Stop or Go? Playing Violent Games Reduces Inhibitory Control in Adolescents

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Abstract

Despite a growing body of research on video game effects, a relationship between violent video game exposure (VVGE) and inhibitory control is still poorly understood. Investigating inhibitory control mechanisms in relation to VVGE may help to better explain processes underlying social behavior of video game players. This holds especially for adolescent players, who often play M-rated violent video games, and whose ability to inhibit responses is still developing. In two studies performed in adolescent samples, we examined how habitual VVGE may be related to inhibitory control (Study 1; $N = 150$) and whether inhibitory control can be affected by 30-minute violent video gameplay (Study 2; $N = 62$). Inhibitory control in both studies was measured with a well-validated method: the Stop-Signal Task. Results of Study 1 showed that increased VVGE was related lower inhibitory control. Results of experimental Study 2 supported a causal relationship: participants who played a violent video game showed reduced inhibitory control compared to those who played a non-violent game. Our findings bring new theoretical and empirical insights into violent video games research and highlight the importance of studying inhibitory control as a possible mechanism underlying impulsive reactions, e.g., aggression, in adolescents. Based on the current correlational and experimental findings, future studies could investigate possible long-term effects of VVGE on the development of inhibitory control in adolescents.

Keywords: violent video games, inhibitory control, adolescence

Stop or Go? Playing Violent Games Reduces Inhibitory Control in Adolescents

Exposure to violence in video games has stimulated considerable interest in studying its possible effects on cognition, affect, and behavior, including aggression (Anderson et al., 2010; Bushman & Anderson, 2021; Ferguson et al., 2020; Prescott et al. 2018). Especially the latter is subject of a fierce debate among scholars (Bushman & Huesmann, 2014 vs. Elson & Ferguson, 2014; Bushman et al., 2015 vs. Ivory et al., 2015). Among other issues, media researchers highlighted problems in measuring aggression (Elson & Ferguson, 2014; Warburton & Bushman, 2019). As a possible solution, it was proposed to study mechanisms underlying aggression, rather than aggression itself (Ferguson & Konijn, 2015). Moreover, such underlying mechanisms may be measured with more reliable and standardized methods and bring new insights into aggression-related outcomes from violent media exposure (Ferguson & Konijn, 2015). Therefore, we aimed to contribute to violent media research by examining relationships and effects of violent video game exposure on inhibitory control as a mechanism underlying aggression (Bushman, 2014; Denson et al., 2012; Ferguson, 2015) and an important social skill developing during adolescence (Blakemore & Robbins, 2012). To meet this goal, we applied a reliable and well-validated measure of inhibitory control in two adolescent samples.

Inhibitory Control and Adolescent Development

Inhibitory control is a key mechanism of self-control (e.g., Baumeister, 2014). It can be understood as the ability to inhibit imminent reactions (Muraven, 2010; Verbruggen & Logan, 2008). Inhibitory control develops from childhood until late adolescence, which was observed in different inhibition paradigms, both in neuroimaging and in behavioral studies (Blakemore & Robbins, 2012; Casey & Caudle, 2013; Cohen-Gilbert & Thomas, 2013). The improvement in inhibitory control in brain imaging research was marked by an increase of prefrontal cortex activity when performing an inhibition task in a magnetic resonance study

(Blakemore & Robbins, 2012). Furthermore, neuroimaging evidence highlighted that while the development of inhibition during adolescence is rather slow and linear, the non-linear development of the reward system makes adolescents hyper-sensitive to rewards (Blakemore & Robbins, 2012). In all, structural and functional changes of the teenage brain make adolescence a sensitive period of social, emotional, and cognitive development (Blakemore & Mills, 2014; Crone & Dahl, 2012; Strasburger et al., 2010). Yet, this sensitivity may act as a double-edged sword: advantageous in facilitating the learning of complex cognitive skills, but perhaps more challenging in case of engaging in unhealthy (Busch & De Leeuw, 2013), risky (Hull et al., 2014), or even anti-social impulsive behavior as in violent video games (Greitemeyer & Mügge, 2014; Olson et al., 2009). Such sensitivity may make young gamers a vulnerable group to possible violent media effects (Crone & Konijn, 2018; Konijn et al., 2015). This was confirmed by a recent meta-analysis, which indicated that mid-adolescents, between 13 and 14 years old, are especially vulnerable to the effects of violent video games on aggression (Burkhardt & Lenhard, 2021). Therefore, in the current studies we focused on adolescent boys who play violent video games more frequently than girls (Krahé & Möller, 2010; Rideout et al., 2010).

Violent Video Games and Adolescents

Video games are unique among other youth entertainment media such as television and movies. Besides a high level of graphic realism (Jansz, 2005; Ribbens et al., 2016), interaction, immersion and flow (Michailidis et al., 2018), there are also other features which make video games especially appealing to adolescent players. Video games provide participants with immediate feedback on their performance and enhance motivation (Lorenz et al., 2015), which corresponds to adolescents' hyper-sensitivity to rewards (Blakemore & Robbins, 2012). Action video games create opportunities for players to get involved in risky behaviors in 'safe' virtual environments – without negative real-life outcomes (Hull et al.,

2014; Jansz, 2005). Importantly, some action video games actively position players into the perspective of a protagonist. They facilitate players to identify with a violent hero and engage with them in violent actions (Carnagey & Anderson, 2004; Konijn et al., 2007; Schneider et al., 2004). These features of (violent) video games may account for their high popularity among young players. In the United States alone, 91% of teen boys owned a game console (e.g., Lenhart, 2015), and an average gamer aged 13 and older spent 6.3 hours a week playing video games (e.g., Nielsen, 2014). Moreover, most top-selling video games often contain violence (Busching et al., 2015); 6 out of the 10 best-selling games in 2015 for the Sony Play Station 4 (Nielsen, 2015) had a Mature or 18+ age label and contained extreme violence according to the Pan European Game Information rating (PEGI; 2017). However, such M-rated violent video games are even more attractive to young players through a ‘forbidden fruit’ mechanism (Nije Bijvank et al., 2009).

Theoretical Implications: Violent Video Games, Aggression, and Inhibitory Control

Until now, various models proposed theoretical implications of the relationship between digital violent gaming and aggressive behavior. However, these models have not included inhibitory control. Therefore, in order to explain the mutual relationships between violent video game exposure (VVGE), aggression, and inhibitory control, we integrated insights from three theories: *I³ theory*, the General Aggression Model, and the Reflective Impulsive Model (Figure 1).

[Figure 1 here]

The *I³ theory* (Slotter & Finkel, 2011) proposes that aggression is governed by three processes: (1) instigation, (2) impellance¹, and (3) inhibition. Instigation refers to the social dynamics (e.g., provocation) that would act as a trigger for aggressive behavior, while impellance refers to factors associated with a situation or a person (e.g., trait aggressiveness) that would increase the tendency to act aggressively. When combined, these two processes

can lead to a stronger impulse to behave aggressively. The third process, inhibition, refers to situational or personal factors (e.g., trait self-control) that influence the ability to suppress an impulse. When a person's inhibitory control is stronger than an aggressive urge, aggressive behavior will not occur, however, when the opposite is true, one may behave aggressively (Finkel, 2014). Thus, aggressive behavior can be displayed as a result of inhibitory control failure (Denson et al., 2012) while such behavior is curbed by inhibitory control (DeWall et al., 2011).

Research, thus far, has found support for the I³ theory (Denson et al., 2012). For example, results of an experiment have demonstrated that two weeks of self-control training helped to inhibit aggressive behavior in people high in trait aggressiveness (Denson et al., 2011a). Also, more recent research showed that violent offenders had weaker inhibitory control as compared to non-violent offenders (Meijers et al., 2017). Moreover, the I³ theory could be supported by neural processes. If prefrontal regions of the cortex that are responsible for inhibition, do *not* initiate top-down control processes, then activity in limbic and subcortical brain regions is associated with impulsive aggression (for a review, see Davidson et al., 2000). Based on that, we propose inhibitory control as a process underlying impulsive behavior in social situations: aggression.

Similar to the I³ theory, the *General Aggression Model* (GAM; Allen et al, 2018; Anderson & Bushman, 2002) describes how personal and situational factors affect a person's internal state, which in turn influences appraisals and decision-making processes. As a result of these processes, people may behave either aggressively (an impulsive action), or non-aggressively (a reflective action). The GAM predicts that short-term exposure to violent video games may influence one's internal state and may thus prime aggressive behavior. The outcome of the decision-making process, namely, aggressive behavior, may be reinforced by repetitions and thus affect one's knowledge structures. Based on that, habitual exposure to

violent video games may eventually lead to the development of an aggressive personality. The GAM was frequently used in earlier media violence research to explain the relationship between VVGE and aggression (Allen et al., 2018).

Impulsive or reflective behavior, as an outcome of a decision-making process, connects the GAM to the Reflective Impulsive Model (RIM; Strack & Deutsch, 2004; Hofmann et al., 2009). The RIM is a dual-process model which proposes that behavior is a result of automatic and reflective processes. While inhibitory control is a reflective process, failure to inhibit a reaction could be seen as resulting from an automatic reaction in response to cues initiating behavior, such as aggression in response to provocation (cf., Denson et al., 2011b). The RIM can predict the negative feedback loop between impulsive and reflective processes, and also connects violent video game exposure to inhibitory control. Hence, integrating these three theories (I³, GAM and RIM) provides an explanation for how violent video game exposure may relate to changes in inhibitory control as underlying aggressive behavior.

Based on the assumption that an ability to inhibit impulses can be modified by repeating certain actions (Muraven, 2010; Denson et al., 2011a), we argue that habitual, but also short-term exposure to violent video games may have an impact on inhibitory control. The environment of violent games may support learning impulsive behavioral schemata related to the violent content (e.g., shooting enemies). Players of violent video games have to be fast and decisive in order to be successful in a game. For example, they may need to persistently use a button that fires a rifle in order to eliminate an opponent. After some time of gameplay and repeating violent actions in a game, players may adapt to such a violent virtual environment, which can (temporarily) change the decision-making processes from reflective to more automatic (Allen et al., 2018; Anderson & Bushman, 2002; Hofmann et al., 2009; Strack & Deutsch, 2004). Such automatic decision-making processes may stimulate faster and

in general more impulsive reactions (i.e., easier to execute, more difficult to inhibit) as depicted by Bushman and Anderson (2018; Figure 6, p. 406). Repeating acts of virtual violence may eventually change behavioral schemata and increase accessibility of impulsive behavior (Allen et al., 2018; Anderson & Bushman, 2002). The increase in impulsive behavior should then be observed in limited inhibitory control (cf. Denson et al., 2012), because inhibitory control requires (reflective) decision-making processes.

Moreover, players are rewarded for their impulsive actions in a violent game, which could positively reinforce repetition of such behavior, by automatizing such actions in future encounters and affecting knowledge structures to more aggressive (Allen et al., 2018; Anderson & Bushman, 2002). As brain imaging studies showed, rewards can initiate a motivational process which substantially influences both attentional control (e.g., Padmala & Pessoa, 2011) and inhibitory control (e.g., Padmanabhan et al., 2011). This can be especially apparent in adolescents due to protracted development of the prefrontal cortex (Crone & Konijn, 2018; Telzer, 2016). In this light, it is important to understand how playing violent video games may affect adolescents, whose brains have been shown to be hyper-sensitive to rewards (cf. Blakemore & Robbins, 2012).

Violent Video Game Exposure and Inhibitory Control

Thus far, studies that have investigated the relationship between violent gameplay and inhibitory control in adolescents and adults present mixed evidence. A correlational study in an adolescent sample found that higher exposure to violent media, including violent games was related to lower performance in a Stroop test, reflecting weaker inhibition of automatic responses (Kronenberger et al., 2005). Findings of a neuroimaging experiment suggested that violent games might reduce inhibitory control by priming aggressive behavior during violent gameplay (Hummer et al., 2010). In this study, adolescents either played a violent or non-violent video game for 30 minutes. Immediately thereafter, they performed an inhibitory

control task (in a go/no-go paradigm) during a functional magnetic resonance imaging (fMRI) procedure. This task required participants to press a button when a letter (target stimulus) was presented (go trial) or withhold their response when they were presented with the letter “X” (a non-target stimulus) (no-go trial). Their findings indicated that adolescents exposed to a violent game exhibited a lower activation (lower Blood Oxygenation Level Dependent response) in the right dorsolateral prefrontal cortex (DLPFC) during no-go trials than those who were exposed to a non-violent game (Hummer et al., 2010). The DLPFC is often found to be involved in motor inhibition tasks (Garavan et al., 2002; Liddle et al., 2001; Rubia et al., 2001), indicating its role in the control of behavior. Thus, the lower DLPFC activation in the current context reflected lower inhibitory control ability as a short-term effect of a violent (vs. non-violent) gameplay. Taken together, these results suggest that playing violent video games reduces an adolescent’s ability to suppress an impulsive action, at least in a short-term perspective (Hummer et al., 2010).

Problems with self-control were also reflected in adolescents who ate more chocolates while playing a violent video game (despite receiving information about the possible side effects of eating unhealthy food) as compared to participants who were playing a non-violent game (Gabbiadini et al., 2013); similar results were published recently (Gabbiadini et al., 2021). This suggests that extensive violent gaming could increase likelihood of evolutionary-determined tendencies (i.e., impulsive reaction) for food high in calories (MacDonald, 2008). Thus, behavior of individuals playing violent video games can be explained in terms of decreased inhibitory control (Bartholdy et al., 2016).

In contrast, a correlational study that used a *Stop-Signal Task* (Colzato et al., 2013) found no relationship between habitual playing violent first-person shooter (FPS) games and inhibitory control in adults. However, experience with violent FPS games was related to faster reaction times for go trials. Similar results were found in another correlational study with

adults (Steenbergen, 2015): playing violent FPS games was related to enhanced response execution, but was not related to inhibitory control in the stop-change paradigm. In contrast, another cross-sectional study among adults found that a higher frequency of playing FPS games was related to lower inhibitory control in stop-signal trials (Deleuze et al., 2017). In line with the earlier studies among adults, more frequent playing FPS games was related to faster reactions (Deleuze et al., 2017).

In sum, findings thus far on the relationship between violent video games and inhibitory control are mixed and may depend on different paradigms measuring inhibitory control, differences in the measurement of violent video game exposure, different criteria of participants' group recruitment and distinguishing sub-groups, different developmental stages related to inhibitory control abilities (adolescents vs. adults). To the best of our knowledge, the relationship between inhibitory control and violent video game exposure was not yet tested with the Stop-Signal Task (SST; Logan, 1994) in adolescents. Therefore, we aimed to fill this gap with an implementation of the SST in adolescent samples and testing both for relationship and causal effects of playing violent video games. Our approach is relevant given that adolescence is a sensitive period for cognitive development (Crone & Dahl, 2012), marked with developmental changes in inhibitory control (Blakemore & Robbins, 2012), and that adolescents may be especially susceptible to violent media effects (Crone & Konijn, 2018). Our studies are further important in the light of a longitudinal evidence, indicating that problems with inhibitory control in adolescents could predict higher risk of delinquency in emerging adulthood (Fosco et al., 2019). Therefore, as a first step to prevent such a risk, it would be relevant to test whether playing violent video games could be related to or in a short-term impede inhibitory control in adolescents.

The Stop-Signal Task as a Measure of Inhibitory Control

The Stop-Signal Task is a well-validated measure of inhibitory control (Lipszyc &

Schachar, 2010). Its primary advantage over the go/no-go paradigm (cf. Hummer et al., 2010) or the Stroop task (cf. Kronenberger et al., 2005) is that the SST enables the measurement of the time a person needs to inhibit a response (i.e., *stop-signal reaction time*; SSRT).

Successful performance in the SST indicates inhibition of an ongoing action and can be understood as a more precise form of response inhibition than that of the go/no-go paradigm (cf. Cohen & Lieberman, 2010). In this light, the SST seems to be a more accurate measure of inhibitory control than a go/no-go task (Wessel, 2017). Besides that, different inhibitory processes are involved in the SST and Stroop task in adolescents (Khng & Lee 2014), which could make results of different studies using these methods more difficult to compare.

The reasoning behind the SST assumes that the response to a go-stimulus and a response to a stop-signal represent two different processes (Logan & Cowan, 1984; Verbruggen & Logan, 2008). When the stop-signal is presented, a few milliseconds after the presentation of the go-stimulus, a competition between a go-process and a stop-process occurs. The presentation of a go-stimulus activates a go-process (pressing a button), and hearing a stop-signal activates a stop-process (inhibiting pressing a button). If the stop-process is stronger, the participant is able to inhibit the response. But if the go-process is stronger, the participant fails to inhibit the response (cf. Verbruggen & Logan, 2008). The more time a person needs to inhibit a reaction, the higher the SSRT, and the weaker the inhibitory control.

The SSRT is the latency of the stop-process that cannot be measured directly and is alternatively estimated using a stochastic model known as the independent race model. This involves varying the *stop-signal delay* (SSD), the time between the go-stimulus onset and the presentation of the stop-signal, in order to influence the probability that the go-process will win, and comparing this to the go-stimulus reaction time. The lower the SSD, the easier inhibition becomes, and reversely, the higher the SSD, the harder to inhibit a reaction (Logan & Cowan, 1984; Verbruggen & Logan, 2008). In other words, the longer the interval between

presentation of the go-stimulus and the stop signal, the more difficult it is to inhibit a response, because “the stop process starts later and, therefore, finishes later relative to the go process” (Verbruggen & Logan, 2008, p. 420). The shorter the interval between the presentation of the go-stimulus and the stop-signal, the easier it is to inhibit a response, because the stop process starts sooner after the go process onset. Based on that, we used the SSRT as a main dependent variable, and also, we measured the SSD as a control variable in order to check whether the SST works according to the task’s assumptions. We used the SST in our two studies.

The Current Studies

The aim of the current research was to investigate the relationship between playing violent video games and inhibitory control as measured with the SST (Verbruggen & Logan, 2008). We investigated this relationship in Study 1 through a cross-sectional design. In Study 2, we applied an experimental design to test short-term effects of playing a violent video game (as compared to playing a non-violent video game) on inhibitory control. In both studies, we focused on adolescent gamers because they appear to be more susceptible to violent media effects and because their inhibitory control is still developing, as discussed earlier.

Based on the integrated insights from three theories (I^3 , GAM and RIM; Allen et al., 2018; Anderson & Bushman, 2002; Hofmann et al., 2009; Slotter & Finkel, 2011; Strack & Deutsch, 2004) and previous research on adolescents (Gabbiadini et al., 2021; Hummer et al., 2010; Kronenberger et al., 2005) and on adults (Deleuze et al., 2017), we hypothesized that frequent violent gameplay would be related to weaker inhibitory control reflected by higher SSRT in the SST (H1, Study 1). Moreover, we expected that 30-minute experimental exposure to a violent video game would impede inhibitory control in a short-term, compared to exposure to a non-violent game (H2, Study 2). In both studies, we controlled for trait

aggressiveness, because it may be an important factor for both lower inhibitory control (cf. Pawliczek et al., 2013) and for stronger tendencies to behave impulsively (cf. Finkel, 2014). Additionally, in both studies, we further explored whether players of violent games were faster (in go trials) in the SST than a control group, which could support earlier research (Colzato et al., 2013; Deleuze et al., 2017; Steenbergen et al., 2015) and help to understand the mechanism of inhibitory control in players of violent video games.

Study 1

Method

Participants

Participants were 151 adolescents ($M_{\text{age}} = 16.97$; $SD = 1.01$; 58.3% males; mainly Caucasians). They were recruited from two secondary schools in a European country (details left out for blinded review) and participated voluntarily. The study's protocol was approved by the Institutional Ethical Review Board, and the study conforms to the standards of Declaration of Helsinki. One participant was discarded because of missing data (demographic variables, frequently played video games, and VVGE). Therefore, the final sample was $N = 150$ participants. The final data set has been shared at https://osf.io/bxrd3/?view_only=ac4c643e6a0b41b681bd6786ad67aed0.

Measures

Violent Video Game Exposure (VVGE). A 4-question survey was applied to measure VVGE following recommendations by Busching et al. (2015). First, participants were asked whether they play video games at all. If the answer was 'no', the participant was asked to score '0' and was redirected to the end of the VVGE survey. If the answer was 'yes', then, the participant proceeded with the following questions: (2) 'How many hours per day did you play in the last month?', (3) 'What kind of games did you play most often?', (4) 'What is your favorite game?'. Pan European Game Information (PEGI, 2017) was used to

rank the participants' favorite game's content in terms of violence and age labels. Each game title and game type reported in answer to question (3) and (4) was coded in accordance with the age label and violence indicators of the PEGI classification.

Based on the answers to the VVGE survey, participants were classified into either a violent gameplay group or a non-violent gameplay group. There were two conditions that had to be fulfilled in order to classify gamers into the violent gameplay group. First, they had to play video games. Second, a mentioned game type contained any level of violence (cf. Busching et al., 2015), or their favorite game title contained any level of violence according to the PEGI-rating system (2017). Therefore, all participants who indicated playing games such as a first-person shooter (FPS), as well as all participants that played games containing mild or extreme violence according to the PEGI ratings (i.e., rated 12+, 16+, and 18+ with a violence label) were classified into a violent gameplay group. If participants indicated that they played non-violent game types (rated by PEGI as 3+ or 7+; e.g., sports, racing, RPG, logic, strategic or games such as FIFA, NBA, The Sims), they were classified into the non-violent gameplay group. Participants who reported not playing any games (non-gamers) were combined with the non-violent gameplay group (cf. Colzato et al., 2013).

Inhibitory control. The computer version of the SST (Verbruggen et al., 2008) was used with the software Inquisit 4 (2013), lab version, based on an Inquisit script available on the Millisecond webpage (2017). The participants responded by pressing a button to a go-stimulus (presented on a screen as an arrow). Occasionally, the go-stimulus was immediately followed by a stop-signal through a pair of headphones as a brief tone. The participants were instructed to withhold their response to a go-stimulus when the stop-signal was presented. The software automatically calculated in milliseconds both the averaged stop-signal reaction time (SSRT) and the averaged stop-signal delay (SSD) over all trials in the task, which are being used as dependent measures. Moreover, the software also calculated reaction time for go

trials, which were considered as an additional measurement in the SST and were used in exploratory analyses. Shorter (faster) reaction times for the go trials could reflect more impulsive reactions.

At the start, instructions were presented on a screen, and participants were informed that they could press any button to begin the task. Initially, a white circle on a black screen was presented, and after 250 milliseconds a go-stimulus, an arrow, appeared inside this circle. The arrow remained on the screen until the participant responded or until 1250 milliseconds passed without a response. If the go-stimulus was an arrow directed to the left, the participant had to press the 'D' button at the left side of a computer keyboard. If the go-stimulus was an arrow directed to the right, the participant had to press the 'K' button at the right side of the keyboard. This sequence was a go trial. The default interval between each go-stimulus was 2000 milliseconds.

In 25% of the trials, the stop-signal was presented for which the participant only had a very short time-window to inhibit the response (see examples of the SST go trial and stop trial in Figure 2). Before the first trial, the SSD was set at 250 milliseconds after the go-stimulus and later on this interval was dynamically adjusted using a staircase tracking procedure (Logan & Cowan, 1984). When a participant successfully inhibited a response to the go-stimulus (arrow followed by tone), the SSD increased by 50 milliseconds, making the next response after the stop-signal harder to inhibit. When the response was not inhibited, the SSD decreased by 50 milliseconds, making the next response after the stop-signal easier to inhibit. This procedure ensured that participants were able to inhibit their responses in about 50% of the stop-signal trials, while also compensating for the variability within reaction time between participants and allowing accurate estimates of the SSRT.

[Figure 2 here]

The SST used in this study consisted of two randomized blocks with 32 trials each. Participants waited 10 seconds between blocks and then received feedback on their performance in the previous block. This included: (1) the number of incorrect responses on no-signal trials, (2) the number of missed responses on no-signal trials, (3) the mean RT on no-signal trials, and (4) the percentage of correctly inhibited reactions (cf. Verbruggen et al., 2008).

The SST was performed on a MacBook Pro laptop (13.3 inch, LED-backlit glossy widescreen display, a native resolution of 1280 by 800 pixels, refresh rate of 60 Hz). Over-the-ear headphones were used to provide the tone that represented the stop-signal (50-60% of maximum volume).

Trait aggression. The Aggression Questionnaire (BPAQ; Buss & Perry, 1992) was used to measure trait aggression. It utilizes 29 items in four subscales to measure Physical Aggression, Verbal Aggression, Anger and Hostility. Examples of the items included are: 'If somebody hits me, I hit back' and 'If I have to resort to violence to protect my rights, I will.' The scale range is from 1 (*extremely uncharacteristic of me*) to 7 (*extremely characteristic of me*). Given the study's purpose, the trait aggression scale was used as one composite scale variable (Cronbach's $\alpha = .87$), included as a control variable in the statistical analyses.

Procedure

After a general introduction about the procedure and obtaining active consent, the SST was started in the software Inquisit 4 (2013). Before starting the training block of the SST, all participants received instructions about the task to make sure everybody understood how it works. After completing the SST, the trait aggressiveness, and VVGE questionnaires followed (and some additional measures unrelated to the current study). The procedure ended with some demographic questions (age, gender). Upon completion, the participants received a candy reward and were debriefed.

Results and Discussion

Preliminary Analyses

The participants answered the VVGE survey as follows: (1) Out of 150, 106 participants reported that they played video games, (2) on average they played 2.24 hours per day in a past month, (3) the most popular game types were FPS and shooting games (36 participants), and (4) the most popular game titles were: *FIFA* (10 participants), *League of Legends* (9 participants), and *Call of Duty* (9 participants). Reported game titles were entered into the PEGI-database (www.pegi.info) to assess whether the game contained violence. Based on the participants' answers, they were divided into two groups: violent gameplay or non-violent gameplay, as described below.

The most frequently played *violent* games were: *Battlefield*, *Call of Duty*, *Counterstrike*, *DOTA*, *Far Cry*, *Tomb Raider*, *Grand Theft Auto*, *Crysis*. In all, 46.7% of participants were classified as violent video games players ($n = 70$). This group consisted of participants who reported that they played both violent game types (based on VVGE-question 3) and violent game titles (based on VVGE-question 4) ($n = 53$), participants who played violent game types (e.g., FPS), but their favorite game title was non-violent according to the PEGI rating ($n = 6$), and participants who reported to play a non-violent game type (VVGE-question 3), but named a violent game title based on the PEGI rating ($n = 11$). On average, they reported that they played violent games for 2.51 hours per day in the previous month.

Based on the VVGE survey, 26.0% of the participants were classified as non-violent video game players ($n = 39$). On average, they reported that they played non-violent games 1.87 hours per day in the last month. Finally, participants, who did not play any games at all, were classified as non-gamers ($n = 41$; 27.3%). For comparison purposes, we merged the non-violent video game players and the non-gamers into one reference group of $n = 80$.

Descriptive statistics and correlations between variables are presented in Table 1. The SSRT

and the SSD were negatively related, indicating that the SST measuring inhibitory control worked according to expectations. Gender and age did not correlate with SSRT, nor with the SSD, and were therefore not included as control variables in the main analyses. Trait aggression was not related to any measure of inhibitory control.

[Table 1 here]

Hypothesis Testing

In order to test our hypothesis that frequent violent gameplay is related to lower inhibitory control among adolescents, we used two indicators of inhibitory control in the SST: average SSRT and average SSD. These two indicators were included as dependent variables in a MANOVA with the groups (violent gameplay versus the reference group) as independent factor. Results of the multivariate test revealed a significant effect of groups, Wilk's $\lambda = 0.87$, $F(2, 147) = 11.45$, $p < .001$, $\eta^2 = .14$, 90% CI [0.05, 0.21]. Inspection of univariate analyses revealed a significant effect of groups on both the SSRT, $F(1, 148) = 16.14$, $p < .001$, $\eta^2 = .10$, 90% CI [0.03, 0.18], and the SSD, $F(1, 148) = 12.49$, $p = .001$, $\eta^2 = .08$, 90% CI [0.02, 0.15]. Participants who played violent games displayed longer SSRT ($M = 266$, $SD = 65$) than the reference group ($M = 224$, $SD = 64$, respectively). Furthermore, violent game players showed shorter SSD ($M = 272$, $SD = 135$) compared to the reference group ($M = 369$, $SD = 190$, respectively). Both the longer time needed to inhibit a reaction (reflected in longer SSRT) and the shorter delay between the go-stimulus and the stop-signal (reflected in shorter SSD) indicate greater difficulty in inhibiting one's response. Thus, the results support H1 that habitual exposure to violent video games is related to weaker inhibitory control.

To control for trait aggression (BPAQ) we also performed a MANCOVA (i.e., including BPAQ as a covariate). This did not change the main results and the covariate was not significant, Wilk's $\lambda = 0.99$, $F(1, 146) = 0.58$, $p = .559$, $\eta^2 = .01$, 90% CI [0.00, 0.04], which is consistent with the (lack of) correlations in Table 1. Moreover, we also included the

gender of participants as a covariate in a MANCOVA in order to control for the effect of participants' gender. We included the SSRT and the SSD as dependent variables, the groups as independent variable and gender (1 = female, 2 = male) as the covariate. The video game groups factor was still statistically significant, Wilk's $\lambda = 0.88$, $F(2, 145) = 8.31$, $p < .001$, $\eta^2 = .10$, 90% CI [0.03, 0.18]. Neither the gender factor was statistically significant, $F(2, 145) = 0.30$, $p = .741$, $\eta^2 = .004$, 90% CI [0.00, 0.03], nor the Groups x Gender interaction, $F(2, 145) = 0.17$, $p = .845$, $\eta^2 = .001$, 90% CI [0.00, 0.02]. Thus, the differences between violent game players and the reference group on the SSRT and the SSD were still statistically significant, supporting H1 while controlling for trait aggressiveness and gender. These results were further confirmed in an alternative Bayesian analysis.²

Exploratory Analysis

A comparison of reaction time for go trials showed that the violent video games players were slightly faster ($M = 560$, $SD = 161$) than the reference group ($M = 565$, $SD = 64$); however, by applying ANOVA, we found that the difference between the groups was not significant, $F(1, 148) = 0.30$, $p = .865$, $\eta^2 = .001$, 90% CI [0.00, 0.03]. The code for all the analyses is stored at https://osf.io/4qtpk/?view_only=e89185c8523e4fbe82633224a7eef375.

Conclusion

In all, the findings of Study 1 supported the relationship between frequent habitual violent gameplay and weaker inhibitory control (H1) as indicated by the longer stop-signal reaction time and shorter stop-signal delay times measured in the SST, also when controlled for trait aggression and gender. In addition, players of violent games and the reference group did not differ in reaction times for go trials. Thus, these findings cannot be explained by high efficiency in response execution of players of violent video games (cf. Colzato et al., 2013; Deleuze et al., 2017; Steenbergen et al., 2015). Importantly, due to the cross-sectional design, these results are only correlational and cannot assess the direction of the observed

relationships (cf. Gentile et al, 2012). To examine a possible causal effect of violent video gaming on inhibitory control, we conducted an experiment.

Study 2

In Study 2, we experimentally tested the hypothesis that exposure to a violent video game would result in lower inhibitory control in the SST than exposure to non-violent games (H2). Thus, Study 2 was designed to test the potential impact of violent gameplay on inhibitory control. However, we controlled for habitual exposure to violent video games (high vs. low) and tested if this variable would interact with the experimental short-term exposure to violent vs. non-violent video games in the lab. Finally, we controlled for trait aggressiveness, while limiting gender to males only, to test if this would limit the effects of the experimental manipulation.

Method

Participants

Participants were recruited from a general secondary school in a European country (details blinded for review; mainly Caucasian pupils). The initial group of participants consisted of 570 (both girls and boys) aged 12-16 years old ($M = 13.98$, $SD = 1.10$). They completed an online survey through the school's website. From this sample, a smaller group of participants was selected for the experiment based on two criteria.

The first inclusion criterion was gender: only boys ($n = 179$) were selected to avoid potential differences in the effects of violent games on boys and girls (cf. Eastin, 2006). The second inclusion criterion was the frequency of violent video game exposure (VVGE; Anderson & Dill, 2000; Busching et al., 2015). An index of VVGE was created based on data collected in the group of boys, and from this group the highest and lowest quartiles were selected for comparison purposes (cf. Engelhardt et al., 2011). The highest quartile was classified as the high violent video game exposure group (high-VVGE; $n = 35$) who played

violent games relatively often ($M_{\text{high-VVGE}} = 13.59$) and the lowest quartile was classified as the low violent video game exposure group (low-VVGE; $n = 28$) who hardly ever or did not play violent games, or played non-violent games ($M_{\text{low-VVGE}} = 9.33$).

Finally, sixty-three boys were selected as relatively high ($n = 35$) versus low ($n = 28$) in VVGE to take part in our experiment. The final data set has been shared at https://osf.io/bxrd3/?view_only=ac4c643e6a0b41b681bd6786ad67aed0. Active consent was obtained from the school's authorities as well as all participants and parents. The study was conducted in accordance with and approved by the Institution's Ethical Review Board, and the study conforms to the standards of Declaration of Helsinki.

Design

The experiment included two conditions to which participants were randomly assigned. They either played a violent video game (experimental condition; $n = 32$) or a non-violent game (control condition; $n = 31$) in the lab. Crossed with the frequency of gameplay factor (i.e., high-VVGE vs. low-VVGE), four groups were created: (1) a low exposure group that played a violent game ($n = 14$), (2) a low exposure group that played a non-violent game ($n = 14$), (3) a high exposure group that played a violent game ($n = 18$), and (4) a high exposure group that played a non-violent game ($n = 17$).

Procedure

After the selection procedure as described in the above, each participant was invited to come to the lab at a certain time slot. Data were collected at two locations, for practical reasons: a psychological laboratory at the authors' university ($n = 29$) and at an arranged lab at the participants' school ($n = 34$). Participants either came to the school's lab or to the university's lab based on their parental consent and availability. In both labs, similar conditions were created and the same equipment was used (i.e., an Xbox 360 with 32-inch screen to play the games and a 13-inch Mac Book Pro laptop for the measurements). Location

of the data collection did not influence the SST outcomes³. After a general introduction about the procedure and approving active consent, the experiment started. Each participant played one out of four (depending on the condition) randomly assigned video games for 20 minutes and immediately thereafter performed the SST (Verbruggen et al., 2008), and finally, completed the questionnaires. Adolescents, who participated in the study at the university's lab, completed another procedure unrelated to the current study only *after* measuring the SST. Upon completion, each participant was given a small financial reward and debriefed.

Materials and Measures

Game manipulation. All participants played the games on an Xbox 360 using a standard wired controller. They played one of eight possible games after random assignment; either a violent game (*Gears of War 3*, *Max Payne 3*, *Grand Theft Auto 5*, *Dead Island*) or a non-violent game (*FIFA 14*, *Fez*, *Portal 2*, *Forza Motorsport 4*). A website that combines ratings from media critics and assigns a popularity score on a 100-point scale (Metacritic, 2022), was consulted to determine which games were popular and would likely be of interest to the participants. All games selected were rated with 80 points and beyond on Metacritic, suggesting that they were all quite popular. In order to increase the generalizability of the results, games were selected from a variety of genres, such as first-person and third-person perspective games. Moreover, most of the games that we used for the violent condition have been used in previous research on violent video games: the *Gears of War* series (Coyne & Stockdale, 2021), *Max Payne* series (Konijn et al., 2007) and *Grand Theft Auto* series (Coyne & Stockdale, 2021; Engelhardt et al., 2015; Teng et al., 2011).

These violent games were all M-rated, that is, had a recommended age of 18+ according to the Pan European Game Information system (PEGI, 2017) and each featured cases of realistic violence. In contrast, non-violent games were rated as suitable for everybody (3+) according to PEGI, except for *Portal 2*, which was rated as 12+ (PEGI, 2017). However,

according to Entertainment Software Rating Board (2017), *Portal 2* is a game for everyone. We used *Portal 2* as a non-violent game because settings of this game are very similar to the FPS games in terms of first-person perspective and use of a weapon. However, in contrast to FPS games that focus on shooting enemies, *Portal 2* aims to solve a puzzle by creating portals in walls. Moreover, this game was used as a non-violent control condition in earlier research on adolescents (Ferguson et al., 2015).

Violent video game exposure (VVGE). Following a standard procedure to measure VVGE (Anderson & Dill, 2000; Busching et al., 2015), participants were asked to list their favorite video games (max. five), rate each of them on a scale of 1 to 7 on how often they played the game (from 1 = *rarely* to 7 = *often*), and how violent they rate the games' content and graphics (from 1 = *little, or no violent content* to 7 = *extremely violent content, or extremely violent graphics*). Hardly any participant listed more than three violent games as their favorite (1.0% listed 4), 13.0% listed three violent games, 31.0% listed two violent games, 34.0% listed one violent game, and 21.0% did not mention any violent game at all or no game. The index of overall VVGE for each participant was computed by adding the violent content ratings and multiplying the result by how often they played (Anderson & Dill, 2000). The scores were then averaged with the number of reported games to calculate a video game violence exposure index. As described in the Participants section, we selected boys according to high versus low in VVGE and included this grouping as a fixed factor in the experimental design.

Inhibitory control. As in Study 1, the SST was used to measure both the SSD and the SSRT (Verbruggen & Logan, 2008). The SST in Study 2 was used in the same way as in Study 1, including a similar computer, software and headphones. However, in Study 2 we increased the number of trials up to 64, and the number of blocks up to 3 to provide more sensitive measurements of inhibitory control and to compensate for a smaller sample size than

in Study 1 (cf. Smith & Little, 2018). The average SSRT was calculated using data from all three blocks.

Trait aggression. An adjusted version, adapted for adolescents, of the Aggression Questionnaire (BPAQ; Buss & Perry, 1992; Konijn et al., 2007) was used to measure trait aggression and limited to the 9-item Physical Aggression subscale (Cronbach's $\alpha = .89$).

Results

Preliminary Analyses

Upon inspection of the raw data for outliers and related irregularities in the SST, one participant from the experimental violent game condition, at the school's lab, was excluded from further analyses due to having a negative stop-signal reaction time (-50ms). This was interpreted as indicating that he did not follow the SST instructions. Normally, a negative SSRT would not occur. Thus, the final sample size was $N = 62$.

Descriptive information and correlations between variables are presented in Table 2. The only observed significant correlation was a negative relationship between the SSD and the SSRT, which is in accordance with expectations. Trait aggression was not related to any measure of inhibitory control (as in Study 1).

[Table 2 here]

Hypothesis Testing

The average SSRT and average SSD were calculated using data from all three blocks. A MANOVA was then performed with two independent factors: (1) game type (i.e., violent vs. non-violent game condition) and (2) prior VVGE (i.e., high vs. low exposure to violent video games), with the SSRT and the SSD as the dependent variables.

Multivariate tests revealed a significant effect of the type of game played in the lab on both the SSRT and the SSD, Wilk's $\lambda = 0.88$, $F(2, 57) = 3.80$, $p = .028$, $\eta^2 = .12$, 90% CI [0.01, 0.23]. However, no significant effect of participants' VVGE was shown, Wilk's $\lambda =$

1.00, $F(2, 57) = 0.13$, $p = .881$, $\eta^2 = .004$, 90% CI [0.00, 0.03], nor did we find a significant interaction between the experimental conditions and VVGE, Wilk's $\lambda = 0.98$, $F(2, 57) = 0.63$, $p = .537$, $\eta^2 = .02$, 90% CI [0.00, 0.09].

Post-hoc univariate analyses and comparing the means for both groups, showed that the type of game played affected both the SSRT, $F(1, 58) = 4.58$, $p = .037$, $\eta^2 = .07$, 90% CI [0.01, 0.19], and the SSD, $F(1, 58) = 6.75$, $p = .012$, $\eta^2 = .10$, 90% CI [0.01, 0.23].

Participants who played a violent game showed a significantly longer SSRT ($M = 293$, $SD = 75$) and significantly shorter SSD ($M = 334$, $SD = 176$) than participants who played a non-violent game ($M_{SSRT} = 259$, $SD_{SSRT} = 50$; and $M_{SSD} = 451$, $SD_{SSD} = 165$, respectively). A longer stop-signal reaction time reflected that more time was needed to inhibit the initial go-reaction, and that a shorter delay between the go-stimulus and the stop-signal (SSD) was needed for a successful inhibition. Thus, the results support H2: violent video gameplay temporarily reduced inhibitory control. These results were further confirmed in an alternative Bayesian analysis.⁴

To control for trait aggression (BPAQ) we also performed a MANCOVA, including trait aggression as a covariate. This did not change the main results and the covariate was not significant, Wilk's $\lambda = 0.97$, $F(2, 56) = 0.75$, $p = .475$, $\eta^2 = .03$, 90% CI [0.00, 0.10], which is consistent with correlations in Table 2.

Exploratory Analysis

A comparison of averaged reaction time for go trials showed that participants who played a violent game were significantly faster ($M = 609$, $SD = 135$) than participants who played a non-violent game ($M = 687$, $SD = 128$); $F(1, 58) = 4.85$, $p = .032$, $\eta^2 = .08$, 90% CI [0.02, 0.26]. Neither habitual VVGE, $F(1, 58) = 0.43$, $p = .513$, $\eta^2 = .01$, 90% CI [0.00, 0.07], nor the interaction between habitual VVGE and the video game manipulation, $F(1, 58) = 0.27$, $p = .604$, $\eta^2 = .01$, 90% CI [0.00, 0.05], significantly predicted averaged reaction time

for go trials. The code for all the analyses has been stored at

https://osf.io/4qtpk/?view_only=e89185c8523e4fbe82633224a7eef375.

Conclusion

In sum, our findings indicated that playing violent video games impedes inhibitory control (longer SSRT and shorter SSD) as compared to playing a non-violent game in the lab. Our results can be partially explained by decreased reaction time for go trials found in the violent game condition as compared to the non-violent game condition in Study 2. In contrast to the earlier findings based on the SST paradigm (Colzato et al., 2013; Deleuze et al., 2017; Steenbergen et al., 2015), this effect cannot be explained by an adaptation to the task or high efficiency in response execution, but rather can be understood as an impulsive reaction (cf. Slotter & Finkel, 2011, Figure 1). Self-reported habitual exposure to violent video games did not interact with the experimental manipulation with violent vs. non-violent gameplay and did not affect inhibitory control. Nevertheless, our hypothesis (H2) that inhibitory control would be reduced after playing a violent video game as compared to a non-violent game was supported. Moreover, the impact of violent gameplay on inhibitory control was not driven by the individuals' predispositions as VVGE did not interact with the experimental manipulation, and trait aggression did not correlate with the indicators of inhibitory control.

General Discussion

The present research aimed to test whether playing violent video games was related to and might lead to reduced inhibitory control in adolescents. The results of Study 1 showed that habitual playing violent video games was related to weaker inhibitory control compared to habitual playing non-violent games or not playing video games at all. The results of experimental Study 2 provided support for a causal short-term effect of playing violent video games on reduced inhibitory control as compared to playing non-violent video games while controlling for habitual violent gameplay.

Our results are in line with the expectations based on the I³ Theory (Slotter & Finkel, 2011), the General Aggression Model (Allen et al., 2018; Anderson & Dill, 2000; Anderson & Bushman, 2002), and Reflective-Impulsive Model (Strack & Deutsch, 2004). We suggested that repeated fast reactions in violent video games may stimulate the impulsive system and release automatic behavioral tendencies. Violent video games, like FPS games, encourage participants' fast decisions and automatic reactions, and reward violent actions such as eliminating opponents by shooting as quick and effective as possible. If players are too slow, they may be eliminated from a game, lose points, life or energy, yet acting fast and successful is rewarded by scoring points, credits, getting new equipment, etcetera. Thus, settings of violent video games provide players with immediate positive or negative feedback about their performance, and reinforce learning of violent actions in a game.

After repeated exposure to violent video games, players' reactions to various cues may automatize and become impulsive, increasing likelihood of the execution of other automatic tendencies, e.g., related to food (cf. MacDonald, 2008). This change in the behavioral regulation system could be reflected in faster reactions on go trials immediately after a violent game, and longer stop-signal reaction times (i.e., indicating weaker inhibitory control) in stop trials, similarly to these found in Study 2. Thus, an underlying mechanism explaining the short-term effects of violent video gameplay could be faster onset of a go-process relative to slower onset of a stop-process (cf. Verbruggen & Logan, 2008, Figure II, p. 420) in players of violent video games than in players of non-violent video games.

Given that, our findings are important for understanding of the role of inhibitory control problems related to and resulting from violent video game exposure. Following our results, exposure to violent video games could increase impulsive reactions and decrease reflective reactions, weakening inhibitory control. Lower ability to suppress an impulse may ease aggressive behavior (Slotter & Finkel, 2011). The I³ theory predicts that a provocation

may enhance chances of impulsive responses, such as interpersonal aggression (Slotter & Finkel, 2011). Based on our findings, we further propose that this tendency could be strengthened through violent gameplay. Therefore, we argue that a lower inhibitory control of violent video game players may be understood as a factor underlying aggressive behavior (Slotter & Finkel, 2011).

Our main results hold when controlling for trait aggressiveness which is a well-studied factor that may increase the probability of aggressive behavior and lower the probability to inhibit an impulse (Finkel, 2014). Trait aggressiveness is often studied in violent video game research (e.g., Anderson et al. 2010; Bartholow et al., 2005; Ferguson et al., 2015; Konijn et al., 2007; Veenstra et al., 2017). Our results show that violent video gameplay was related to reduced inhibitory control beyond individual levels of trait aggression.

In general, our findings are in line with previous research on playing violent video games and inhibitory control in adolescents (Kronenberger et al., 2005; Gabbiadini et al., 2013; Gabbiadini et al., 2021; Hummer et al., 2010) and adults (Deleuze et al., 2017). However, our studies are not in line with research that did not find associations between (action) violent video game exposure and inhibitory control measured with the SST in adults (Colzato et al., 2013; Steenbergen et al., 2015). A possible explanation for this mismatch with our results is the difference in the age of the participants: adults in previous studies vs. adolescents in our research. Adolescent gamers are likely a more susceptible group than adults to the effects of violent games on inhibitory control, because adolescents' inhibitory control abilities are still developing (Casey & Caudle, 2013; Cohen-Gilbert & Thomas, 2013). In contrast, adults' abilities to inhibit their reactions are fully developed, explaining why they may perform better in tasks involving inhibition than adolescents. Therefore, adults could be less vulnerable to the effects of violent video games on inhibition than adolescents.

Further, our studies contribute to the existing literature on the use of *emotional* SST in

the violent video game context task (Miedzobrodzka et al, 2021b; Stockdale 2017). While earlier studies indicated *better* inhibitory control over emotional faces in adolescent and in adult samples (Miedzobrodzka et al, 2021b; Stockdale 2017), our findings suggest *worse* inhibitory control over neutral stimuli (i.e., arrows). A possible explanation of such difference is that, in line with the Violent Media Desensitization Model (Carnagey et al., 2007) and recent research (Miedzobrodzka et al., 2021a), exposure to violent video games may desensitize gamers to negative emotional expressions. Such lower sensitivity to emotional stimuli may allow participants to *better* focus on the SST, reflected in shorter SSRT, and not to be distracted by emotional content, which is the case in non-gaming samples (Buczny & Miedzobrodzka, 2019). Application of neutral stimuli in the SST allowed us to better understand the relationship between violent gaming and more generic inhibitory control, without emotional context. Our findings suggest that when processing of emotional stimuli is not involved, exposure to violent video games may have negative effects on inhibitory control.

Some of our results need more careful consideration. In the correlational analyses (Study 1) we found that habitual VVGE was related to reduced inhibitory control. However, in the experimental Study 2 we did not observe such a relationship between habitual VVGE and inhibitory control. There are three possible explanations for such an apparent inconsistency in our results. First, the direct effect of the experimental manipulation (20 minutes of violent vs. non-violent gameplay) in the lab prior to the inhibitory control measure might have overruled a potential effect of habitual VVGE. Playing a violent game in the lab could sort an immediate and stronger effect than habitual violent gaming, however, this might last for a relatively short period of time after gameplay in the lab (cf. Barlett et al., 2009). In contrast, the relationship between habitual VVGE and inhibitory control over longer periods of time might be subtle (cf. Prescott et al., 2018). Therefore, this relationship is less likely to

be found in a long-lasting experimental procedure using the SST (cf. Leong et al., 2022), which could include multiple measurements of an effortful cognitive process (cf. McMorris et al., 2018). Hence, the more lingering effect of habitual VVGE was statistically non-significant compared to the immediate effect of playing a violent game in the lab.

A second alternative explanation is related to different ways of the habitual VVGE measurement in the two studies and the assignment of participants to either high or low VVGE groups in Study 2. In Study 1, violent game exposure was based on the frequency of playing violent games according to M-rated game titles (cf. Colzato et al., 2013). However, in Study 2, the VVGE index was based on self-reported gaming frequency combined with self-rated violent content (cf. Engelhardt et al., 2011). Self-ratings of the level of violence in a game may be different from official game ratings like PEGI (cf. Busching et al., 2015).

A third reason for not finding a relationship between VVGE and inhibitory control in Study 2 could be the fact that the experimental Study 2 had much smaller sample size than the cross-sectional Study 1. However, the alternative Bayesian ANCOVA analyses, which we run for both studies, excluded a possibility of false positive outcomes (cf. Wagenmakers et al., 2018). Given a higher sensitivity of Study 1, the true relationship between habitual VVGE and inhibitory control might be lower than this study suggests (see the 90% CIs for the η^2 ; cf. Albers & Lakens, 2018). In all, the results of Study 1 and Study 2 regarding self-reported frequency of violent gameplay cannot be directly compared but are complementary in providing support for the conceptual model.

Our results inform the field of violent media research in an important way. We consider inhibitory control as a mechanism underlying aggressive behavior that can be studied in a less ambiguous way than aggression as related to playing violent video games (cf. Ferguson & Konijn, 2015). Weaker inhibitory control has been shown to be one of the factors preceding aggression (e.g., Denson et al., 2012; DeWall et al., 2011; DeWall et al., 2011).

Focusing on underlying mechanisms such as inhibitory control can bring clearer insights in understanding how violent video games may affect behavior for several reasons. First, measuring inhibitory control in lab conditions with a well-validated the SST (Lipszyc & Schachar, 2010) is more reliable than any measure of aggression used in gaming research thus far. Second, computer tasks, like the SST, designed to measure behavior or psychological mechanisms are more implicit than self-report questionnaires, and can therefore provide less biased results (cf. Duckworth & Kern, 2011).

In addition, our findings can be relevant to policy makers. As Moffit et al. (2011) indicated, individuals who have higher self-control and are better able to inhibit their reactions, are also more successful in their life as they have better health, wealth, and public safety. Moreover, high self-control enables individuals to set and achieve long-term goals (Tangney et al, 2004), better avoid temptations (Ent et al., 2015), and more effectively control their impulses (De Ridder et al., 2012). Therefore, it is important to encourage the development of self-control (e.g., inhibitory control) and to investigate its possible disruptors, in particular during adolescence. Because inhibitory control still develops during adolescence (Casey & Caudle, 2013; Cohen-Gilbert & Thomas, 2013; Padmanabhan et al., 2011), it is highly relevant to study the role of media use in adolescents during this sensitive developmental period (Crone & Konijn, 2018). Notably, violent games may have the strongest impact on individuals' behavior in early adolescence (Burkhardt & Lenhard, 2021).

Limitations and Future Directions

Whereas our correlational study could not assess a causal direction of effects, this was compensated by conducting an experiment. Still, one may argue that the current experiment has some limitations. For example, in the Study 2, we did not set a baseline of inhibitory control prior to the video gameplay manipulation. Measuring inhibitory control before and immediately after playing a video game would (1) enable a better control for individual

differences in inhibition, (2) provide an insight about an actual *change* in inhibition abilities before and after playing a game (cf. Leong et al., 2022), and finally (3) would allow to test more accurately for the relationship between habitual VVGE and inhibitory control before an experimental manipulation. Therefore, it is recommended that future studies would use within or/and mixed designs (cf. Miedzobrodzka et al., 2022).

It should also be noted that the current experiment (Study 2) did not account for any mechanical differences between the games, such as first vs. third person perspective or level of competitiveness. One important characteristic that should be considered in future research is video game difficulty. Previous studies (Engelhardt et al., 2015) have found that playing video games caused a reduction in cognitive control, though interestingly this effect was only observed when participants perceived the game as difficult. Moreover, Engelhardt et al. (2015) also controlled for variations in video game mechanics by using a violent and nonviolent version of the same game (*Doom*) as well by surveying participants' perceptions of difficulty after the experiment. Implementing both of these methods is worth considering for future research.

Moreover, we acknowledge that using two different measurements of habitual VVGE in our studies complicates a direct comparison between Study 1 and Study 2. In Study 1, the VVGE measurement was based on an objective measures of gaming frequency (hours per day) and violent game content (PEGI rating). In Study 2, the VVGE frequency and violent game content assessment were based on a standard self-report procedure (Anderson & Dill, 2000). Despite this approach to measure VVGE was frequently used in previous research (Busching et al, 2015), using a self-report measurement creates a risk that participants may overestimate or underestimate their gaming habits. Further, a recent study indicated that using different indicators of VVGE may lead to different outcomes (Miedzobrodzka et al., 2021b). Thus, diverse methods to measure VVGE may be a possible explanation why we found the

effect of habitual VVGE in Study 1, but not in Study 2. Based on that, we recommend careful selection of VVGE measures. Future research should apply more objective measurement of VVGE frequency, such as direct estimates (Fikkers et al., 2016) and telemetry data (Johannes et al., 2021), and objective ratings of violent video game content (Busching et al., 2015), as has been done in our Study 1.

Furthermore, trait aggressiveness was not related to any measure of inhibitory control in our two studies as one would have expected (e.g., Pawliczek et al., 2013). Future research could consider other individual differences that may be relevant for studying effects of violent gameplay on inhibitory control. Gray's reinforcement theory describes differences in personality based on two systems grounded in behavior and brain functioning: the Behavioral Inhibition System (BIS) promoting inhibition and the Behavioral Approach System (BAS) promoting approach (Gray, 1970). Past studies showed that the BIS/BAS were related to inhibitory control measured with the SST (Avila & Parcet, 2001) and violent game use in adolescents was negatively related to the BIS and positively related to the BAS (Vangeel et al., 2016). Therefore, future studies could focus on the BIS/BAS as a perhaps more relevant control variable for inhibitory control than trait aggressiveness.

Moreover, our results cannot be generalized to long-term effects of violent gaming (cf. Bushman & Gibson, 2011). A future study could investigate possible long-term effects of violent games regarding changes in inhibitory control in the developing brain. Without such research, we cannot draw any conclusions whether VVGE may interact with the neurodevelopmental processes related to inhibitory control (Coyne et al., 2020). While developmental differences in inhibitory control between adolescents and adults could not always be observed with behavioral studies (e.g., in reaction times), these differences may be measured by applying neuroimaging techniques (Vara et al., 2014). Therefore, future longitudinal studies in diverse age groups could further provide new insights into

developmental changes in inhibitory control among violent game players, both on the behavioral and neural level (cf. Riva et al., 2017).

Further, since we have not measured aggressive behavior, we could not empirically test our theory that inhibitory control may play a mediating role between inhibitory control and aggression. However, in the current work we provided a valid theoretical rationale, which should be fully tested in future studies (see Figure 1).

Nevertheless, considering the ongoing debate about violent video game effects, it would be important to replicate our findings with a preregistered study. Given that we implemented a reliable, well-validated (Verbruggen et al., 2019) and online available measure of inhibitory control (i.e., Millisecond, 2019), it would be feasible to run replication studies, and also consider reciprocal relationships between inhibitory control and violent gaming (Gentile et al., 2012). Finally, a promising avenue for future research is to investigate ways to decrease possible effects of violent video gaming on aggression through a self-control (inhibition) training (Gabbiadini et al., 2021; Frieze et al., 2017).

Conclusion

In all, our findings bring an important theoretical and empirical contribution to the current debate on effects of exposure to violent video games. We highlighted the importance of studying inhibitory control as a possible underlying mechanism of aggressive behavior. We applied a well-validated measure of inhibitory control: the Stop-Signal Task. Our results demonstrated that violent video gameplay is related to and may temporarily result in weaker inhibitory control in adolescents. Future research should further scrutinize the role of habitual exposure to violent video games in and long-term perspective, accounting for inhibitory control development during adolescence.

References

- Albers, C., & Lakens, D. (2018). When power analyses based on pilot data are biased: Inaccurate effect size estimators and follow-up bias. *Journal of Experimental Social Psychology*, 74, 187–195. <https://doi.org/10.1016/j.jesp.2017.09.004>
- Allen, J. J., Anderson, C. A., & Bushman, B. J. (2018). The General Aggression Model. *Current Opinion in Psychology*, 19, 75–80. <https://doi.org/10.1016/j.copsyc.2017.03.034>
- Anderson, C. A., & Bushman, B. J. (2002). Human aggression. *Annual Review Psychology*, 53, 27–51. <https://doi.org/10.1146/annurev.psych.53.100901.135231>
- Anderson, C. A., & Dill, K. E. (2000). Video games and aggressive thoughts, feelings, and behavior in the laboratory and in life. *Journal of Personality and Social Psychology*, 78, 772–790. <https://doi.org/10.1037/0022-3514.78.4.772>
- Anderson, C. A. Shiubuya, A., Ihori, N., Swing, E. L., Bushman, B. J., & Sakamoto, A. et al. (2010). Violent video game effects on aggression, empathy, and prosocial behavior in Eastern and Western countries: A meta-analytic review. *Psychological Bulletin*, 136, 151–173. <https://doi.org/10.1037/a0018251>
- Avila, C., & Parcet, M. (2001). Personality and inhibitory deficits in the stop-signal task: The mediating role of Gray's anxiety and impulsivity. *Personality and Individual Differences*, 31, 975–986. [https://doi.org/10.1016/s0191-8869\(00\)00199-9](https://doi.org/10.1016/s0191-8869(00)00199-9)
- Barlett, C., Branch, O., Rodeheffer, C., & Harris, R. (2009). How long do the short-term violent video game effects last? *Aggressive Behavior*, 35, 225–236. <https://doi.org/10.1002/ab.20301>
- Bartholdy, S., Dalton, B., O'Daly, O., Campbell, I., & Schmidt, U. (2016). A systematic review of the relationship between eating, weight and inhibitory control using the stop signal task. *Neuroscience and Biobehavioral Reviews*, 64, 35–62. <https://doi.org/10.1016/j.neubiorev.2016.02.010>
- Bartholow, B., Sestir, M., & Davis, E. (2005). Correlates and consequences of exposure to video

- game violence: Hostile personality, empathy, and aggressive behavior. *Personality and Social Psychology Bulletin*, 31, 1573–1586. <https://doi.org/10.1177/0146167205277205>
- Baumeister, R. F. (2014). Self-regulation, ego depletion, and inhibition. *Neuropsychologia*, 65, 313–319. <https://doi.org/10.1016/j.neuropsychologia.2014.08.012>
- Blakemore, S.-J., & Mills, K. L. (2014). Is adolescence a sensitive period for sociocultural processing? *Annual Review of Psychology*, 65, 187–207. <https://doi.org/10.1146/annurev-psych-010213-115202>
- Blakemore, S.-J., & Robbins, T. W. (2012). Decision-making in the adolescent brain. *Nature Neuroscience*, 15, 1184–1191. <https://doi.org/10.1038/nn.3177>
- Buczny, J., Międzobrodzka, E. (2019, March). *Stop or go: Disgust and anger expressions moderate inhibitory control*. Poster presented at the International Convention of Psychological Science, Paris. <https://doi.org/10.17605/OSF.IO/AS7HC>
- Burkhardt, J., & Lenhard, W. (2021). A meta-analysis on the longitudinal, age-dependent effects of violent video games on aggression. *Media Psychology*, 25, 1–14. <https://doi.org/10.1080/15213269.2021.1980729>
- Busch, V., & De Leeuw, J. (2013). Unhealthy behaviors in adolescents: Multibehavioral associations with psychosocial problems. *International Journal of Behavioral Medicine*, 21, 439–446. <https://doi.org/10.1007/s12529-013-9316-z>
- Busching, R., Gentile, D., Krahé, B., Möller, I., Khoo, A., Walsh, D., & Anderson, C. (2015). Testing the reliability and validity of different measures of violent video game use in the United States, Singapore, and Germany. *Psychology of Popular Media Culture*, 4, 97–111. <https://doi.org/10.1037/ppm0000004>
- Bushman, B. J. (2014). *Aggression often starts when self-control stops*. TEDx talk. Retrieved from: <http://tinyurl.com/kau7xfk>
- Anderson, C. A., & Bushman, B. J. (2018). Media Violence and the General Aggression Model.

- Journal of Social Issues*, 74, 386–413. <http://doi.org/10.1111/josi.12275>
- Bushman, B. J., & Anderson, C. A. (2021). Solving the puzzle of null violent media effects. *Psychology of Popular Media*. Advance online publication. <http://doi.org/10.1037/ppm0000361>
- Bushman, B. J., & Gibson, B. (2011). Violent video games cause an increase in aggression long after the game has been turned off. *Social Psychological and Personality Science*, 2, 29–32. <http://doi.org/10.1177/1948550610379506>
- Bushman, B. J., Gollwitzer, M., & Cruz, C. (2015). There is broad consensus: Media researchers agree that violent media increase aggression in children, and pediatricians and parents concur. *Psychology of Popular Media Culture*, 4, 200–214. <https://doi.org/10.1037/ppm0000046>
- Bushman, B. J., & Huesmann, L. R. (2014). Twenty-five years of research on violence in digital games and aggression revisited. *European Psychologist*, 19, 47–55. <https://doi.org/10.1027/1016-9040/a000164>
- Buss, A. H., & Perry, M. (1992). The aggression questionnaire. *Journal of Personality and Social Psychology*, 63, 452–459. <https://doi.org/10.1037/0022-3514.63.3.452>
- Carnagey, N. L., & Anderson, C. A. (2004). Violent video game exposure and aggression: A literature review. *Minerva Psichiatrica*, 45(1), 1–8. Retrieved from: <http://www.minervamedica.it/en/journals/37inerva-psichiatrica/article.php?cod=R17Y2004N01A0001>
- Carnagey, N. L., Anderson, C., & Bushman, B. (2007). The effect of video game violence on physiological desensitization to real-life violence. *Journal of Experimental Social Psychology*, 43, 489–496. <https://doi.org/10.1016/j.jesp.2006.05.003>
- Casey, B., & Caudle, K. (2013). The teenage brain: Self control. *Current Directions in Psychological Science*, 22, 82–87. <https://doi.org/10.1177/0963721413480170>
- Cohen, J. R., & Lieberman, M. D. (2010). The common neural basis of exerting self-control in multiple domains. In: R. R. Hassin, K. N. Ochsner & Y. Trope (Eds.), *Self control in society*,

mind, and brain (pp. 141–162). Oxford: Oxford University Press.

<https://doi.org/10.1093/acprof:oso/9780195391381.003.0008>

Cohen-Gilbert, J., & Thomas, K. (2013). Inhibitory control during emotional distraction across adolescence and early adulthood. *Child Development, 84*, 1954–1966.

<https://doi.org/10.1111/cdev.12085>

Colzato, L., van den Wildenberg, W. M., Zmigrod, S., & Hommel, B. (2013). Action video gaming and cognitive control: Playing first person shooter games is associated with improvement in working memory but not action inhibition. *Psychological Research, 77*, 234–239.

<https://doi.org/10.1007/s00426-012-0415-2>

Coyne, S., & Stockdale, L. (2021). Growing up with Grand Theft Auto: A 10-year study of longitudinal growth of violent video game play in adolescents. *Cyberpsychology, Behavior, and Social Networking, 24*, 11–16. <https://doi.org/10.1089/cyber.2020.0049>

Coyne, S. M., Stockdale, L. A., Warburton, W., Gentile, D. A., Yang, C., & Merrill, B. M. (2020). Pathological video game symptoms from adolescence to emerging adulthood: A 6-year longitudinal study of trajectories, predictors, and outcomes. *Developmental Psychology, 56*, 1385–1396. <https://doi.org/10.1037/dev0000939>

Crone, E. A., & Dahl, R. E. (2012). Understanding adolescence as a period of social-affective engagement and goal flexibility. *Nature Reviews Neuroscience, 13*, 636–650.

<https://doi.org/10.1038/nrn3313>

Crone, E. A., & Konijn, E. A., (2018). Media use and brain development during adolescence. *Nature Communications, 9*, 558. <https://doi.org/10.1038/s41467-018-03126-x>

Davidson, R. J., Putnam, K. M., & Larson, C. L. (2000). Dysfunction in the neural circuitry of emotion regulation—A possible prelude to violence. *Science, 289*, 591–594.

<https://doi.org/10.1126/science.289.5479.591>

Deleuze, J., Christiaens, M., Nuyens, F., & Billieux, J. (2017). Shoot at first sight! First person

shooter players display reduced reaction time and compromised inhibitory control in comparison to other video game players. *Computers in Human Behavior*, 72, 570–576.

<https://doi.org/10.1016/j.chb.2017.02.027>

Denson, T. F., Capper, M. M., Oaten, M., Friese, M., & Schofield, T. P. (2011a). Self-control training decreases aggression in response to provocation in aggressive individuals. *Journal of Research in Personality*, 45, 252–256. <https://doi.org/10.1016/j.jrp.2011.02.001>

Denson, T. F., DeWall, C. N., & Finkel, E. J. (2012). Self-control and aggression. *Current Directions in Psychological Science*, 21, 20–25. <https://doi.org/10.1177/0963721411429451>

Denson, T. F., Pedersen, W. C., Friese, M., Hahm, A., & Roberts, L. (2011b). Understanding impulsive aggression: Angry rumination and reduced self-control capacity are mechanisms underlying the provocation-aggression relationship. *Personality and Social Psychology Bulletin*, 37, 850–862. <https://doi.org/10.1177/0146167211401420>

De Ridder, D. T. D., Lensvelt-Mulders, G., Finkenauer, C., Stok, F. M., & Baumeister, R. F. (2012). Taking stock of self-control: A meta-analysis of how trait self-control relates to a wide range of behaviors. *Personality and Social Psychology Review*, 16, 76–99. <https://doi.org/10.1177/1088868311418749>

DeWall, C. N., Deckman, T., Gailliot, M. T., & Bushman, B. J. (2011). Sweetened blood cools hot tempers: Physiological self-control and aggression. *Aggressive Behavior*, 37, 73–80. <https://doi.org/10.1002/ab.20366>

DeWall, C. N., Anderson, C. A., & Bushman, B. J. (2011). The General Aggression Model: Theoretical extensions to violence. *Psychology of Violence*, 1, 245–258. <https://doi.org/10.1037/a0023842>

Duckworth, A. L., & Kern, M. L. (2011). A meta-analysis of the convergent validity of self-control measures. *Journal of Research in Personality*, 45, 259–268. <https://doi.org/10.1016/j.jrp.2011.02.004>

- Eastin, M. (2006). Video game violence and the female game player: Self- and opponent gender effects on presence and aggressive thoughts. *Human Communication Research*, 32, 351–372. <https://doi.org/10.1111/j.1468-2958.2006.00279.x>
- Elson, M., & Ferguson, C. J. (2014). Twenty-five years of research on violence in digital games and aggression. *European Psychologist*, 19, 33–46. <https://doi.org/10.1027/1016-9040/a000147>
- Engelhardt, C., Bartholow, B., Kerr, G., & Bushman, B. (2011). This is your brain on violent video games: Neural desensitization to violence predicts increased aggression following violent video game exposure. *Journal of Experimental Social Psychology*, 47, 1033–1036. <https://doi.org/10.1016/j.jesp.2011.03.027>
- Engelhardt, C., Mazurek, M., Hilgard, J., Rouder, J., & Bartholow, B. (2015). Effects of violent-video-game exposure on aggressive behavior, aggressive-thought accessibility, and aggressive affect among adults with and without autism spectrum disorder. *Psychological Science*, 26, 1187–1200. <https://doi.org/10.1177/0956797615583038>
- Ent, M., Baumeister, R., & Tice, D. (2015). Trait self-control and the avoidance of temptation. *Personality and Individual Differences*, 74, 12–15. <https://doi.org/10.1016/j.paid.2014.09.031>
- Entertainment Software Rating Board. (2022). Retrieved from: <http://www.esrb.org/ratings/search.aspx?from=home&titleOrPublisher=portal%202>
- Ferguson, C. (2015). Do angry birds make for angry children? A meta-analysis of video game influences on children's and adolescents' aggression, mental health, prosocial behavior, and academic performance. *Perspectives on Psychological Science*, 10, 646–666. <https://doi.org/10.1177/1745691615592234>
- Ferguson, C. J., Copenhaver, A., & Markey, P. (2020). Reexamining the findings of the American Psychological Association's 2015 Task Force on Violent Media: A meta-analysis. *Perspectives on Psychological Science*, 15, 1423–1443. <http://doi.org/10.1177/1745691620927666>
- Ferguson, C. J., Barr, H., Figueroa, G., Foley, K., Gallimore, A., & LaQuea, R. et al. (2015). Digital

- poison? Three studies examining the influence of violent video games on youth. *Computers in Human Behavior*, 50, 399–410. <https://doi.org/10.1016/j.chb.2015.04.021>
- Ferguson, C. J., & Konijn, E. A. (2015). She said/he said: A peaceful debate on video game violence. *Psychology of Popular Media Culture*, 4, 397–411. <https://doi.org/10.1037/ppm0000064>
- Fikkers, K., Piotrowski, J., & Valkenburg, P. (2016). Assessing the Reliability and Validity of Television and Game Violence Exposure Measures. *Communication Research*, 44, 117–143. <https://doi.org/10.1177/0093650215573863>
- Finkel, E. J. (2014). Chapter one – The I³ model: Metatheory, theory, and evidence. In: M. O. James & P. Z. Mark (Eds.), *Advances in Experimental Social Psychology* (vol. 49, pp. 1–104): Academic Press. <https://doi.org/10.1016/B978-0-12-800052-6.00001-9>
- Fosco, W., Hawk, L., Colder, C., Meisel, S., & Lengua, L. (2019). The development of inhibitory control in adolescence and prospective relations with delinquency. *Journal of Adolescence*, 76, 37–47. <https://doi.org/10.1016/j.adolescence.2019.08.0083>
- Friese, M., Frankenbach, J., Job, V., & Loschelder, D. D. (2017). Does self-control training improve self-control? A meta-analysis. *Perspectives on Psychological Science*, 12, 1077–1099. <http://doi.org/10.1177/1745691617697076>
- Gabbiadini, A., Riva, P., Andrighetto, L., Volpato, C., & Bushman, B. J. (2013). Interactive effect of moral disengagement and violent video games on self-control, cheating, and aggression. *Social Psychological and Personality Science*, 5, 451–458. <https://doi.org/10.1177/1948550613509286>
- Gabbiadini, A., Riva, P., Andrighetto, L., Volpato, C., & Bushman, B. J. (2021). Preliminary evidence of the effectiveness of a brief self-control intervention on reducing the short-term harmful consequences of violent video games on adolescents. *Journal of Applied Social Psychology*. Advance online publication. <https://doi.org/10.1111/jasp.12854>
- Garavan, H., Ross, T. J., Murphy, K., Roche, R. A., & Stein, E. A. (2002). Dissociable executive

functions in the dynamic control of behavior: Inhibition, error detection, and correction.

NeuroImage, 17, 1820–1829. <https://doi.org/10.1006/nimg.2002.1326>

Gentile, D. A., Swing, E. L., Lim, C. G., & Khoo, A. (2012). Video game playing, attention problems, and impulsiveness: Evidence of bidirectional causality. *Psychology of Popular Media Culture*, 1, 62–70. <https://doi.org/10.1037/a0026969>

Gray, J. A. (1970). The psychophysiological basis of introversion-extraversion. *Behaviour Research and Therapy*, 8, 249–266. [https://doi.org/10.1016/0005-7967\(70\)90069-0](https://doi.org/10.1016/0005-7967(70)90069-0)

Greitemeyer, T., & Mügge, D. O. (2014). Video games do affect social outcomes: A meta-analytic review of the effects of violent and prosocial video game play. *Personality and Social Psychology Bulletin*, 40, 578–589. <https://doi.org/10.1177/0146167213520459>

Hofmann, W., Friese, M., & Strack, F. (2009). Impulse and self-control from a dual-systems perspective. *Perspectives on Psychological Science*, 4, 162–176. <https://doi.org/10.1111/j.1745-6924.2009.01116.x>

Hull, J., Brunelle, T., Prescott, A., & Sargent, J. (2014). A longitudinal study of risk-glorifying video games and behavioral deviance. *Journal of Personality and Social Psychology*, 107, 300–325. <https://doi.org/10.1037/a0036058>

Hummer, T. A., Wang, Y., Kronenberger, W. G., Mosier, K. M., Kalnin, A. J., Dunn, D. W., & Mathews, V. P. (2010). Short-term violent video game play by adolescents alters prefrontal activity during cognitive inhibition. *Media Psychology*, 13, 136–154. <https://doi.org/10.1080/15213261003799854>

Inquisit 4.0.4.0 [Computer software]. (2013). Seattle, WA: Millisecond Software.

Ivory, J. D., Markey, P. M., Elson, M., Colwell, J., Ferguson, C. J., Griffiths, M. D., . . . Williams, K. D. (2015). Manufacturing consensus in a diverse field of scholarly opinions: A comment on Bushman, Gollwitzer, and Cruz (2015). *Psychology of Popular Media Culture*, 4, 222–229. <https://doi.org/10.1037/ppm0000056>

- Jansz, J. (2005). The emotional appeal of violent video games for adolescent males. *Communication Theory*, 15, 219–241. <https://doi.org/10.1111/j.1468-2885.2005.tb00334.x>
- Johannes, N., Vuorre, M., & Przybylski, A. (2021). Video game play is positively correlated with well-being. *Royal Society Open Science*, 8. <https://doi.org/10.1098/rsos.202049>
- Khng, K. H., & Lee, K. (2014). The relationship between Stroop and stop-signal measures of inhibition in adolescents: Influences from variations in context and measure estimation. *PloS ONE*, 9, e101356. <https://doi.org/10.1371/journal.pone.0101356>
- Konijn, E. A., Nije Bijvank, M., & Bushman, B. J. (2007). I wish I were a warrior: The role of wishful identification in the effects of violent video games on aggression in adolescent boys. *Developmental Psychology*, 43, 1038–1044. <https://doi.org/10.1037/0012-1649.43.4.1038>
- Konijn, E.A., Veldhuis, J., Plaisier, X. S., Spekman, M., & Den Hamer, A. (2015). Psychology of digital media and youth. In: S. S. Shyam (Ed.), *Handbook on the psychology of communication technology* (pp. 332–363). Hoboken, NJ: Wiley-Blackwell.
- Krahé, B., & Möller, I. (2010). Longitudinal effects of media violence on aggression and empathy among German adolescents. *Journal of Applied Developmental Psychology*, 31, 401–409. <https://doi.org/10.1016/j.appdev.2010.07.003>
- Kronenberger, W. G., Mathews, V. P., Dunn, D. W., Wang, Y., Wood, E. A., & Giauque, A. L. et al. (2005). Media violence exposure and executive functioning in aggressive and control adolescents. *Journal of Clinical Psychology*, 61, 725–737. <https://doi.org/10.1002/jclp.20022>
- Leong, A. Y. C., Yong, M. H., & Lin, M.-H. (2022). The effect of strategy game types on inhibition. *Psychological Research*. Advance online publication. <https://doi.org/10.1007/s00426-021-01632-0>
- Lenhart, A. (2015). Teens, social media and technology overview 2015. Retrieved from: <http://www.pewinternet.org/2015/04/09/teens-social-media-technology-2015>
- Liddle, P., Kiehl, K., & Smith, A. (2001). Event-related fMRI study of response inhibition. *Human*

- Brain Mapping*, 12, 100–109. [https://doi.org/10.1002/1097-0193\(200102\)12:2<100::aid-hbm1007>3.0.co;2-6](https://doi.org/10.1002/1097-0193(200102)12:2<100::aid-hbm1007>3.0.co;2-6)
- Lipszyc, J., & Schachar, R. (2010). Inhibitory control and psychopathology: A meta-analysis of studies using the stop signal task. *Journal of the International Neuropsychological Society*, 16, 1064–1076. <https://doi.org/10.1017/s1355617710000895>
- Logan, G. D. (1994). On the ability to inhibit thought and action: A users' guide to the stop signal paradigm. In: D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 189–239). San Diego, CA, US: Academic Press.
- Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review*, 91, 295–327. <https://doi.org/10.1037/0033-295X.91.3.295>
- Lorenz, R. C., Gleich, T., Gallinat, J., & Kühn, S. (2015). Video game training and the reward system. *Frontiers in Human Neuroscience*, 9. <https://doi.org/10.3389/fnhum.2015.00040>
- MacDonald, K. B. (2008). Effortful control, explicit processing, and the regulation of human evolved predispositions. *Psychological Review*, 115, 1012–1031. <https://doi.org/10.1037/a0013327>
- McMorris, T., Barwood, M., Hale, B. J., Dicks, M., & Corbett, J. (2018). Cognitive fatigue effects on physical performance: A systematic review and meta-analysis. *Physiology & Behavior*, 188, 103–107. <https://doi.org/10.1016/j.physbeh.2018.01.029>
- Miedzobrodzka, E., Buczny, J., Konijn, E. A., & Krabbendam, L. C. (2021a). Insensitive players? A relationship between violent video game exposure and recognition of negative emotions. *Frontiers in Psychology*, 12, 1731. <https://doi.org/10.3389/fpsyg.2021.651759>
- Miedzobrodzka, E., Konijn, E., & Krabbendam, L. (2021b). Emotion recognition and inhibitory control in adolescent players of violent video games. *Journal of Research on Adolescence*. Advance online publication. <https://doi.org/10.1111/jora.12704>
- Miedzobrodzka, E., van Hooff, J. C., Konijn, E. A., & Krabbendam, L. (2022). Is it painful? Playing violent video games affects brain responses to painful pictures: An event-related potential

- study. *Psychology of Popular Media*, 11, 13–23. <https://doi.org/10.1037/ppm0000290>
- Meijers, J., Harte, J., Meynen, G., & Cuijpers, P. (2017). Differences in executive functioning between violent and non-violent offenders. *Psychological Medicine*, 47, 1784-1793. <https://doi.org/10.1017/S0033291717000241>
- Metacritic. (2022). Retrieved from: <http://www.metacritic.com/about-metacritic>
- Michailidis, L., Balaguer-Ballester, E., & He, X. (2018). Flow and immersion in video games: The aftermath of a conceptual challenge. *Frontiers in Psychology*, 9. <https://doi.org/10.3389/fpsyg.2018.01682>
- Millisecond. (2019). The Stop Signal Task. Retrieved from: <http://www.millisecond.com/download/library/stopsignaltask/>
- Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., & Harrington, H. et al. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences*, 108, 2693–2698. <https://doi.org/10.1073/pnas.1010076108>
- Morey, R. D., & Rouder (2018). BayesFactor: Computation of Bayes factors for common designs (R package version 0.9.12-4.2) [Computer software]. Retrieved from <https://CRAN.R-project.org/package=BayesFactor>
- Muraven, M. (2010). Practicing self-control lowers the risk of smoking lapse. *Psychology of Addictive Behaviors*, 24, 446–452. <https://doi.org/10.1037/a0018545>
- Nielsen. (2014). Multi-platform gaming: For the win! Retrieved from: <http://www.nielsen.com/us/en/insights/news/2014/multi-platform-gaming-for-the-win.html>
- Nielsen. (2015). Tops of 2015: Video games. Retrieved from: <http://www.nielsen.com/us/en/insights/news/2015/tops-of-2015-video-games.html>
- Nije Bijvank, M., Konijn, E., Bushman, B., & Roelofsma, P. (2009). Age and violent-content labels make video games forbidden fruits for youth. *Pediatrics*, 123, 870–876. <https://doi.org/10.1542/peds.2008-0601>

- Olson, C. K., Kutner, L. A., Baer, L., Beresin, E. V., Warner, D. E., & Nicholi II, A. M. (2009). M-rated video games and aggressive or problem behavior among young adolescents. *Applied Developmental Science, 13*, 188–198. <https://doi.org/10.1080/10888690903288748>
- Padmanabhan, A., Geier, C. F., Ordaz, S. J., Teslovich, T., & Luna, B. (2011). Developmental changes in brain function underlying the influence of reward processing on inhibitory control. *Developmental Cognitive Neuroscience, 1*, 517–529. <https://doi.org/10.1016/j.dcn.2011.06.004>
- Padmala, S., & Pessoa, L. (2011). Reward reduces conflict by enhancing attentional control and biasing visual cortical processing. *Journal of Cognitive Neuroscience, 23*, 3419–3432. https://doi.org/10.1162/jocn_a_00011
- Pawliczek, C. M., Derntl, B., Kellermann, T., Kohn, N., Gur, R. C., & Habel, U. (2013). Inhibitory control and trait aggression: Neural and behavioral insights using the emotional stop signal task. *NeuroImage, 79*, 264–274. <https://doi.org/10.1016/j.neuroimage.2013.04.104>
- PEGI. Pan European Game Information. (2017). Retrieved from: www.pegi.info
- Prescott, A., Sargent, J., & Hull, J. (2018). Metaanalysis of the relationship between violent video game play and physical aggression over time. *Proceedings of The National Academy of Sciences, 115*, 9882–9888. <https://doi.org/10.1073/pnas.1611617114>
- R Core Team (2022). R: A language and environment for statistical computing [Computer software]. R Foundation for Statistical Computing, Vienna, Austria Retrieved from <https://www.r-project.org/>
- Ribbens, W., Malliet, S., van Eck, R., & Larkin, D. (2016). Perceived realism in shooting games: Towards scale validation. *Computers in Human Behavior, 64*, 308–318. <https://doi.org/10.1016/j.chb.2016.06.055>
- Rideout, V., Foehr, U. G., & Roberts, D. F. (2010). Generation M2: Media in the lives of 8- to 18-year-old. Retrieved from <http://kff.org/other/report/generation-m2-media-in-the-lives-of-8-to-18-year-olds/>

- Riva, P., Gabbiadini, A., Romero Lauro, L. J., Andrighetto, L., Volpato, C., & Bushman, B. J. (2017). Neuromodulation can reduce aggressive behavior elicited by violent video games. *Cognitive, Affective, & Behavioral Neuroscience*, 17, 452–459. <https://doi.org/10.3758/s13415-016-0490-8>
- Rubia, K., Russell, T., Overmeyer, S., Brammer, M. J., Bullmore, E. T., Sharma, T. et al. (2001). Mapping motor inhibition: Conjunctive brain activations across different versions of go/no-go and stop tasks. *NeuroImage*, 13, 250–261. <https://doi.org/10.1006/nimg.2000.0685>
- Schneider, E. F., Lang, A., Shin, M., & Bradley, S. D. (2004). Death with a story: How story impacts emotional, motivational, and physiological responses to first-person shooter video games. *Human Communication Research*, 30, 361–375. <https://doi.org/10.1111/j.1468-2958.2004.tb00736.x>
- Slotter, E. B. E., & Finkel, E. E. J. (2011). I³ theory: Instigating, impelling, and inhibiting factors in aggression. In: P. R. Shaver & M. Mikulincer (Eds.), *Human aggression and violence: Causes, manifestations, and consequences* (pp. 35–52). <https://doi.org/10.1037/12346-002>
- Smith, P. L., & Little, D. R. (2018). Small is beautiful: In defense of the small-N design. *Psychonomic Bulletin & Review*, 25, 2083–2101. <https://doi.org/10.3758/s13423-018-1451-8>
- Steenbergen, L., Sellaro, R., Stock, A., Beste, C., & Colzato, L. (2015). Action video gaming and cognitive control: Playing first person shooter games is associated with improved action cascading but not inhibition. *PLOS ONE*, 10, e0144364. <https://doi.org/10.1371/journal.pone.0144364>
- Strack, F., & Deutsch, R. (2004). Reflective and impulsive determinants of social behavior. *Personality and Social Psychology Review*, 8, 220–247. https://doi.org/10.1207/s15327957pspr0803_1
- Strasburger, V. C., Jordan, A. B., & Donnerstein, E. (2010). Health effects of media on children and adolescents. *Pediatrics*, 125, 756–767. <https://doi.org/10.1542/peds.2009-2563>

- Tangney, J. P., Baumeister, R. F., & Boone, A. L. (2004). High self-control predicts good adjustment, less pathology, better grades, and interpersonal success. *Journal of Personality*, 72, 271–324. <https://doi.org/10.1111/j.0022-3506.2004.00263.x>
- Telzer, E. H. (2016). Dopaminergic reward sensitivity can promote adolescent health: A new perspective on the mechanism of ventral striatum activation. *Developmental Cognitive Neuroscience*, 17, 57–67. <https://doi.org/10.1016/j.dcn.2015.10.010>
- Teng, S., Chong, G., Siew, A., & Skoric, M. (2011). Grand Theft Auto IV comes to Singapore: Effects of repeated exposure to violent video games on aggression. *Cyberpsychology, Behavior, and Social Networking*, 14, 597–602. <https://doi.org/10.1089/cyber.2010.0115>
- Vangeel, J., Beullens, K., Vervoort, L., Cock, N., Lippevelde, W., Goossens, L., & Eggermont, S. (2016). The role of behavioral activation and inhibition in explaining adolescents' game use and game engagement levels. *Media Psychology*, 20, 116–143. <https://doi.org/10.1080/15213269.2016.1142378>
- Vara, A., Pang, E., Vidal, J., Anagnostou, E., & Taylor, M. (2014). Neural mechanisms of inhibitory control continue to mature in adolescence. *Developmental Cognitive Neuroscience*, 10, 129–139. <https://doi.org/10.1016/j.dcn.2014.08.009>
- Veenstra, L., Schneider, I., Bushman, B., & Koole, S. (2017). Drawn to danger: Trait anger predicts automatic approach behaviour to angry faces. *Cognition and Emotion*, 31, 765–771. <https://doi.org/10.1080/02699931.2016.1150256>
- Verbruggen, F., Aron, A. R., Band, G. P., Beste, C., Bissett, P. G., Brockett, A. T., et al. (2019). A consensus guide to capturing the ability to inhibit actions and impulsive behaviors in the stop-signal task. *eLife*, 8, e46323. <http://doi.org/10.7554/eLife.46323>
- Verbruggen, F., & Logan, G. D. (2008). Response inhibition in the stop-signal paradigm. *Trends in Cognitive Sciences*, 12, 418–424. <https://doi.org/10.1016/j.tics.2008.07.005>
- Verbruggen, F., Logan, G. D., & Stevens, M. A. (2008). STOP-IT: Windows executable software for

the stop-signal paradigm. *Behavior Research Methods*, 40, 479–483.

<https://doi.org/10.3758/BRM.40.2.479>

Wagenmakers, E.-J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., et al. (2018). Bayesian inference for psychology. Part I: Theoretical advantages and practical ramifications.

Psychonomic Bulletin & Review, 25, 35–57. <http://doi.org/10.3758/s13423-017-1343-3>

Warburton, W. A., & Bushman, B. J. (2019). The competitive reaction time task: The development and scientific utility of a flexible laboratory aggression paradigm. *Aggressive Behavior*, 45, 389–396. <http://doi.org/10.1002/ab.21829>

Wessel, J. R. (2017). Prepotent motor activity and inhibitory control demands in different variants of the go/no-go paradigm. *Psychophysiology*, 55, e12871. <https://doi.org/10.1111/psyp.12871>

8 Footnotes

¹ “*Impellance* characterizes the potentially aggressive person’s <<urge readiness>> at the moment of encountering the instigation” (Denson et al., 2012, p. 21).

² In order to exclude a possibility that our analyses could lead to false positive outcomes (cf. Wagenmakers et al., 2018), we performed an alternative analysis applying a Bayesian ANCOVA model in R (R Core Team, 2022) using the *BayesFactor* package (Morey & Rouder, 2018). We used default settings for priors. For SSRT used as a dependent variable, results showed that a model which included VVGE as a fixed factor provided the strongest support for H1, $BF_{10} = 226.29$. Further, a model which included VVGE with trait aggression yielded very strong evidence, but substantially weaker than the first model, $BF_{10} = 55.44$, similarly to a model which included VVGE, trait aggression, and gender, $BF_{10} = 10.79$. For SSD as a dependent variable, results showed that a model which included VVGE as a fixed factor provided very strong evidence, $BF_{10} = 46.97$. Further, a model, which included VVGE trait aggression yielded substantially weaker evidence, $BF_{10} = 10.97$, similarly to a model which included VVGE, trait aggression, and gender, $BF_{10} = 2.83$. The analysis code is available at https://osf.io/4qtpk/?view_only=e89185c8523e4fbe82633224a7eef375.

³ We analyzed whether the location of data collection differed. An independent samples *t*-test showed that the mean SSRT at the university’s lab ($n = 29$, $M = 291$, $SD = 76$) and at the school’s lab ($n = 33$, $M = 264$, $SD = 53$) did not differ significantly, $t(60) = 1.63$, $p = .110$, Cohen’s $d = 0.42$.

⁴ As the sample size in Study 2 could be considered small, and thus, our analyses could lead to false positive outcomes (cf. Wagenmakers et al., 2018), we run a Bayesian ANCOVA. We used default settings for priors. For SSRT used as a dependent variable, analysis showed that a model, which included the type of game as a fixed factor, provided anecdotal support for H2, $BF_{10} = 1.50$. Further, a model which included the type of game and

VVGE as two factors provided no substantial evidence, $BF_{10} = 0.41$, similarly to a model which included the type of game, VVGE, and an interaction the Game Type x VVGE, $BF_{10} = 0.18$. Lastly, a model with the type of game, VVGE, an interaction the Game Type x VVGE, and trait aggression showed similar results, $BF_{10} = 0.05$. For SSD used as a dependent variable, results showed that a model with the type of game as a fixed factor provided the strongest yet moderate support for H2, $BF_{10} = 4.91$. A model with the type of game and VVGE as fixed factors provided anecdotal evidence, $BF_{10} = 1.31$. A model with the type of game, VVGE, and an interaction the Game Type x VVGE, provided no substantial evidence, $BF_{10} = 0.44$. Finally, a model with the type of game, VVGE, an interaction the Game Type x VVGE, and trait aggression showed similar results, $BF_{10} = 0.14$. The code is available at https://osf.io/4qtpk/?view_only=e89185c8523e4fbe82633224a7eef375.

Table 1

Means, Standard Deviations, and Correlations between Variables in Study 1 (N = 150)

Variable	1	2	3	4	5
1. SSRT	—	−0.31**	−0.04	0.11	0.07
2. SSD		—	0.04	−0.16	−0.02
3. BPAQ			—	−0.08	0.06
4. Gender				—	0.23*
5. Age					—
<i>M</i>	244	324	2.72	1.58	16.98
<i>SD</i>	68	173	.57	.05	1.01

Note. SSRT = average stop-signal reaction time (in milliseconds). SSD = average stop-signal delay (in milliseconds). BPAQ = trait aggression. Gender: 1 = female, 2 = male.

* $p < .05$. ** $p < .01$.

Table 2

Means, Standard Deviations, and Correlations between Variables in Study 2 (N = 62)

Variable	1	2	3	4
1. SSRT	—	−0.53*	−0.03	0.12
2. SSD		—	−0.11	0.02
3. BPAQ			—	−0.01
4. Age				—
<i>M</i>	276	391	2.17	14.02
<i>SD</i>	66	179	.83	1.08

Note. SSRT = average stop-signal reaction time (in milliseconds). SSD = average stop-signal delay (in milliseconds). BPAQ = trait aggression.

* $p < .001$.

Figure 1. Integration of three theories explaining relationships between aggression and inhibitory control – *I³ theory*, aggression and violent video game exposure (VVGE) – *General Aggression Model* (GAM; Anderson & Bushman, 2002), and violent video game exposure and inhibitory control – *Reflective Impulsive Model* (RIM; Strack & Deutsch, 2004).

Figure 2. Examples of go trials (A) and stop trials (B) in the SST (Verbruggen & Logan, 2008). In the go trials (75% of all trials), participants are instructed to, as fast as possible, press ‘K’ for the right arrow (go-stimulus), or ‘D’ for the left arrow (go-stimulus). In the stop trials (25% of all trials), a go-stimulus is followed by a stop signal through headphones. In the stop trial, participants are instructed to withhold their response and to not press any button on the keyboard. More details could be found in Method section of Study 1.