.

## Methods

### *Participants*

The study was started by 620 gamers, of whom 600 completed the entire study procedure. Due to technical bugs at various stages of the experimental procedures, data from 49 gamers were removed. Additionally, in line with previous recommendations (Redick, 2014), the data of 24 participants were removed due to insufficient correct answers in AX sequences (< 70%). Consequently, the final sample comprised 527 gamers (268 females; M = 22.12 years, SD = 2.84, age range: 18-38 years). All gamers were active and played videogames at least two hours a week during the previous 12 months. Among the participants, 24.10% came from villages, 5.69% came from cities with up to 20,000 inhabitants, 15.75% came from cities with 20,000 to 100,000 inhabitants, and 54.46% came from cities with over 100,000 inhabitants. Participants used the following gaming platforms: stationary computers (41.94%), laptops (73.43%), consoles (39.47%), tablets (7.59%), and smartphones (71.94%).

Participants who participated in the study received compensation of 100 PLN. The research was conducted following the Declaration of Helsinki, and the first author's university's ethics committee approved the study protocol. Participants gave written consent to participate in the study. The study is part of a larger project on gamers' cognitive functioning.

The required sample size was calculated using Schoemann et al.'s (2017) guidelines. More specifically, given the sequential indirect effects model, and power of 0.8, sample size was calculated using the Monte Carlo method (1000 replications; random seed of 1000; 95% confidence level) and resulted in a sample size of 470 participants. In the required sample size analysis, the following correlation coefficients between variables from previous studies were included: (i) action videogame use and gaming disorder (approximately $r = 0.3$; Cudo, Montag & Pontes, 2022); (ii) action videogames use and working memory capacity (approximately $r = 0.1$; Unsworth et al., 2015); (iii) action videogame use and cognitive control (approximately $r = 0.05$; Unsworth et al., 2015); (iv) gaming disorder and working memory capacity (approximately $r = -0.2$; Farchakh et al., 2020; Ngetich et al., 2023); (v) gaming disorder and cognitive control (approximately $r = -0.15$; Lee et al., 2022); and (vi) working memory capacity and cognitive control (approximately $r = 0.2$; see Wang et al., 2021).

***Measures***

Gaming disorder was assessed using the nine-item Internet Gaming Disorder Scale Short-Form (IGDS9-SF; Pontes & Griffiths, 2015; Polish version: Schivinski et al., 2018). The items (e.g. *"Have you lost interest in previous hobbies and other entertainment activities as a result of your engagement with the game?"*) are responded to using a five-point response scale from 1 (*never*) to 5 (*very often*). Higher scores indicate greater risk of GD. The reliability assessed by Cronbach's alpha was 0.80 in the present study.

Depressive symptoms was assessed using nine-item Patient Health Questionnaire (PHQ-9; Kroenke et al., 2001; Polish version: Kokoszka et al., 2016). The items (e.g. *"Little interest or pleasure in doing things.“*) are responded to using a four-point response scale from 0 (*not at all*) to 3 (*nearly every day*). Higher scores reflect more depressive symptoms. The reliability assessed by Cronbach's alpha was 0.81 in the current study.

The playing of action videogames was assessed using classifications presented in the Video Game Questionnaire (VGQ; see Green et al., 2017). The VGQ consists of questions regarding the amount of time spemt playing in the following videogame genres: first/third-person shooters, action-RPG/adventure, sports/driving, real-time strategy/MOBA, turn-based/non-action role-playing /fantasy, turn-based strategy/life, simulation/puzzle, music games, and other. Participants answered a question about their weekly use of the videogame genres in the past 12 months using the following responses: 1 (*never*), 2 (*less than 1 hour*), 3 (*between 1 and 3 hours*), 4 (*between 3 and 5 hours*), 5 (*between 5 and 10 hours*) and 6 (*more than 10 hours*). The following game genres were considered as action videogames: first/third-person shooters, action-RPG/adventure, sports/driving, and real-time strategy/MOBA. Consequently, the time spent playing action videogames was characterised as the average weekly gaming time of these four videogame genres. The time spent playing non-action videogames during past year was also assessed. More specifically, the following game genres were considered non-action videogames: turn-based strategy/life, simulation/puzzle, music games, and other games. The time spent playing non-action videogames was defined as the average weekly gaming time of these four videogame genres. Participants also answered questions regarding sociodemographic variables (gender, age, residence) and gaming platforms.

***Experimental procedures***

The cognitive control in the DMCC model (Braver, 2012; Braver et al., 2007; 2009) was assessed using a modified version of the AX-Continuous Performance Task (AX-CPT) task in the form proposed by Braver et al. (2021) in the baseline version. Pairs of letters as trials were shown during the task. There were six possible trial types: AX-type trial with a cue (letter 'A') followed by a probe (letter 'X'); AY-type trial with a cue (letter 'A') followed by a probe (letter other than 'X'); BX-type trial with a cue (letter other than 'A') followed by a probe (letter 'X'); BY-type trial with a cue (letter other than 'A') followed by a probe (letter other than 'X'); Ang-type trail with a cue (letter 'A') followed by a probe (digit); and Bng-type trial with a cue (letter other than 'A') followed by a probe (digit). It should be noted that Ang-type trials and Bng-type trials were the control trials.

It is important to highlight that the bias in response patterns for AY and BX sequences, evident in both errors and reaction times related to probe responses, is associated with the cognitive control mode. Specifically, individuals adopting a proactive control mode rely on contextual cues to anticipate and prepare a motor response for the probe letter. A strong expectation linked to the cue may result in difficulty suppressing the prepared motor response when an unexpected or infrequent probe appears. For instance, in the AX-CPT task, participants operating in a proactive control mode may strongly expect the letter X to follow the A-cue as a probe. This anticipation may lead them to pre-prepare a motor response for X. As a result, when the A-cue is followed by a probe other than X (such as in the AY sequence), they may struggle to inhibit their pre-prepared response, which can result in longer reaction times and increased errors for AY sequences. Conversely, participants employing a reactive control mode process the contextual information associated with the cue only after the probe appears. Without the anticipatory expectation tied to the cue, they may find it challenging to inhibit the most frequent response to the probe. For example, in the AX-CPT task, participants using reactive control mode might attempt to respond to the X probe in the BX sequence in the same manner as in the AX sequence due to the higher frequency of AX trials compared to BX trials. This approach could lead to more errors and slower reaction times in BX sequences relative to AY sequences (see Braver et al., 2021).

A single trial began with presenting a white letter as a cue for 500 ms on a black screen. Next, there was a delay of 3500ms when a black screen with a white fixation cross was presented. After the delay, the black screen with a white border was presented for 250 ms. Next, the white letter or digit was presented in the centre of the white border as a probe for 500ms. After the probe appeared, the participant was required to press the appropriate button when the letter appeared or to stop responding when the digit appeared. Next, the black screen with three white fixation crosses was presented as the inter-trial interval for 1000ms (see Figure 2). In the training part of the experimental procedure, the participant received feedback on the accuracy of the task performance. In contrast, no such feedback was given in the experimental part. The experiment procedure consisted of 8 training and 216 experimental trials (see Figure 2). Participants were instructed to press the '1' key as quickly as possible when they saw the cue. They were also instructed to press the '2' key as quickly as possible when they saw the X-probe presented after the A-cue. They also were instructed to press the '1' key as quickly as possible when they saw the Y-probe presented after the A-cue or B-cue or when they saw the X-probe presented after the B-cue. Participants also were instructed not to press any key when they saw the digit as a probe. All letters were showed presented in 52-point Courier New font. The procedure was implemented using the E-Prime software 2.0 (Psychology Software Tools, Inc.).

Figure 2. Scheme of AX-CPT task

The Operation Span Task and Symmetry Span Task were used to assess working memory capacity (WMC; see Redick et al., 2012), which was operationalised as an average of standardised scores from at least two span tasks, where one of them must include no semantic stimuli (i.e., Symmetry Span Task) and the other one must contain semantic stimuli (i.e., Operation Span Task). Higher scores reflect higher WMC, whereas lower scores reflect lower WMC (Redick et al., 2012).

*Operation Span Task:* The Operation Span Task is an experimental task where participants are presented with individual letters and asked to memorise them in order of appearance. The participants are expected to do simple mathematical calculations between subsequent letters and answer whether the presented number is a true or false result of the calculation. Towards the end of a single block, participants are asked to give the letters in order of appearance. The number of letters each participant is expected to remember varies. At each trial's onset, one letter is shown for 800 ms, followed by a screen with math tasks to do. Next, another screen with a number is shown, and the participant is expected to answer whether that number is the correct result of the previous math task. Further on, another letter is displayed for 800 ms, followed by another math task. The block size might contain from three to seven letters to memorise. After the block has finished, a board presenting letters is shown, and the participant puts them in order of appearance. Next, a feedback screen is shown for 2000 ms, containing information about the number of correctly remembered letters, the number of errors made in the math tasks, and the percentage of math tasks done correctly in one block. All the stimuli are displayed in black, 28 pt Arial font (see Redick et al., 2012).

*Symmetry Span Task:* The Symmetry Span task is a test where research participants are presented with red squares positioned on a 4x4 grid and asked to memorise the sequence and position of subsequent shapes appearing. In between these location tasks, the participant is expected to do a spatial task consisting of answering questions about whether the displayed figure is symmetrical. Toward the end of a single block, research participants are asked to indicate positions where red squares appeared on a 4x4 grid in a proper sequence. The number of shapes to memorise within a single block vary between three and seven. At the beginning of each test, one red square is presented on a 4x4 grid for 800ms. After that, a screen displaying a geometrical shape appears. The participant is expected to decide whether it is symmetrical. Next, a screen appears asking about the symmetry of the shape previously presented, requiring the participant to choose 'true' or 'false'. Following this, another square appears for 800 ms, followed by another symmetry task. One block might contain from three to seven square positioning tasks. After the block has finished, a board presenting a blank 4x4 grid is shown. The participant marks where the red squares appeared, all in the correct order. Next, a feedback screen is shown for 2000 ms, containing information about the number of correctly remembered positions of the squares, the number of errors in the block, information about the symmetry, and the percentage of correct answers in the symmetry task ( see Redick et al., 2012).

***Behavioural data***

Considering the DMCC model (Braver et al., 2009; 2021) and previous studies (Cudo et al., 2019; 2023; Gonthier et al., 2016; Mattioni et al., 2023; Mäki-Marttunen et al., 2019; Tang et al., 2023; Wiwatowska et al., 2022), cognitive control was operationalised as proactive behavioural indices (PBIs), composite PBI, A-cue bias index, and d′-context index. The PBI was calculated for error rate and median reaction time in AY and BX trials using the formula (AY-BX)/(AY+BX). These indices reflect the relationship between AY and BX error rate/reaction time in the AX-CPT. More specifically, proactive control is related to reduced error rate and decreased reaction time in BX trials because the proper performance of these trials indicates the use of the B-cue to suppress the automatic response induced by the X probe. On the other hand, increased error rate and reaction time in AY trials reflect difficulty inhibiting the reaction on a non-X probe when an A-cue preceded it. Consequently, positive PBI scores reflect the tendency towards a proactive control modality. Additionally, the composite PBI was also applied. Based on previous research (Gonthier et al., 2016), this index was calculated as the mean (after standardisation) of PBI calculating for error rate and PBI calculating for reaction time. It takes into account the trade-off between accuracy and speed in AX-CPT. This index has the same interpretation as the other PBI indices.

With regards the behavioural indices associated with proactive control, the A-cue bias index and the d′-context index were calculated (Gonthier et al., 2016; Tang et al., 2023). The A-cue bias index (Richmond et al., 2015) was calculated as the mean of z-transformed scores of AX hit rate and AY error rate according to the following formula: 1/2*[(hits on AX) + (false alarms on AY)]. This index reflects the ability to use the A-cue to prepare a response to the probe occurring after the A-cue. The A-cue bias index tends to be higher for proactive control (Richmond et al., 2015). The d′-context index was calculated as the difference between z-transformed scores of AX hit rate and BX error rate according to the following formula: (hits on AX trials) minus (false alarms on BX). This index reflects the general tendency to prepare a response to the probes based on the context information associated with cues. Consequently, the higher d′-context index may reflect greater proactive control (Gonthier et al., 2016; Tang et al., 2023). It should be noted that the error rates were recalculated before calculating cognitive control indices. More specifically, taking into account the previous guidelines (Gonthier et al., 2016), the levels equalling zero were recalculated according to the following formula: error rate = (number of errors + 0.5)/(number of trials + 1).

***Statistical analysis***

The relationship between variables was examined using Spearman's rho correlation coefficient. In order to analyse the relationship between time spent playing action videogames, GD, and working memory capacity, the sequential indirect effects model was applied (see Hayes, 2013). More specifically, the sequential indirect effect of GD and working memory capacity on the relationship between the time spent playing action videogames and cognitive control was examined. In line with the DMCC model (Braver et al., 2009; 2021) and previous studies (Cudo et al., 2019; 2023; Gonthier et al., 2016; Mattioni et al., 2023; Mäki-Marttunen et al., 2019; Tang et al., 2023; Wiwatowska et al., 2022), cognitive control was operationalised as the proactive behavioural indices (PBIs) calculated for error rate and reaction time, composite PBI, A-cue bias index, and d'-context index. Consequently, sequential indirect models were calculated for each cognitive control outcome separately.

Additionally, time spent playing non-action videogames, and age were included as covariates. Moreover, considering previous research about the relationship between GD and depressive symptoms (see Ostinelli et al., 2021) as well as the relationship between depressive symptoms and working memory function (see Baddeley et al., 2013; Rose & Ebmeier, 2006), depressive symptoms were also included as covariates. The homoscedasticity assumption was tested independently using the Breusch-Pagan test for each model. The homoscedasticity assumption retained for PBI calculated for error rates ($\chi^2_{(df=1)} = 2.65$; $p = 0.104$), PBI calculated for reaction time ($\chi^2_{(df=1)} = 0.28$; $p = 0.595$), A-cue bias index ($\chi^2_{(df=1)} = 0.83$; $p = 0.362$) and d'-context index ($\chi^2_{(df=1)} = 0.92$; $p = 0.337$). The homoscedasticity assumption also retained for composite PBI ($\chi^2_{(df=1)} = 3.43$; $p = 0.064$). The PROCESS macro for SPSS (version 4.2; Hayes, 2013) was used to compute sequential indirect effect analysis (Model 6). The indirect effects were tested with bias-corrected bootstrapping (N = 5,000) and 95% confidence intervals (CIs). When a 95% bootstrapped CI does not include zero, it indicates the parameter is statistically significant. SPSS 29 was used to perform statistical analysis.

## Results

Descriptive statistics are shown in Table 1. There was a positive relationship between all cognitive control indices. WMC was positively correlated with cognitive control indices such as A-cue bias and d'-context index. Also, there was a positive relationship between WMC and action videogame playing time. The action videogame playing time was negatively correlated with cognitive control indices such as the A-cue bias index and PBI calculated for error rates. There was a positive relationship between action and non-action videogame playing time. GD was positively correlated with action and non-action videogame playing time. Additionally, depressive symptoms positively correlated with GD and non-action videogame playing time. There was a negative relationship between depressive symptoms and action videogame playing time. The detailed results are shown in Table 1.

Table 1

The sequential indirect effect models showed that action videogame playing time was positively associated with working memory capacity (B = 0.109; SE = 0.032; $p$ = .001; β = 0.159). Additionally, gaming disorder was positively associated with action videogame playing time (B = 0.091; SE = 0.021; $p$ < .001; β = 0.186) and depressive symptoms (B = 0.366; SE = 0.045; $p$ < .001; β = 0.338) . There was no relationship between gaming disorder and working memory capacity (B = -0.044; SE = 0.065; $p$ = .498; β = -0.032). The detailed results are shown in Tables 2 and 3.

Moreover, there was no significant relationship between action videogame playing time and cognitive control indices including PBI calculated for error rates (B = -0.015; SE = 0.015; $p$ = .312; β = -0.048), PBI calculated for reaction time (B = 0.005; SE = 0.003; $p$ = .106; β = 0.078), and composite PBI (B = 0.012; SE = 0.032, $p$ = .702; β = 0.018). Analogously, there was no significant relationship between gaming disorder and cognitive control indices including PBI calculated for error rates (B = 0.010; SE = 0.031; $p$ = .753; β = 0.015), PBI calculated for reaction time (B = -0.003; SE = 0.007; $p$ = .685; β = -0.019), and composite PBI (B = -0.004; SE = 0.064; $p$ = .954; β = -0.003). Also, there were no significant relationships between working memory capacity and cognitive control indices including PBI calculated for error rates (B = 0.009; SE = 0.021; $p$ = .653; β = 0.020), PBI calculated for reaction time (B = 0.003; SE = 0.005; $p$ = .505; β = 0.029), and composite PBI (B = 0.020; SE = 0.043; $p$ = .485; β = 0.031). The detailed results are shown in Table 2.

There was a positive relationship between working memory capacity and cognitive control indices including the A-cue bias index (B = 0.075; SE = 0.034; $p$ = .028; β = 0.096) and d'-context index (B = 0.404; SE = 0.083; $p$ < .001; β = 0.209). Additionally, the time spent playing action videogames was negatively associated with the A-cue bias index (B = -0.080; SE = 0.025; $p$ = .002; β = -0.150). There was no significant relationship between gaming disorder and A-cue bias index (B = 0.016; SE = 0.051; p= .751; β = 0.015) and d'-context index (B = -0.023; SE = 0.125; $p$ = .853; β = -0.008). The detailed results are shown in Table 3.

Tables 2 and 3

The sequential indirect effects analysis showed that indirect effects were only present for the A-cue bias index model and the d'-context index model. More specifically, the findings showed a significant standardized indirect effect between time spent playing action videogames and A-cue bias index via working memory capacity (indirect effect = 0.015; SE = 0.008; 95%CI [0.003 0.032]). Additionally, there was a direct significant effect between time spent playing action videogames. Consequently, these results may indicate partial mediation (see Zhao et al., 2010). There was a significant indirect effect between time spent playing action videogames and d'-context index via working memory capacity (indirect effect = 0.033; SE = 0.012; 95%CI [0.013 0.058]). Additionally, the direct effect between time spent playing action videogames and the d'-context index was not statistically significant. Consequently, these results may indicate indirect-only mediation (full mediation; see Zhao et al., 2010). The detailed results are shown in Table 4.

Table 4

**Discussion**

The present study mainly aimed to examine the association between gaming disorder, action videogames, working memory capacity, and cognitive control. The results showed a positive relationship between playing action videogames and GD (supporting $H_1$). Additionally, playing non-action videogames was also positively correlated with GD (see Table 1). These findings suggest that the development of GD is associated with different genres of videogames. In this context, on the one hand, different genres of videogames can be associated with different motives for playing (see Brandtner et al., 2022; Scharkow et al., 2012). On the other hand, according to the I-PACE model (Brand et al., 2016; 2019), different personal motives can lead to the choice of different behaviours, which can sometimes lead to the development of specific behavioural addictions such as GD. More specifically, according to the I-PACE model, gamers can choose the videogame genre according to their own personal motivation and needs that are not satisfied in the real world. Consequently, gamers can be absorbed by both action and non-action videogames.

It is also important to pay attention to the blurring boundaries between videogame genres. Here, it should be noted that videogame development has contributed to the blurring of boundaries between different videogame genres (Dale & Green, 2017). More specifically, elements of action videogames (e.g., quick reactions to appearing elements on the screen's periphery, first-person and third-person view, etc.) are implemented in other videogame genres. For example, the game *Valkyria Chronicles 3* includes elements from turn-based strategy, role-playing, and third-person shooter games (Dale & Green, 2017). Additionally, increasing numbers of gamers are playing mobile games (Statista, 2024b), which can be a separate issue in terms of GD because of the very quick access to the game and the ability to play almost anywhere (Columb et al., 2022; Syvertsen et al., 2022). Consequently, differences between videogame genres may be less important for GD development. It is important to point out that a more important issue may be the impact of the specific mechanics present in the game on the GD development rather than the game genre itself (see Griffiths & Nuyens, 2017; Király et al., 2023; Rehbein et al., 2021).

The findings showed no association between GD and working memory capacity, which did not support $H_2$. In a systematic review, Ngetich et al. (2023) reported a negative association between GD and working memory task performance. However, they also noted that some studies they reviewed found no difference between gamers with GD and gamers without GD in working memory task performance. Therefore, it is conceivable that there may be other variables that can modify the relationship between GD and working memory that were not included in the present study. However, this supposition requires scientific verification.

The findings also indicated that there was no relationship between GD and cognitive control indices, which did not support $H_3$. One possible explanation could be the relationship between specific videogame genres, particularly action videogames, and cognitive control, as discussed in more detail below. More specifically, a positive relationship between time spent playing action videogames and GD, and a negative relationship between time spent playing action videogames and proactive cognitive control mode were found (see Table 3). Consequently, it is important to consider whether previous research findings examining the relationship between GD and cognitive control were driven by the specifics of the videogame genres (e.g., action videogames) played by gamers with GD or strictly by the GD development.

However, it should be noted that the present study considered only specific aspects of cognitive control, which was associated with the DMCC model (Braver, 2012; Braver et al., 2007; 2009). Therefore, further research is needed that considers the importance of videogame mechanics, especially action videogames, in the context of the relationship between GD and cognitive control. Additionally, cognitive bias towards gaming-related stimuli has been observed among gamers with GD symptoms (Dong, Wang et al., 2017; Wang et al., 2017). Consequently, it can be surmised, according to the I-PACE model (Brand et al.. 2016; 2019), that the presence of addiction-related stimuli can lead to dysfunction in the control mechanisms. However, in the present study, game-related stimuli were not presented. Consequently, this may be one of the other possible explanations for the absence of a relationship between GD and cognitive control.

It was hypothesised that playing action videogames would be positively associated with working memory capacity, therefore $H_4$ was supported. It should be noted that greater time spent playing action videogames was associated with better working memory capacity and higher GD symptoms. However, the time spent playing non-action videogames was not associated with working memory capacity. These results are consistent with previous studies showing a positive relationship between playing action videogames and working memory capacity (Blacker et al., 2014; Bediou et al., 2018; 2023; Waris et al., 2019). Here, it can be assumed that action videogames can serve as training for working memory functions (see Blacker et al., 2014; Bediou et al., 2018; 2023). However, it should be noted that the effect size of this relationship was low, and as with other studies (Redick et al., 2017; Unsworth et al., 2015), did not confirm this relationship. Consequently, more research is needed on which elements of action videogames may contribute to enhancing working memory and which do not. Therefore, it can be assumed that playing action videogames can have two sides. The positive side is related to the development of working memory functions, while the negative side is associated with the possibility of developing gaming disorder. At the same time, it should be noted that the effect size of both relationships was weak.

There was a positive relationship between working memory capacity and cognitive control indices such as the A-cue bias index and d'-context index (supporting $H_5$) (see Table 3). However, no such relationship was found for PBI-based indices of cognitive control (see Table 2). According to the Dual Mechanisms of Cognitive Control (DMCC) model (Braver, 2012; Braver et al., 2007; 2009), cognitive control may operate on a continuum from proactive to reactive control mode, with increased reactive control associated with decreased proactive control (Braver et al., 2007; Chiew & Braver, 2017). However, previous research (Mäki-Marttunen et al., 2019) has shown that proactive to reactive control modes can operate independently and simultaneously. Additionally, Mäki-Marttunen et al. (2019) postulated that PBIs may obscure the reactive shift in cognitive control. Consequently, it can be surmised that when the two cognitive control modes operate independently, PBI may be sensitive to the bias associated with the independent activation of the two control modes.

On the other hand, the A-cue bias index and the d′-context index are primarily related to the change in proactive control, which can be understood as an early selection mechanism, where relevant goals are actively maintained before encountering demanding tasks, to effectively guide attention, perception, and actions toward achieving these goals (Braver, 2012; Braver et al., 2007; 2009). More specifically, the A-cue bias index reflects the ability to use the A-cue to prepare a response to the probe occurring after the A-cue (Richmond et al., 2015). The d′-context index reflects the general tendency to prepare a response to the probes based on the context information associated with cues (Gonthier et al., 2016; Tang et al., 2023). Consequently, it can be reported that working memory capacity was positively associated with proactive cognitive control mode. Meanwhile, caution should be exercised in concluding there is a relationship between working memory capacity and reactive cognitive control mode. This conclusion is consistent with previous studies indicating that higher working memory capacity is related to higher proactive cognitive control (Redick, 2014; Wiemers & Redick, 2018).

Previous research findings examining the relationship between time spent playing action videogames and cognitive control have been mixed (see Bediou et al., 2018; 2023; West et al., 2020). Consequently, a research question (RQ1) was postulated. The present study's results showed only a negative relationship between playing action videogames and the A-cue bias index (see Table 3). There was no similar relationship for other indices of cognitive control. Given the explanation of cognitive control indices above, it can be cautiously postulated that the time spent playing action videogames was negatively related to proactive cognitive control mode. These results were in line with previous research (West et al., 2020), which showed that action videogame training leads to decreased proactive control. West et al. (2020) pointed out that action videogame players need to react quickly to changing game conditions to deal with emerging in-game situations effectively. In order to achieve the best possible results in the game, action videogame players should allocate attention when interference (e.g., an opponent) is detected as soon as possible. Consequently, it can be surmised that the proactive cognitive control mode, associated with the maintenance and use of prior task information, may not be very useful for action videogame gameplay to achieve high scores.

However, it should be noted that the results of the present study also showed a positive indirect effect between time spent playing action videogames and cognitive control indices such as the A-cue bias index and d’-context index (supporting $H_6$) (see Table 4). Consequently, it can be speculated that action videogames may indirectly promote proactive cognitive control mode by enhancing working memory capacity. Here, two plausible, opposing mechanisms can be identified for the relationship between time spent playing action videogames and proactive cognitive control mode. On the one hand, the gameplay mechanics of an action videogame can reward reactive player action based on quick reactions to suddenly appearing elements (e.g., the appearance of an opponent) during the game. These mechanics can impair the proactive cognitive control mode, which is associated with reacting on the basis of prior information about the goal of the action (West et al., 2020). On the other hand, playing action videogames can be a form of training for cognitive functions related to working memory (Blacker et al., 2014; Bediou et al., 2018; 2023; Waris et al., 2019), which are associated with manipulating information in working memory, and maintaining and shifting attention between memory representations (see Engle, 2010; Engle & Kane, 2004; Kane et al., 2007). Consequently, in this context, playing action videogames may be indirectly associated with enhancing proactive cognitive control mode. These results may partially explain previous inconsistencies between results obtained in studies examining the relationship between videogames, particularly action videogames, and cognitive control (e.g., Bailey et al., 2010; Bediou et al., 2018; 2023; West et al., 2020). However, more research is needed on the possible oppositional relationship between playing action videogames and cognitive control in the DMCC model (Braver, 2012; Braver et al., 2007; 2009). In the present study, there was no indirect effect between playing action videogames and cognitive control via gaming disorder. Therefore, $H_7$ was not supported.

Furthermore, it should be pointed out that the results of this study may indicate that an aspect related to the impact of game mechanics per se on gamers' cognitive functioning would be worth expanding in the I-PACE model. More specifically, the mechanics of action videogames can be related to decreased and increased proactive cognitive control mode, as presented in the previous paragraph. In this context, it can be discussed whether general inhibitory control, one of the cognitive control processes included in the I-PACE model, may be modified due to playing action videogames. According to the I-PACE model, the general inhibitory control modified the relationship between affective/cognitive responses to triggers and decisions to behave in a specific way at the early stages of addictive behaviour development. The general inhibitory control also modified the relationship between cue-reactivity/craving and specific habitual behaviours at later stages of addictive behaviour development. Consequently, it can be assumed that playing action videogames may be an additional factor modifying the above relationships. However, this mechanism may be specific to videogames and not occur in other addictive behaviours.

Regarding the DMCC model (Braver, 2012; Braver et al., 2007; 2009), the results may indicate that some activities (e.g. playing action videogames) may be oppositional but complementary mechanisms that may contribute to both an indirect increase in proactive cognitive control mode through working memory capacity and a direct decrease in proactive cognitive control mode through the specificity of the activity itself (e.g. action game mechanics). Additionally, these results demonstrate the composite nature of the cognitive control mechanism and the importance of working memory capacity in activating cognitive control modes (see Redick, 2014; Wiemers & Redick, 2018). The results also showed that time spent playing action videogames may primarily be related to the ability to use the context information associated with cues to prepare a response to the probe (see Table 3). Consequently, the presented results may provide a basis for a more detailed analysis of the mechanisms underlying the relationship between playing videogames and cognitive control in the DMCC model.

The results presented may also have important implications for interventions and treatments for gaming disorders. On the one hand, gamers who play action videogames may initially perceive positive consequences of gaming in the form of improved cognitive functioning. However, excessive use of action videogames can sometimes lead to the development of GD. For this reason, professionals should be vigilant when addressing preventive and therapeutic action for gamers, especially e-sports gamers, to consider all the possible consequences of playing action videogames. On the other hand, Shahrajabian et al. (2023) and Emadi Chashmi et al. (2023) showed that emotional working memory training reduced the symptoms of problematic Internet use and improved participants' working memory, attention and inhibition. Consequently, it can be considered whether working memory training can be a form of enhancing cognitive control and, thus, a form of intervention for gamers with GD symptoms. However, further research is needed in this direction.

### *Limitations*

The findings of the present study should be interpreted taking into account its limitations. Firstly, the gamer group was selected from the Polish population, so caution is needed when generalising the results to other populations. Cultural factors related to gaming (Chen, 2014) and gaming disorder prevalence (Stevens et al., 2021) must be considered. Therefore, cultural contexts should be considered when applying these results more broadly. Secondly, the symptoms of gaming disorders and the time spent playing games were self-reported, which could introduce response bias influenced by participants' attitudes towards the study. Thirdly, the study was cross-sectional, so only longitudinal research could more accurately and causally assess the relationships between time spent playing videogames, gaming disorder, working memory capacity, and cognitive control within the DMCC model. Fourthly, no game-related stimuli were used in the experimental procedures. Considering that cognitive bias towards gaming-related stimuli was observed among gamers with GD symptoms (Dong, Wang et al., 2017; Wang et al., 2017), caution should be exercised when generalizing these results to situations related to the presence of game-related stimuli. Fifthly, it should be pointed out that the proposed model (Figure 1) is just one of the possible models of the relationship between gaming disorder, action videogames, working memory capacity, and cognitive control. Consequently, the results here should be interpreted in light of this model and its rationale.

### *Conclusions*

Overall, the findings showed a positive relationship between action and non-action videogames and GD. In contrast, there was only one positive relationship between action videogames and working memory capacity. Additionally, there was a direct and indirect relationship between action videogames and cognitive control. More specifically, the present study addressed a research gap by showing the possible oppositional relationship between playing action videogames and cognitive control within the DMCC model. However, there was no statistically significant relationship between working memory capacity, cognitive control, and GD. Consequently, the results of the present study indicate that the relationship between GD and cognitive functions may be more complex than it seems, and further research on GD should consider the impact of game genre on gamers' cognitive functioning.

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Table 1. Descriptive statistics and correlations between variables.

| | Variables | M | SD | [1] | [2] | [3] | [4] | [5] | [6] | [7] | [8] | [9] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [1] Age | 22.12 | 2.84 | | | | | | | | | |
| | [2] Gaming disorder | 1.89 | 0.58 | -0.05 | | | | | | | | |
| | [3] Action games time | 1.99 | 1.20 | -0.02 | 0.18*** | | | | | | | |
| | [4] Non-action games time | 1.67 | 0.98 | -0.02 | 0.16*** | 0.27*** | | | | | | |
| | [5] Working memory capacity# | 0.00 | 0.82 | 0.02 | -0.03 | 0.16*** | 0.02 | | | | | |
| Cognitive control indices | [6] PBI: error rates | -0.36 | 0.38 | -0.06 | -0.04 | -0.10* | -0.08 | 0.00 | | | | |
| | [7] PBI: reaction time | 0.04 | 0.08 | 0.04 | -0.06 | 0.05 | -0.06 | 0.07 | 0.29*** | | | |
| | [8] Composite RBI# | 0.00 | 0.80 | -0.02 | -0.06 | -0.02 | -0.08 | 0.05 | 0.79*** | 0.80*** | | |
| | [9] A-cue bias# | 0.00 | 0.64 | -0.06 | 0.01 | -0.11* | 0.01 | 0.10* | 0.52*** | 0.09* | 0.37*** | |
| | [10] d'-context# | 0.00 | 1.58 | -0.09* | 0.01 | 0.07 | 0.08 | 0.21*** | 0.30*** | 0.12** | 0.26*** | 0.46*** |

Note: ****p*<.001; ***p*<.01; **p*<.05; # the variables' scores were calculated using standardized values, so the mean value is zero.

Table 2. Testing the indirect effects between action games playing time and cognitive control indices (PBI calculated for error rate, PBI calculated for reaction time, and composite PBI) via gaming disorder and working memory capacity (Model 6).

| Predictors | On gaming disorder | | | | On working memory capacity | | | | On PBI: error rate | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B | SE | *p* | *β* | B | SE | *p* | *β* | B | SE | *p* | *β* |
| Action games playing time | 0.055 | 0.022 | .013 | .112 | 0.114 | 0.031 | .001 | .167 | -0.019 | 0.015 | .195 | -.061 |
| Gaming disorder | | | | | -0.055 | 0.062 | .378 | -.039 | 0.015 | 0.029 | .618 | .022 |
| Working memory capacity | | | | | | | | | 0.009 | 0.021 | .663 | .019 |
| | | | | | | | | | | | | |
| Non-action games playing time | 0.078 | 0.027 | .005 | .128 | -0.013 | 0.039 | .730 | -.016 | -0.016 | 0.018 | .377 | -.041 |
| Age | -0.001 | 0.009 | .917 | -.004 | 0.001 | 0.012 | .950 | .003 | -0.010 | 0.006 | .084 | -.076 |
| | | | | | | | | | | | | |
| Constant | 1.673 | 0.207 | | | -0.119 | 0.310 | | | -0.093 | 0.146 | | |
| $R^2$ | 0.038 | | | | 0.026 | | | | 0.012 | | | |
| F | 6.847 | | .001 | | 3.525 | | .007 | | 1.226 | | .295 | |
| Predictors | On gaming disorder | | | | On working memory capacity | | | | On PBI: reaction time | | | |
| | B | SE | *p* | *β* | B | SE | *p* | *β* | B | SE | *p* | *β* |
| Action games playing time | 0.055 | 0.022 | .013 | .112 | 0.114 | 0.031 | .001 | .167 | 0.005 | 0.003 | .144 | .068 |
| Gaming disorder | | | | | -0.055 | 0.062 | .378 | -.039 | -0.002 | 0.006 | .796 | -.011 |
| Working memory capacity | | | | | | | | | 0.003 | 0.005 | .516 | .029 |
| | | | | | | | | | | | | |
| Non-action games playing time | 0.078 | 0.027 | .005 | .128 | -0.013 | 0.039 | .730 | -.016 | -0.006 | 0.004 | .170 | -.064 |
| Age | -0.001 | 0.009 | .917 | -.004 | 0.001 | 0.012 | .950 | .003 | 0.000 | 0.001 | .745 | .014 |
| | | | | | | | | | | | | |
| Constant | 1.673 | 0.207 | | | -0.119 | 0.310 | | | 0.034 | 0.032 | | |
| $R^2$ | 0.038 | | | | 0.026 | | | | 0.008 | | | |
| F | 6.847 | | .001 | | 3.525 | | .007 | | 0.809 | | .543 | |
| Predictors | On gaming disorder | | | | On working memory capacity | | | | On composite PBI | | | |
| | B | SE | *p* | *β* | B | SE | *p* | *β* | B | SE | *p* | *β* |
| Action games playing time | 0.055 | 0.022 | .013 | .112 | 0.114 | 0.031 | .001 | .167 | 0.003 | 0.031 | .917 | .005 |
| Gaming disorder | | | | | -0.055 | 0.062 | .378 | -.039 | 0.009 | 0.061 | .881 | .007 |
| Working memory capacity | | | | | | | | | 0.029 | 0.043 | .497 | .030 |
| | | | | | | | | | | | | |
| Non-action games playing time | 0.078 | 0.027 | .005 | .128 | -0.013 | 0.039 | .730 | -.016 | -0.054 | 0.038 | .158 | -.065 |
| Age | -0.001 | 0.009 | .917 | -.004 | 0.001 | 0.012 | .950 | .003 | -0.011 | 0.012 | .380 | -.038 |
| | | | | | | | | | | | | |
| Constant | 1.673 | 0.207 | | | -0.119 | 0.310 | | | 0.308 | 0.306 | | |
| $R^2$ | 0.038 | | | | 0.026 | | | | 0.006 | | | |
| F | 6.847 | | .001 | | 3.525 | | .007 | | 0.644 | | .667 | |

Note: PBI = Proactive Behavioural Index

Table 3. Testing the indirect effects between action games playing time and cognitive control indices (A-cue bias index and d'-context index) via gaming disorder and working memory capacity (Model 6).

| Predictors | On gaming disorder | | | | On working memory capacity | | | | On A-cue bias index | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B | SE | *p* | *β* | B | SE | *p* | *β* | B | SE | *p* | *β* |
| Action games playing time | 0.055 | 0.022 | .013 | .112 | 0.114 | 0.031 | .001 | .167 | -0.080 | 0.025 | .001 | -.151 |
| Gaming disorder | | | | | -0.055 | 0.062 | .378 | -.039 | 0.007 | 0.048 | .891 | .006 |
| Working memory capacity | | | | | | | | | 0.076 | 0.034 | .027 | .097 |
| | | | | | | | | | | | | |
| Non-action games playing time | 0.078 | 0.027 | .005 | .128 | -0.013 | 0.039 | .730 | -.016 | 0.034 | 0.030 | .257 | .052 |
| Age | -0.001 | 0.009 | .917 | -.004 | 0.001 | 0.012 | .950 | .003 | -0.016 | 0.010 | .100 | -.071 |
| | | | | | | | | | | | | |
| Constant | 1.673 | 0.207 | | | -0.119 | 0.310 | | | 0.443 | 0.242 | | |
| $R^2$ | 0.038 | | | | 0.026 | | | | 0.030 | | | |
| F | 6.847 | | .001 | | 3.525 | | .007 | | 3.226 | | .007 | |
| **Predictors** | **On gaming disorder** | | | | **On working memory capacity** | | | | **On d'-context index** | | | |
| | B | SE | *p* | *β* | B | SE | *p* | *β* | B | SE | *p* | *β* |
| Action games playing time | 0.055 | 0.022 | .013 | .112 | 0.114 | 0.031 | .001 | .167 | -0.006 | 0.060 | .926 | -.004 |
| Gaming disorder | | | | | -0.055 | 0.062 | .378 | -.039 | -0.024 | 0.118 | .837 | -.009 |
| Working memory capacity | | | | | | | | | 0.405 | 0.083 | .001 | .209 |
| | | | | | | | | | | | | |
| Non-action games playing time | 0.078 | 0.027 | .005 | .128 | -0.013 | 0.039 | .730 | -.016 | 0.111 | 0.074 | .136 | .067 |
| Age | -0.001 | 0.009 | .917 | -.004 | 0.001 | 0.012 | .950 | .003 | -0.059 | 0.024 | .014 | -.105 |
| | | | | | | | | | | | | |
| Constant | 1.673 | 0.207 | | | -0.119 | 0.310 | | | 1.164 | 0.590 | | |
| $R^2$ | 0.038 | | | | 0.026 | | | | 0.060 | | | |
| F | 6.847 | | .001 | | 3.525 | | .007 | | 6.897 | | .001 | |

Table 4. Standardized indirect effects with 95% confidence intervals.

| Model pathways | Point estimates | Standard error | 95% CI Lower | 95% CI Upper |
|---|---|---|---|---|
| PBI (error rate) model | | | | |
| Action games playing time →GD→PBI (error rate) | 0.002 | 0.006 | -0.012 | 0.014 |
| Action games playing time →WMC→PBI (error rate) | 0.003 | 0.008 | -0.012 | 0.019 |
| Action games playing time →GD→WMC→PBI (error rate) | 0.000 | 0.000 | -0.001 | 0.000 |
| PBI (reaction time) model | | | | |
| Action games playing time →GD→PBI (reaction time) | -0.001 | 0.006 | -0.014 | 0.009 |
| Action games playing time →WMC→PBI (reaction time) | 0.005 | 0.008 | -0.011 | 0.021 |
| Action games playing time →GD→WMC→PBI (reaction time) | 0.000 | 0.000 | -0.001 | 0.000 |
| Composite PBI model | | | | |
| Action games playing time →GD→composite PBI | 0.001 | 0.006 | -0.013 | 0.012 |
| Action games playing time →WMC→composite PBI | 0.005 | 0.008 | -0.010 | 0.022 |
| Action games playing time →GD→WMC→composite PBI | 0.000 | 0.000 | -0.001 | 0.000 |
| A-cue bias index model | | | | |
| Action games playing time →GD→A-cue bias index | 0.001 | 0.005 | -0.010 | 0.012 |
| **Action games playing time →WMC→A-cue bias index** | **0.016** | **0.008** | **0.003** | **0.034** |
| Action games playing time →GD→WMC→A-cue bias index | 0.000 | 0.001 | -0.002 | 0.000 |
| d'-context index model | | | | |
| Action games playing time →GD→d'-context index model | -0.001 | 0.006 | -0.014 | 0.010 |
| **Action games playing time →WMC→d'-context index model** | **0.035** | **0.011** | **0.015** | **0.059** |
| Action games playing time →GD→WMC→d'-context index model | -0.001 | 0.001 | -0.004 | 0.001 |

Note: PBI = Proactive Behavioral Index; WMC = working memory capacity; GD = gaming disorder