What's in a game: Examining the effect of video game experience across reading and attentional domains

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By
Shaylyn Kress

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OR

Dean
College of Graduate and Postdoctoral Studies
University of Saskatchewan
116 Thorvaldson Building, 110 Science Place
Saskatoon, Saskatchewan S7N 5C9 Canada

ABSTRACT

Previous studies have suggested playing action video games can improve reading ability in children with dyslexia, but the mechanisms behind this relationship are not fully understood. In this thesis, we evaluate whether attentional processes may be a driving force behind the relationship between reading and video game experience. We additionally examined lexical and sublexical processing more precisely than previous studies by using exception words to encourage lexical processing and pseudohomophones to encourage sublexical processing. In Experiment 1, we tested whether video game experience was related to lexical and sublexical reading aloud in skilled adult readers. Results indicated that video game experience was associated with faster lexical reading reaction times. In Experiment 2, we tested whether action video game experience was related to performance in an orthographic-phonological decision paradigm, and found action video game experience was associated with slower reaction times when responding to exception words. Additionally, we conducted an attentional cueing task with various cue types. Action video game experience shared variance with the interaction between cue type and cue validity. Furthermore, we observed relationships between performance in the orthographic-phonological lexical decision task and performance in the attentional task, highlighting the overlapping nature of reading and attentional processes. In Experiment 3 we used a hybrid attention/reading aloud task to explore the relationship between video games, reading and attention. Video game experience was related to faster reaction times during phonetic decoding and validly cued trials. Finally, in Experiment 4, we conducted a visual-spatial demand analysis with the data from Experiment 3 for an objective measure of visual demands. We found that peripheral visual demands in video games were associated with faster reaction times during validly cued trials. Taken together, these findings provide support for the theory that relationships between video games and reading may be driven by attentional mechanisms. Specifically, these results demonstrate that video game experience is related to reading in skilled adult readers, and that there is a beneficial relationship through the peripheral attentional demands of video games.

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I would like to thank my supervisor, Dr. Ron Borowsky, for your guidance and feedback throughout these projects and for making sure I had funding for both years of my program. Thank you for helping me make the most out of my Master's program with opportunities in co-instructing, research, and writing. I look forward to continuing my graduate studies in your lab.

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LIST OF ABBREVIATIONS

CG	Central Graphic
CT	Central Text
EW	Exception Word
GLM	General Linear Model
OPLDT	Orthographic-Phonological Lexical Decision Task
PG	Peripheral Graphic
PH	Pseudohomophone
PT	Peripheral Text

CHAPTER 1: Introduction

This introductory chapter is adapted from the content of two manuscripts:

Kress, S., Neudorf, J., Borowsky, B., & Borowsky, R. (in preparation). What's in a game: Visual-spatial demands in video games are associated with attentional cueing and reading processes. *To be submitted to Neuropsychologia*.

Kress, S., Neudorf, J., & Borowsky, R. (in preparation). Orthographic-phonological lexical decision performance and video game experience account for attentional cueing reaction times. *To be submitted to Attention, Perception, and Psychophysics*.

Playing video games is a popular hobby. In the Entertainment Software Association of Canada's recent *Real Canadian Gamer Essential Facts* report (2020), 61% of surveyed Canadians reported playing video games and 80% of teens who play video games played more during the Covid-19 pandemic. In the United States of America, 65% of adults play video games and 70% of families have a child who plays video games (Entertainment Software Association, 2019). With video games present in the daily lives of so many people, it is important to understand its impact on cognition. Some studies have demonstrated that playing video games is beneficial to various cognitive domains, particularly reading (e.g., Basak et al., 2008; Dye et al., 2009; Franceschini et al., 2017; Franceschini & Bertoni, 2019; Green & Bavelier, 2003; see Franceschini et al., 2015 for a review). Other researchers have suggested screen-use/video games may have a detrimental effect on brain structure (e.g., Hutton et al., 2019; West et al., 2018). Determining how video games are related to cognitive and brain function will help researchers gain knowledge on what factors are involved in the development and maintenance of various cognitive processes.

The extant research on video games and cognitive processes focuses heavily on the specific genre of action video games, and action/adventure games are the most popular video game genres among children and teenagers (Entertainment Software Association of Canada, 2020). Games that fit within the action video game genre are defined in the literature as those with high speeds (in terms of object appearance/disappearance speeds as well as movement speeds), high perceptual, cognitive, and motor loads, high temporal/spatial unpredictability, and an emphasis on peripheral processing (Green & Bavelier, 2012). Typical exemplars of the action video game genre are first- and third-person shooter games such as *PlayerUnknown's Battlegrounds* (*PUBG*; a first-person shooter game) or *Fortnite* (a third-person shooter game).

1.1 Reading Processes

1.1.1 Models of Reading

According to dual-route models of reading (e.g., Borwosky et al., 2006; Coltheart et al., 2001; Perry et al., 2009, 2010, 2013) there are two different streams in the brain for processing written words into sound. The first is the dorsal-sublexical stream which is involved in phonetic decoding. This stream originates in the occipital lobe and proceeds anteriorly through the parietal lobe (e.g., Borowsky et al., 2006). Sublexical-phonetic decoding involves accessing a word's pronunciation via spelling-sound correspondences and is typically employed when reading unfamiliar words (i.e., "sounding a word out"). Pseudohomophones (PHs) are ideal stimuli to encourage sublexical-phonetic decoding because items in this special class of nonwords sound like real words if phonetic decoding is utilized (e.g., the PH "shue" would sound like the real word "shoe; Borowsky et al., 2006), unlike a pronounceable-but-meaningless nonword. Regions involved in the dorsal-sublexical stream include regions of the angular gyrus, supramarginal gyrus, inferior and superior parietal lobules, and inferior, middle, and superior frontal gyri (Borowsky et al., 2006).

The second stream is the ventral-lexical stream. Like the dorsal-sublexical stream, the ventral-lexical stream originates in the occipital lobe, but it proceeds anteriorly through the temporal lobe (e.g., Borowsky et al., 2006). Lexical/whole-word reading is the process by which a word's pronunciation can be accessed directly rather than using phonetic decoding and is typically employed when reading highly familiar words (i.e., "sight reading"; see Borowsky et al., 2006; Borowsky et al., 2007; Sandak et al., 2004 & Pugh et al., 2000 for more information about these two processing systems). The best stimuli to encourage lexical-whole word reading and activate the ventral-lexical stream are exception words (EWs; e.g. Borowsky et al., 2006). EWs are words that cannot be correctly pronounced if phonetically decoded, and thus require lexical/whole-word reading. The word "shoe" is one example of an EW, as if one attempted to phonetically decode "shoe", it would sound like "shoh". Regions involved in the ventral-lexical stream include the inferior temporal gyrus, middle temporal gyrus, and temporal pole (e.g., Borowsky et al., 2006). Figure 1.1 depicts some of these key regions of the dorsal-sublexical and ventral-lexical streams.

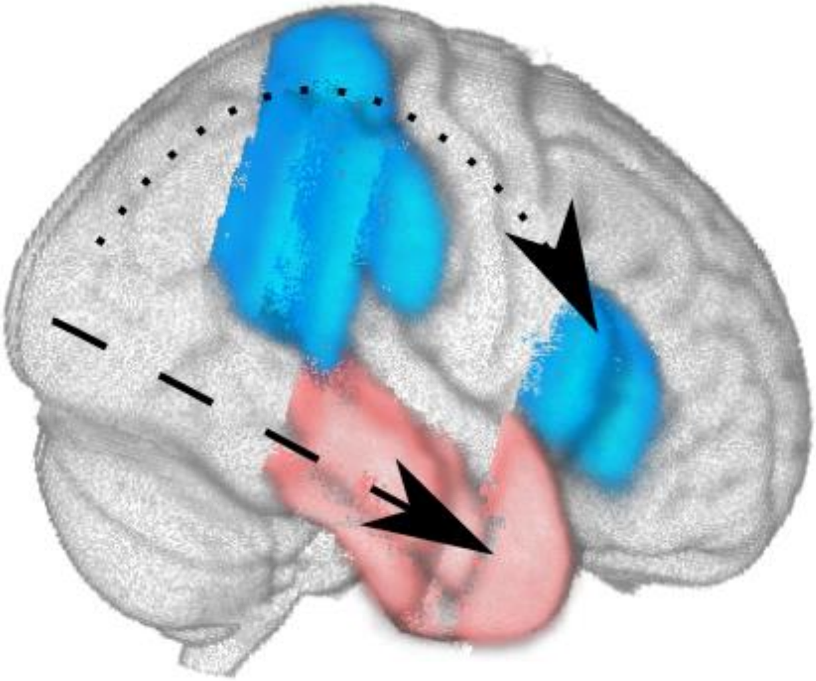

Figure 1.1. Regions of the dorsal-sublexical and ventral-lexical reading streams. The dorsal-sublexical stream is depicted with blue regions and a dotted line. The ventral-lexical stream is depicted with pink regions and a dashed line.

The dorsal-sublexical and ventral-lexical streams of the brain are relevant to the field of dyslexia, where subtypes of dyslexia have been defined based on which reading process has been impacted. Phonological dyslexia is characterized by poor phonetic decoding ability, suggesting deficits in dorsal-sublexical processing, while surface dyslexia is characterized by poor sight reading ability, suggesting deficits in ventral-lexical processing (e.g., Castles & Coltheart, 1993; McDougall et al., 2005). Castles & Coltheart (1993) indicated that in their study of children with dyslexia, deficits in phonetic decoding (i.e., phonological dyslexia) were more prevalent and more severe than deficits in sight reading. In their sample of 53 children with dyslexia, 55% of the children had poorer phonetic decoding skills than sight reading skills, while 30% of the children had poorer sight-reading skills than phonetic decoding skills (Castles & Coltheart, 1993). Dorsal-sublexical processes are therefore a key focus in the field of developmental dyslexia, but for completeness both sublexical and lexical processes were examined in this thesis.

1.1.2 Reading and Video Games

Recent studies indicate that reading ability improves in children with dyslexia after a period of training with action video games (Bertoni et al., 2021; Franceschini et al., 2013; Franceschini et al., 2017; and Franceschini & Bertoni, 2019). This field of research has the potential to motivate the design of specially tailored video games to help children with dyslexia with their reading skills (see Franceschini et al., 2015 for a review). These studies (e.g., Bertoni et al., 2021; Franceschini & Bertoni, 2019; Franceschini et al., 2017) specifically observed improvements in sublexical-phonetic decoding after action video game play in their samples of children with dyslexia, but this was based on a rather coarse measure of overall list reading time for nonwords and lexical reading (using EWs) has not been specifically examined. More work needs to be done to determine exactly which aspects of reading are related to video game experience. In particular, determining whether video game experience is related to lexical/whole-word reading ability or sublexical-phonetic decoding would not only advance models of basic reading processes, but also indicate which types of dyslexia (i.e., surface dyslexia or phonological dyslexia) might benefit from such a treatment technique.

1.2 Attention Processes

1.2.1 Models of Attention

Much like reading processes, a dual-route model can be applied to attentional orienting processes (see Corbetta & Shulman, 2002 for a review). In the dual-route model of attention, the two types of attention that are highlighted are dorsal-endogenous attention and ventral-exogenous attention. Endogenous attention is also called voluntary or top-down attention and can be cued with centrally presented symbolic cues such as coloured symbols (e.g., Ekstrand, Neudorf, Kress, & Borowsky, 2019; historically, arrow cues were a popular voluntary cue choice but some research argues that arrow cues may reflect an attentional process distinct from typical exogenous or endogenous attention, Ristic & Kingstone, 2012). Regions involved in endogenous attention include dorsal-posterior parietal and frontal regions, such as the intraparietal sulcus, superior parietal lobule and frontal eye field (see Corbetta & Shulman, 2002). Exogenous attention is also called automatic attention and can be cued with peripheral visual indicators at the target location (e.g., a flashing box on the left side of the screen). Regions involved in exogenous attentional processing include right temporoparietal and ventral-frontal regions, such as the temporal-parietal junction (inferior parietal lobule and superior temporal gyrus) and inferior frontal gyrus (see Corbetta & Shulman, 2002). Additionally, in research relating reading and attention, the temporal-parietal junction was involved during both reading processes and attentional cueing processes during a typical 2-location Posner attentional cueing paradigm (Ekstrand, Neudorf, Gould, et al., 2019; Ekstrand, Neudorf, Kress, & Borowsky, 2019). Specifically, the researchers identified overlap between lexical reading and exogenous peripheral visual attention processes and between phonetic decoding and endogenous central visual attention processes. Figure 1.2 depicts some of these key regions of the dorsal-endogenous and ventral exogenous streams.

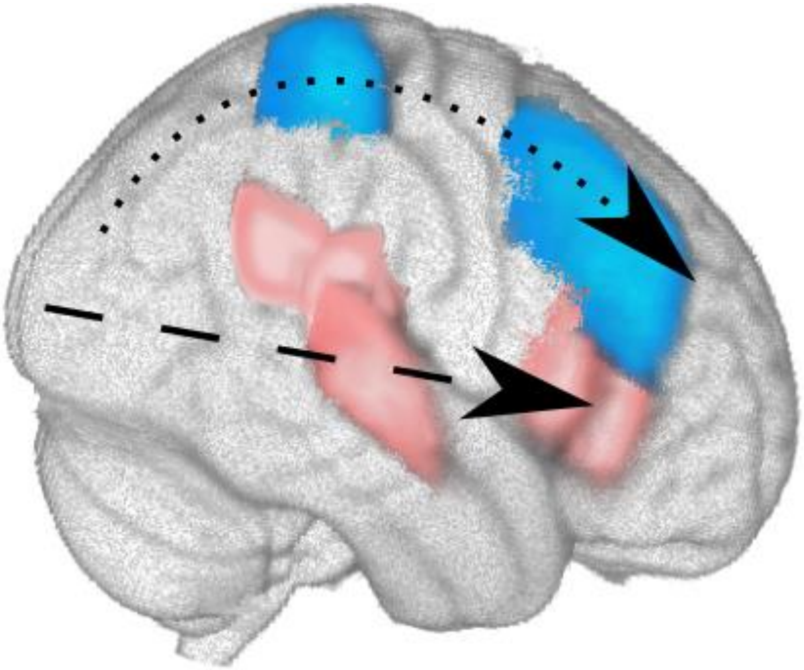

Figure 1.2. Some regions of the dorsal-endogenous and ventral-exogenous attention streams. The dorsal-endogenous stream is depicted with blue regions and a dotted line. The ventral-exogenous stream is depicted with pink regions and a dashed line.

1.2.2 Attention and Video Games

In their seminal research, Green & Bavelier (2003) observed action video game experience was related to visual-spatial attention in adults (specifically, increased attentional capacity and decreased attentional blink – the duration between two targets before the second target can be easily perceived), both in group analyses of action video game players versus non-video game players, and in training studies. The relationship between action video games and decreased attentional blink has been replicated (e.g., Li et al., 2015; Dye & Bavelier, 2010) as has the relationship between action video games and increased attentional capacity (e.g., Wilms et al., 2013). A relationship between video games and attentional orienting processes has also been observed in the voluntary Attentional Network Test (e.g., Dye et al., 2009) but not in an automatic two-location cueing task (e.g., Castel et al., 2005). More recently, structural neuroimaging studies have identified an occipital-parietal network of increased connectivity in experienced real-time strategy players (a video game genre that includes some action video game elements) compared to non-video game players, including regions such as the angular gyrus, and inferior parietal lobule (Kowalczyk et al., 2018).

1.3 Video Games, Reading, and Attentional Overlap

It has not yet been fully determined what characteristics of action video games are related to this improvement in reading ability. Given the extensive research that has already associated action video games with performance in attentional tasks, it may be the case that attentional processing ability underlies the observed improvements in reading ability after video game play. Previous research on video games, reading, and attention have theorized that regions related to the magnocellular dorsal stream, occipital-parietal network, and fronto-parietal network may be important to understanding the relationship between video games and these cognitive processes (e.g., Bertoni et al., 2021; Kowalczyk et al., 2018; and Dye et al., 2009, respectively). In dyslexia research, dysfunction in regions such as posterior superior temporal gyrus and angular gyrus are thought to be related to the observed reading and attentional deficits (Shaywitz et al., 1998), and the magnocellular dorsal stream is a key stream in most hypothesized explanations for the deficits observed in dyslexia (see Boden & Giaschi, 2007, for a review). In neuroimaging studies of adult readers, the angular gyrus was identified as an active region for both lexical and sublexical reading (e.g., Borowsky et al., 2006) and in research on video games and attention, the angular gyrus was part of an occipital-parietal network that exhibited increased connectivity in video-game players compared to non-gamers (Kowalczyk et al., 2018). Research on children with dyslexia has revealed that these children are delayed in their attentional allocation ability in comparison to their age-matched peers in an attentional blink task, demonstrating that attentional deficits are relevant to the reading disorder (Visser et al., 2004). During video game training studies involving children with dyslexia, improvements in attentional ability have been observed alongside the previously mentioned improvements in reading ability (e.g., Franceschini et al., 2017; Bertoni et al., 2021). This combination of findings in the literature suggests that visual-spatial attentional processes may be driving the relationship between video games, reading, and attention.

1.4 The Current Research

This thesis consists of multiple experiments to unravel the relationship between video games, reading, and attention. Experiment 1 (Chapter 2) used trial reaction times with lexical EW and sublexical PH stimuli to more precisely evaluate which reading processes may be related to video game experience. Experiment 2 (Chapter 3) tested the relationships between action video game experience, reading, and attention with button-press tasks. Experiment 3 (Chapter 4) examined the proposed link between video games, attention and reading, with a more demanding 8-location hybrid reading-attention task (attentional cueing paradigms typically use only two locations; see Chica et al., 2014 for a review of spatial attentional cueing task design). Finally, Experiment 4 (Chapter 5) used the data from Experiment 3 to investigate whether specific visual features in video games are related to performance differences in reading and attention across the continuum of video game experience.

CHAPTER 2: Experiment 1 - Video Games and Reading Aloud

This chapter is based on the journal manuscript:
Kress, S., Neudorf, J., Borowsky, B., & Borowsky, R. (in preparation). What's in a game: Visual-spatial demands in video games are associated with attentional cueing and reading processes. *To be submitted to Neuropsychologia*.

The goal of Experiment 1 was to test whether the previously observed relationship between video game experience and reading performance in children with dyslexia could be extended to skilled adult readers using precise onset RTs and EW and PH stimuli to distinguish between lexical and sublexical reading processes. These methods will be an improvement in stimulus control and dependent variable precision compared to previous studies which used words and non-words (if the words are not EWs, lexical processing is not guaranteed) and coarse syllables/second measurements (for example, reading the 9-syllable list "table, kitchen, soda, bicycle" in 3 seconds would correspond to a speed of 3 syllables/second; see Bertoni et al., 2021; Franceschini & Bertoni, 2019 for examples of studies that use this measure).

2.1 Hypotheses

If the relationship between video game experience and reading performance observed in children by Franceschini et al. (2013, 2017) extends to skilled adult readers, then participant video game experience should be correlated with reading performance whereby reading reaction times (RTs) are faster for participants with more video game experience than participants with less video game experience.

2.2 Method

2.2.1 Participants

Twenty-four participants (4 male, 20 female, $M = 21.21$ years, $SD = 2.95$ years) were recruited from the University of Saskatchewan student participant pool. All participants spoke English as their first language. Each participant provided informed written consent before taking part in the study and received a bonus course credit in exchange for their participation. This study was approved by the University of Saskatchewan Research Ethics Board.

2.2.2 Apparatus and Stimuli

Thirty pairs of monosyllabic EWs (optimal stimuli for engaging lexical/whole-word reading) and corresponding PHs (optimal stimuli for sublexical-phonetic decoding) from Wingerak et al. (2017) were selected as the stimuli for this study (see Appendix A). These stimuli were grouped in two 30 trial blocks (one containing only EWs, the other containing only PHs) for a total of 60 trials. The order of trials within a block was randomized, and the order of blocks was counterbalanced. The experiment was run using E-Prime (Psychology Software Tools, https://pstnet.com) with a Compaq 7500 CRT monitor and stimuli were presented in 12 pt. white Courier New font on a black background. Participant reaction time (RT) was recorded by a microphone connected to the voice-key of an E-Prime serial-response box which recorded the RT when the onset of speech was detected.

2.2.3 Procedure

Participants were tested individually in a dimly lit, quiet room with an experimenter present. At the beginning of the EW block, the experimenter instructed participants to read the presented word as quickly and accurately as possible. At the beginning of the PH block, the experimenter instructed participants to read the presented letter string as quickly and accurately as possible and to sound the letter string out as if it were a real word. EW and PH block order was counterbalanced across participants. Participants pressed a button on the serial-response box to begin each trial. The target EW or PH appeared in the centre of the screen, and participants read the presented target into the microphone. The voice-key and computer recorded the onset time of participant speech (RT) and the experimenter coded whether the response was correct, incorrect or a spoiled trial (i.e., the microphone was triggered either before or after the vocal onset). Figure 2.1 illustrates the progression of a single trial. Either before or after the experiment, participants would respond to some questions about their video game experience (see Appendix B for a detailed description about the design of these questions).

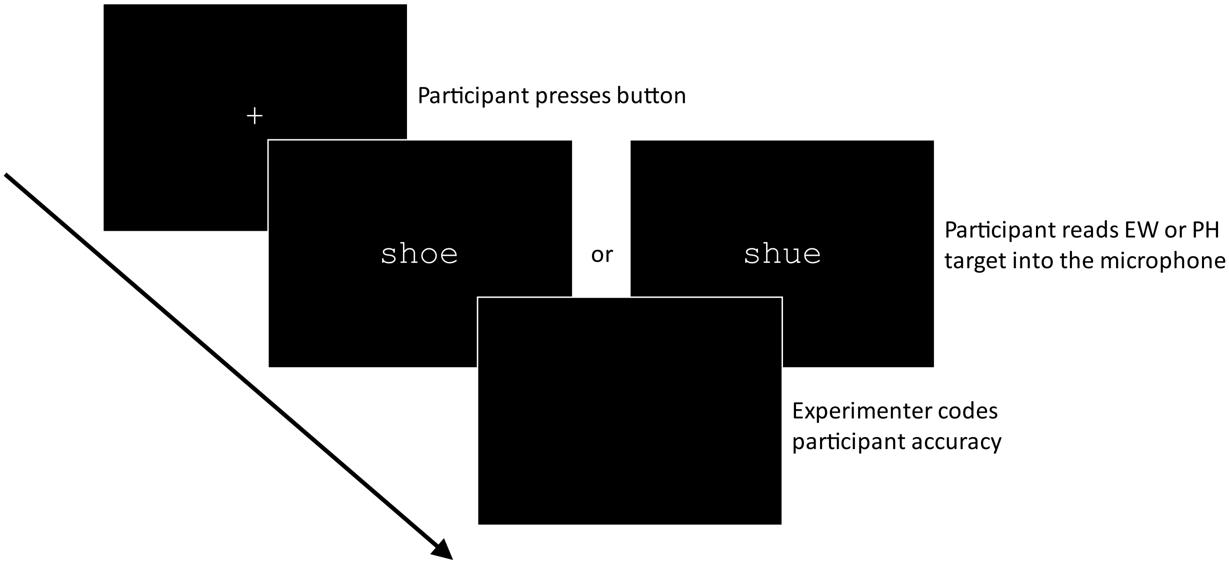

Figure 2.1. Experiment 1 Trial Progression.

2.3 Results

Median RT for each participant was determined using the RTs from correct trials only. Mean-of-median EW RT was 643.13 ms (*SD* = 107.48 ms) and mean-of-median PH RT was 794.63 ms (*SD* = 185.71). Participants' mean video game experience was 3.21 hrs/week (*SD* = 4.53 hrs/week; min = 0 hrs/week, max = 15 hrs/week). Before analysing the data, the skewness of our video game experience measure was assessed. A measure is considered significantly skewed if the skewness value divided by the standard error of skewness is greater than the critical $z = 1.96$ (or approximately 2). Based on this criterion, our video game experience measure was significantly skewed (skewness = 1.72, *SE* = .47), so the values were $\log_{10}$-transformed prior to analysis (all video game experience values had 1 added to avoid indeterminate $\log_{10}$-transformation values; skewness after transform = .49, *SE* = .47). Mean $\log_{10}$-transformed video game experience (logGames) was 0.42 (*SD* = .42). Mean EW error rate was 4.53% (*SD* = 4.74) and mean PH error rate was 9.42% (*SD* = 9.89); there were no speed-accuracy trade-offs.

A single factor (Target: EW vs PH) general linear model (GLM) was conducted on RT, with logGames included as a continuous variable. There was a main effect of Target, EW reading RTs (*M* = 643.13, *SD* = 100.43) were significantly faster than PH reading RTs (*M* = 794.63, *SD* = 184.25), $F(1, 22) = 16.565$, *MSE* = 8456.28, $p = .001$. There was no overall significant effect of logGames, *F*(1, 22) = 2.52, *MSE* = 35600.52, *p* = .127. There was no significant interaction between Target and logGames, *F*(1, 22) = 0.003, *MSE* = 8456.28, *p* = .959. Coefficient t-tests indicated EW RTs were at the threshold of significance in relation to logGames (*b* = -102.24ms/*logGameHours*, *t*(22) = -2.072, *r* = -.404, *p* = .050), but PH RTs were not (*b* = -105.56ms/*logGameHours*, *t*(22) = -1.167, *r* = -.242, *p* = .256; see Figure 2.2).

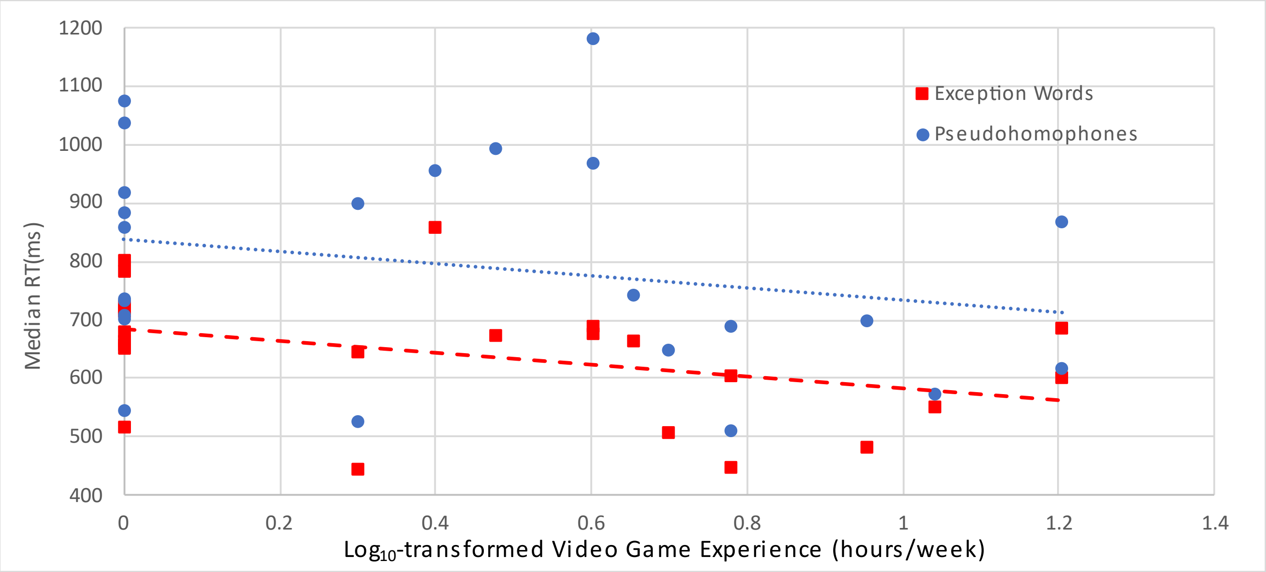

Figure 2.2. Mean RT as a function of Log$_{10}$-transformed Weekly Game Hours.

2.4 Discussion

In this experiment, a relationship between video game experience and EW RTs was observed, providing some support for a link between video game experience and reading performance in adult skilled readers. These results differ somewhat from the observed relationship between video games and reading performance in children with dyslexia, as in those cases it was typically phonetic decoding speeds that were improved by video game training (e.g. Bertoni et al., 2021; Franceschini et al., 2017; Franceschini & Bertoni, 2019). In young readers it may be harder to assess lexical reading ability, because lexical processing may still be developing for familiar words and exception words. It may also be the case that phonetic decoding skills have reached their plateau in adulthood, so a relationship between video games and phonetic decoding may only be possible to observe in developing readers.

It is important to note that the previous studies with children with dyslexia typically measured reading speed in terms of list reading speed (the time in seconds it took the child to read the list of stimuli; e.g., Franceschini et al., 2017) or syllable reading speed (reading speed in syllables per second; e.g., Bertoni et al., 2021; Franceschini & Bertoni, 2019). To address this in Experiment 1, we used precise, millisecond-level measures of onset RT. However, reading onset RTs may still be limited as some studies have found onset RTs are optimal for testing effects of lexical reading, but not sublexical reading (e.g., Wingerak et al., 2017). The research on video games and reading should therefore be extended to paradigms that do not rely on naming aloud. A lexical decision paradigm would require participants to respond only when stimulus processing is complete, so the differences in reading aloud between sublexical reading and lexical reading should no longer be a concern.

CHAPTER 3: Experiment 2 – Video Games, Orthographical-Phonological Lexical Decision, and Attentional Cueing

This chapter is based on one manuscript:
Kress, S., Neudorf, J., & Borowsky, R. (in preparation). Orthographic-phonological lexical decision performance and video game experience account for attentional cueing reaction times. *To be submitted to Attention, Perception, and Psychophysics*.

For Experiment 2, we designed the orthographic-phonological lexical decision task (OPLDT) as a task that would encourage both orthographic and phonological processing and extend the literature on video game experience and reading processes beyond reading aloud. In a typical lexical decision task where a participant must distinguish word targets from non-word foils, only responses from the word target trials are typically analyzed. The non-word foil trials are often ignored. The OPLDT is intended to be more similar to a 2-alternative forced choice task, with two positive choices for analysis. In the OPLDT, correct "spells and sounds like a word" decisions about EWs should reflect successful processing along the direct lexical orthographic-phonological path, whereas correct "sounds like a word" decisions about PHs should reflect successful processing of the indirect sublexical (phonetic decoding) orthographic-phonological path (see Figure 3.1).

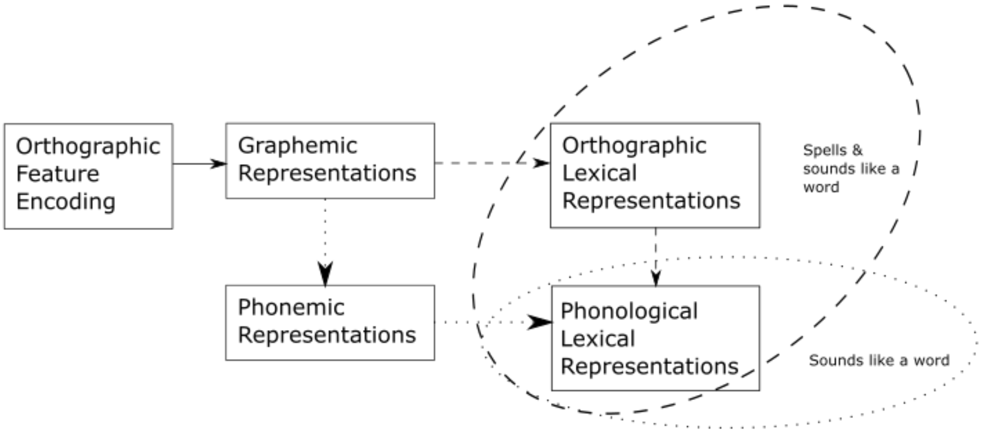

Figure 3.1. Diagram of processes engaged during the OPLDT. Dashed lines represent the lexical path for processing EWs. Dotted lines represent the sublexical path for processing PHs. Adapted from Owen & Borowsky's (2003) figure of the dual route model of reading aloud.

In addition to the OPLDT, we tested attentional orienting using a 4-location cueing paradigm. Our test of attentional orienting included endogenous (compass, clock), exogenous (asterisk), and arrow cues to evaluate which types of attentional processing may be related to video game experience. Testing the effectiveness of compass and clock cues is of interest given their use in video games (for example, mini-maps may include compass directions, and players may warn a teammate about "an enemy at 6 o'clock"). If compass and/or clock cues are effective as endogenous cues, these cues could then be used to design more ecologically valid attention tasks or as components of a video game designed to train reading and attention skills. For each task, we have hypotheses regarding generalizing previous in-person experimental results to our new online testing environment in addition to our hypothesized effects of video game experience on each task.

3.1 Hypotheses

OPLDT

1. Given previous research that found word reading speeds were faster than pseudohomophone reading speeds in mixed stimuli lists (i.e., lists containing both words and PHs; see Marmurek & Kwantes, 1996), participants should respond more quickly to EWs than PHs in the OPLDT.
2. If the relationship between video game experience and language processes extends beyond reading aloud, we expected increased action game experience to be associated with improved performance in our novel OPLDT paradigm for PH targets, particularly because other researchers (e.g., Bertoni et al, 2021; Franceschini et al., 2013; Franceschini et al., 2017) have also observed a relationship between video game experience and phonetic decoding speeds.

Attention Task

1. We expected to replicate previous exogenous vs. endogenous results, whereby exogenous cueing effect sizes should be larger than endogenous cueing effect sizes (e.g., Ekstrand, Neudorf, Kress, & Borowsky, 2019, although note the size of the exogenous and endogenous cueing effects were not statistically compared in that study).
2. Given previous arguments that arrow cues might reflect more exogenous cueing processes (e.g., Ristic & Kingstone, 2012), we would expect arrow cueing effect sizes

to be larger than other endogenous cueing effect sizes.

3. Given previous studies that have observed effects of video game experience on attentional orienting (e.g., Dye et al., 2009), we expect video game experience should interact with cue validity.

OPLDT × Attention

1. If the neurobiological relationship between lexical processing and exogenous attention (e.g., Ekstrand, Neudorf, Gould, et al., 2019; Ekstrand, Neudorf, Kress, & Borowsky, 2019) can also be observed behaviourally, OPLDT performance for EWs and exogenous attentional cueing performance should be related.
2. If the neurobiological relationship between phonetic decoding and endogenous attention (e.g., Ekstrand, Neudorf, Gould, et al., 2019; Ekstrand, Neudorf, Kress, & Borowsky, 2019) can also be observed behaviourally, OPLDT performance for PHs and endogenous attentional cueing performance should be related.

3.2 Method

3.2.1 Participants

Forty-two participants currently living in the United States or Canada were recruited from the online participant platform Prolific (www.prolific.co) and completed both the behavioural and demographic parts of the study. Participants were pre-screened for the following criteria: normal or corrected-to-normal vision, English first language, no language disorders, and 3+ hours of video game experience per week. Pre-screening on Prolific is covert; participants provided this information to Prolific when they first signed up on the platform, and Prolific only sent recruitment invitations to participants who met the criteria. Participants received £6.00 as compensation for completing the experiment. Two participants were excluded prior to the main analysis for inconsistent reports of their first language demographics and two participants were excluded prior to the main analysis because their RTs were significantly slower than mean, leaving 38 participants (20 cisgender men, 11 cisgender women, 7 non-binary/transgender individuals[1]; *M* = 27.45 years, *SD* = 5.54 years) in the main analyses.

3.2.3 Procedure

The behavioural experiment was designed in PsychoPy 3.0 (https://www.psychopy.org; see Peirce et al., 2019) and hosted on the Pavlovia platform (https://www.pavlovia.org).

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[1] Biological sex demographics were also collected: 23 male, 13 female, 1 X, and 1 preferred not to respond.

Participants were instructed to complete the experiment using a desktop computer with a 14 inch (35.6 cm) or larger monitor. After providing consent to participate, participants calibrated their screen size for the experiment by adjusting the size of a box on screen to match that of a credit card (code adapted from Morys-Carter, n.d.) then were instructed to sit 70 cm away from their computer monitor, with alternate measuring strategies provided if a measuring device was unavailable. Participants completed three task blocks: the OPLDT block, the exogenous attention block, and the endogenous attention block. The order of blocks was counterbalanced such that half the participants received the OPLDT block first, and half the participants received the attention blocks first. The attention blocks were additionally counterbalanced such that half of the participants received the exogenous block before the endogenous block and vice versa. Within the endogenous block, the order of the different cue-type sub-blocks (arrow, compass, clock; described in the following paragraphs) was randomized. Participants were presented with some practice trials prior to each block to become accustomed to the procedure. The behavioural experiment took approximately 30 minutes to complete.

The OPLDT block stimuli were identical to those used in Experiment 1 (see Appendix A). Each EW and PH was presented once per participant, for a total of 60 trials, and these trials were randomly ordered. Participants pressed the spacebar to initiate each trial. The EW or PH target would then appear in the centre of the screen (white Arial font on a black background; letter height between 1.0 cm and 1.5 cm – 0.8 and 1.2 degrees of visual angle with a sitting distance of 70 cm). Participants were instructed to press F if the target "spells and sounds like a real word" (i.e. EW) and press J if the target "only sounds like a real word" (i.e. PH). If no key was pressed, the target would disappear after 3 seconds, no response would be recorded, and the experiment would wait for the participant to initiate the next trial. Figure 3.2 illustrates the procedure of a trial from the OPLDT.

Figure 3.2. Trial procedure for OPLDT.

The exogenous attention task consisted of 96 randomly ordered trials. Participants pressed the spacebar to initiate the trial. After a 100ms delay, the exogenous cue (asterisk, white Arial font, height of approximately 0.5 cm – 0.4 degrees of visual angle) appeared at either the top, bottom, left, or right location (7.0 cm from centre, 5.7 degrees of visual angle at a 70 cm distance) for 150 ms. The target letter (A or H, white Arial font, height of 1.5 cm – 1.2 degrees of visual angle at 70 cm distance) then appeared at one of the four locations, with a cue validity of 50% (the typical validity used given an automatic exogenous cue; e.g. Chica et al., 2014; Ekstrand, Neudorf, Gould, et al., 2019; Ekstrand, Neudorf, Kress, & Borowsky, 2019). Participants pressed the F key if the target was the letter A, and the J key if the target was the letter H. If no key was pressed, the target would disappear after 3 seconds, no response would be recorded, and the experiment would wait for the participant to initiate the next trial (see Figure 3.3).

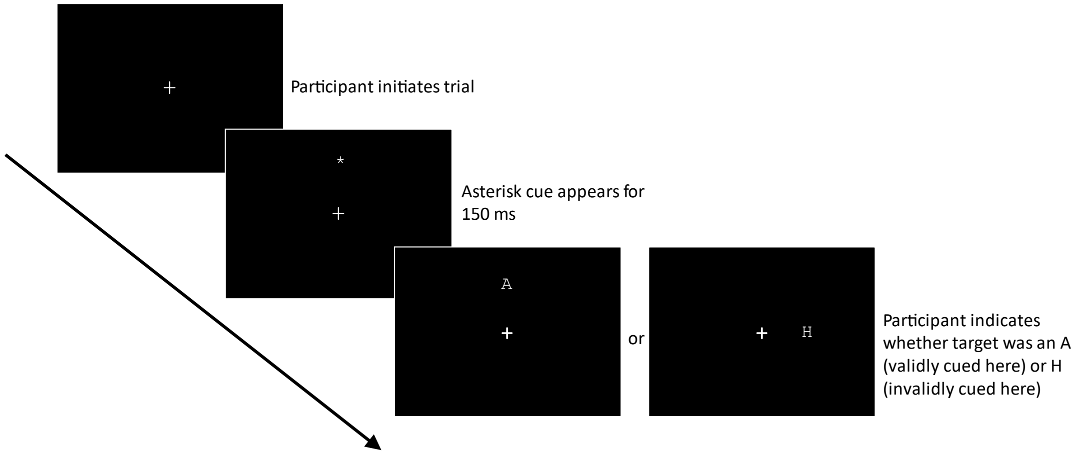

Figure 3.3. Trial procedure for exogenous attention task.

Endogenous attention

The endogenous attention block consisted of three sub-blocks of 96 trials each. The order of the sub-blocks was random, and the order of trials within the sub-blocks was also random. The different sub-blocks corresponded to the different endogenous cues that were presented. The "Arrow" sub-block used arrow cues pointing to the top, bottom, left, or right regions of the screen (white, 2.0 cm long – 1.6 degrees visual angle at sitting distance of 70 cm). The "Clock" sub-block used clock cues whereby "12", "3", "6", and "9" corresponded to top, right, bottom, and left, respectively (white, 1.5 cm tall – 1.2 degrees visual angle at sitting distance of 70 cm). The "Compass" sub-block used compass cues whereby "N", "E", "S", "W" corresponded to top, right, bottom, and left, respectively (white, 1.5 cm tall – 1.2 degrees visual angle at sitting distance of 70 cm). The procedure of all sub-blocks was identical. Participants pressed the spacebar to initiate the trial. After a 100 ms delay, the endogenous arrow, compass, or clock cue appeared at the centre of the screen for 1000 ms. The target letter (A or H, white Arial font, height of 1.5 cm – 1.2 degrees of visual angle at 70 cm distance) then appeared at one of the four locations (7.0 cm from the centre – 5.7 degrees of visual angle at 70 cm sitting distance), with a cue validity of 75% (the typical validity used given endogenous cues; e.g., Chica et al., 2014; Ekstrand, Neudorf, Kress, & Borowsky, 2019). Participants pressed the F key if the target was the letter A, and the J key if the target was the letter H. If no key was pressed, the target would disappear after 3 seconds, no response would be recorded, and the experiment would wait for the participant to initiate the next trial. Figure 3.4 illustrates the procedure of a trial form the endogenous attention block.

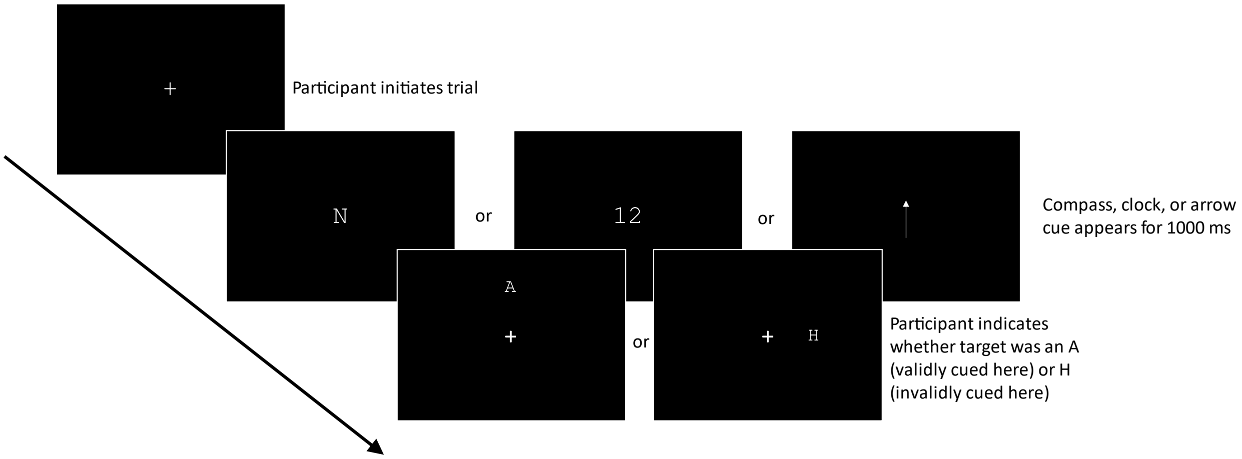

Figure 3.4. Trial procedure for endogenous attention block

Video Game Experience Questions

After completing the behavioural portion of the experiment, participants answered a set of questions through SurveyMonkey (www.surveymonkey.com) about their demographics and video game experience (see Appendix C for the full list of these questions). The question set was expected to take 15 minutes for participants to complete.

3.3 Results

Mean video game experience was 20.45 hours/week (*SD* = 11.81). Mean action video game experience was 8.94 hours/week (*SD* = 9.62). Action video game experience was the continuous variable of interest for these analyses. The skewness of action game experience was 1.16 (*SE* = 0.69). The skewness value was not more than double the value of the standard error of the skewness, and therefore no transformations were needed to normalize the data. Median RTs of correct trials were used for all analyses.

3.3.1 Orthographic-Phonological Lexical Decision

The results of the OPLDT task were initially considered without action video game experience to evaluate the effectiveness of this task at assessing reading processes. A paired t-test revealed a main effect of Target, EWs (*M* = 689.56 ms, *SD* = 82.71) are significantly faster than PHs (*M* = 731.27, *SD* = 91.33), *t*(37) = -6.85, *p* < .001(see Figure 3.5).

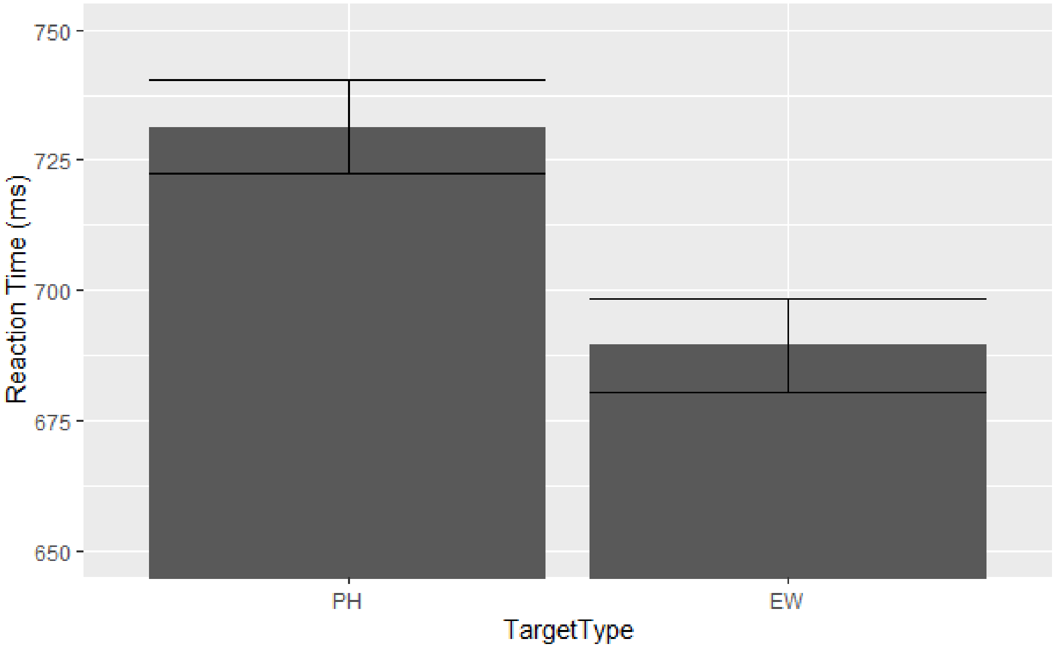

Figure 3.5. Reaction time as a function of Target Type during OPLDT.

When Action Video Game Experience is included as a continuous variable in a GLM there is a main effect of Target *F*(1, 36) = 51.20, *MSE* = 608.48, *p* < .001. There was no main effect of Action Video Game Experience *F*(1, 36) = 0.27, *MSE* = 14767.60, *p* = .605. There was a significant Target × Action Video Game Experience interaction whereby the difference in RTs between PHs and EWs decreased as a function of Action Video Game Experience, *F*(1, 36) = 6.82, *r* = -.399, *MSE* = 608.48, *p* = .013 (see Figure 3.6)[2].

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[2] Given previous research that has found sex/gender effects on both video game habits (e.g., Rehbein et al., 2016) and reading (in terms of laterality, e.g. Shaywitz et al., 1995), this analysis was repeated with gender included in the model as a between-subjects factor with 3 levels (Cisgender Man, Cisgender Woman, and Non-Binary/Transgender, although note that the N's of the between-subjects gender groups are unequal). The main effect of Target, F(1, 32) = 33.47, MS = 21016.91, MSE = 627.907, p < .001 and Target × Action Video Game Experience interaction, F(1, 32) = 5.691, MS = 3573.52, p = .023 were preserved. There is no Target × Gender interaction, F(2,32) = 0.47, MS = 293.59, p = .631, and no three-way interaction, F(2, 32) = .150, MS = 94.22, p = .861.

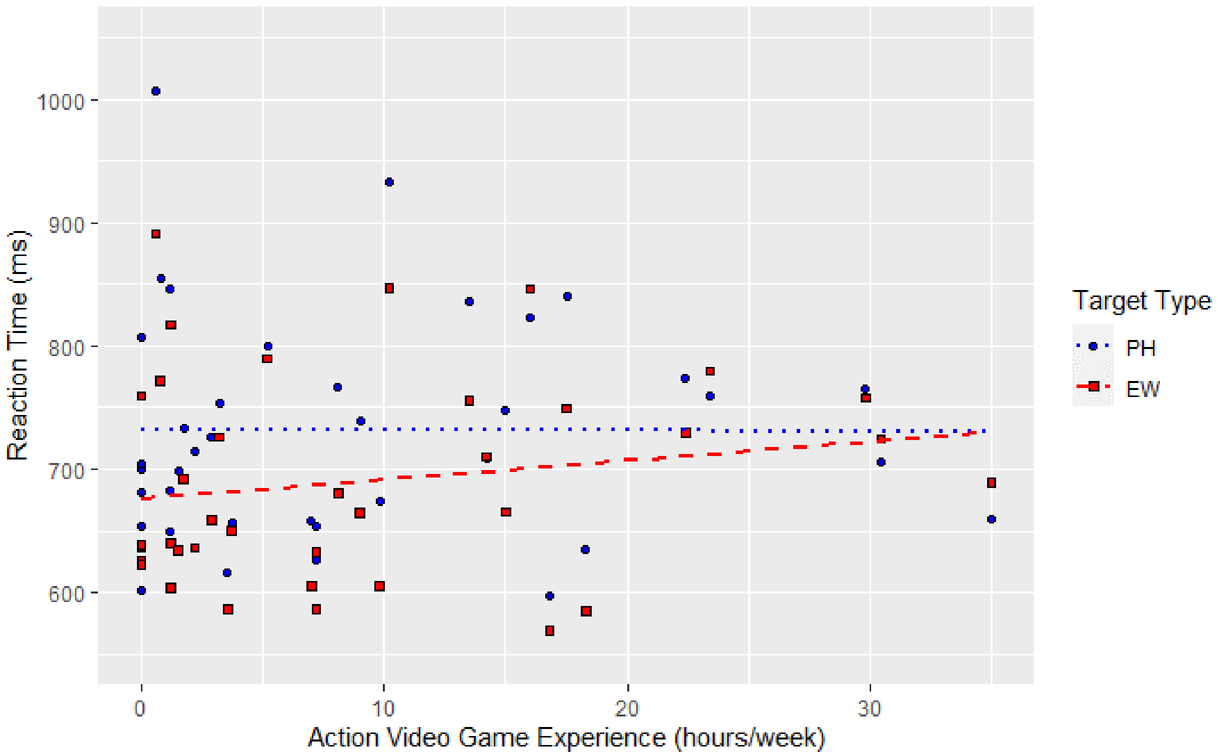

Figure 3.6. OPLDT performance as a function of Action Video Game Experience and Target Type

3.3.2 Attentional Cueing

A 2 (Validity: Valid vs Invalid) × 4 (Cue Type: asterisk vs arrow vs compass vs clock) GLM was conducted to examine the results of the attention task without video game experience to evaluate the effectiveness of the different cue types. There was a main effect of Validity, validly cued trials (*M* = 483.39 ms, *SD* = 45.43) were responded to significantly faster than invalidly cued trials (*M* = 502.85 ms, *SD* = 47.52), *F*(1, 37) = 41.37, *MSE* = 695.58, *p* < .001. There was a main effect of Cue Type, *F*(3, 111) = 4.50, *MSE* = 2339.02, *p* = .005. There was a Validity × Cue Type interaction *F*(3, 111) = 3.10, *MSE* = 528.22, *p* = .030. As can be seen with the 95% confidence intervals (Loftus and Masson, 1994) illustrated in Figure 3.7, during invalidly cued trials the reaction times for arrow, asterisk and clock cues are similar, but during validly cued trials arrow cues are the fastest, and clock cues are the slowest of the three cue types. The compass cues are the slowest of all the cue types, for both validly cued and invalidly cued trials. The nature of the Validity × Cue Type interaction was evaluated with paired t-tests on the cueing effects (invalid RT minus valid RT) of each cue type. The arrow cueing effect did not significantly differ from the asterisk cueing effect, $t(37) = 1.23$, $p = .227$. The arrow cueing effect was significantly larger than the clock cueing effect, $t(37) = 2.34$, $p = .025$ and significantly larger than the compass cueing effect, $t(37) = 2.61$, $p = .013$. The asterisk cueing effect did not significantly differ from the clock cueing effect, $t(37) = 1.25$, $p = .218$, or the compass cueing effect, $t(37) = 1.53$, $p = .135$. The clock cueing effect and compass cueing effect did not significantly differ from each other, $t(37) = 0.09$, $p = .929$.

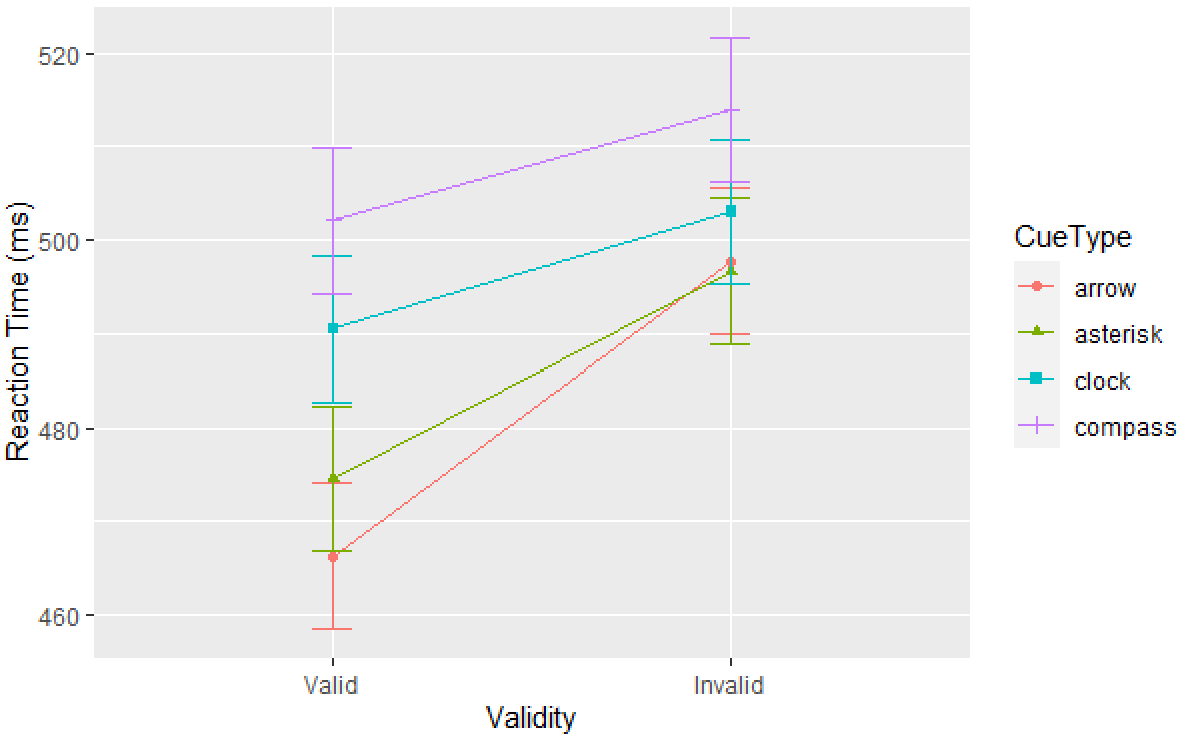

Figure 3.7. Attentional cueing task performance as a function of cue validity and cue type.

When Action Video Game Experience was included in the model, both the main effect of Validity ($F(1, 36) = 34.79$, $MSE = 666.04$, $p < .001$) and main effect of Cue Type ($F(3,108) = 3.04$, $MSE = 2305.43$, $p = .032$) persisted. The main effect of Action Video Game Experience was not significant, $F(1, 36) = .007$, $MSE = 17046.81$, $p = .933$. The interactions were not significant (Validity × Cue Type, $F(3, 108) = 1.52$, $MSE = 536.14$, $p = .214$; Action Video Game Experience × Validity, $F(3, 108) = 2.64$, $MSE = 666.05$, $p = .113$; Action Video Game

Experience × Cue Type, *F*(3, 108) = 1.54, *MSE* = 2305.43, *p* = .209; Action Video Game Experience × Validity × Cue Type, *F*(3, 108) = .454, *MSE* = 536.14, *p* = .715)[3].

3.3.3 OPLDT & Attention

To assess the overlap between reading and attentional processes the 2 (Validity) x 4(Block) GLM was repeated with either PH RT (to represent dorsal-sublexical processes) or EW RT (to represent ventral-lexical processes) included as a continuous variable in the model.

When PH RT was included as a continuous variable there was a main effect of PH RT, *F*(1, 36) = 14.25, *MSE* = 12216.05, *p* = .001. There was a main effect of Cue Type, *F*(3, 108) = 3.52, *MSE* = 2202.02, *p* = .018. There was also a PH RT × Cue Type interaction, *F*(3, 108) = 3.30, *MSE* = 2202.02, *p* = .023. The other main effects and interactions were not significant (Validity, *F*(1, 36) = 1.13, *MSE* = 713.26, *p* = .295; PH RT × Validity, *F*(1, 36) = 0.08, *MSE* = 713.26, *p* = .775; Cue Type × Validity, *F*(3, 108) = 0.79, *MSE* = 528.70, *p* = .504; PH RT × Cue Type × Validity, *F*(3, 108) = 0.97, *MSE* = 528.70, *p* = .411). To provide another perspective on the PH RT × Cue Type interaction, the individual correlations between PH RT and each attentional cue type were examined (see Figure 3.8). All cue types' RTs were positively correlated with PH RT, although the correlation with clock cues was not significant, *t*(36) = 1.97, *r* = .313, *p* = .056. Of the significant correlations, asterisk cue RT was most related to PH RT, *t*(36) = 5.15, *r* = .651, *p* < .001. Compass cues were also related to PH RT, *t*(36) = 2.92, *r* = .437, *p* = .006. Arrow cues were also significantly related to PH RT, but this was the weakest of the significant relationships, *t*(36) = 2.33, *r* = .361, *p* = .026.

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[3] As in the reading analysis, given previous research that has found sex/gender effects on both video game habits (e.g., Rehbein et al., 2016) and attentional processes (e.g., Rubia et al., 2010 in terms of functional activation), this analysis was repeated with gender included in the model (although note that the N's of the between-subjects gender groups are unequal). The main effect of Validity persisted, *F*(1, 32) = 24.35, *MSE* = 668.11, p < .001, as did the main effect of Cue Type, *F*(3, 32) = 3.20, *MSE* = 2376.02. There were no interactions with Gender or Action Video Game Experience.

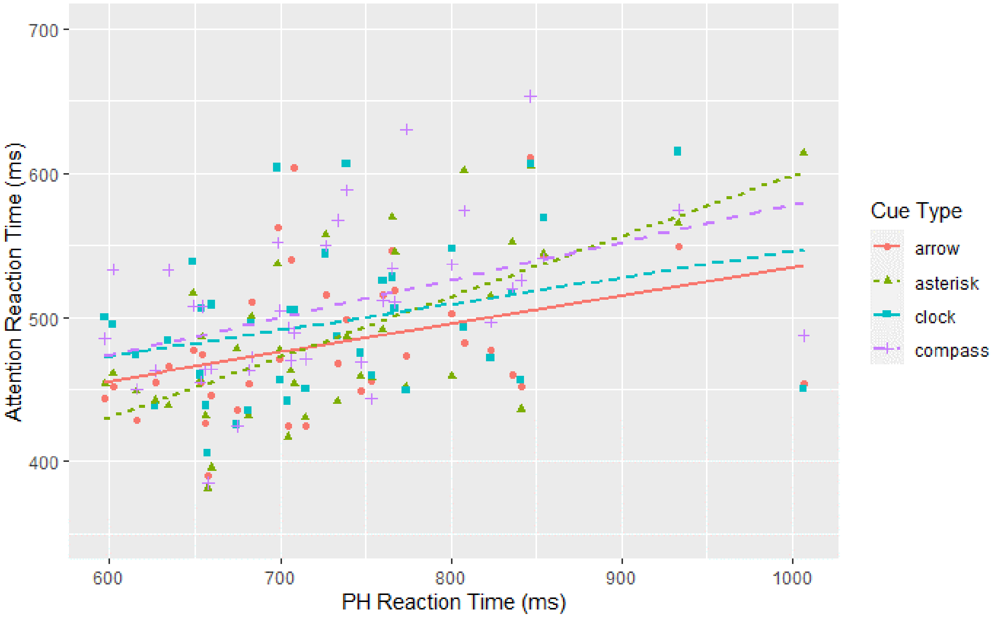

Figure 3.8. Attentional cueing task performance as a function of PH reaction time and cue type.

When EW RT was included as a continuous variable in the model there was a main effect of EW RT, *F*(1, 36) = 15.27, *MSE* = 11973.12, *p* < .001 (see Figure 3.9). The other main effects and interactions were not significant (Cue Type, *F*(3, 108) = 1.79, *MSE* = 2305.09, *p* = .153; EW RT × Cue Type, *F*(3, 108) = 1.55, *MSE*= 2305.09, *p* = .207; Validity, *F*(1, 36) = 0.94, *MSE* = 713.90, *p* = .339; EW RT × Validity, *F*(1, 36) = 0.05, *MSE* = 713. 90 *p* = .824; Cue Type × Validity, *F*(3, 108) = 0.90, *MSE* = 528.49, *p* = .444; EW RT × Cue Type × Validity, *F*(3, 108) = 0.98, *MSE*= 528.49, *p* = .404).

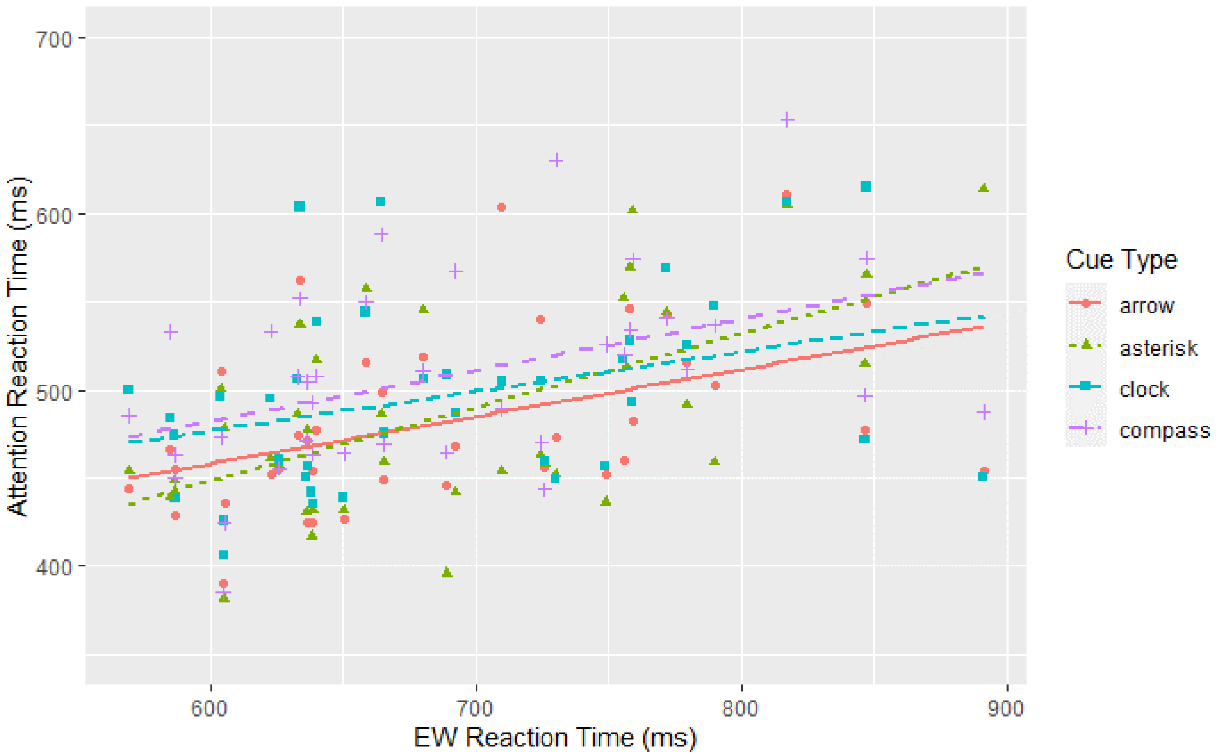

Figure 3.9. Attentional cueing task performance as a function of EW reaction time and cue type.

3.4 Discussion

In this experiment the results of our OPLDT, designed as a task to assess reading processes, differed substantially from our results during the reading aloud task of Experiment 1. In Experiment 1 we observed faster EW RTs as a function of video game experience, but in this case EW RTs in the OPLDT were slower as a function of video game experience. Although these results initially seem contradictory – one would typically hope to see EWs exhibit performance improvements in both experiments – there is a reasonable explanation for this finding. The reading task in Experiment 1 was a blocked task, meaning EWs and PHs were presented separately, which would optimally encourage isolated activation of the ventral-lexical and dorsal-sublexical streams, respectively. In contrast, the OPLDT is a mixed stimuli task by nature, as EWs and PHs must be present in the same block for participants to be forced to make a decision. This means that both the ventral-lexical and dorsal-sublexical streams have to operate throughout the duration of the task, and the streams could interfere with each other. In particular, our instructions were to indicate if the target "**spells** and **sounds** like a word" (both orthographic and phonological activation) or "**only sounds** like a word" (phonological activation only; see

Figure 3.1). The nature of EWs is that they are exceptions to standard English grapheme-to-phoneme representations, therefore when both these streams are active, conflicting phonology would result (e.g., Paap & Noel, 1991). Our observed slower EW RTs as a function of action video game experience could therefore suggest greater levels of sublexical processing in our action video game players, which aligns with the previous research in children with dyslexia (e.g., Bertoni et al., 2021; Franceschini et al., 2017; Franceschini & Bertoni, 2019). More research comparing this novel OPLDT to naming is needed to determine whether increased sublexical processing is the reason for our observed results. Alternatively, it might be the case that experienced video game players have better multitasking skills (as can be inferred from their improved attentional resource capacity; e.g., Green & Bavelier, 2003) which could result in greater interference between the lexical and sublexical processing streams.

In our attention task we were able to identify that arrow cues had a cueing effect pattern distinct from the other endogenous cue types and more similar to the exogenous cue type (supporting the theory of automated symbolic orienting, Ristic & Kingstone, 2012), but action video game experience shared variance with this interaction. Visual cues in video games are highly valid (as invalid visual cues would mislead to the player and lead to a poor gameplay experience), and arrows are a highly recognized directional symbol. It is reasonable to suspect that the originally observed distinct arrow cueing pattern in our results was driven by experienced action video game players responding quickly to a cue to which they may be accustomed. Another interesting point of note was that of our two endogenous cues (clock cues and compass cues), compass cues exhibited the slowest reaction times, which means they would be a good choice in cases where the difficulty of an endogenous attentional cueing task is to be maximized.

Our final key finding in this study was the behavioural relationship we observed between performance in the OPLDT and attention task. When either EW RTs or PH RTs are accounted for in our analysis model, the typically observed effect of cue validity, is no longer significant. This suggests that the processes involved in our OPLDT share variance with the processes involved in attentional cue validity. Additionally, EW RTs shared variance with cue type, but PH RTs did not, as the main effect of cue type was present when PH RTs but not when EW RTs were included in the model. Furthermore, when PH RTs are included in our model, there is an interaction with PH RT and Cue Type. This may mean that a process distinct to PH processing overlaps with attention to varying degrees, depending on the type of cue presented.

In Experiment 2 we have observed how video game experience relates to reading and attentional processes in separate tasks. Although participants completed these tasks in their own home, the tasks were still highly controlled, with EW or PH targets only appearing in the centre of the screen, and single letter targets being used for the attention tasks. Hybridized tasks should also be considered, because these tasks will increase the attentional demands for participants, and additionally be more naturalistic, which could help generalize results beyond the lab setting.

CHAPTER 4: Experiment 3 – Video Games and Hybridized Reading-Attentional Cueing

This chapter is based on the journal manuscript:
Kress, S., Neudorf, J., Borowsky, B., & Borowsky, R. (in preparation). What's in a game: Visual-spatial demands in video games are associated with attentional cueing and reading processes. *To be submitted to Neuropsychologia*.

Given the high attentional demands present in action video games, for Experiment 3 we designed a multiple location hybrid reading-attention task to maximize the attentional demands participants would experience when completing the experiment. This task involved reading PHs and EWs aloud, similar to Experiment 1, and the attentional cues were compass cues, the most difficult cue type from Experiment 2.

4.1 Hypotheses

Previous research has observed larger spatial cueing effects in video game players than non-video game players (e.g., Dye et al., 2009), therefore we would also expect cueing effects to be of a larger magnitude for individuals with higher levels of video game experience in our attentional cueing paradigm. Alternatively, one could predict that increased video game experience would be related to decreased cueing effect sizes given studies that have observed video game players are better at attending to multiple locations than non-video game players (e.g., West et al., 2008), which could suggest that in our demanding multiple-location paradigm, video game players will not be as impacted by the invalid cues.

4.2 Method

4.2.1 Participants

Twenty-four participants were recruited through the University of Saskatchewan participant pool or an online bulletin on the University of Saskatchewan website. If recruited through the participant pool they received 1 bonus course credit and if recruited through the online bulletin they received $5 as compensation. One participant was excluded prior to analysis because their video game experience exceeded three standard deviations greater than the mean. As such 23 participants were included in the analyses below (14 female, 9 male, *M* = 26.82 years, *SD* = 9.26 years). All participants spoke English as their first language and provided informed written consent before taking part in the study. This study was approved by the University of Saskatchewan Research Ethics Board.

4.2.2 Apparatus and Stimuli

Thirty-two pairs of monosyllabic EWs and the corresponding PHs were selected as the stimuli for this study (see Appendix A). As in Experiment 1, the stimuli were grouped in EW and PH blocks, which were further subdivided into "cued" or "uncued" blocks. Trials in the cued block included a one or two letter cue representing one of eight cardinal compass directions and cue validity was 75% (see Figure 4.1 for the 8 cues organized by the general location they would validly cue). Uncued trials did not include any location cue. Cued and uncued blocks were counterbalanced within the larger EW or PH blocks, and these larger blocks were also counterbalanced. The order of trials within a block was randomized. The apparatus for this experiment was the same as Experiment 1. Stimuli were in 18 pt. Courier New white font on a black background.

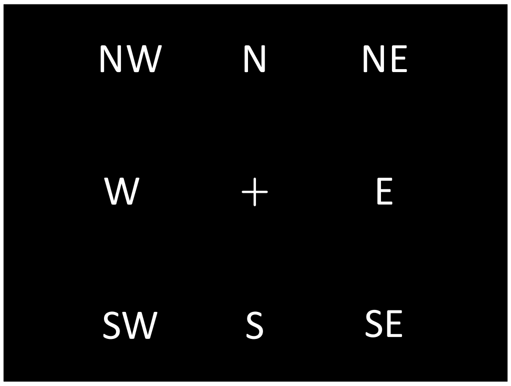

Figure 4.1. Layout of the eight target locations in Experiment 3

4.2.3 Procedure

Participants were tested individually in a dimly lit, quiet room with an experimenter present. As in Experiment 1, at the beginning of the EW blocks, the experimenter instructed participants to read the presented word as quickly and accurately as possible. At the beginning of the PH blocks, the experimenter additionally instructed participants to sound the letter string out as if it were a real word. Participants would press a button on the serial-response box to begin each trial. During cued blocks, the cardinal compass cue would appear on screen for 1000 ms, then the target EW or PH would appear at one of the eight locations (cue validity was 75%, as in

Experiment 2, and the eight location layout was adapted from Borowsky et al., 2005). During uncued blocks, no cue appeared. Instead, to keep the time between trial initiation and target presentation the same between blocks, the fixation cross would briefly flash by disappearing for 250 ms before reappearing for 750 ms prior to target presentation. To ensure all eight locations were utilized equally, the locations of the stimuli were randomized with the constraint that each location occurred once every 8 trials. Participants read the presented target into the microphone as quickly and accurately as possible, and the experimenter would code participant accuracy. Figure 4.2 illustrates the progression of a single trial during the cued version of the task. After the experiment, participants would respond to some questions about their video game experience (see Appendix B).

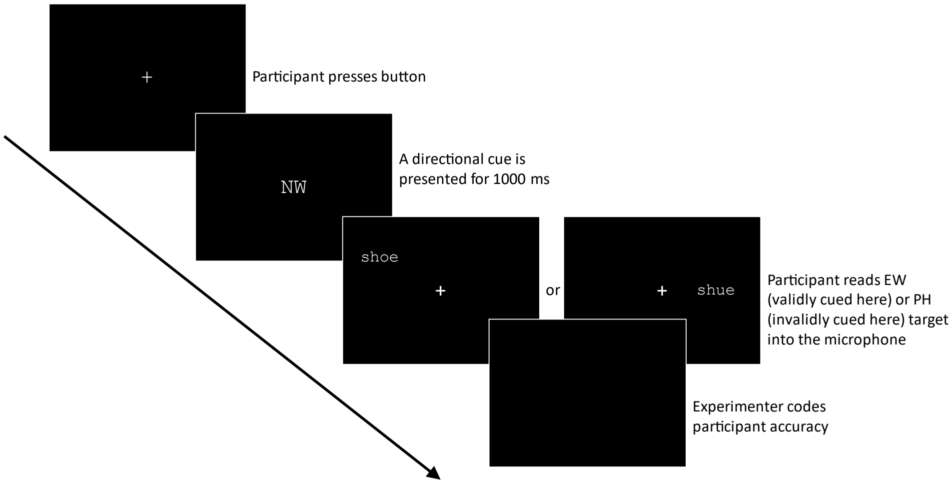

Figure 4.2. Experiment 2 trial progression for the cued version of the task.

4.3 Results

Participants' mean video game experience was 7.39 hours/week (*SD* = 9.84) and 51 unique video games were reported when participants were asked to list their top five games (Question 1 of Appendix B , see Appendix D for the list of reported games). Video game experience was log10-transformed to resolve skewness using the same technique as Experiment 1 (*M* = 0.63, *SD* = .53; skewness before transform = 1.53, *SE* = .481; skewness after transform = .321, *SE* = .481). The median RT of each participant's correct trials was determined and used as the RT measure for the following analyses and there were no speed-accuracy trade-offs.[4]

General effects of validity and stimulus type on median RT were assessed in a 2 (Validity: Valid vs Invalid) × 2 (Target Type: EW vs PH) GLM. The main effect of Validity on median RT did not reach significance, $F(1, 22) = 3.060$, $MSE = 3442.447$, $p = .094$. The effect of Target Type was significant, whereby participants were faster when presented with EWs (M = 693.21 ms, $SD = 96.06$) than PHs (M = 783.59 ms, $SD = 167.37$), $F(1, 22) = 17.967$, MSE= 10456.931 $p < .001$. The interaction between Target Type and Validity was not significant, $F(1, 22) = 0.752$, $MSE = 1202.664$ $p = .395$.

A 2 (Validity: Valid vs Invalid) × 2 (Target Type: EW vs PH) GLM with logGames included as a continuous variable was then conducted to assess the influence of video game experience in the hybrid reading – attention task. The between subjects effect of logGames was not significant, $F(1, 21) = 1.482$, $MSE = 62644.168$, $p = .237$. The main effect of Validity on RT was not significant, $F(1, 21) = 0.189$, $MSE = 2965.629$, $p = .669$. The main effect of Target Type was significant, whereby participants were faster when reading EWs (M = 693.21 ms, $SD = 97.93$) than PHs ($M = 783.59$, $SD = 161.14$), $F\ (1, 21) = 24.12$, $MSE = 8481.17$, $p < .001$. The interaction between Target Type and Validity was not significant, $F(1, 21) = 0.514$, $MSE = 1110.32$, $p = .481$. The Validity × logGames interaction was significant, $F(1, 21) = 4.537$, $MSE = 2965.63$, $p = .045$, whereby validly cued trials (b = -84.32ms/*logGameHours*, $t(21) = -1.614$, $r = -.332$, $p = .121$) sped up more quickly as a function of video game experience than invalidly cued trials (b = -37.82ms/*logGameHours*, $t(21) = -.75$, $r = -.161$, $p = .462$; see Figure 4.3). The Target Type × logGames interaction was significant, $F(1, 21) = 6.125$, $MSE = 8481.168$, $p = .022$, whereby PH trials (b = -106.76ms/*logGameHours*, $t(21) = -1.652$, $r = -.339$, $p = .113$) sped up more quickly as a function of video game experience than EW trials (b = -15.38ms/*logGameHours*, $t(21) = -.392$, $r = -.085$, $p = .699$; see Figure 4.4). The Target Type × Validity × logGames interaction was not significant, $F\ (1, 21) = 2.830$, $MSE = 1110.32$, $p = .107$.

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[4] Linear regression analysis of the uncued condition revealed no relationship between logGames and RT in the uncued PH (M = 782.89 ms, SD = 140.11, r = -0.285, p = .188) or EW trials (M = 690.48 ms, SD = 81.99, r = -0.156, p = .478), so all analyses in this section focus on the cued conditions of the task.

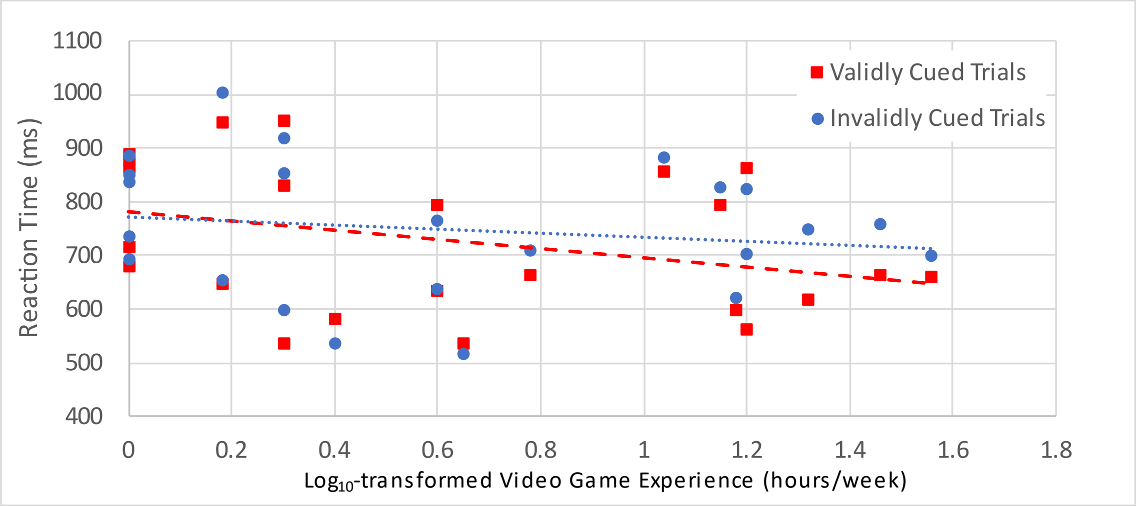

Figure 4.3. Reaction Times for Valid and Invalid Cues as a Function of Log$_{10}$-Transformed Video Game Experience

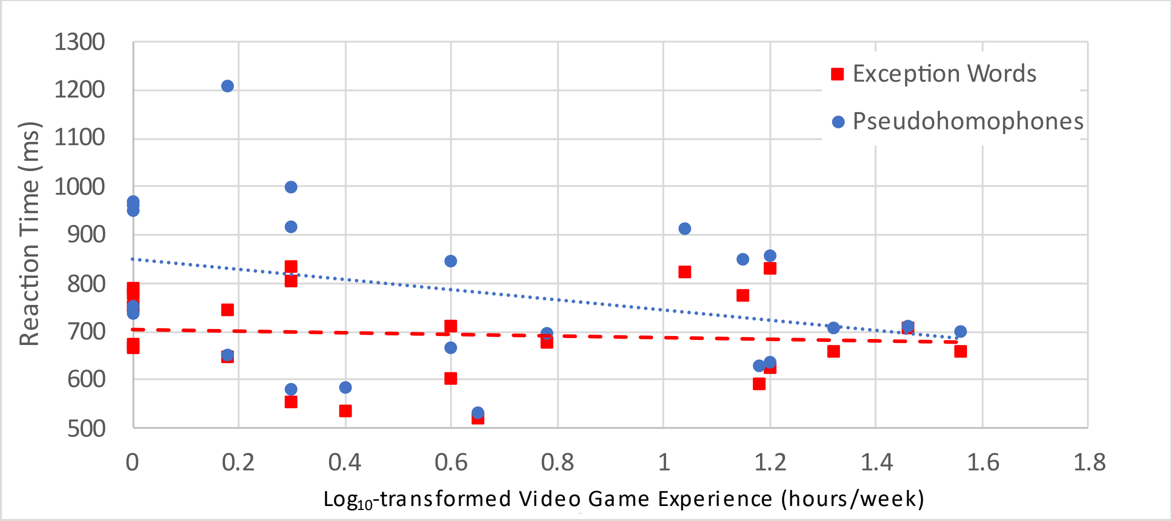

Figure 4.4. Reaction Times for PHs and EWs as a Function of Log$_{10}$-Transformed Video Game Experience

4.4 Discussion

Consistent with our hypotheses, we observed relationships between video game experience and both reading and attentional processes in this 8-location hybrid attentional cuing and reading task. Specifically, as video game experience increased, participants' RTs improved during validly cued trials more so than invalidly cued trials. Visual cues in video games have incredibly high validity (if some form of visual cue or indicator appears on screen, that means an important event is occurring that should be attended to), so it may also be the case that video game players of visually demanding games place a lot of trust in the visual cues they observe, resulting in the RT improvements observed here. This is similar to the results observed in Experiment 2, where the large effect of arrow cues was accounted for when action video game experience was included in the model. In Experiment 3 we also see participants' RTs improved at a faster rate for PH trials than EW trials. This aligns with the results observed in previous studies (e.g., Bertoni et al., 2021; Franceschini & Bertoni, 2019; Franceschini et al., 2017), which observed improvements in sublexical reading speeds (although with a rather coarse measure of nonword list reading) as a function of video game experience, and additionally aligns with our Experiment 2 results, which suggested action video game experiment may be associated with an increased reliance on sublexical processing. Throughout Experiments 1, 2, and 3, we have observed relationships between video game experience and both reading and attentional processes, however it remains to be seen precisely what aspects of video games drive these relationships.

CHAPTER 5: Experiment 4 - Visual Demand Analysis

This chapter is based on the journal manuscript:
Kress, S., Neudorf, J., Borowsky, B., & Borowsky, R. (in preparation). What's in a game: Visual-spatial demands in video games are associated with attentional cueing and reading processes. *To be submitted to Neuropsychologia*.

Given the previously discussed overlap between reading and attentional processes, it may be the case that the frequency of visual-spatial attention demands in video games drives the observed relationship between video game experience and these cognitive processes. This idea is supported by the commonly used action vs non-action video games categorization, where action games are subjectively distinguished by high perceptual, cognitive, and motor loads (Green & Bavelier, 2012).

5.1 Limitations of the Action/Non-Action Categorization

Historically researchers have focused on these "action" vs "non-action/non-gamer" group analyses (e.g., Franceschini et al., 2017; Green & Bavelier 2003; Kowalczyk et al., 2018) which facilitates the replication of results with training studies (however, the practice of group analyses has been criticized by some researchers; see Unsworth et al., 2015; see Green et al., 2017 for a rebuttal). There are also some issues with the action vs non-action categorization, which were of primary concern for the present experiment. Action games have typically been the focus in previous studies, however the definition of an action video game is somewhat subjective, even with the criteria outlined in the introduction (Green & Bavelier, 2012). As discussed by Bavelier & Green (2019), modern video games tend to blend genres, which makes categorization complicated. For example, Bavelier & Green (2019) mention the game, *The Elder Scrolls V: Skyrim*, which blends role-playing game mechanics (historically role-playing games would be considered non-action) with shooter game mechanics (consistently considered part of the action genre).

Additionally, technological advances have allowed game developers to improve game mechanics and increase the complexity of games, which means the latest release of a game from a given franchise is likely to be more complex and visually/attentionally demanding than a previous game in the franchise. The *Nintendo Switch* game *Tetris 99* is a good example of this phenomenon. The original *Tetris* is considered a non-action game (e.g., Green & Bavelier, 2003 and Dye et al., 2009; see also Bediou et al., 2018 who describes *Tetris* as a puzzle game) and has been used as a non-action control game in training studies (e.g., Green & Bavelier, 2003). In the original *Tetris,* the single-player game involves the player managing the placement of various shaped blocks that fall one at a time from the top of the screen. In contrast, *Tetris 99* is a multiplayer game where the player still is managing the placement of blocks that fall one at a time while also adapting to the actions of many opponents, making it less clear whether this game belongs in the non-action category with its predecessor.

Another issue with the action/non-action categorization of video games is the inconsistency between studies when classifying sub-genres, for example real-time strategy and driving-racing games. Some studies classify these sub-genres as non-action games (see Dye et al., 2009, where their appendix of non-action games includes real-time strategy games such as *Starcraft* and driving-racing games such as *Need for Speed*) however other studies argue that driving-racing games and real-time strategy games are action games. Wu & Spence (2013) used a driving-racing game from the *Need for Speed* franchise in their training study and observed reaction time improvements in a visual search task. These reaction time improvements were also observed in participants trained with a first-person shooter game, but not when participants were trained with a 3-D puzzle game. In another study, Kowalcyzk et al. (2018) compared structural connectivity of white matter tracts in the brains of experienced *Starcraft II* players versus novice/non-video game players and observed increased numbers of white matter fibres in occipital-parietal tracts for the *Starcraft II* players. In both these studies, driving-racing and real-time-strategy games were selected because the researchers argue these games meet the action game criteria, even though previous studies have categorized games from the same genres and same franchises as non-action (Dye et al., 2009). This issue is also related to the previously discussed problem of genre blending and game evolution, as Dye et al. (2009) classified the first *Starcraft* game as non-action, while Kowalczyk et al. (2018) were investigating the sequel, *Starcraft II*.

Dobrowolski et al. (2015) have examined these issues in action game classification. In their study, group differences were observed between real-time strategy players and non-video game players in task switching and multiple object tracking paradigms, but no differences were observed between first-person shooter players and non-video game players in these same tasks.

The researchers argue that both real-time strategy and first-person shooter games fit within the action game genre, demonstrating the importance of moving past broad genre classification to determine which games (or specific characteristics of games) drive differences in cognitive performance. In this case, the real-time strategy game used by Dobrowolski et al. (2015) was *Starcraft II*, supporting Kowalczyk et al.'s (2018) decision to categorize the game as action.

In Experiment 4, we have developed an objective and continuous measure of visual-spatial demands in the video games regularly played by our participants to evaluate whether the frequency of these demands is related to reading and attentional performance, and thus move beyond the problematic dichotomous "action" vs "non-action" classification.

5.2 Hypotheses

Our previous neuroimaging research identified overlap between EW (lexical) reading and exogenous peripheral visual attention processes and between PH reading (phonetic decoding) and endogenous central visual attention processes (e.g., Ekstrand, Neudorf, Gould, et al., 2019; Ekstrand, Neudorf, Kress, & Borowsky, 2019). Given these relationships, one would expect that phonetic decoding should show stronger associations to game-specific centrally located visual-spatial demands than peripherally located visual-spatial demands. The opposite should be the case during lexical reading, which we expect should be associated with peripherally located visual-spatial demands.

5.3 Method

5.3.1 Participants, Stimuli, Procedure

The data collected in Experiment 3 (Chapter 4) were used to conduct the visual demand analysis.

5.3.2 Visual Demand Analysis

The visual-spatial demand analysis conducted in this experiment is a novel technique we have developed as an objective method of evaluating the visual-spatial demands of a video game. Brief gameplay segments from each reported game were collected and analysed for the frequency of visual-spatial demands. For computer (PC) and console games (e.g. *Nintendo Switch*, *PlayStation 4*), three one-minute segments of gameplay for each game were collected from the popular streaming platform *Twitch.tv* where individuals publicly share their gameplay videos. To collect the one-minute segments, an archived video of a gameplay stream that was at least one hour in duration was selected. Videos with additional user-added overlays (e.g., stream camera, extra chat dialogs, notifications, etc.) were avoided if possible. If unavoidable, a video was selected where these overlays took up as little space as possible. From this gameplay stream, one-minute segments were randomly chosen. If the randomly selected one-minute segment consisted primarily of non-gameplay footage, a new random one-minute segment was selected. For mobile games, an iPhone 6 was used to download the reported games. Between 17 and 40 minutes of gameplay was captured with the screen record feature, and three one-minute segments were randomly selected from this recording. When conducting feature analysis, the PC and console game clips were watched on a 16:9, 61.0 cm (24 inch) HP monitor, and the mobile game clips were watched on the iPhone 6 with a 16:9, 11.9 cm (4.7 inch) display. Each clip was viewed at least once to score each visual demand measurement separately. Complete analysis typically took 30 minutes per game. The visual demand measurements are described below:

Central graphical (CG) demands were defined as the average number of graphical changes per minute within the central area of the screen, peripheral graphical (PG) demands were defined as the graphical changes per minute that occurred outside the central area, central textual (CT) demands were text-based changes within the central area, and peripheral textual (PT) demands were text-based changes outside the central area. The radius of the central area was dependent on whether the game clip was PC/console, or mobile, and was designed to encompass the foveal area, which has a radius of 2.5° visual angle (as discussed by Gutwin et al., 2017; see also Strasburger et al., 2011 for a review of peripheral vision). The radius of the central area was drawn to 3.5 cm (2.5° visual angle at an eye-to-screen distance of 80 cm). On the mobile device, the radius of the central area was drawn to 1.5 cm (2.5° visual angle at an eye-screen distance of 34 cm). An item appearing or changing were the events that were counted as a visual demand for one of these categories. For example, the text notification of an in-game event in the corner of the screen would be considered a PT demand, a cooldown text timer in the centre of the screen would be a CT demand, a red flash on the border of the screen indicating the direction of enemy fire would be a PG demand, and a cooldown bar in the centre of the screen would be a CG demand (see Figure 5.1). Events of the same category that occurred in close temporal and spatial proximity (approximately < 500ms and < 1° apart) were clustered as a single event. For example, multiple notifications appearing at the same time would be counted as one text demand.

Figure 5.1. Depiction of central and peripheral demand locations in a game. The yellow circle represents the center area of the screen. Blue dotted lines indicate potential central demand locations (a central graphic demand is not pictured). Red dashed lines indicate potential peripheral demand locations. The original image was posted by BagoGames (2014) and adapted under Creative Commons Licence 2.0 (https://creativecommons.org/licenses/by/2.0/legalcode).

5.4 Results

Weighted scores for each of the four analysed video game visual demands (CG, CT, PG, and PT) were calculated for each participant, using the following formula:

$$Weighted\ score\ = \sum_{i=1}^{5}(monthly\_hours_{game_i} * measure_{game_i})$$

Descriptive statistics for the four weighted scores can be found in Table 5.1. All values were $\log_{10}$-transformed to resolve skewness, which can also be found in Table 5.1.

Table 5.1. Descriptive Statistics for Visual Demand Scores of Video Games

	Untransformed		**Log$_{10}$-transformed**	
Weighted Score	*M* (*SD*)	*Skewness* (*SE skewness)*	*M* (*SD*)	*Skewness* (*SE skewness)*
Central Text	46.22 (79.30)	3.01 (0.48)	1.13 (0.81)	-0.25 (0.48)
Peripheral Text	483.68 (677.30)	1.52 (0.48)	1.88 (1.18)	-0.58 (0.48)
Central Graphic	86.50 (124.69)	1.27 (0.48)	1.20 (0.98)	-0.01 (0.48)
Peripheral Graphic	386.47 (601.81)	2.20 (0.48)	1.83 (1.12)	-0.66 (0.48)

A pair of GLMs was used to assess the effect of the four log$_{10}$-transformed weighted scores on our 2 (Validity: Valid vs Invalid) × 2 (Target Type: EW vs PH) repeated measures design. Given our interest in reading processes, we separated the visual-demand scores by whether they were text-based or graphical-based. As such, the first GLM included lg$_{10}$CT weighted score and lg$_{10}$PT weighted score, while the second GLM includes lg$_{10}$CG weighted score and lg$_{10}$PG weighted score.

When lg$_{10}$CT and lg$_{10}$PT weighted scores are the continuous variables of the model (GLM 1) there was a significant main effect of Target Type whereby EWs (M = 693.21 ms, SD = 96.77) were significantly faster than PHs (M = 783.59 ms, SD = 156.48), $F(1, 20) = 21.483$, $MSE = 8148.33$, $p < .001$. There was also a significant Target × lg$_{10}$PT interaction, $F(1, 20) = 6.08$, $MSE = 8148.33$, $p = .023$. Finally, there was a significant Validity × lg$_{10}$PT interaction, $F(1, 20) = 5.85$, $MSE = 2846.66$, $p = .025$. No other main effects or interactions were significant. When lg$_{10}$CG and lg$_{10}$PG are the continuous variables of the model (GLM 2), there was a main effect of Target Type whereby participants responded significantly faster to EWs (M = 693.21 ms, SD = 87.67) than PHs (M = 783.59, SD = 147.18) , $F(1, 20) = 18.933$, $MSE = 8939.82$, $p < .001$. There was also a significant Target × lg$_{10}$PG interaction, $F(1, 20) = 4.44$, $MSE = 8939.82$, $p = .048$. The other main effects and interactions were not significant.

To evaluate the nature of the interactions between the log$_{10}$-transformed visual demand scores and our behavioural measures of interest, the partial-coefficients from each GLM were examined (see Table 5.2). Increases in lg$_{10}$PG were associated with decreases in RT during invalidly cued PH trials (Figure 5.1 a), validly cued PH trials (Figure 5.1 b), and validly cued EW trials (Figure 5.1 c). Increases in lg$_{10}$CG were associated with increases in RT during validly cued EW trials (Figure 5.1 d) and to a lesser extent in validly cued PH trials (Figure 5.1 e).

Table 5.2. Summary of Partial-Coefficients from GLM 1 and GLM 2

			Visual Demand Type			
			Text (GLM 1)		**Graphic (GLM 2)**	
Target	**Validity**		**Central**	**Peripheral**	**Central**	**Peripheral**
PH	**Invalid**	*b*	79.33	-101.88	116.82	-138.56 *
		t	.83	-1.56	1.95	-2.62
		p	*.415*	*.136*	*.066*	*.016*
	Valid	*b*	117.98	-133.09	126.49 *	-154.35 *
		t	1.23	-2.02	2.09	-2.89
		p	*.233*	*.057*	*.050*	*.009*
EW	**Invalid**	*b*	-22.00	10.18	61.60	-49.40
		t	-.36	.24	1.90	-1.45
		p	*.722*	*.811*	*.125*	*.161*
	Valid	*b*	52.18	-63.78	95.67 *	-104.41 *
		t	.90	-1.60	2.88	-3.57
		p	*.379*	*.126*	*.009*	*.002*

Note. B-values are in milliseconds per log$_{10}$-transformed weighted demand score.

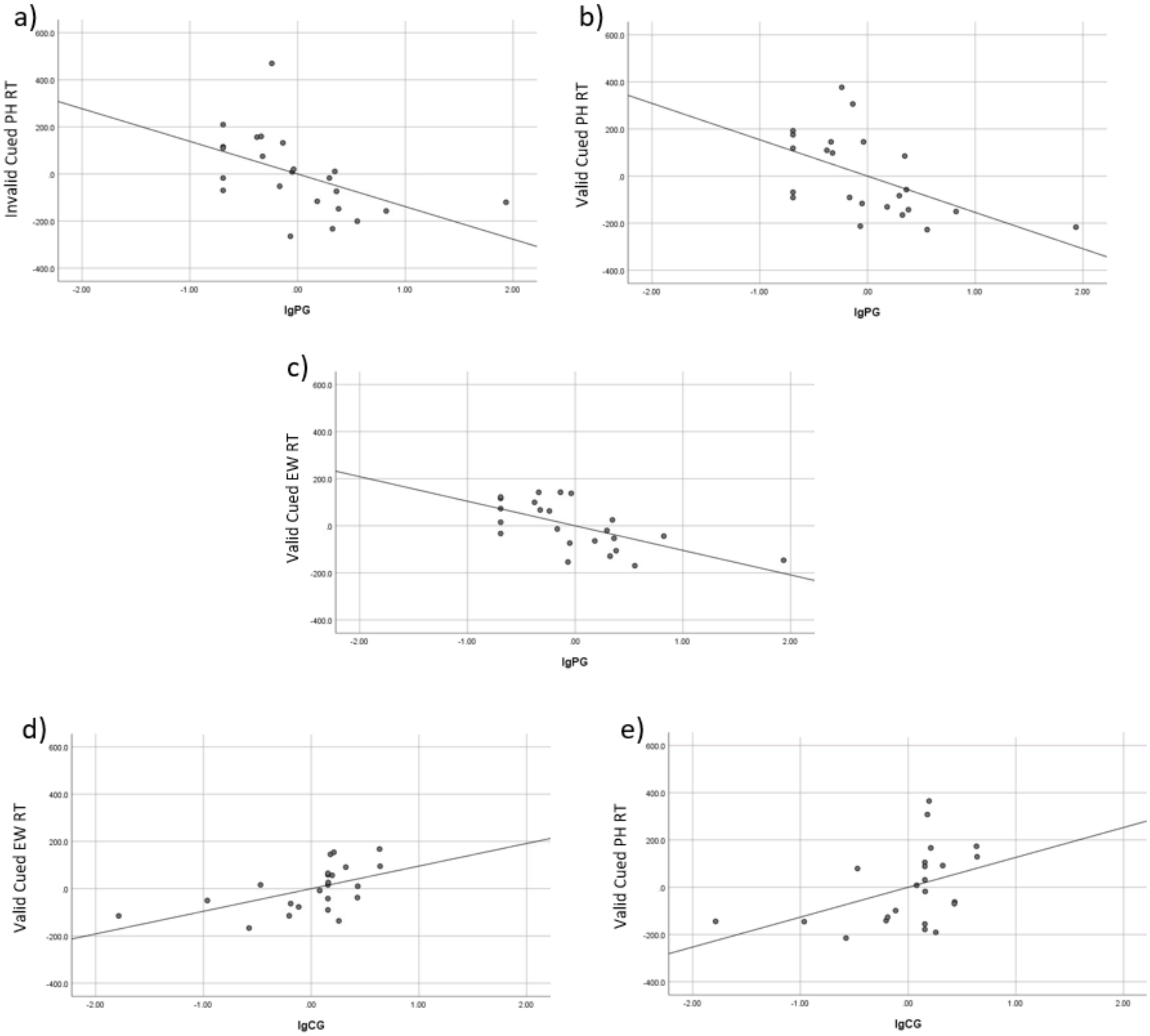

Figure 5.2. Partial Regression Plots of Reaction Time as a Function of $\log_{10}$-transformed weighted demand scores.

5.5 Discussion

With this experiment, we have demonstrated a technique for measuring the visual-spatial demands in video games and have shown that these visual-spatial demands may be a key characteristic that drives the relationship between video games, reading, and attention. In the case of our experiment, these measures of visual-spatial demands may have been able to include the experience from games that would not typically be captured by the “action” game definition. Furthermore, the distinction between central and peripheral visual-spatial demands has highlighted that it is peripheral visual-spatial processing that is particularly important in the beneficial relationship between video games and reading while central visual-spatial demands appear to have a detrimental association with reading speeds.

CHAPTER 6: General Discussion

This chapter is based on the content of two manuscripts:
Kress, S., Neudorf, J., Borowsky, B., & Borowsky, R. (in preparation). What's in a game: Visual-spatial demands in video games are associated with attentional cueing and reading processes. *To be submitted to Neuropsychologia*.
Kress, S., Neudorf, J., & Borowsky, R. (in preparation). Orthographic-phonological lexical decision performance and video game experience account for attentional cueing reaction times. *To be submitted to Attention, Perception, and Psychophysics.*

In this combination of experiments, we have found evidence for a link between video game experience and adult readers, extending the work by Franceschini et al. (2013, 2017) on children with dyslexia. In Experiment 1 we observed a relationship between video game experience and EW reading speeds in our skilled adult readers, suggesting reading processes beyond the phonetic decoding improvements observed by previous researchers (e.g., Bertoni et al., 2021; Franceschini & Bertoni, 2019; Franceschini et al., 2017) could benefit from video game experience. In Experiment 2 we observed a different relationship between reading and video game experience in the OPLDT paradigm; responses to EWs were slower as action video game experience increased. Given the processes involved in the OPLDT, these results in Experiment 2 likely indicate increased sublexical processing in our experienced video game players (possibly due to multitasking efficiency in video game players), which interfered with their ability to process EWs lexically. Action video game experience, when included in our GLM of attentional cueing and cue type effects, was able to account for the interaction between validity and cue type. Additionally, OPLDT performance correlated with attentional performance, and shared variance with our effects of cue validity and cue type, which demonstrated a behavioural overlap between attention and reading processes.

In Experiment 3 we observed a relationship between video game experience and PH reading speeds. We also observed interactions between cue validity and video game experience and between target type and video game experience, with the slope of the linear relationship between RT and video game experience depending on the target type (greater for sublexical PH stimuli) and cue validity (greater for valid cuing conditions). These findings supported our hypotheses that video game experience would be related to both reading and attentional processes. In terms of cue validity, RTs improved more substantially as a function of video game experience during validly cued trials. This is supported by the research of Dye et al. (2009), who found action video game players exhibited larger orienting effects during an attentional network test than non-video game players.

With our development of the visual-demand analysis technique in Experiment 4 to measure visual-spatial demands in video games, we were able to determine peripheral visual demands are associated with this improvement in reading RTs during validly cued trials, while central graphic demands were associated with slower RTs. The beneficial relationship between peripheral visual demands and reading RTs is consistent with previous research that found action video games were related to improvements in reading ability (e.g., Bertoni et al, 2021; Franceschini et al., 2013; Franceschini et al., 2017) because a defining feature of action video games is an emphasis on peripheral processing (Green & Bavelier, 2012). The finding that central graphic demands were associated with slower RTs was only possible to observe because of the use of our novel visual demand analysis technique, which demonstrates the importance of assessing the characteristics of video games (such as central vs peripheral demands) rather than relying on action vs. non-action categorizations to determine the relationship between reading, attention and video game experience.

6.1 Implications

6.1.1 Models of Reading and Attention

In our experiments, we observed the relationship between reading and video game experience take different forms, depending on task type. Experiment 1 was a blocked task, which allowed for effective isolation of lexical-processing, and it was here we observed a beneficial effect of video game experience on EWs. In contrast, the OPLDT of Experiment 2 mixed stimuli, and in this case sub-lexical processing appeared to interfere with lexical processing of EWs, resulting in slower responses as a function of action video game experience. Experiment 3 was an interesting case, as the hybridized reading-attention task used central cues which are thought to activate endogenous attention (see Chica et al., 2014 for a review of spatial attention paradigms). In Experiment 3 the hybridization of reading with a voluntary attention task likely encouraged activation of the dorsal stream, where voluntary attention and sublexical reading share regions of activation (e.g., Ekstrand, Neudorf, Gould, et al., 2019; Ekstrand, Neudorf, Kress, & Borowsky, 2019), which may explain why PHs (stimuli optimal for sub-lexical reading) were associated with video game experience in Experiment 3. The blocked nature of Experiment 3 may have prevented sublexical processes from interfering with lexical processes during the EW block, as we still observed a relationship between peripheral visual demands and lexical reading in Experiment 4. These patterns of results are an excellent demonstration of how task demands can facilitate or interfere with cognitive processes of interest.

Peripheral visual demands (Experiment 4) were related to both lexical (EW) and sublexical (PH) reading, rather than just to EW reading. This suggests lexical and sublexical reading may employ some shared attentional processes, and video game experience can improve these shared processes. It could be the case that the early visual processing of letter units in a word is a relevant shared process, as both lexical and sublexical reading involve letter identification (e.g., orthographic feature encoding or orthographic analysis in dual route models of reading; see Coltheart et al., 2001 or Owen & Borowsky, 2003). Although lexical and sublexical reading speeds were both improved by peripheral visual demands, these peripheral visual demands were most beneficial for sublexical reading. Sublexical reading would require more reliance on early visual processing of letter units than lexical reading (see Figure 3.1; see also the grapheme-to-phoneme route of the dual route cascade model, Coltheart et al., 2001), so if early visual letter processing is the language process involved in this relationship between reading and attention, that could explain why sublexical reading sees the most benefit. The combined associations of peripheral graphic demands with faster reading RTs and central graphic demands with slower reading RTs could be explained by effects of video games on oculomotor control (e.g., West et al., 2013). When a video game player frequently experiences a high degree of peripheral visual demands, their oculomotor performance may be improved, resulting in faster RTs during tasks that involve multiple peripheral locations, such as the task analysed in Experiments 3 and 4. In contrast, if a video game primarily involves fixating on the centre of the screen (as would be suggested by high central visual demand scores), the player will not be required to do much shifting of the eyes, and their oculomotor performance might not see improvement. It could also be the case that movement of one’s attentional scope is exercised when processing many peripheral demands, and given how some dyslexia theories are based on attentional impairments (e.g., Boden & Giaschi, 2007; Visser et al., 2004), future research will need to be conducted to clarify the nature of this apparent double dissociation between peripheral vs central graphic demands and reading performance.

6.1.2 Video Games and Cognition

With the visual-demand analysis technique introduced in Experiment 4, we hope future studies will consider this technique as an option to objectively evaluate the visual demands of video games, rather than being limited by the binary action/non-action video game classification. Given the presently observed relationship between peripheral demands and combined reading and attentional processes, we find the peripheral demand measures in particular to more effectively capture the relationships one would expect to see between video game experience and reading/attention, with the added benefit that players of ambiguously classified genres (such as driving games or real-time strategy games) will not have portions of their video game experience excluded from consideration. Along with the application of this measure in cross-sectional studies, experimental training studies can also benefit. The visual-spatial demand scores for each reported video game in Experiment 4 are included in Appendix D, and we invite researchers to refer to this data when selecting video games for their training study to verify that the games are sufficiently different in their visual-spatial demands.

6.2 Future Directions

Future behavioural studies can expand the field further by manipulating the complexity of attentional tasks, as well as the cue type. In Experiment 3 we used cardinal compass cues and eight possible target locations to maximize complexity, but given the research that has found performance differences in video game players compared to non-video game players as attentional demands increase (e.g., Green & Bavelier, 2003), easier task designs are also important to consider. Additionally, future studies should also include different visual language processing tasks, for example by comparing our OPLDT to the classic lexical decision task, to help determine which aspects of language processing are improved by video games. Given that these studies were cross-sectional investigations of participants with a variety of video game experience, causative effects cannot be concluded with respect to video game experience. It is possible that video games, reading, and attention are related because individuals with excellent reading and attentional processes are drawn to video games which challenge those skills. Future training studies would be able to assess this question.

Future research could investigate the potential for educational video games to be developed to help children practice their reading skills. Sella et al. (2016) demonstrated the use of the educational video game "*The Number Race"* as a tool to improve numerical ability, and Franceschini et al. (2017) have shown training with commercial video games improves reading ability in children with dyslexia. The present study has demonstrated that video game experience is related to reading ability in adults as well, so an educational video game to train reading skills could benefit all ages, if designed in an adaptive matter such as "*The Number Race*". In particular, such a video game may want to emphasize peripheral visual-spatial demands, as we observed this characteristic to be related to beneficial reading and attentional processes.

The current studies were behavioural in nature. It will be important for future studies to examine the relationship between video games, reading, and attention through neuroimaging techniques, such as with functional magnetic resonance imaging. Of substantial interest will be occipital-parietal regions, especially the angular gyrus and neighbouring temporal-parietal junction, which have already been associated with video games, reading, and attention (temporal-parietal junction and reading/attention: Ekstrand, Neudorf, Gould, et al., 2019; Ekstrand, Neudorf, Kress, & Borowsky, 2019; angular gyrus and video games: Kowalczyk et al., 2018). The middle occipital gyrus may also be a region of interest, as it has been found to be a region of interaction between reading and attentional processes (e.g., Ekstrand, Neudorf, Kress, & Borowsky, 2019) and may be a key region for early visual processing before the dorsal and ventral streams of the brain diverge (e.g., Laycock et al., 2009). Finding ways for participants to play video games during neuroimaging will also be an important consideration, as this will allow researchers to identify which regions are most active during video game play, rather than being limited to inferences from pre/post-training data.

6.3 Conclusions

The series of studies presented in this thesis have helped clarify that nature of the relationship between reading and video game experience. In Experiment 1's reading aloud task, we observed faster lexical reading RTs as a function of video game experience, generalizing the reading-video games relationship to skilled adult readers. Experiment 2's OPLDT and attentional cueing tasks highlighted the overlapping nature of reading and attentional processes. Experiment 3's hybrid reading-attention task demonstrated how both reading and attentional performance are related to video game experience. Taken together, these studies have helped us identify attentional mechanisms as a key component in the reading-video game relationship. Our visual-demand analysis in Experiment 4 provides an objective measure with which future studies can assess visual demands in video games of interest. With our visual-demand analysis we have identified video game peripheral demands as associated with improved performance in both lexical and sublexical reading, while central demands appear detrimental to lexical and sublexical reading performance. Overall, these results demonstrate that video game experience is related to reading processes in skilled adult readers, and there may be a beneficial relationship through the peripheral attentional demands of video games. With the novel techniques and results presented here, this research will help inform models of reading and attention, as well as aid game developers in designing games and mechanics that promote reading ability, which would provide immense benefits to individuals with reading deficits such as surface or phonological dyslexia.

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Appendix A: Exception Word and Pseudohomophone Stimuli

Exception Word	EW LogHAL Word Frequency**	Pseudohomophone
bear	10.066	bair
blood	10.855	bludd
break	10.774	braik
broad	9.442	brawd
comb*	7.386	coam
foot	10.095	fuht
front	11.263	frunt
gauge	8.504	gaige
glove*	6.461	gluv
great	12.469	grait
heart	10.732	hawrt
monk	8.236	munk
month	11.242	munth
mould	6.817	mohld
mourn	6.347	mohrn
ninth	7.557	nynth
pear	6.878	payr
pint	7.293	pynt
pour	9.337	pohr
roll	9.986	rohl
seize	7.563	seeze
shoe	8.558	shue
soot	5.645	suht
soul	10.384	soal
soup	8.707	soop
sponge	7.376	spunge
steak	7.320	staik
ton	9.372	tun
tour	10.064	toor
wear	10.347	wair
wood	10.087	wuhd
world	12.597	werld

*****These words were only in Experiments 3 and 4.

**See the English Lexicon Project (Balota et al., 2007)

Appendix B: Experiments 1, 3, & 4 Video Game Experience Question Set

The set of video game experience questions used in these studies was designed based on the common conventions of recent literature investigating links between video game experience and cognitive ability. The goals in mind with these questions were to maximize self-report accuracy, maintain consistency with previous researchers' video game experience measures, and investigate specific video game characteristics.

1. *The following questions are about your video game expertise. When answering these questions, please think back on the past 6 months. Consider your average daily gameplay sessions before answering with your weekly averages.*

   This statement opened the set of video game experience questions. Previous literature typically asked participants to respond based on the past 6 months to 1 year of video game experience (see Benady-Chorney et al., 2020; Dobrowolski et al., 2015; Green & Bavelier, 2003; Kowalczyk et al., 2018 for examples using a 6-month timeframe; see Dye et al., 2009; Dye & Bavelier, 2010 for examples using a 12-month timeframe), so 6 months was chosen for this study. We also asked participants to reflect on their daily gameplay sessions before answering with weekly or monthly values to encourage more accurate self-report.

2. *What are your five most frequently played games? (Game: hours per game session, game sessions PER MONTH; ...) ex. Breath of the Wild: 4, 4; Diablo 3: 3, 12; Stardew Valley: 1, 14; ....*

   This question allowed participants to report the specific games they play most frequently. The responses from this question allowed us to gather the information needed to find and conduct visual feature analysis for each reported game. This question is adapted from the procedure of Dye et al. (2009) who asked participants to report their top 10 played games in the past 12 months, along with length of a typical session and sessions played per month.

3. *How many hours PER WEEK do you play video games on average? (this includes your top games as well as other games)*

   By preceding this question with the top five games report (Question 2), we hoped to encourage accurate self-report of weekly average game hours.

4. *This question is about ACTION GAMES*

   Of the [VideoGameHours.RESP] hours spent playing games in general, how many hours are spent playing ACTION video games? (these are games involving high speed, quick *actions, and divided attention: for example first person shooters or real time strategy)*

This question is based on the common definition of action video games found in the literature (see introduction for a description of this definition from Green & Bavelier, 2012). Based on this definition, first- and third-person shooter games are considered action video games. Some real-time strategy games have been considered action video games (e.g. Kowalczyk et al., 2018), however this is inconsistent (e.g., Dye et al., 2009). Fighting games, racing games, and sports games have been considered non-action based on this definition (e.g., Dye et al., 2009), so the researcher clarified that time spent playing those genres of games should not be included in this category but this has also been inconsistent (e.g. Wu & Spence, 2013).

5. *This question is about NON-ACTION games*
   Of the [VideoGameHours.RESP] hours spent playing games in general, how many hours are spent playing NON-ACTION video games that require HIGH COORDINATION or FAST REACTIONS? (for example: 2D platformers and racing games)

This question is intended to capture the games that would not be captured by Green and Bavelier's definition of action video games (Green & Bavelier, 2012) because they do not have a significant divided attention component, but do still involve high coordination and quick reactions. Time spent playing previously mentioned fighting, racing, and sports games would be relevant to this response. The responses to this question were collected but not analysed for the reported experiment.

6. *This question is about ACTION games*
   Of the [ActionVideoGameHours.RESP] hours spent playing ACTION video games, how many hours are spent playing games that require a high degree of spatial learning and navigational skills? (for example, first person shooters without a mini-map such as Left for Dead 2)
7. *This question is about NON-ACTION games*
   Of the [VideoGameHours.RESP] hours spent playing video games in general, how many hours are spent playing NON-ACTION video games that require a high degree of spatial learning and navigational skills? (for example, 3D platformers such as Mario Odyssey or Spyro)

These two questions capture the time spent playing spatially demanding video games, which some researchers have found relevant due to associations with hippocampal and caudate nucleus volume (e.g West et al., 2017). The responses to these questions were collected but not analysed for the reported experiment.

8. *This question is about ACTION games*
   Of the [ActionVideoGameHours.RESP] hours spent playing ACTION video games, how many hours are spent playing games that require a high degree of logic or strategizing? (for example, real-time strategy games)
9. *This question is about NON-ACTION games*
   Of the [VideoGameHours.RESP] hours spent playing video games in general, how many hours are spent playing NON-ACTION video games that require a high degree of logic or strategizing? (for example, turn-based strategy games)

These two questions capture the time spent playing strategic video games, which some researchers have found relevant to cognitive ability in various domains (e.g., Basak et al., 2008). The responses to these questions were collected but not analysed for the reported experiment.

Appendix C: Experiment 2 Video Game Experience Question Set

The question set from Appendix B was updated for the online delivery platform of Experiment 2.

The following set of questions is about your video game experience. Please reflect on the past six months and consider your average daily gameplay sessions before answering with weekly or monthly averages.

1. *How many days of the week do you typically spend playing video games?*
    3. *None, I do not play any video games.*
    4. *1-2*
    5. *3-5*
    6. *6-7*

The following questions used an open box response.

2. *When you play video games on a single WEEKDAY, how much time do you spend (in hours)?*
3. *When you play video games on a single WEEKEND DAY, how much time do you spend (in hours)?*
4. *In a typical WEEK, for how long do you play video games (in hours)?*

The following questions used a 0-100 slider response to indicate proportions.

5. *What portion of your game time do you spend playing games with ACTION elements (unpredictable and face-paced demands, NOT sports, fighting, or rhythm games)?*
6. *What portion of your game ntime do you spend playing SHOOTER games (e.g. Fortnite, CounterStrike)?*
7. *What portion of your game time do you spend playing SPORTS games (e.g. FIFA)?*
8. *What portion of your game time do you spend playing RACING games (e.g. Need for Speed, Mario Kart)?*

9. *What portion of your game time do you spend playing FIGHTING games (e.g. Mortal Kombat, Smash Brothers)?*
10. *What portion of your game time do you spend playing RHYTHM games (e.g. Beat Saber, Crypt of the Necrodancer)?*
11. *What portion of your game time do you spend playing games with REAL-TIME STRATEGY elements?*
12. *What portion of your game time do you spend playing games with TURN-BASED STRATEGY elements?*
13. *What portion of your game time do you spend playing gmaes with PUZZLE elements?*
14. *What portion of your game time do you spend playing games with ROLE-PLAYING GAME elements?*
15. *What portion of your game time do you spend playing games with OPEN WORLD elements?*
16. *What portion of your game time do you spend playing games with SOCIAL elements (e.g. multiplayer team-based games)?*
17. *If you feel any genres you typically play were missed, please note them here.* (**Open box response)**

The following questions used an open box response.

18. *Please list your top five most frequently played video games in the past six months.*
    - *Name of Game:*
    - *Device (e.g. mobile, PC, Xbox One, Nintendo Switch, PlayStation 4, etc):*
    - *When you choose to play this game for how long do you play it (in hours)?*
    - *How many times PER MONTH do you play this game?*

    (repeat for Games 2-5)

Appendix D: Video Game List from Experiments 3 & 4

		Demands/Minute			
		Peripheral		Central	
Game	Platform	Text	Graphic	Text	Graphic
2048	Mobile	28	19	8.33	4.33
Agar.io	Mobile	5.67	18.67	0	4.67
Angry Birds 2	Mobile	19	9.33	4.67	6.67
Anthem	Console/PC	8.67	12.67	3.33	7
Assassin's Creed: Odyssey	Console/PC	5	7.67	0.67	1
Blackjack	Mobile	25	0	6.67	0
Call of Duty: Modern Warfare 2	Console/PC	23.67	22.67	3.67	8.67
Candy Crush	Mobile	26.33	23.67	19	15.67
Chess	Mobile	20	24	0.33	9
Civilization 5	PC	8.67	4	0	0
Counter Strike: Condition Zero	PC	12.67	3	3.33	0.67
Counter Strike: Global Offensive	Console/PC	11	10	0.33	1.67
Destiny 2	Console/PC	9.33	9.67	0.33	5.67
Fairway	Mobile	28.67	15.33	4.67	0.67
Fallout 4	Console/PC	8.33	4.67	0.33	2.67
Far Cry 5	Console/PC	5	4.67	0	2
FIFA 2017	Console/PC	23.67	9.33	0	0.33
Final Fantasy VII	Console/PC	14.67	6.33	0.67	0
Harry Potter: Wizards Unite	Mobile	16.67	11.33	10.33	4
Hearts	Mobile	5	24.33	18.33	18.67
Hollow Knight	Console/PC	3.67	10	0	0.33
Jewel Chase	PC	0.33	29.33	0	0.67
Kirby Star Allies	Console	5	2.67	0.33	0
LaTale	PC	31.33	26.67	13	0.67
League of Legends	PC	11	22.33	7.67	8.33
Luxor	Mobile	6	21	3	15
Mario Kart 8	Console	12.67	15	0.67	1

Monster Hunter: World	Console/PC	6.66	4.67	1	0.33
Need for Speed: Most Wanted (2012)	Console/PC	9	8	1	0
PlayerUnknown's Battlegrounds	All	9.33	3.67	1	1.33
Pokemon Showdown	PC	37.67	9.67	6.33	5.67
Sam & Max Save the World	Console/PC	16	1.33	0	0
Sims 4	Console/PC	21.33	14	1.67	0.67
Slime Ranchers	Console/PC	6.33	3	0.33	0.67
Solitaire	Mobile	7.33	12.67	0	0
Spiderman (PS4)	Console	12	24.3	0	1.33
Starcraft 2	PC	10.67	13.67	0.33	1
Stonehearth	PC	7.67	6	0	0.33
Sudoku	Mobile	7.33	9.33	1	1.33
Super Mario Odyssey	Console	2	1.33	0	0
Super Smash Bros. Ultimate	Console	15.33	4.67	0	0
Temple Run	Mobile	3	12.33	0.67	0
The Elder Scrolls V: Skyrim	Console/PC	3	2	0.33	0.33
Total War Rome 2	PC	9	17.67	0	0
Toy Blast	Mobile	7.33	21.33	4	7
Warframe	Console/PC	7.67	3.67	0	1.33
Warthunder	Console/PC	11.33	12.33	0.67	2
Witcher 3: Wild Hunt	Console/PC	6	3.67	0.33	0.33
Word Cross	Mobile	6.33	11	12.33	0.33
World of Tanks	All	6.67	5.67	0.33	3.33
XCOM 2	PC	6.33	10.67	0.67	0