Transportation Research Part F: Psychology and Behaviour 97 (2023) 170–180

Contents lists available at ScienceDirect

Transportation Research Part F: Psychology and Behaviour

journal homepage: www.elsevier.com/locate/trf

Do action video games make safer drivers? The effects of video game experience on simulated driving performance

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ARTICLE INFO

Keywords:
Action video games
Driving
Lane maintenance
Speed variability
DRT

ABSTRACT

Research suggests, action video games (AVGs) can benefit cognitive performance across multiple domains including attention, visual-spatial awareness, psychomotor control, and executive functioning. Many of these domains overlap with the skills needed to safely drive a vehicle. We therefore predicted that experience playing AVGs may be associated with improved driving performance and greater spare capacity. One-hundred-and-thirty-eight participants who varied in action video game experience, completed a driving simulation under distracted and non-distracted conditions. Driving performance was measured through participants' ability to maintain a consistent speed and lane position, and their spare cognitive capacity (via detection response task; DRT). Results showed participants with experience playing AVGs performed significantly better than non-gamers, demonstrating lower speed variability, improved lane maintenance, and better performance on the DRT. The effects of distraction were predictably observed, though distraction negated the improvements to DRT response times for AVG players. These findings indicate action video game players had better driving performance and increased spare cognitive capacity compared to individuals who did not play AVGs and highlight a potential avenue for improving driver safety through video game use.

1. Introduction

Driving is a complex, skill based, task performed regularly by more than 1.4 billion people worldwide. Tragically, not all drives end safely, with traffic accidents responsible for roughly 1.35 million deaths and up to 50 million non-fatal injuries per year (World Health Organization, 2018). Younger drivers (aged 17 – 25) are significantly over-represented in these statistics, with road accidents a leading cause of death for young people in many countries (International Traffic Forum, 2018). This increased accident risk is thought to reflect a combination of social (i.e. peer influences), situational (e.g. mobile phones, intoxicants), ability-based (i.e., lower skill), and cognitive factors (Bates et al., 2014).

Current interventions successfully target social, situational, and ability-related risk factors through methods such as road safety campaigns, graduated licensing, and changes to traffic laws in order to reduce accident risk. However, programs addressing cognitive risk factors have yet to be deployed on a similar scale. This is a critical gap in light of the clear links between safe driving and cognitive skills including visuospatial awareness, object/space perception, psychomotor control, attention, working memory and executive functioning (see: Aksan et al., 2015; Barkley et al., 2002; Ledger et al., 2019; Reger et al., 2004; Ross et al., 2015; Woodward et al.,

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https://doi.org/10.1016/j.trf.2023.07.006
Received 12 February 2023; Received in revised form 30 May 2023; Accepted 10 July 2023
Available online 21 July 2023

2000; Zicat et al., 2018).

Support for the idea that training cognitive skills can improve driving comes from studies showing that computer-based cognitive training targeting processing speed (Edwards et al., 2009; Nouchi et al., 2019), working memory, dual attention (Nouchi et al., 2019; Seidler et al., 2010) and response inhibition (Seidler et al., 2010) in older adults led to improved driving ability/mobility outcomes. However, a significant obstacle to the wider adoption of such interventions is the resource-intensive nature of the training, typically requiring time investments of 20–30 min per session over 20+ sessions, as well computer resources (Nouchi et al., 2019; Seidler et al., 2010). In turn such training typically targets a very limited number of cognitive skills at a time. Using this approach, training a range of driving-relevant cognitive skills would require a significant investment of time and money, limiting the potential to deploy such interventions at scale (Nozawa et al., 2015; Ross et al., 2017). Moreover, it is not known whether all at-risk drivers would benefit similarly, as studies have not examined whether these programs are helpful for younger drivers. Given the costs involved, it is important to determine if a more cost-effective alternative might be available.

A promising alternative for improving cognitive skills, particularly for younger drivers, may be video games. Video games are a popular form of interactive digital entertainment that have become virtually synonymous with childhood and adolescence, and a passion that continues for many into adulthood (Lenhart et al., 2015; Williams et al., 2009). Of particular relevance to driving are action video games (AVGs), which are characterised by a high energy style of gameplay that, much like driving, is dependent on high temporal and spatial precision, as well as fast adaptation to rapidly updating, complex situations and environments (Bediou et al., 2018; Green & Bavelier, 2003; Green & Bavelier, 2015; Oei & Patterson, 2015).

Over twenty years of research (for review see Bediou et al., 2018) has linked AVG experience with improved performance on a range of tasks such as functional field of view (Feng et al., 2007), temporal attention (Green & Bavelier, 2003), visual search (Wu & Spence, 2013), multiple object tracking (Boot et al., 2008), and sequential target identification (Oei & Patterson, 2015). These tasks tap into multiple domains of cognitive functioning associated with safe driving including visual-spatial awareness, attention, executive functioning, and working memory. Moreover, training inexperienced non-gamers with AVGs for 10–20 hrs has been shown to significantly improve performance on many of these same tasks (Chandra et al., 2016; Green & Bavelier, 2015; Oei & Patterson, 2013). This has been observed in pre- to post-training comparisons of AVG-trained participants, as compared to active (puzzle game) and waitlist (no-training) controls.

Notably, and in contrast to these findings, some researchers have argued against the cognitive benefits of AVGs. For example, in their *meta*-analytic review, Sala et al. (2018) pointed to widespread evidence of null findings in the literature. Similarly, Roque and Boot (2018) pointed to potential methodological issues within the video game literature including inadequate control groups and improper blinding of researchers and participants. Such critiques highlight that further research is therefore necessary, with the potential advantages of AVGs to driving being an important avenue for investigation.

Given the evidence that playing AVGs may improve a range of cognitive skills, and that these same skills have been closely linked to driving, it is reasonable to expect that playing AVGs could also improve driving performance. However, only two studies to date have examined this possibility. Belchior (2007) trained a sample of 19 older (>65yrs) non-gamer drivers to play an AVG for nine hours. They found no significant improvement in lane-maintenance performance or braking speed compared to controls who received no training. Conversely, Li et al. (2016) compared 12 AVG players (played > 5 hrs of AVGs per week over the last six months) with 12 Non-AVG players (played < 1 hr of AVGs per month over the last two years). Participants (a mix of licensed and unlicensed drivers, aged 20-35yrs) drove at a fixed speed down a straight road while compensating for randomly occurring crosswinds designed to alter their vehicle's course. Results suggested AVG players were significantly faster and more accurate when correcting for wind-induced lateral deviations and were overall better able to maintain their lane position compared to their non-AVG peers. Given this limited and seemingly contradictory evidence obtained using samples of widely differing ages, distinct outcome tasks and different methodological approaches, further research investigating whether AVGs have the potential to improve driving performance and safety is clearly warranted.

1.1. The current study

We compared two groups who were categorised as either AVG players or non-video game players based on their prior gaming experience. We assessed their driving performance in a simulator, and recorded several different measures to capture the complexity of real-world driving (Papantoniou et al., 2017) including speed variability, lane maintenance, and spare cognitive capacity (necessary for responding safely to unexpected events or environmental changes). All of these measures have previously been linked to drivers' ability to safely operate a motor vehicle in a range of conditions (Cooper et al., 2013; Quddus, 2013; Young & Stanton, 2007).

As frequent changes in vehicle speed have been linked to higher accident risk (Aarts & Van Schagen, 2006; Garber & Gadirau, 1988), low speed variability is considered an indicator of good driving performance. Achieving low speed variability requires sustained attention (monitoring current speed), visual spatial awareness (being aware of changes in terrain and driving conditions) and psychomotor control (adjust acceleration accordingly) (Alosco et al., 2013; Zicat et al., 2018).

Failing to keep a vehicle within its lane increases the risk of unintentionally entering an adjacent lane (Cao & Liu, 2013; Wang et al., 2019). Thus, better lane maintenance (operationalized as low lateral variability) is considered an indicator of good driving performance. Achieving low lateral variability requires visuospatial awareness (observing the road environment), directed attention (monitoring shifts in trajectory relative to lane markings), psychomotor control (ongoing steering corrections), and executive functioning (planning for lane changes and steering manoeuvres) (Cooper et al., 2013; Kaber et al., 2016; Salvucci & Beltowska, 2008).

Finally, we also assessed spare cognitive capacity, as reduced capacity has been linked to poor vehicle control and increased accident risk (Cooper et al., 2013). Spare capacity was assessed using the international standard Detection Response Task (DRT;

International Organization for Standardization, 2016) which asks participants to respond to a frequent, peripherally-presented visual probe while driving. Slow response times and low accuracy (i.e. more probes missed) are both indicators of reduced spare capacity. An added benefit of this technique is that responses to probes can be used to infer a driver's ability to detect and respond to potential hazards while driving (Bowden et al., 2017; Strayer et al., 2015; Van Winsum, 2018).

AVG experience was assessed using a questionnaire developed by Green and Bavelier (2003) This 'video game playing questionnaire' has been used in numerous previous studies (including, but not limited to: Dale et al., 2019; Green & Bavelier, 2003; Green & Bavelier, 2015; Unsworth et al., 2015) to measure time spent playing video games across different time periods and game genres. It was used here to categorise participants as either Action video game players (AVGPs) or Non-video game players (NVGPs). Correlational designs are common within the AVG literature and are much simpler than intervention designs to execute overall. Such a design is also necessary to establish the existence of a relationship between driving and AVGs before investing in more costly alternatives, such as training designs. As a result, while comparing AVGPs to NVGPs allows us to make inferences about the relationship between AVGs and driving performance, we cannot conclude whether this relationship is causal in nature.

Here, we predicted that AVGPs would have lower speed variability, better lane-maintenance, and faster/more accurate performance on the DRT, compared to NVGPs. We also assessed whether AVG experience would moderate the detrimental impact of driver distraction on driving performance. Distraction occurs whenever attention is directed away from the task of driving, such as when using mobile devices, interacting with in-car systems or speaking with passengers (Vegega et al., 2013). Driver distraction is estimated to be involved in nearly 20% of all road traffic accidents, negatively impacts speed variability and lane maintenance, and reduces spare cognitive capacity (Bowden et al., 2019; Papantoniou et al., 2017). Moreover, distraction disproportionally affects younger drivers (Pope et al., 2019; World Health Organization, 2018).

Distracted driving places an additional load on several of the cognitive functions discussed here, including task switching, working memory, inhibition, and attention (Lee & Lee, 2019; Verhoeven et al., 2011). Thus, since evidence suggests playing AVGs improves these specific areas of cognitive functioning (Green et al., 2012; Strobach et al., 2012), we predicted that AVGPs would show a smaller decrement in driving performance during cognitive distraction, compared to NVGPs.

2. Methods

2.1. Participants

One-hundred-and-thirty-eight (81 Male, 57 Female) undergraduate student participants (Age: $M = 20.3$ years, range 17–34, $SD = 3.44$), possessing a current Australian car drivers' licence were recruited from The University of Western Australia. Each received course credit, plus a monetary bonus of up to AUD$5, in exchange for participating. Participants were invited to complete the study based on their responses to a set of four screening questions related to recent experiences playing video games in general and AVGs specifically. Recruitment continued until we had 40 participants who met video gaming experience criteria (described below) in each condition. This was based on a G-power (Faul et al., 2007) analysis which suggested $n = 40$ was required to detect a small to medium effect with 80% power. Participants provided informed consent, and this study was approved by The University of Western Australia Human Research and Ethics Office.

2.2. Tasks and stimuli

2.2.1. Driving simulator

Participants drove in a medium-fidelity simulation (Fig. 1), which consisted of three 32-inch monitors providing a 140° field of view, housed within an Obutto gaming cockpit, and running SCANeR Studio software (Oktal Software; Version 1.4). The front windscreen view was presented on the central monitor situated approximately 85 cm from the seated participant, with a digital speedometer displayed centrally at the bottom. Two side monitors, arranged at a 35° horizontal angle, were used to present side window views. Rear and side view mirror displays were also presented in the central and side monitors respectively. Participants

Fig. 1. Left image shows the driving simulator cockpit and displays. Right image shows central monitor with four lanes and DRT stimulus visible.

controlled the vehicle via a Logitech G27 steering wheel and pedal set. The simulated vehicle was configured for automatic transmission and Australian left-hand driving conditions.

Participants drove for a total of 39 min on a four-lane, gently winding country road with two lanes in each direction (see Fig. 1). Participants always drove in the left-most lane (reflecting Australian conditions), with no other traffic present in their lane. The other three lanes were lightly populated with other vehicles (approx. five per minute). There were no intersections and participants were instructed to drive at 50 km/h. Vehicle speed and lane position data were recorded continuously at 1000 Hz and down-sampled to 50 Hz for analysis.

2.2.2. Distraction task

Cognitive distractions were presented while participants were driving via a Samsung Galaxy A8 tablet with Android version 11 operating system. The distraction task consisted of a series of self-paced basic addition problems with two randomly generated operands between 0 and 10 (e.g., “9 plus 4 equals?”) presented via headset (Harbluk et al., 2007). Participants provided their answers by speaking into the headset microphone, and a tone was played to confirm each response before the next question was presented.

The driving scenario was divided into six 6-min blocks of driving. This included three distraction blocks (in which the addition task was performed concurrently with driving) and three non-distraction blocks (no distraction, only driving). Distraction and non-distraction blocks alternated, and whether the participant commenced with a distraction or non-distraction block was counterbalanced between participants. Prior to each block, the simulation was paused for 30 s, and participants were told whether the next block contained addition questions.

2.2.3. Detection Response Task (DRT)

A modified DRT was used (Bowden et al., 2017), in which participants responded to a series of small (0.49° of visual angle) red dot probes presented on the central monitor. A total of 160 probes were presented in equal numbers across four horizontal eccentricities: ‘Inner’ probes were presented randomly between 6.80° and 10.13° of visual angle to the left or right of the vertical midline, and ‘Outer’ probes were presented randomly between 18.14° and 21.17° of visual angle to the left or right of the vertical midline. All probes appeared randomly within 2-4° of visual angle above the horizontal midline. Probes appeared for 2 s, or until a response was made, and were separated by a random interval of 10–15 s. Participants were instructed to respond to probes as quickly and accurately as possible by pressing a button on the steering wheel.

2.2.4. Questionnaires

An online questionnaire assessed driving experience, demographics (including gender, with options for male, female and other), and video gaming experience (Dale et al., 2019; Green & Bavelier, 2012; available at https://osf.io/pkmdv/). Experience playing seven different types of video game was assessed based on the average number of hours spent playing each week using a 7-point scale ranging from ‘never’ to ‘10 + hours per week’. Participants were asked to respond based on their gameplay experience over the last 12 months, and whether they had any significant gameplay experience prior to this period.

2.3. Procedure

Following task instructions, participants completed a 10-minute training scenario to familiarise themselves with driving in the simulator. During training, they practiced driving in the left lane, maintaining a speed of 50 km/h, responding to DRT stimuli, and performing the distraction task. Participants were instructed that they would receive an initial bonus of AUD$5, “which would be reduced if they drove either too fast or too slow”, in order to incentivise adherence to the speed limit, in line with real-world penalties for speeding. In turn this encouraged participants to monitor their speed, with final bonuses paid according to randomly occurring speed checks. The experimental driving component was divided into two 19.5-minute blocks each with a short rest break in between. Following the driving component, participants completed the online questionnaires. The entire experiment took ~ 90 mins to complete.

Table 1
Criteria for classification as an Action Video Game player (AVGP). Participant must meet one of the four sets of criteria to qualify. E.g. criteria set 2 requires playing an average of 3 to 5 h per week of action first/third person shooters in the last 12 months, plus an average of more than 5 h per week of action first/third shooters during a significant period prior to the last 12 months.

	Criteria Set:			
Criteria:	1	2	3	4
Min average hours playing Action 1st/3rd Person Shooter games in last 12 months	5+	3–5	3–5	3–5
Min average hours playing Action 1st/3rd Person Shooter games prior to the last 12 months	.	5+	3–5	.
Min average hours playing Action RPG/Sporting/Driving/Adventure games in the last 12 months	.	.	5+	5+
Min average hours playing Action RPG/Sporting/Driving/Adventure games prior to the last 12 months	.	.	.	3–5
Max average time spent playing all other types of video games in the last 12 months	1	1	1	1

3. Results

Following the Dale et al. (2019) guidelines, participants were classified as AVGPs if they met one of four sets of criteria outlined in Table 1. Each criterion incorporated time spent playing action first- and third- person shooting games in the last 12 months, in addition to time spent playing other action style video games or playing shooting games during significant periods more than a year ago. Only participants who reported having never played any type of video game were classified as NVGPs.

Of the 138 participants who were screened, 40 were classified as AVGPs, 40 as NVGPs, and 58 qualified for neither group. Driving data for three of these 80 classified participants were deemed outliers (Tabachnick et al., 2007) and excluded from further analyses. Two had speed variability more than 3.29 SDs above the sample mean, while another had a DRT hit rate more than 3.29 SDs below the sample mean. This left 37 participants in the NVGP group and 40 in the AVGP group. A notable characteristic of these groups (which can be readily seen in Table 2) is a significant gender imbalance, with far more males in the AVGP group and far more females in the NVGP group. This is not an uncommon problem in the video game literature, and we will address it further in the Results and Discussion.

3.1. Distraction task performance

Accuracy while completing the cognitive distraction task was at ceiling for both AVGPs (M = 0.98) and NVGPs (M = 0.98), indicating an appropriate level of engagement and no difference between the two groups. AVGPs ($M = 238.7$, $SD = 38.4$) and NVGPs ($M = 253.2$, $SD = 25.3$) did not differ significantly in the number of maths questions answered, $t(75) = 1.93$, $p = .057$, $d = 0.44$, with a trend toward NVGPs responding to more questions.

3.2. Speed variability

Speed variability was calculated as the standard deviation of vehicle speed in km/h, with larger values representing poorer speed control (Fig. 2). Mean speed variability was analysed using a 2 (Distraction: present, absent) × 2 (Gamer Type: AVGP, NVGP) mixed design analysis of variance (ANOVA), where Distraction was within-subjects and Gamer Type was between-subjects. This analysis yielded main effects of Distraction, $F(1,75) = 9.69$, $p = .003$, $\eta_p^2 = 0.11$, indicating speed variability was greater when performing the concurrent distraction task, and Gamer Type, $F(1, 75) = 5.64$, $p = .020$, $\eta_p^2 = 0.07$, indicating the AVGP group had lower speed variability than the NVGP group. There was no interaction, $F < 1$, $p = .403$, $\eta_p^2 = .009$. This suggests that AVGPs were better able to maintain their speed relative to NVGPs.

3.3. Lane maintenance

Lane maintenance was defined as the standard deviation of vehicle lane position in meters, with larger values representing greater movement variability within a lane and thus poorer lane maintenance (Fig. 3). Mean lane maintenance was analysed using a 2 (Distraction: present, absent) × 2 (Gamer Type: AVGP, NVGP) mixed design ANOVA. This analysis yielded main effects of Distraction, $F(1,75) = 55.26$, $p < .001$, $\eta_p^2 = 0.42$, indicating lane maintenance was better when performing the concurrent distraction task, and Gamer Type, $F(1, 75) = 14.08$, $p < .001$, $\eta_p^2 = 0.16$, indicating the AVGP group had better lane maintenance than the NVGP group. There was no interaction, $F < 1$, $p = .987$, $\eta_p^2 < .001$. This suggests that AVGPs were better able to maintain their lane position relative to NVGPs.

3.4. Detection response task

Responses made within 2.5 s of probe onset were counted as hits, while responses made outside this window were counted as false alarms. The total number of false alarms did not differ between the AVGP ($M = 2.45$, $SD = 3.10$) and NVGP groups ($M = 3.19$, $SD = 2.66$), $t(75) = 1.36$, $p = .179$, $d = 0.31$. DRT accuracy was calculated as the number of hits divided by the total number of probes presented, while DRT RTs were calculated as the median response time on hit trials (Table 3).

3.5. Adjusted RT

Initial analysis of the DRT comprised separate evaluations of both RTs and accuracy. However, during this process, it became

Table 2
Participant demographics for Action Video Game Players (AVGPs) and Non-Video Game Players (NVGPs). Mean age and driving experience are provided, with standard deviations in brackets.

	AVGP	NVGP
N	40	37
Males / Females	36 / 4	11 / 26
Age (years)	20.12 (2.92)	20.76 (4.32)
Driving Experience (years)	3.53 (1.48)	3.78 (1.70)

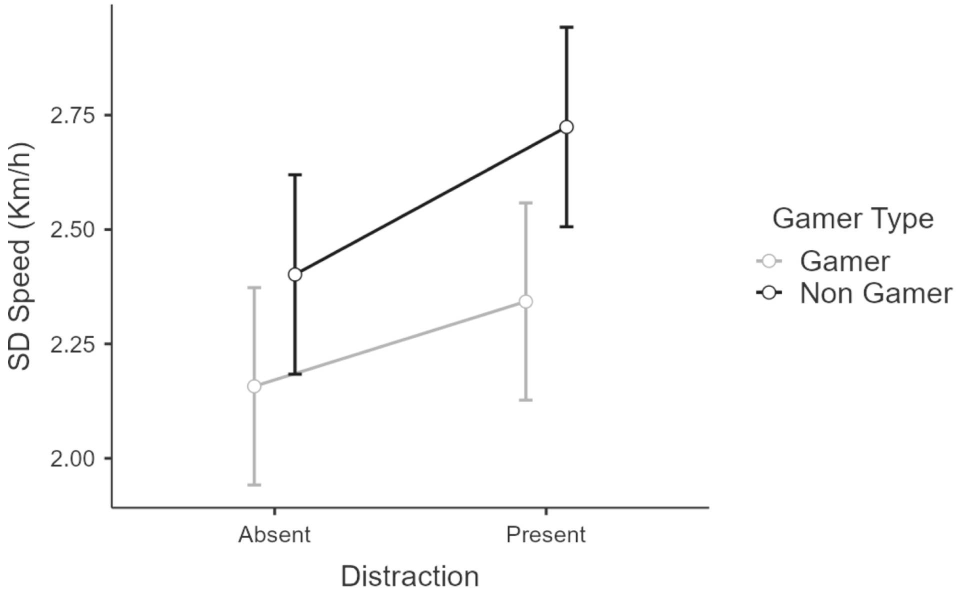

Fig. 2. Speed variability (standard deviation in km/h) for AVGP and NVGP groups with/without distraction. Error bars indicate 95% between-subjects confidence intervals.

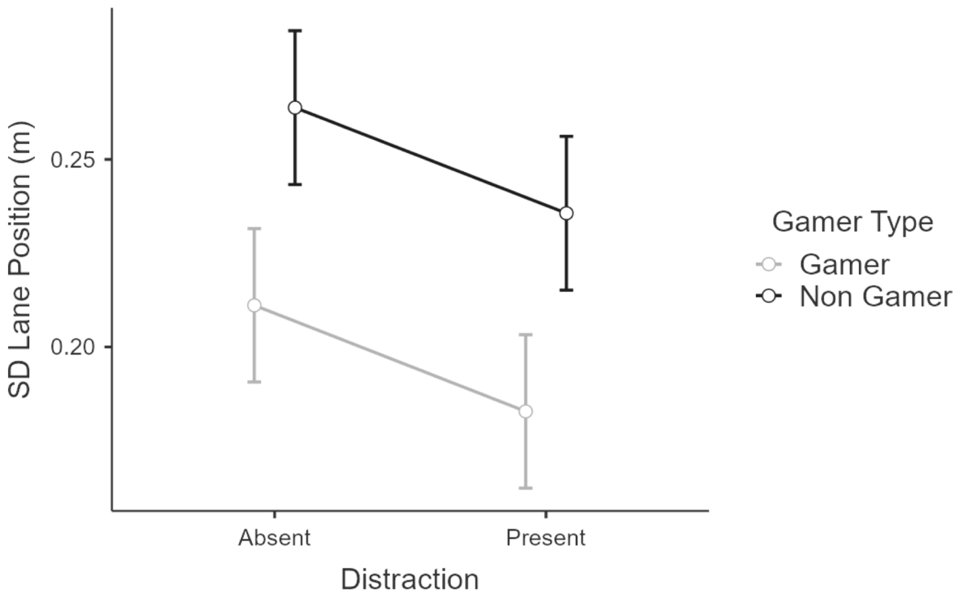

Fig. 3. Lane Maintenance (standard deviation in meters) for AVGP and NVGP groups with/without Distraction. Error bars indicate 95% between-subjects confidence intervals.

evident that there was a trade-off occurring between RT and accuracy, particularly within the more demanding conditions of distraction and eccentricity. To address this trade-off, we combined RT and accuracy into a single aggregate measure. An adjusted RT was calculated as RT divided by Accuracy, effectively amending RTs to account for differences in accuracy (Townsend & Ashby, 1983). The adjusted DRT RT was analysed using a 2 (Distraction: present, absent) × 2 (Eccentricity: inner, outer) × 2 (Gamer Type: AVGP, NVGP) mixed-design ANOVA. This analysis yielded a main effect of Distraction, $F(1, 75) = 99.13$, $p < .001$, $\eta_p^2 = 0.57$, indicating lower performance (higher adjusted RT) during the concurrent distraction task, a main effect of Eccentricity, $F(1, 75) = 436.34$, $p < .001$, $\eta_p^2 = 0.8$, indicating lower performance (higher adjusted RT) for probes presented at outer eccentricities, and a main effect of Gamer Type, $F(1, 75) = 7.04$, $p = .0097$, $\eta_p^2 = 0.09$ indicating better performance (lower adjusted RT) for the AVGP group compared to the NVGP group (Fig. 4). There were no significant interactions (smallest $p = .107$).

Table 3
Summary of DRT response time and accuracy. Means and standard deviations (in brackets) are presented separately for within-subject conditions of distraction (on/off) and eccentricity (inner/outer visual field).

	Distraction	DRT target Eccentricity	AVGPs	NVGPs
DRT RT (ms)	*Absent*	*Outer*	606 (77)	677 (107)
		Inner	533 (67)	594 (69)
	Present	*Outer*	750 (126)	763 (109)
		Inner	616 (92)	649 (85)
DRT Accuracy	*Absent*	*Outer*	0.82 (0.08)	0.78 (0.08)
		Inner	0.99 (0.02)	0.99 (0.02)
	Present	*Outer*	0.78 (0.10)	0.74 (0.09)
		Inner	0.99 (0.02)	0.98 (0.03)

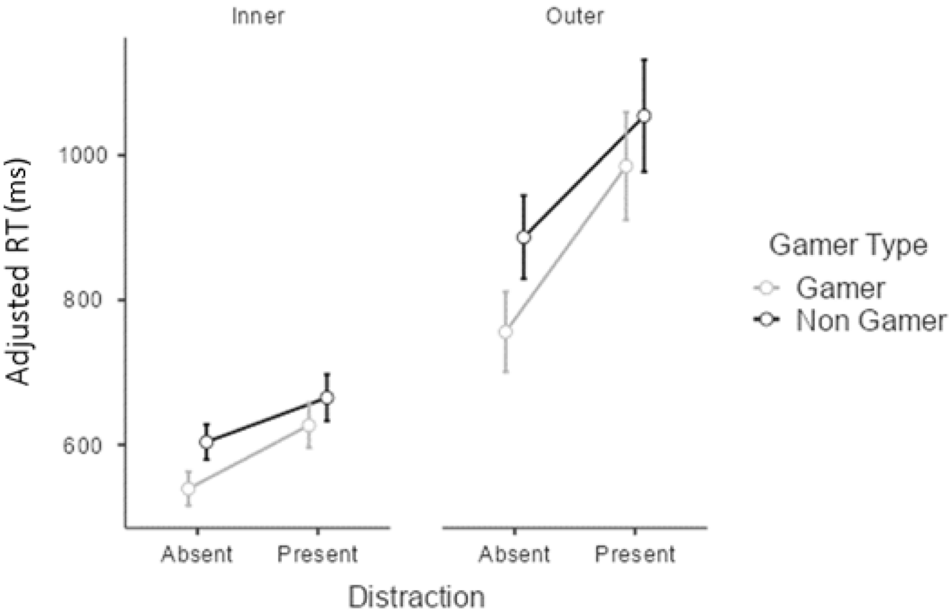

Fig. 4. The interaction between DRT target eccentricity (inner, outer) and gamer type (AVGP, NVGP), and Distraction (present, absent) on adjusted RT. Error bars indicate 95% between-subjects confidence intervals.

Table 4
Summary of DRT response time and accuracy, speed, and lane measures for male (upper) and female (lower) participants. Means and standard deviations (in brackets) are presented separately for the between subject condition of gamer type, plus the within-subject conditions of distraction (on/off) and eccentricity (inner/outer visual field), applicable to DRT only.

Eccentricity	Distraction	Gamer Type	DRT(RT)	DRT(ACC)	Speed (SD)	Lane (SD)
Males						
Inner	Absent	Gamer	528 (67.9)	0.99 (0.02)	2.21 (0.9)	0.21 (0.08)
		Non-Gamer	605 (74.1)	0.99 (0.02)	2.1 (0.52)	0.23 (0.06)
	Present	Gamer	616 (96.8)	0.99 (0.02)	2.39 (0.56)	0.18 (0.06)
		Non-Gamer	652 (106.5)	0.98 (0.02)	2.39 (0.65)	0.21 (0.05)
Outer	Absent	Gamer	601 (78.1)	0.82 (0.08)	–	–
		Non-Gamer	662 (93.6)	0.78 (0.09)	–	–
	Present	Gamer	755 (131.7)	0.78 (0.11)	–	–
		Non-Gamer	768 (102.9)	0.74 (0.08)	–	–
Females						
Inner	Absent	Gamer	583 (28.7)	0.99 (0.01)	1.75 (0.47)	0.22 (0.05)
		Non-Gamer	591 (68.5)	0.99 (0.02)	2.54 (0.61)	0.28 (0.07)
	Present	Gamer	620 (42.4)	0.99 (0.03)	0.21 (0.05)	0.21 (0.05)
		Non-Gamer	648 (76.4)	0.97 (0.03)	0.25 (0.06)	0.25 (0.06)
Outer	Absent	Gamer	648 (53.8)	0.79 (0.02)	–	–
		Non-Gamer	684 (113.8)	0.77 (0.08)	–	–
	Present	Gamer	710 (57.2)	0.79 (0.06)	–	–
		Non-Gamer	761 (112.9)	0.74 (0.09)	–	–

3.6. Gender

After classifying participants by Gamer Type, a clear gender imbalance was observed, with more AVGPs identifying as male compared to NVGPs. We therefore repeated each analysis reported above with gender added as a second between-subjects factor to test whether these effects were due to gender differences between AVGPs and NVGPs. For speed variability, there was a Gamer Type × Gender interaction, $F(1,75) = 5.95, p = .017\ \eta^2 = 0.07$, such that a significant difference between AVGPs and NVGPs was observed only for female participants. Gender did not interact significantly with Gamer Type for analyses involving lane maintenance, DRT accuracy, or DRT RT (all F's < 1, p's > 0.44). These findings are discussed below. While further meaningful analysis of this gender imbalance is not possible due to small sample size, we also present a summary of our measures for both males and females (Table 4).

4. Discussion

Playing action video games (AVGs) has been shown to improve performance across multiple cognitive domains, many of which are also associated with safe driving (Green & Bavelier, 2003; Groeger, 2013; Oei & Patterson, 2015; Zicat et al., 2018). At the same time, young drivers, who are often overrepresented in road traffic accident statistics, typically have more exposure to AVGs. This has led us to investigate whether playing AVGs might be associated with better driving performance in a population of younger drivers.

We recruited experienced action video games players (AVGPs) and non-video game players (NVGPs) and compared their simulated driving performance using metrics of speed variability, lane maintenance, and spare cognitive capacity (via DRT). It was predicted that AVGPs would show superior performance on these metrics compared to NVGPs. We also evaluated driving performance when a concurrent cognitive distraction task was included, which is analogous to many distractions encountered in real-world driving (i.e., talking with a passenger or using a hands-free smart phone). It was predicted that AVGPs would be less detrimentally impacted by distractions compared to NVGPs due to superior cognitive skills - such as task switching and directed attention abilities previously linked to playing AVGs (Lee & Lee, 2019; Verhoeven et al., 2011).

Under all driving conditions, our first prediction was supported, with AVGPs better able to control their speed and maintain lane position compared to NVGPs. Further, AVGPs responded faster and more accurately to DRT targets than NVGPs, suggesting they may have had more spare cognitive capacity. However, our predictions that AVGPs would be less impacted by distraction were not supported. Gamer type did not moderate the effect of distraction on either speed variability or lane maintenance. Further, in the case of DRT, we found that neither distraction nor eccentricity interacted with gamer type when DRT RT and accuracy were combined into a single aggregate measure.

Taken together, our results suggest that experience playing AVGs is related to improved driving performance. A likely explanation for this relationship is that playing AVGs trains cognitive skills in areas that are also key to driving. For example, playing an AVG proficiently requires sustained and directed attention, spatial awareness, and psychomotor control to navigate and track the relative positions of obstacles and opponents, and adjust gameplay as necessary (Baniqued et al., 2013; Boot et al., 2008). In driving, both maintaining a consistent speed and lateral position relative to lane markings have been shown to require many of these same cognitive skills (Alosco et al., 2013; Cooper et al., 2013; Kaber et al., 2016; Salvucci & Beltowska, 2008; Zicat et al., 2018). It is, however, important to highlight that we cannot definitively conclude causality from the current study (i.e., that playing AVGs directly *caused* the improved driving performance). For example, it may be the case instead that individuals with superior cognitive skill are more inclined to play AVGs and better able to drive safely. Thus, to establish a causal relationship, future studies will need to incorporate an intervention design, providing non-gamers with training on an AVG and comparing driving performance pre- and post-training.

With respect to drivers' spare cognitive capacity, we found that AVGPs performed better than NVGPs when detecting peripheral DRT probes. However, we do note that when first evaluating DRT RTs in isolation, we found that contrary to our prediction, there was an interaction with gamer type such that a spare capacity advantage for AVGPs was evident only when driving without distraction. This advantage became non-significant when a distraction was introduced. This corresponded with a similar interaction between gamer type and eccentricity on measures of DRT accuracy, in turn leading us to suspect that a trade-off between DRT RT and accuracy was occurring. For this reason, the analyses reported here aggregated DRT RT and accuracy into a single measure to assess spare cognitive capacity.

As well as an indicator of spare cognitive capacity, the visual DRT task has been conceptualized as a proxy for real-world hazard detection (Strayer et al., 2017). In our driving task, DRT probes were presented peripherally at random intervals and locations, mimicking the task of identifying potential hazards in real-world driving. The DRT and hazard perception also share a reliance on the size of a driver's useful field of view (UFOV), which is linked to driver safety and accident risk (Horswill et al., 2008; see also Myers et al., 2000; Owsley, 1994). Thus, our finding that AVGPs show superior DRT performance implies that they have a larger UFOV and thus may be better at detecting peripheral hazards while driving (although this may not translate to improved recognition or risk assessment of a hazard).

The evidence for a link between playing AVGs and improved driving performance could sensibly be explained by the enhancement of cognitive skills required for safe driving derived from playing AVGs. However, such a finding remains unusual in the training literature where near transfer of skills (between highly similar tasks) is typically the norm (Sala & Gobet, 2017; Woodworth & Thorndike, 1901) and far transfer of skills (between highly dissimilar tasks like video games and driving) is the exception. It has been proposed that engagement with AVGs can facilitate far transfer of skills through attention based benefits, or improved multi-tasking capability derived from the rapid paced, multi-faceted demands of video games (Green & Bavelier, 2003). Later theories alternatively suggest a more general enhancement of learning or 'learning to learn' (Green & Bavelier, 2012; Spence & Feng, 2010). In these accounts, video gamers learn to obtain the most relevant information from a given situation to maximise performance, owing to the very dynamic and complex nature of video game environments. This, in turn, facilitates acquisition of skills applicable to a wide variety of tasks that have similar properties as video game environments. Our findings of a link between unrelated activities – AVGs and driving – is consistent with this conceptualization and buttresses the possibility of video games facilitating far transfer effects.

Finally, the current findings support the feasibility of using AVGs to improve driving performance in at-risk groups, particularly in younger drivers who are already likely to be engaged with video games. Due to the sheer volume of drivers on the road worldwide, even minor improvements in vehicle control and hazard detection could contribute substantially to reducing accidents and fatalities (Aarts & Van Schagen, 2006). Whether custom-made AVGs are developed to form part of advanced driver training, or young drivers are simply encouraged to play AVGs, such interventions have the potential to be effective, engaging, cost effective, and deployable at scale.

4.1. Limitations and future directions

As with much of the video game literature (Dale et al., 2019; Green et al., 2012) and in the general population, our AVGPs were predominantly male and our NVGPs predominantly female. As a result, it is not possible to entirely disentangle the impact of playing video games from gender. That said, our analysis showed that gamer type had an effect even when we accounted for gender on all outcome variables except speed variability. In this case female AVGPs were more consistent than NVGPs (noting the substantial imbalance in group membership), while there was no such difference in males. In light of this, we suggest the preponderance of evidence favours a link between playing AVGs and better driving, while acknowledging that it remains possible that the magnitude of this advantage may vary with gender.

Driving is a complex task involving encounters with many situations in different environments and requiring a variety of actions to be taken to maintain safety. Simulations, while clearly a valid tool for evaluating various road safety outcomes (Galante et al., 2018; Meuleners & Fraser, 2015; Wang et al., 2010), can provide only a constrained set of situations and environments. Thus, to better establish the boundary conditions within which playing AVGs benefits driving performance, future research should incorporate more heterogenous driving environments and situations while evaluating additional skills such as hazard perception and collision avoidance.

Lastly, as with much of the existing video gaming literature (Bediou et al., 2018; Dale et al., 2019; Green & Bavelier, 2015), we have classified gamers and non-gamers based on their self-reported video gaming *experience*. However, on the assumption that video game skill is a more reliable indicator of the benefits that accrue from playing games, a sensible next step may be to instead assess *proficiency* by measuring performance on an AVG. This would capture individual differences in video game ability amongst players with similar experience profiles (Mosing et al., 2014), e,g., participants who all meet the criteria as AVGPs, but whose levels of skill at playing video games differs wildly. In turn, this might reveal benefits of AVGs that might have been obscured in previous studies by the inclusion of participants who were either very skilled NVGPs or very unskilled AVGPs.

4.2. Conclusion

The current study provides novel evidence that experience playing AVGs is associated with improved performance on multiple measures relevant to safe driving amongst younger, relatively novice drivers, a group typically overrepresented amongst accident statistics. The findings also highlight the pervasive detrimental impact of distraction on driving performance - with AVGPs unable to compensate for distraction any better than NVGPs. Our research offers new evidence of the generalisable and practical benefits of playing AVGs and suggests the potential benefit of using video games as a new approach for improving driver ability and safety.

Funding

This research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

James Howard: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. **Vanessa Bowden:** Software, Supervision, Writing – review & editing. **Troy Visser:** Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

Thanks are given to the staff and students at the University of Western Australia for all their assistance. Thank you to Isabeau Tindall for support provided. This research was supported by an Australian Government Research Training Program (RTP) Scholarship.

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