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REVIEW ARTICLE

The Empirical Analysis of Non-problematic Video Gaming and Cognitive Skills: A Systematic Review

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Abstract Videogames have become one of the most popular leisure activities worldwide, including multiple game genres with different characteristics and levels of involvement required. Although a small minority of excessive players suffer detrimental consequences including impairment of several cognitive skills (e.g., inhibition, decision-making), it has also been demonstrated that playing videogames can improve different cognitive skills. Therefore, the current paper systematically reviewed the empirical studies experimentally investigating the positive impact of videogames on cognitive skills. Following a number of inclusion and exclusion criteria, a total of 32 papers were identified as empirically investigating three specific skills: taskswitching (eight studies), attentional control (22 studies), and sub-second time perception (two studies). Results demonstrated that compared to control groups, non-problematic use of videogames can lead to improved task-switching, more effective top-down attentional control and processing speed and increased sub-second time perception. Two studies highlighted the impact of gaming on cognitive skills differs depends upon game genre. The studies reviewed suggest that videogame play can have a positive impact on cognitive processes for players.

Keywords Video games · Cognitive skills · Attention · Time perception · Task-switching

Since the first commercial videogame in 1972 (i.e., *Pong*), and the arrival of console gaming, the playing of videogames has become one of the most popular leisure activities worldwide (Griffiths et al. 2012). As videogames have evolved, a multitude of different genres have been developed varying in the strategy, skills, and attention required, but also in the gameplay and commitment needed by the videogame players. In a minority of cases, this involvement can lead to problematic and/or addictive use of the behavior (e.g., Billieux et al. 2015; Griffiths and Davies 2005). The most studied game genre in the videogame addiction literature is massively multiplayer online

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role-playing games (MMORPGs, e.g., *World of Warcraft*, *Final Fantasy XIV*, *Guild Wars 2*). Indeed, this game genre presents features facilitating the development of pathological use, such as a continual never-ending play universe (i.e., requiring players to connect for long periods daily so not to fall behind the other players), and a powerful and reinforcing reward system (i.e., requiring the player to achieve important quests several times to acquire a specific and powerful item).

However, there is also much research in the gaming studies literature that has focused on the many positive impacts of videogames among typical videogame players (e.g., Appelbaum et al. 2013; Sims and Mayer 2002). Regarding playing performance—either cognitive or visual—the most studied videogame genre is action videogames including first-person shooters (FPSs, e.g., *Overwatch*, *Battlefield*, *Call of Duty*) games. In these games, as the name implies, a first-person perspective is used providing a greater immersive experience for the videogame player. Such games can be played either online or offline. In offline games, the purpose is often to advance from one specific point to another without the game character dying, while completing various sub-missions. In FPS game scenarios, while videogame players always need to kill their opponents' game characters, the main purpose of the session can vary between capturing specific areas and catching flags. This type of game genre has been selected as one to empirically study due to the importance of player flexibility, reflexes, and attention required (e.g., having to focus on several stimuli at the same time, switching between different tasks). Given that improved cognitive skills on a task can be transposed to other tasks (e.g., Karbach and Kray 2009; Pereg et al. 2013), it has been suggested that playing videogames requires important cognitive skills that could improve such skills.

When it comes to problematic and/or addictive videogame playing, several studies have investigated the negative impact of videogame use on diverse cognitive processes, primarily decision-making, inhibition, and multi-second time perception (Nuyens et al. 2017). Research into the effect of problematic and/or addictive videogame playing on decision-making comprises three main strands: *risk-taking*, the ability to make a decision when an individual knows the odds of losing (e.g., Game of Dice Task [GDT]; Brand et al. 2005); *delay-discounting*, the ability to select a larger reward later rather than a smaller reward now (Ainslie 1993); and *ambiguous decision-making*, the ability to adapt one's decision as the situation evolves (e.g., Iowa Gambling Task [IGT]; Bechara et al. 1994). Experiments in these areas have demonstrated that there is an impaired decision-making process in risk-taking situations (e.g., Lin et al. 2015; Wang et al. 2016), but preserved decision-making when it comes to ambiguous situations (Nuyens et al. 2016). Furthermore, pathological videogame players show a significant difficulty in delaying rewards (Nuyens et al. 2016; Weinstein et al. 2016).

Research investigating inhibition processes studies comprise two different paradigms: the restraint of a prepotent response (i.e., not engaging in an action) and the cancelation of a prepotent response (i.e., stopping an already engaged action). Most studies exploring the restraint process have utilized a Go/NoGo paradigm (i.e., engaging in an action for preselected stimuli and not for other stimuli) and have generally found significant associations between gaming addiction and an impaired inhibition (Littel et al. 2012; Yao et al. 2015). However, studies using the Stroop paradigm (i.e., reading color names written in a specific color shade, inhibiting the actual font color) have rarely led to significant findings (Bailey et al. 2010; Yao et al. 2015). Furthermore, videogame players not only show no impaired cancelation process, they outperform control participants, responding faster without sacrificing accuracy (Colzato et al. 2013). Two studies have included gaming stimuli as a way to induce an emotional reaction among study participants and have found significant impairment in inhibition among problematic videogame players (Chen et al. 2015; Ko et al. 2009).

Another process exploring the impact of problematic and/or addictive gaming upon cognitive processes is that of multi-second time perception. This ability comprises two main processes in the literature (Levin and Zakay 1989): *retrospective time perception* (i.e., which is unconscious and post hoc) and *prospective time perception* (i.e., conscious and ad hoc). Two studies have explored the time perception of problematic/addicted videogame players using a retrospective paradigm but neither of these demonstrated significant results (i.e., Rau et al. 2006; Wood and Griffiths 2007). However, the second study (Wood and Griffiths 2007) tried to assess multiple retrospective evaluations of time. But, by asking videogame players several times during the experiment to estimate how long they had been playing, it most likely influenced the unconscious process of time perception, making subsequent evaluations prospective (Grondin and Plourde 2007). Only one study has solely explored prospective time perception, but yielded no significant results (Rivero et al. 2012). However, the small sample of this study (i.e., 18 participants) may have accounted for the lack of significant findings. Finally, one study has explored both time perception paradigms, leading to significant results and demonstrating that addicted videogame players have an impaired time perception (Tobin and Grondin 2009). No conclusion can be drawn on the time perception ability of problematic/addicted videogame players, although the importance of time loss among this population points toward an impaired time perception (Chou and Ting 2003; Wood et al. 2007). For a comprehensive overview of the negative effects of problematic gaming upon cognitive skills, see Nuyens et al. (2017).

The aim of the present review is to review cognitive skills among typical (i.e., non-problematic) videogame players in studies that have used (quasi-)experimental designs comprising non-problematic videogame players. The impact of videogame use upon cognitive skills is a relatively new field, has not been studied widely, and suffers from large gaps due to inconsistent results, different cognitive skills not studied, etc. It has been shown that training cognitive skills on a given task extends to other similar tasks (e.g., task-switching; Karbach and Kray 2009), suggesting that training cognitive skills in-game could improve these skills more generally (i.e., in non-gaming settings) which may have benefits for healthcare generally. The present paper reviews the positive impacts of video gaming on cognitive skills, with further subdivisions according to specific cognitive skills.

Method

An extensive literature search was conducted using four different databases: *Google Scholar*, *ScienceDirect*, *PubMed*, and *PsycINFO* at the end of 2016. All searches included a common set of search words (i.e., videogame, gaming, video game), defining the videogame field of study, and other words to specify the specific cognitive domain studied (e.g., time perception, attention, task-switching). Finally, the studies were included if they (i) dated from the year 2000 (because most videogames prior to this were arguably very basic), (ii) included an experimental (or quasi-experimental) design, (iii) included evaluation of cognitive processes, (iv) were published in English or French (the languages spoken by the co-authors), and (v) were peer-reviewed. Studies in specific areas were also excluded if they had been extensively reviewed before, such as functional magnetic resonance imaging (fMRI) or electroencephalography (EEG) studies examining gaming (Kuss and Griffiths 2012; Pontes et al. 2015) and the use of videogames being beneficial to surgical skills (Jalink et al. 2014; Lynch et al. 2010).

The research on *ScienceDirect*, *PubMed*, and *PsycINFO* included the same type of research terms. Indeed, the only difference was that *ScienceDirect* allowed research of terms in the title, abstract, and paper keywords at the same time, while *PubMed* only allowed research in the title and abstract, and *PsycINFO* only in the abstract. Using the words 'video game', 'videogame', and 'gaming' associated with the specific area sought (e.g., attention, task-switching) led to the following number of papers. On *ScienceDirect*, there were 8 papers on time perception, 159 on attention, and 16 on task-switching. On *PubMed*, there were one paper on time perception, 72 on attention, and 19 on task-switching. Finally, on *PsycINFO*, there were 3 papers on time perception, 85 on attention, and 16 on task-switching.

However, due to the inability to research terms only in the abstract or keywords on *Google Scholar*, several of the exclusion criteria were added directly in the search (i.e., fMRI, EEG, event-related potential [ERP], and surgery) or irrelevant types of studies (i.e., training and teaching).

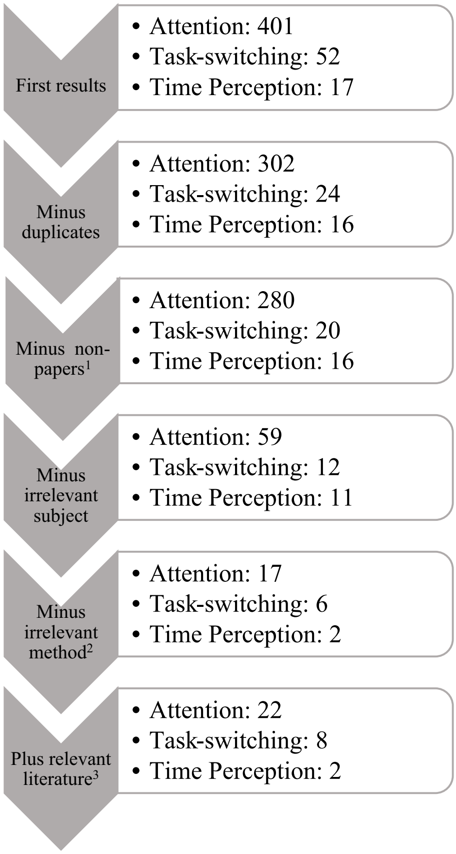

Fig. 1 Detailed paper selection procedure

Note:

[1] e.g., Conference publications, book chapters, errata

[2] e.g., EEG studies, fMRI studies, surveys

[3] Papers cited in the present review

However, as these criteria still yielded unmanageable results on this database (e.g., 1980 papers on attention), the terms characterizing the field of research (i.e., gaming, videogame, video game) were searched only in the titles. Using these criteria led to 5 papers for time perception, 85 for attention, and one for task-switching, leading to a total of 470 papers. After collating the results of the different databases to merge the duplicated papers, removing the unrelated papers, and adding new papers cited in the ones selected, the final number of selected papers was 32 (see Fig. 1).

Results and Preliminary Discussion

Task-Switching

Sophisticated videogames require videogame players to switch between several tasks, especially in action videogames (e.g., focusing on enemies, picking up items, reloading weapons). Task-switching is a representation of cognitive flexibility as it is the ability to alternate between different tasks with distinct demands, without sacrificing any accuracy or speed (i.e., shifting; Miyake 2000). In switching tasks, the variable measured is called the "switching-cost" (i.e., the increase in reaction time [RT] when a participant must switch between tasks). This variable is measured by comparing the RT to a stimulus when the response needed has changed (or not) from the previous stimulus. A well-validated example of a switching task is the Letter-Number Task developed by Rogers and Monsell (1995). Here, one letter and one number are presented together in one of the corners of the screen. If the stimulus appears in the upper part of the screen, participants have to decide whether the number is odd or even, and if it is in the lower part, whether the letter is a vowel or a consonant. Task-switching can be trained through cognitive tasks, leading to diminished switching costs, extending to the other switching tasks (Karbach and Kray 2009; Pereg et al. 2013).

Accordingly, researchers in this field started focusing on task-switching improvement among action videogame players (i.e., see Table 1 for the detailed results of this section). Although there are only a few studies investigating this, most of them have found significant associations between action game play and flexibility, with videogame players showing lower switching cost than non-videogame players (Colzato 2010; Dobrowolski et al. 2015; Green et al. 2012; Hartanto et al. 2016; Karle et al. 2010; Strobach et al. 2012). To our knowledge, only three studies have failed to find differences between action videogame players and non-players (i.e., Cain et al. 2012; Collins and Freeman 2014; Dobrowolski et al. 2015). However, the study from Dobrowolski et al. (2015) is discussed separately below, as it distinguishes between different types of videogames and yields different results.

Three studies have attempted to understand these results by exploring the underlying processes accounting for improved performances. In a study including two experiments, Karle et al. (2010) tested both the difficulty level and the switching level impact on task-switching. In the first experiment, 44 participants (including 23 action videogame players playing 6 h per week and judging their gaming expertise with a score of at least 5 out of 7 on a Likert scale) were tested on a switching task varying in the difficulty to prepare a response, or to respond to a trial. To differ the variables, the authors compared the visual perception level (high-contrast vs. low-contrast), the response mapping (changing which key to press for a given stimulus), the cue-to-target interval length (100 vs. 1000 ms), and the information given by the cue (either giving no information or cueing on the next stimulus type). This study produced the same results as the previous studies (i.e., a significantly smaller switching cost for action videogame players, compared to non-players). Furthermore, although the videogame players were faster overall, not only did they not sacrifice

Table 1 Studies on the attentional processes and the playing of videogames

Authors	Sample	Gaming definition	Type of game	Tasks	Results (effect size)
Wilms et al. (2013)	42 (20 experienced, 10 casual, and 12 NG)	Experienced: > 15 h/M Casual: 4–8 h/M NG: < 2 h/M (Past 6 M)	Action	*CombiTVA* (visual attention) *Enumeration test* (subitizing) Attention network test (alerting, orienting, executive control)	Higher processing speed if experienced ($d = 0.37$ for casual, $d = 0.66$ for non-gamers) Processing speed linked to hours per month (r [39] = .44)
Mack et al. (2016)	98 (36 NG, 62 G)	G: > 4 h/w NG: < 4 h/w	N/A	Nakayama's spatial cueing task	G better mean performance ($\eta^2 = 0.081$)
Green et al. (2006b)	16 (8 G, 8 NG)	G: 3–4 d/w NG: Not playing (past 6 M)	Action	Perceptual load paradigm (PLP) Useful field of view (UFOV)	G outperformed NG on the PLP for the RT ($\eta^2 = 0.33$). G outperformed NG on the UFOV for the peripheral accuracy both with or without distractor ($\eta^2 = 0.73$; $\eta^2 = 0.76$). Same results observed for the central one (no distractors, $\eta^2 = 0.64$)
Chisholm and Kingstone (2015b)	57 (28 G, 29 NG)	G: > 3 h/w NG: little to nothing (past 6 M)	Action	Oculomotor capture task	G had less incorrect saccade ($d = 0.63$), and replied faster ($\eta^2 = 0.19$) without any loss in accuracy ($\eta^2 = 0.02$, $p > .05$)
Hubert-Wallander et al. (2011)	XP1: 21 (10 G, 11 NG) XP2: 34 (19 G, 15 NG)	XP1: G: > 5 h/w NG: < 1 h/w (last year) XP2: G: > 5 h/w (AVG) and > 3 h/w (other) NG: < 1 h/w (AVG) and < 3 h/w (other)	Action	XP1: Visual search task (VST) XP2: Posner cuing task (PCT)	XP1: G found items faster than NG ($\eta^2 = 0.286$) XP2: No difference in exogenous orienting between G and NG, but faster processing for G ($\eta^2 = 0.140$)

Table 1 (continued)

Authors	Sample	Gaming definition	Type of game	Tasks	Results (effect size)
		(last year)			
Unsworth et al. (2015)	XP1: 118 (18 expert G and 29 NG) XP2: 586 (no group, correlational approach)	G: > 5 h/w NG: < 1 h/w	Shooter Action RTS Turn-based RPG Musical	XP1: operation span, symmetry span, reading span, Raven's Advanced Progressive Matrices, number series, letter sets, sustained attention to response (SART), antisaccade task (AT), arrow flankers (AF), spatial Stroop (SS), and psychomotor vigilance XP2: the AT, AF, SART, SS, cued visual search, and the cued flankers	XP1: Extreme G outperformed NG on the antisaccade task (Cohen's $d = 0.67$), were faster on the SART (Cohen's $d = -0.58$), and had better scores on the Psychomotor Vigilance Task (Cohen's $d = 0.60$). Significant correlations between the SART speed and the time spent on turn-based games ($r = -.15$). XP2: Antisaccade task correlated significantly with the RTS ($r = -.09$) and the Cued visual search with the RPG ($r = -.10$). No results for the latent variable analysis
Boot et al. (2008)	21 (11 G, 10 NG)	G: > 7 h/w NG: < 1 h/w (past 2 years)	FPS	Functional field of view, the attentional blink, the enumeration, the multiple object tracking, and the visual short-term memory (VSSM)	Only significant difference in the multiple object tracking ($\eta^2 = 0.45$) and in the visual short-term memory ($\eta^2 = 0.16$); G outperforming NG. The effect in the VSSM was stronger for the larger set size ($\eta^2 = 0.16$)
Dye and Bavelier (2010)	161; 52 between 7 and 10 (6 G), 32 between 11 and 13 (16 G), 30 between 14 and 17 (15 G), and 47 between 18 and 22 (21 G)	Playing FPS/TPS during the prior 12 months	FPS/TPS	Useful field of view (UOV), the attentional blink (AB), and multiple object tracking (MOT)	UOV: Better score for G ($\eta^2 = 0.7$) AB: G exhibited a faster attentional recovery time ($\eta^2 = 0.06$) MOT: G outperformed NG ($\eta^2 = 0.04$)
Appelbaum et al. (2013)	67 (31 G, 36 NG)	G: > 5 on		self-perceived expertise (out of 7) NG: 0 on the same scale	FPS, action, platforming
Visual sensory memory task.	G outperformed NG on all duration of the task ($\eta^2 = 0.15$)				
Murphy and Spencer (2009)	61 (32 G, 29 NG)	G: > 4 h/w NG: never or rarely played	Action	Attentional blink (AB), the useful field of view (UFOV), the inattentional blindness (IB), and the repetition blindness (RB)	AB: G outperformed NG only for the shortest SOA (100 ms, $\eta^2 = 0.06$). UFOV: G were faster overall ($\eta^2 = 0.07$)

Table 1 (continued)

Authors	Sample	Gaming definition	Type of game	Tasks	Results (effect size)
Cain and Mitroff (2011)	44 (11 G, 33 NG)	Past 6 months G: > 6 h/w NG: < 1 h/w Past 6 months	FPS, action	Change detection task	There was no difference between G and NG. But when testing only male participants (7 G and 9 G), G were marginally faster than NG ($\eta^2 = 0.19$, $p = 0.09$)
Cain et al. (2014)	XP1: 40 (19 G, 21 NG) XP2: 52 (23 G, 29 NG)	G: > 5 h/w and > 5 on		self-perceived expertise (out of 7) NG: < 2 h/w and < 2 in expertise Past 6 months	FPS
XP1: Anti-cue task XP2: Attentional blink task	XP1: While NG were faster in the cued condition than the anti-cued one, G did not show this effect (Cohen's $d = 0.22$) in the short SOA only. XP2: No significant effect				
Castel et al. (2005)	XP1: 40 (20 G, 20 NG) XP2: 20 (10 G, 10 NG)	G: > 1 h/w four times a week NG: < 1 h/M Past 6 months	Action	XP1: Visual search task XP2: Detection task	XP1: G were faster overall than NG ($\eta^2 =$ 0.16), but there was no difference in the inhibition of return. XP2: G were faster overall than NG ($\eta^2 =$ 0.40), this effect interacting with set size (G outperforming NG even more with more items, $\eta^2 = 0.15$)
Chisholm et al. (2010)	30 (15 G, 15 NG)	G: > 3 h/w NG: Few or none playing time Past 6 months	Action	Orientation perception task	G were faster overall than NG ($\eta^2 = 0.30$), and the distractors impaired NG to a greater extent than NG ($\eta^2 = 0.44$)
Chisholm and Kingstone (2012)	36 (16 G, 20 NG)	G: > 3 h/w NG: Few or none playing time	Action	Oculomotor capture task	G were waster overall than NG ($\eta^2 = 0.16$); furthermore, G were less affected by an abrupt onset than the NG ($\eta^2 = 0.29$)

Table 1 (continued)

Authors	Sample	Gaming definition	Type of game	Tasks	Results (effect size)
Chisholm and Kingstone (2015a)	32 (16 G, 16 NG)	Past 6 months G: > 3 h/w NG: Few or none playing time	Action	Oculomotor capture task	G were more accurate overall than NG (η^2 = 0.30); furthermore, G were less affected by an abrupt onset than the NG ($\eta^2 = 0.36$)
Dobrowolski et al. (2015)	90 (30 FPS, 30 RTS, 30 NG)	Past 6 months FPS: > 7 h/w on FPS and < 5 h/w on RTS RTS: > 7 h/w on RTS and < 5 h/w on FPS NG: < 2 h/w on RTS and FPS	FPS, RTS	Multiple object tracking	RTS marginally outperformed FPS players ($\eta^2 = 0.106$, $p = 0.058$) overall. This marginal effect is due to the better score of the RTS player when they had to track 3 or 4 items (respectively $p = 0.37$ and $p = 0.015$)
Dye et al. (2009)	131–43 between 7 and 10 (30 G), 28 between 11 and 13 (13 G), 27 between 14 and 17 (12 G), and 27 between 18 and 22 (14 G)	G: Played action games NG: Did not play action games	Action	Attentional network test	There was a main effect of gaming ($\eta^2 = 0.07$), G being faster than NG. Furthermore, there was a main effect of gaming on the orienting score ($\eta^2 = 0.08$). Finally, the G were less distracted by the incongruent flankers than the NG ($\eta^2 = 0.14$)
Irons et al. (2011)	XP1: 32 (19 G, 13 NG) XP2: 32 (17 G, 15 NG)	G: 3–4 times a week NG: Almost not playing	FPS	XP1: Flanker task XP2: Eriksen flanker task	XP1: While NG were slower in the incongruent flankers condition, this effect was absent for the G, these being even faster in this condition (Cohen's $d = 0.13$). Furthermore, G were marginally more accurate than NG ($\eta^2 = 0.10$, $p = 0.08$). XP2: There was no effect of gaming
	24 (12 RPG, 12 FPS)		FPS, RPG	Visual search task	

Table 1 (continued)

Authors	Sample	Gaming definition	Type of game	Tasks	Results (effect size)
Krishnan et al. (2013)		Four 1-h session a week			FPS was systematically better or at least had equal scores than the RPG, this effect being stronger when 4 regions had to be attended
Mishra et al. (2011)	41 (21 G, 20 NG)	G: > 5 h/w NG: 0 h/w Past year	Action	Detection task	G detected more targets than NG ($\eta^2 = 0.10$) and NG had more false alarms than G ($\eta^2 = 0.05$). Finally, G were faster than NG ($\eta^2 = 0.11$)
Schubert et al. (2015)	34 (17 G, 17 NG)	G: > 10 h/w NG: < 1 h/w Past 6 months	Action	Theory of visual attention task	G had better processing speed and perception threshold than NG (respectively $\eta^2 = 0.20$ and $\eta^2 = 0.13$)

For the sake of clarity, only the effect size of significant results was included. In addition, only the relevant non-significant results were mentioned. If no effect size is mentioned next to a significant result, the authors of the original article did not provide enough details for it to be calculated

h, hour; *M*, month; w, week, *d*, day, *G*, gamers; *NG*, non-gamers; *TVA*, theory of visual attention; *ANT*, attentional network; *TD*, top-down; *BU*, bottom-up; *RT*, reaction time; *TPS*, third-person shooter; *SOA*, stimulus onset asynchrony their accuracy, they were significantly more accurate than non-players. Finally, the gap between videogame players and non-players grew larger during the long cue-to-target interval, or when the cue was informative. However, these results do not explain the overall superiority of players on switching tasks, even if this gives some leads (i.e., cue-to-target interval and cue effect). In the second experiment, Karle et al. (2010) tested the switching level among 40 participants (including 20 action videogame players using the same protocol as the first experiment) on a switching task including numbers. To manipulate the switching level, the test included three different task types: deciding if a presented number was odd or even, if it was lower or higher than five, and if it was a prime number or a multiple number. Those three different tasks led to four switching combinations, *repeat* (no switching, two same tasks in a row), *switch* (two different tasks in a row), *two-switch* (three different tasks performed consecutively), and *alternate* (a first task, followed by a second different task, followed by the same first task). The only result of this experiment was a replicated improved switching cost and accuracy among videogame players with none of the switching manipulation showing any differences between videogame players and non-players.

The second study exploring the underlying processes of these improved results was by Green et al. (2012). This study comprised three different experiments. The first experiment evaluated the impact of the output type, in other words, testing whether the players would be better at switching between tasks when they respond using a keyboard compared to a vocal method. The first experiment included 18 participants, with eight action videogame players (spending at least 5 h per week on action games for the past 6 months). The task was a shape vs. color switching task, with participants having to assess the shape of the stimulus when it was in the upper part of the screen, and its color when it was in the lower part of the screen. Although non-players showed shorter RT when they responded orally, there was no such significant difference for the players. Furthermore, considering that the players were faster than non-players in both conditions (i.e., despite the improvement of non-players in the oral condition), it can be inferred that the output type (i.e., responding orally or manually) did not account for the difference between the two groups. In the second experiment, the authors wanted to compare cognitive and perceptual switching. For this purpose, 28 participants (including 14 players using the same criteria) underwent a switching task with two types of blocks. The first kind of block included the same task as the first experiment (i.e., shape vs. color), while the second one needed the participants to decide whether the numbers were odd/even or higher/lower than five. Even though this study replicated the reduced switching cost among players, the task type (i.e., cognitive vs. perceptual-task) did not yield significant results. Finally, the third experiment assessed the stimulus-response mapping switching by asking the participants to respond with other keys if the background color changed. As in the two first experiments, there was no effect of the task type, but a clear and significant lower switch cost for the players. Thus, this study failed to find any underlying process accounting for the improved results of the action videogame players.

The last study exploring how task-switching is affected by recurrent gaming assessed the impact of gaming onset on this executive function (Hartanto et al. 2016). Gaming onset was defined as the age when the participants first started to play videogames. In the experiments, 134 participants were classified into three groups, non-gamers ($n = 49$), early-onset gamers (i.e., started to play before 12 years old, $n = 43$), and late-onset gamers (i.e., started to play after 12 years old, $n = 42$). Relevant literature has indicated that children reach a fully developed shifting function (i.e., reaching the same performance on switching tasks as adults) around the age of 12 years (Anderson et al. 2001; Cepeda et al. 2001). Furthermore, contrary to previous studies, the authors explored both the switching cost and the mixed cost (i.e., slower response in repeated trials in mixed blocks compared to repeated trials in pure blocks—i.e., blocks without any switching), studying a wider range of variables related to the shifting function. The results showed that the onset of gaming had no impact on the number of hours spent on videogames, nor on self-perceived level of expertise. However, despite this lack of difference, once all the variables were included in a stepwise regression, only the age of gaming onset significantly predicted the shifting levels, both for the switching and mixed costs. Finally, when using the same categorization as other studies (i.e., comparing gamers who play more than 6 h per week to non-gamers), gamers had a significantly smaller mixed cost and a marginally smaller switching cost ($p = 0.06$).

Although all the previous studies focused on action videogames, these are not the only games leading to an increased flexibility, as other videogames need players to switch between several important tasks to win. For example, this is the case in real-time strategy (RTS) games where the players must command several groups of units, switching between different categories of units to command them. Furthermore, in these types of games, players must also construct buildings, manage resources, etc. All these tasks are similarly important to win the game because they are all interconnected, and thus require the participants to switch efficiently between them. In a study by Dobrowolski et al. (2015), 30 RTS players, FPS players, and control participants (i.e., having played less than 2 h per week on both RTS and FPS, and no more than 4 h per week on other games during the past 6 months) were tested on both a switching task and a multiple object tracking task (MOTT). To be included in the study, RTS players had to have played at least 7 h per week on RTS games and 5 h on FPS games during the past 6 months, and inversely for the FPS players. This experiment led to significant differences between the three groups, with further analyses showing that RTS players significantly outperformed both the FPS players and the control participants. No significant differences were observed between the latter groups. In the switching task, RTS players had a lower switching cost without any differences in global reaction time or accuracy between the groups. In the MOTT, RTS players showed a significantly better accuracy than controls, and a near-to-significant difference to the FPS players. Although this study goes against other findings examining action videogame players' level of flexibility, it shows some interesting results on the impact of videogame playing on task-switching. By showing that games other than FPS can lead to further improved flexibility, it implies that other studies comparing cognitive processes on different types of videogames are required.

In summary, most of the included studies found significantly improved performance in switching task among players, implying greater flexibility in comparison to non-players (Colzato 2010; Dobrowolski et al. 2015; Green et al. 2012; Hartanto et al. 2016; Karle et al. 2010; Strobach et al. 2012). One possible explanation for the absence of results from some studies could be the lack of control on game playing. Since other types of games than action videogames can induce an improvement in flexibility (e.g., RTS games—Dobrowolski et al. 2015), it is highly possible that some participants in the control groups were playing such games and truthfully reported that they did not play any action videogames. The study by Dobrowolski et al. (2015) raises an important need to focus on what the different genres of videogames can bring to videogame players in terms of skills. Indeed, more than different gameplay, playing different kinds of videogames requires different categories of skill (e.g., strategy, sharpened reflexes, multi-tasking), some games even requiring a combination of those skills. Therefore, more studies are needed to assess abilities developed by playing specific videogames, and the impact of this training on general cognitive tasks. Despite the lack of control on this variable, the studies still yielded consistent results, implying that videogames have an important positive impact on flexibility. Yet, little is known about the underlying processes in the improved performance of videogame players, apart from an increased difference with non-players when stimuli are cued, or when there is more time to prepare a response (Karle et al. 2010). The even greater performance when cues are included in the task could be evidence of a better top-down control of attention, with videogame players exhibiting a somewhat better ability to focus their attention on a stimulus when cued beforehand. Further explanation of this is provided below.

Attentional Control

Videogames require constant attention from players, as even the slightest lapse in attention can lead to death of the character, or to losing the game. Although this can be true for most videogames, this is arguably more important in action videogames. Attentional control can be divided into two different types, top-down and bottom-up control. In top-down control of attention, a person consciously allocates their attention to a chosen stimulus, while in bottom-up control, the more salient stimulus will catch the person's attention (Desimone and Duncan 1995). Furthermore, attention has also been defined by the differentiation of three systems according to the attentional network task (ANT; Fan et al. 2002). These are the *alerting system* (i.e., being able to make use of a clue to prepare for a stimulus), the *orienting system* (i.e., being able to orientate one's attention toward a spatial area after a spatial cue), and the *executive control system* (i.e., being able to inhibit the distractors). The first two systems (i.e., alerting and orienting systems) are associated with bottom-up attention selection because the cue directing the attention occurs despite the will of the person. The third system (i.e., executive control system) is linked with the top-down selection because this system requires the person to direct their attention themselves by ignoring the distractors. Therefore, it would be expected that videogame players exhibit better top-down attention, winning a game requiring inhibiting the distractors, and to focus on the right "stimuli" (e.g., to focus one's attention on important objectives without being distracted). Yet, as important stimuli can appear in a game, requiring a fast relocation of attention, bottom-up selection could also be at stake among action videogame players. Current literature demonstrates that videogame players exhibit better top-down control (Boot et al. 2008; Cain and Mitroff 2011; Cain et al. 2014; Chisholm et al. 2010; Chisholm and Kingstone 2012, 2015a; Dye and Bavelier 2010; Green and Bavelier 2006a; Irons et al. 2011; Mack et al. 2016), although some studies show improved bottom-up processing (Cain and Mitroff 2011; Castel et al. 2005; Chisholm et al. 2010; Mishra et al. 2011; Murphy and Spencer 2009; Schubert et al. 2015; Wilms et al. 2013) (see Table 2 for the detailed results of this section).

Chisholm and Kingstone published three studies on the attentional abilities of videogame players (i.e., 3 h per week for at least the past 6 months), mainly testing their top-down control of attention (Chisholm et al. 2010; Chisholm and Kingstone 2012, 2015a). In these studies, three different tasks were used (i.e., orientation perception task, oculomotor capture task, and compound search task), thus allowing a wide measure of top-down control. All these studies reached the same conclusion that videogame players exhibited better top-down control, which was not explained by other variables assessed (e.g., speed to engage in an eye saccade). Studies by Cain and colleagues (Cain and Mitroff 2011; Cain et al. 2014) confirmed these results despite using different tasks (i.e., change detection task, anti-cue task, and attentional blink task) and a stricter inclusion criterion for being a participating videogame player (i.e., 5 or 6 h per week for the past 6 months). In addition, their first study also demonstrated that videogame players exhibited better bottom-up attention selection (Cain and Mitroff 2011), indicating that videogame players would both consciously direct their attention better than non-videogame players, but would also be more

Table 2 Studies on task-switching and the playing of videogames

Authors	Sample	Gaming definition	Type of game	Tasks	Results (effect size)
Colzato (2010)	34 (17 G and 17 NG)	G: playing 4 times a week NG: / Past 6 months	Any	Global/local switching task	G showed a significantly lower switching cost ($\eta^2 = 0.13$).
Dobrowolski et al. (2015)	90 (30 FPS, 30 RTS, 30 NG)	FPS: > 7 h/w on FPS, < 5 h/w on RTS RTS: > 7 h/w on RTS, < 5 h/w on FPS NG: < 2 h/w on FPS and RTS	FPS, RTS	Global/local switching task	RTS showed lower switching cost than FPS and NG ($\eta^2 = 0.132$) without any difference between these two.
Hartanto et al. (2016)	134 (43 EOG, 42 LOG, 49 NG)	EOG: Started to play before 12 LOG: started to play after 12 NG: never played	RTS, action games	Color/shape switching task	When including all the variables into a regression (i.e., gender, nonverbal intelligence, hours on the game, onset age), the model significantly predicted both the mixed and switching costs (respectively $\Delta r^2 = .042$ and $\Delta r^2 = .037$).
Karle et al. (2010)	XP1: 56 (30 G, 26 NG) XP2: 40 (20 G, 20 NG)	G: > 4 h/w (1 h per session) NG: few or no gaming experience Past 6 months	FPS	XP1: Number/letter switching task including cues and several difficulty settings XP2: Number/letter switching task with three tasks (i.e., different level of switching)	XP1: G reduced their switching cost to a greater extent than NG with longer cue-to-target interval ($\eta^2 = 0.20$) XP2: Lower switching cost for G ($\eta^2 = 0.16$).
Green et al. (2012)	XP1: 18 (8 G, 10 NG) XP2: XP3:	G: > 5 h/w NG: Few or no gaming Past 6 months	Action games	XP1: Color/shape switching task (responding orally or manually) XP2: Color/shape and odd/even + lower/higher than 5 switching tasks XP3: Switching task with different key mapping	XP1: While NG were more accurate when replying manually, there was no difference for G ($\eta^2 = 0.214$). Also, there was a smaller switching cost on the RT for the G ($\eta^2 = 0.535$). XP2: There was a smaller switching cost on the RT for the G ($\eta^2 = 0.258$) XP3: Smaller switching cost on the RT for the G ($\eta^2 = 0.252$).
Strobach et al.	20 (10 G, 10 NG)	G: > 6 h/w NG: > 1 h/w	Action games	Number/letter task	Smaller switching cost for G ($\eta^2 = 0.26$)

Table 2 (continued)

Authors	Sample	Gaming definition	Type of game	Tasks	Results (effect size)
(2012)					
Cain et al. (2012)	44 (23 G, 21 NG)	G: > 6 h/w and > 5 on self-perceived expertise (out of 7) NG: < 2 h/w and < 2 expertise	Action game-s, FPS	Indicating the central arrow direction or the opposite depending on color (with congruent and incongruent flankers)	No actual difference in switching cost apart for a larger switching cost in the correct direction for the NG ($\eta^2 = 0.182$).
Collins and Freeman (2014)	66 (20 PG, 26 G, 20 NG)	PG: according to the short version of the game addiction scale G: average 6.86 h/w NG: N/A	N/A	Higher/lower than 5 or odd/even	No effect

For the sake of clarity, only the effect size of significant results was included. Also, only the relevant non-significant results were mentioned. If no effect size is mentioned next to a significant result, the authors of the original article did not provide enough details for it to be calculated

h, hour; *M*, month; *w*, week; *d*, day; *G*, gamers; *NG*, non-gamers; *PG*, problematic gamers; *RT*, reaction time; *SOA*, stimulus onset asynchrony; *FPS*, first-person shooter; *RTS*, real-time strategy; *EOG*, early-onset gamers; *LOG*, late-onset gamers sensitive to salient stimuli if those were relevant for the ongoing task or activity. Contrary to Cain and Mitroff (2011), Hubert-Wallander et al. (2011) failed to find any association between videogame use and bottom-up attention, because their second experiment did not yield any significant results in that direction. However, their first experiment (comprising ten gamers and ten non-gamers) using a visual search task showed a strong significant difference between the two groups. Because the gamers searched faster than the non-gamers, this study supported a faster processing speed and top-down attention among the gamers.

However, these studies need to be compared to Unsworth et al.'s (2015) paper which pointed out that most studies exploring the effect of playing videogames on attention suffer from two main limitations. These are the systematic use of extreme groups, that is, comparing intense videogames players (e.g., more than 4 h per week) to non-gamers, and the small sample size used in most studies. In order to remedy these issues, Unsworth et al. (2015) reanalyzed two sets of data from previous studies, a first one including 198 participants and a second one including 586 participants. In the first experiment, the participants performed several attention tasks (i.e., the operation span, symmetry span, reading span, Raven's Advanced Progressive Matrices, number series, letter sets, sustained attention to response (SART), antisaccade, arrow flankers, Stroop, and psychomotor vigilance) and completed a questionnaire on their videogame use which included categorical questions on the time spent playing per week (i.e., never, 0 to 1 h, 1 to 3, 3 to 5, 4 to 10, or more than 10 h) on different videogame types (i.e., FPS games, action games, RTS games, turn-base and puzzle games, role-playing games [RPGs], and music games). Using the extreme group analysis, they showed the same pattern of results as the previous studies, that is, an improved attentional focus among the expert gamers. However, once they used a correlational approach using the time spent online on the different games, they only found a small significant correlation between the SART reaction time and the time spent on turn-based games. The lack of significant results regarding the correlational approach may be explained by the categorical data used for the time spent on the games. This criticism led to the second experiment, where the participants provided the time spent on the games in the form of continuous data, thus facilitating the correlational analyses. The tasks used to determine the attentional process were the antisaccade task, the arrow flankers, the SART, the spatial Stroop, the cued visual search, and the cued flankers. Only the cued visual search and the antisaccade task correlated respectively with playing strategy games and RTS. Once using a latent variable analysis (i.e., grouping the different tasks' results as a unique attentional variable), none of the types of games tested showed any correlation with attention. These two experiments therefore suggest that videogames only impact attention when spending a fair amount of time on videogames, explaining the difference only found when comparing extreme groups.

Dye et al. (2009) explored the links between videogame use and attentional processes via the ANT. As defined earlier, this model divides attention into three core systems, the alerting, orienting, and executive control systems (Fan et al. 2002). Throughout the task, the participants must assess in which direction an arrow is pointing (i.e., left or right). To measure the alerting and orienting systems, cues were added before the arrow's appearance. The cues could either indicate the position of the next arrow (i.e., orienting system) or simply indicate the imminent appearance of an arrow, with no indication of the location of it. Comparing this last condition with non-cued trials provides a measure of the alerting system. Finally, these arrows can either be alone or surrounded by other arrows, which can either be congruent (i.e., pointing in the same direction as the main stimulus) or incongruent (i.e., pointing in the opposite direction, i.e., distractors). Calculating the RT difference between those two conditions gives a good measure of the executive control system (Dye et al. 2009). In this study, the authors recruited 131 participants (aged between 7 and 22 years old) including 56 action videogame players (i.e., playing any action videogames during the past 12 months). Although the inclusion criteria were different from those of other studies (i.e., younger participants and less rigorous criteria for videogame players), the results obtained matched previous findings. Videogame players were faster in all the conditions (i.e., exhibiting a faster processing speed). However, videogame players showed a greater improvement than non-players during the cued arrows, exhibiting better orienting and executive control systems, thus, a better top-down control of attention. The results of this study suggest that playing videogames improves both basic processing speed and conscious control of attention. However, the lack of differences between the two groups in the alerting systems indicates that there is no difference in bottom-up control, thus refuting results from other studies (e.g., Cain and Mitroff 2011; Mishra et al. 2011).

Other studies have investigated the theory of visual attention (TVA; Kyllingsbæk 2006) using videogame players. The TVA measures attention via six parameters: the threshold value (T_0—i.e., the minimum time of presentation required for participants to process a stimulus), the visual processing speed (C), the short-term storage memory capacity (K—i.e., amount of stimuli storable concurrently in short-term memory), the iconic memory buffer (μ—i.e., the difference in accuracy between masked and unmasked stimuli), the top-down control (α), and the spatial distribution of attention (w_{lat}—i.e., lateral distribution and w_{vert}—i.e., vertical distribution). To assess these parameters, participants must perform both whole and partial report tasks. In the whole report, participants are presented with a set of five colored letters (i.e., red or green) which are either masked or unmasked. There are three presentation times (i.e., short, medium, and long), and participants have to indicate which letters were presented. This version of the task leads to measuring the parameters C, K, t_0, and μ. In the partial condition, one or two letters are presented on the screen, and participants have to indicate which letter is presented in a preselected color. When two letters are presented, the second letter can either be in the preselected color (participants having to report the two letters) or in another color (participants having to report only one of the letters). The partial report task leads to measuring the parameters α, w_{lat}, and w_{vert} (Kyllingsbæk 2006). Using this model of visual attention, Schubert et al. (2015) explored the underlying mechanisms of the outperformance from videogame players on attentional tasks. They recruited 34 participants including 17 videogame players (i.e., playing 10 h per week in the past 6 months) and tested them with the whole and partial report tasks. Videogame players needed a shorter presentation time to process the stimuli (t_0), and a greater processing speed (C), but no difference was observed in the other parameters. These results confirm other studies examining processing speed, because videogame players were faster than non-players (Cain and Mitroff 2011; Mishra et al. 2011). However, the lack of difference in top-down control goes against the main results of other studies (Cain et al. 2014; Chisholm et al. 2010).

Similar to Unsworth et al.'s (2015) studies, few researchers have compared different types of videogame players to test whether game type would impact the performance on attentional task or not. In their study, Krishnan et al. (2013) tested 24 participants who played either RPGs or FPS games. To be included in this experiment, participants had to play one of those two types of game at least 4 days a week, with a minimum of 1 h of gaming on those days. The participants were all tested on the same task, to press a button every time a preselected stimulus appeared in a given zone of the screen. Depending upon the types of trial, participants had to attend to one, two, or four regions of the screen, thus increasing the difficulty of the task, and the spatial distribution of attention. This experiment led to an overall better performance by the FPS players, the difference reaching its pinnacle when the participants had to attend four locations at the same time. However, as there was no actual control group (i.e., participants who did not play any videogames), the only conclusion of this study was that FPS players improve attentional processes more greatly than RPG players. Consequently, nothing can be concluded on the direct contribution of RPG players compared to non-players.

In conclusion, the current literature on attention agrees on several important points. Firstly, videogame players appear to exhibit a better global attention level, as their processing speed is increased compared to non-players (Cain and Mitroff 2011; Castel et al. 2005; Chisholm et al. 2010; Mishra et al. 2011; Schubert et al. 2015), even though some studies contest these findings (Cain et al. 2014; Irons et al. 2011). To nuance these results, Krishnan et al. (2013) demonstrated that the improvement in the attentional capacities are greatly influenced by the type of games played, with FPS players exhibiting better attentional processing than RPG players. This study, in accordance with Dobrowolski et al. (2015), indicates that more studies exploring the specific impacts of the different types of videogames are greatly needed in the cognitive literature. Secondly, videogame players exhibited greater top-down attentional control, i.e., a greater ability to ignore distractors and to stay focused on the main task (Cain and Mitroff 2011; Cain et al. 2014; Chisholm et al. 2010; Chisholm and Kingstone 2012; Dye et al. 2009; Irons et al. 2011), although one study did not reach statistical significance (i.e., Irons et al. 2011), and another study found opposing results (i.e., Schubert et al. 2015).

Sub-second Time Perception

Although gaming sessions often last many hours, videogame players deal with sub-second time perception. This time perception mainly comprises the ability to differentiate concomitant and serial stimuli, and to perceive which stimulus came first in the case of serial stimuli. Indeed, in some videogames, players can perform several spells and abilities with their character. Therefore, knowing that one of these skills takes less time to be performed than another one is crucial because it allows the player to react fast in dangerous situations. Only two studies have explored sub-second time perception among videogame players (i.e., see Table 3 for the detailed results of this section), reaching the same results that video gaming is associated with improved time perception (Donohue et al. 2010; Rivero et al. 2012).

In the first study (Donohue et al. 2010), multisensory temporal processing was tested, i.e., the ability to discriminate two stimuli, knowing whether they are concomitant or not, and if they are not, which one appeared first. In their experiment, 45 participants were recruited, including 18 videogame players (i.e., 2 h per week on FPS and 4.5 h per week on any other action game for at least 6 months), 18 non-videogame players (i.e., less than 1.5 h per week on any action game and 0 h on FPS for at least 6 months), and 9 "other" participants (i.e., fit in none of the two previous groups and were only included in the correlational analysis). All participants were tested on two different tasks: a simultaneity judgment task (SJT) and a temporal-order judgment task (TOJT). In the two tasks, participants were presented two stimuli (visual and auditory) with random stimulus onset asynchronies (i.e., SOA, duration between the appearance of the two stimuli) varying between 0 ms (i.e., simultaneous stimuli) and 300 ms. Furthermore, the visual stimuli could be presented on either a lateral or central position, as it has been shown that the location of the stimulus can affect multisensory temporal perception (Zampini et al. 2005). However, the findings did not reach significance. Videogame players outperformed the non-players on the TOJT, exhibiting better accuracy than non-players. In the SJT, players also outperformed non-players by being able to perceive that two stimuli were not concurrent with a smaller SOA than non-players on average. However, videogame players were more biased on both tasks when the visual stimulus came first,

Table 3 Studies on sub-second time perception and the playing of videogames

Authors	Sample	Gaming definition	Type of game	Tasks	Results (effect size)
Donohue et al. (2010)	45 (18 G, 18 NG, 9 other)	G: > 2 h/w on FPS, > 4.5 h/w on action games NG: 0 h/w on FPS, < 1.5 h/w on RTS and sport games Other: participant out of these conditions Past 6 months	FPS, action games, sport games	Simultaneity judgment task and a temporal-order judgment task	G could differentiate two stimuli (i.e., determining they were not occurring simultaneously) at shorter SOA than NG (Cohen's $d = 1.06$).
Rivero et al. (2012)	18 (9 G, 9 NG)	G: > 30 h/w NG: < 5 h/w	Any	Temporal discrimination and temporal bisection tasks	G were more able to discriminate two short durations than NG ($\eta^2 = 0.63$). G were also more accurate on the bisection task (N/A).

For the sake of clarity, only the effect sizes of significant results were included. Also, only the relevant non-significant results were mentioned. If no effect size is mentioned next to a significant result, the authors of the original article did not provide enough details for it to be calculated

h, hour; *w*, week; *G*, gamers; *NG*, non-gamers; *SOA*, stimulus onset asynchrony; *FPS*, first-person shooter which is the opposite from non-players who were more biased for auditory ones. This can be explained by the higher importance of visual stimuli compared to auditory ones in videogames.

In the second study (Rivero et al. 2012), there were two types of time perception: sub-second perception and multi-second perception. This study comprised 18 participants, with 9 frequent players (i.e., 30 h per week during the past month) and 9 occasional players (less than 5 h per week during the past month). For sub-second time perception, participants underwent a temporal discrimination task (TDT) and a temporal bisection task (TBT). In the TDT, participants were presented a reference stimulus lasting 500 ms, then a test stimulus lasting between 100 and 1000 ms. Participants had to decide whether the test stimulus lasted as long as the reference stimulus, or was longer or shorter. In the TBT, participants were first primed with 200 and 800 ms stimuli in a training phase, to be able to differentiate them. In the testing phase, participants were presented stimuli lasting between 200 and 800 ms (with increments of 100 ms) and were asked whether these were of long (800 ms) or short (200 ms) duration. For the multi-second duration, participants performed a time estimation task (TET) and a time production task (TPT). In the TET, participants had to estimate three randomly presented durations (10, 30, and 60 s), and in the TPT, participants had to press a button for 5 or 45 s. While there was a clear and significant outperformance by the videogame players for both the TDT and the TBT, there was no difference between the two groups for both the multi-second tasks. Although sub-second time perception was affected by videogame play, it was unlikely that short durations above the second would be affected by this activity. Indeed, while sub-second perception is important in videogames, being able to perceive duration above 5 s would be important only in specific game genres (e.g., in online games where players can fight an opponent, knowing that they will not be able to use a specific ability before 5 s is crucial because they know that they have a clear advantage during those 5 s). However, as it has been shown that videogame players can present severe time loss while playing (Chou and Ting 2003; Meerkerk et al. 2009), assessing time perception for longer durations (e.g., above 30 min) is warranted.

In conclusion, these two studies suggest that videogame players exhibit a better time perception in the sub-second area. However, further studies are needed to explore this perception, and its underlying mechanisms, because little is currently known. Furthermore, it would also be interesting to explore the impact of playing different game genres on time perception (e.g., how a game including several short sessions would affect it differently than a game with one continuous session), as it is expected that videogames which do not focus on reflexes would not improve sub-second time perception. Furthermore, some games need the players to be attentive on several delays (i.e., delays before using their own abilities, and the delays before an opponent can use their own abilities).

Discussion

From the presented empirical evidence, it appears that playing videogames has the potential to impact cognitive processes positively. Firstly, compared to controls, videogame players appear to have a better conscious control of their attention (i.e., top-down attention; Cain and Mitroff 2011; Chisholm and Kingstone 2012) and a better processing speed (Castel et al. 2005; Mishra et al. 2011). However, such performances appear to be differently affected depending on the videogame genre played because FPS game players displayed better results than RPG players (Krishnan et al. 2013). However, when using a correlational approach rather than an extreme group comparison, Unsworth et al. (2015) failed to find any significant results despite the inclusion of several measures of attention compiled into a main attentional variable, and different videogame genres. This study suggests that only intense gaming interferes with attention. Even if one could argue that this is the only study using a correlational approach, the fact that they still obtained significant results using a group comparison tends to support their conclusion. Indeed, since they obtained significant results using an extreme group comparison, they showed that the intense gamers exhibited improved cognitive functions when compared to non-gamers. However, the lack of results in the correlational approach tends to show that when including the whole spectrum of gaming, the results are not significant, and therefore gaming does not improve cognition.

Secondly, videogame players exhibited a better cognitive flexibility through improved results on the switching tasks (Colzato 2010; Karle et al. 2010). This improved flexibility may also be dependent upon the game genre played because FPS players were significantly outperformed by RTS players (Dobrowolski et al. 2015). Furthermore, three studies explored the underlying mechanisms of superior performance by videogame players finding that gamers exhibited even better results when they were cued, or had more time to prepare their response to a stimulus (Karle et al. 2010). These studies match the results from the attentional studies, as better top-down attention also led to such results. Furthermore, Hartanto et al. (2016) showed that although the amount of time spent on a game significantly improves cognitive flexibility, the age of gaming onset is a better predictor of this flexibility. This study suggests that when a gamer starts playing before the age of 12 years (i.e., when switching skills are at the level of adult performance), their switching and mixed costs are greatly improved compared to gamers starting later, with an equivalent amount of time spent on games per week.

Thirdly, videogame players showed better multisensory temporal processing, that is, the ability to differentiate simultaneous stimuli from consecutive ones, and the ability to decide which stimulus came first when stimuli were presented consecutively (Donohue et al. 2010; Rivero et al. 2012). Nonetheless, despite their better overall cognitive performance, videogame players exhibited a clear bias toward visual stimuli compared to auditory ones (i.e., a trend reporting that the visual stimulus came first instead of the auditory one), conversely with the control participants showing the opposite trend (Donohue et al. 2010). In short, videogame players outperformed non-videogame players on three different cognitive processes: task-switching, sub-second time perception, and attention. Additionally, two studies raised an important issue by comparing different game genres in their experiment, leading to significant differences between those genres (Dobrowolski et al. 2015; Krishnan et al. 2013). Such differences may indicate that all game genres could impact on cognitive processes differently, depending upon their structural characteristics. It should also be noted that almost all the studies reviewed assessing the positive impacts part explored action videogames as a global construct, despite that this is an umbrella designation grouping very different game genres (e.g., FPS, RTS, multiplayer online battle arena [MOBA]).

Although these studies generally showed improved cognitive processes among videogame players, due to the quasi-experimental design used, no causal link can be confirmed. Nonetheless, several studies explored the training effect of videogames on several cognitive processes. Even if these were not included in the review, as the researchers did not recruit gamers *per se* but non-gamers that were asked to play in order to improve specific skills, they are noteworthy. Indeed, these studies tend to support a causal effect of videogames on the improvement observed instead of the possibility that individuals with improved cognitive skills would play games because they would be better at playing them. Concerning the switching costs, several studies found that training non-gamers, or unexperienced gamers, on videogames led to significant improvements, with reduced switching costs (e.g., Glass et al. 2013; Oei and Patterson 2014; Strobach et al. 2012). Regarding attention, the same pattern of results was observed in several studies using videogames in order to improve processing speed or visual attention (e.g., Belchior et al. 2013; Schubert et al. 2015). However, to the best of our knowledge, there is no study that has explored how videogame training could improve or worsen sub-second time perception. Therefore, little can be concluded on a possible causal effect of playing videogames on time perception.

Despite some differences found in the results, the studies exploring the improvement among videogame players yielded relatively consistent results including improved (i) sub-second time perception, (ii) switching abilities, and (iii) attentional abilities (mostly the top-down control, and processing abilities). However, these studies mainly recruited healthy videogame players (only Collins and Freeman 2014 explored the difference between problematic and healthy players, failing to find any difference) and mostly studied the action game genre that comprises numerous game genres (e.g., RTS, FPS, RPGs). Studies yielding a negative impact on the cognitive processes among videogame users do not raise such consistency, as they show contrasting results for both the multi-second time perception and the inhibition studies (Nuyens et al. 2017). While the studies exploring the positive consequences of videogames reported in this review recruited participants from the healthy population, studies on the negative consequences of videogame play tend to recruit problematic videogame players (Nuyens et al. 2017). Therefore, no definitive conclusion can be drawn because no study has ever compared problematic and non-problematic players in the studies outlined. Consequently, the current literature examining the effect of videogame use on cognitive ability requires further study comparing the two populations.

Future studies investigating the impact of gaming on cognitive processes should examine executive functions using validated models of cognitive processes. For example, the Miyake model of executive functions (Miyake 2000) includes three different functions: (i) shifting (or task-switching), (ii) inhibition, and (iii) updating. According to this model, several tasks are needed to fully explore each of these functions, and despite the number of studies exploring both inhibition and shifting, only part of the tasks have been used. For example, in the switching task, there were no studies examining local-global shifting, which is the ability to identify either a bigger figure (e.g., a triangle, a square) or smaller figures composing the bigger one. Finally, the updating function (i.e., the ability to encode information in working memory, and gradually delete old and unnecessary information when it becomes useless, and replace with new more important information) has yet to be explored. Videogame play may improve this function, as most current videogames require players to monitor different stimuli during their session (e.g., objectives, ammunition, team member still alive).

In conclusion, the studies reviewed suggest that videogame play can have a positive impact on cognitive processes for players. However, this field of study needs more rigor because little is known about the (i) different impacts concerning pathological, excessive, or casual use of videogames, or (ii) impact concerning different game genres. Such studies may be of use for the videogame industry because the results indicate that videogames can have a positive impact on the players, as long as gameplay is non-problematic. Moreover, these findings may have positive impacts on general healthcare as the presented research suggests cognitive skills can be improved via gaming, with possible benefits in delaying cognitive decline and related applications (see Griffiths et al. 2013, for an overview).

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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