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What's in a game: Video game visual-spatial demand location exhibits a double dissociation with reading speed☆

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ABSTRACT

This research sought to clarify the nature of the relationship between video game experience, attention, and reading. Previous studies have suggested playing action video games can improve reading ability in children with dyslexia. Other research has linked video game experience with visual-spatial attention, and visual-spatial attention with reading. We hypothesized that the visual-spatial demands of video games may drive relationships with reading through attentional processing. In this experiment we used a hybrid attention/reading task to explore the relationship between video game visual-spatial demands, reading and attention. We also developed novel visual-spatial demand measures using participants' top five played video games for an individual-specific measure of visual demands. Peripheral visual demands in video games were associated with faster reading times, while central visual demands were associated with slower reading times for both phonetic decoding and lexical reading. In addition, video game experience in terms of hours spent playing video games each week interacted with the cueing effect size in the lexical reading condition, with experienced video game players exhibiting a larger cueing effect than participants with less video game experience. These results suggest that exposure to peripheral visual spatial demands in video games may be related to both lexical and sublexical reading processes in hybrid attentional reading tasks such as ours with skilled adult readers, which has implications not only for models of how ventral and dorsal stream reading and visual-spatial attention are integrated, but also for the development of dyslexia diagnostics and remediation.

1. Introduction

Playing video games is a popular hobby. In the Entertainment Software Association of Canada's *Real Canadian Gamer Essential Facts* report (2020), 61 % of surveyed Canadians reported playing video games. 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) and in 2020, 50 % of the surveyed European population between the ages of 6 and 64 play video games (Europe's Video Games Industry & European Games Developer Federation, 2021). 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., Antzaka et al., 2017; Basak et al., 2008; Bertoni et al., 2021; 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 reading and associated cognitive and brain functions will help researchers gain knowledge on what factors are involved in the development and maintenance of various reading processes.

The extant research on video games and cognitive processes focuses heavily on the specific genre of action video games, which is one of 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

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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 *Call of Duty: Black Ops Cold War* (a first-person shooter game and among the top 5 best-selling games of 2020 in Europe; Europe's Video Games Industry & European Games Developer Federation, 2021) 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., Borowsky et al., 2006; see also Coltheart et al., 2001; Ziegler et al., 2009; Perry et al, 2010, 2013) there are two streams in the brain, typically left-hemisphere dominant, for processing written words into sound. One 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. Pseudohomophones (PHs) are ideal stimuli to encourage realistic 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" is pronounced like the real word "shoe; Borowsky et al., 2006).

The other 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. 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, 2007; Cummine et al., 2013; Ekstrand, Neudorf, Gould, et al., 2019; Ekstrand, Neudorf, Kress, & Borowsky, 2019; Ekstrand et al., 2020; Neudorf et al., 2019; Pugh et al., 2000; Sandak et al., 2004 for more information about these two processing systems). The optimal stimuli to encourage lexical-whole word reading and activate the ventral-lexical stream are exception words (EWs). 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". Fig. 1 depicts some of these key regions of the dorsal-sublexical and ventral-lexical streams.

1.1.2. Reading and video games

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 (see Cummine et al., 2015; Dębska et al., 2019; Saygin et al., 2013 for studies relating sublexical processing performance to the dorsal stream and lexical processing performance to the ventral stream; see also McDougall et al., 2005). It is important to note that these subtypes of dyslexia are not exclusive, and individuals with dyslexia may exhibit deficits in both lexical and sublexical processing (e.g., Castles & Coltheart, 1993; see also Ziegler et al., 2020 for a proposed computational model of dyslexia based on a dual route reading model).

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 et al., 2017; Franceschini & Bertoni, 2019) 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 pronounceable but non-pseudohomophonic nonwords. Lexical reading (using EWs) has not been examined closely, as many of these previous studies were conducted in Italian, where syllabic stress in words longer than two syllables is considered one of the only pronunciation features that requires lexical processing (see Franceschini et al., 2021). Determining whether video game experience is related to lexical/whole-word reading ability as well as sublexical-phonetic decoding would not only advance models of basic reading processes, but also indicate which reading processes might benefit from the use of video games as a training tool.

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

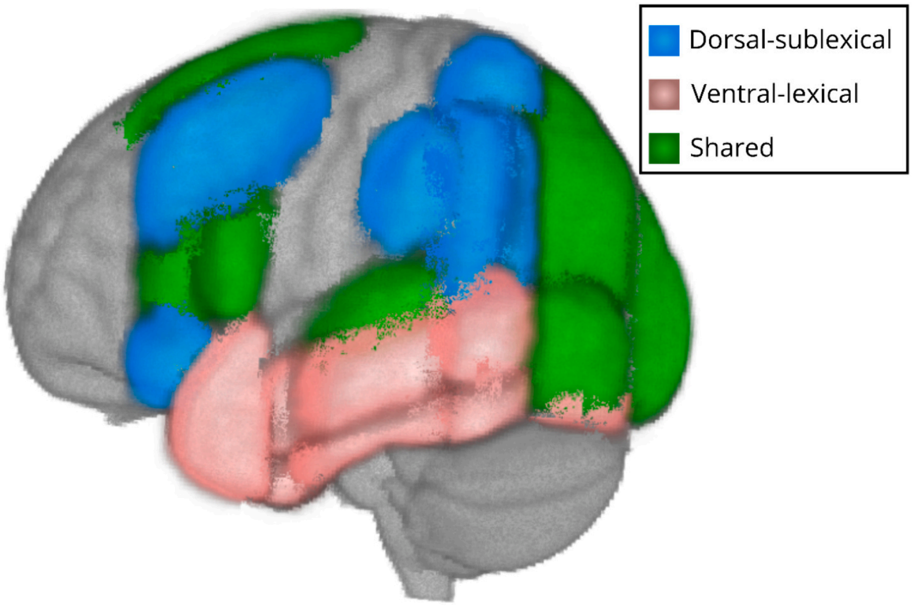

Fig. 1. The dorsal-sublexical and ventral-lexical reading streams

Note. The dorsal-sublexical stream is depicted in blue and includes regions such as the angular gyrus/inferior parietal lobule, superior parietal lobule, middle frontal gyrus, and orbital gyrus. The ventral-lexical stream is depicted in pink and includes regions such as the fusiform gyrus, inferior and middle temporal gyri, and temporal pole. Shared regions are depicted in green and include the lateral occipital cortex, posterior superior temporal gyrus, pars opercularis, pars triangularis, and superior frontal gyrus. Language processes are typically left-hemisphere dominant, and recent research has demonstrated some shared reading and attention activation in both hemispheres (e.g., Ekstrand, Neudorf, Gould, et al., 2019; Ekstrand, Neudorf, Kress, & Borowsky, 2019; see Borowsky et al., 2006, 2007; Cummine et al., 2013; Ekstrand et al., 2020; Neudorf et al., 2019; Pugh et al., 2000; Sandak et al., 2004). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

review). In the dual-route model of attention, the two types of attention that are highlighted are the typically right hemisphere dominant 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). Exogenous attention is also called automatic or stimulus-driven 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). 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. Fig. 2 depicts some of these key regions of the dorsal-endogenous and ventral-exogenous streams.

1.2.2. *Attention and video games*

In their seminal research, Green and Bavelier (2003) observed action video game experience was related to attentional processes 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., Dye & Bavelier, 2010; Li et al., 2015) although the relationship between video games and attentional capacity is less consistent (e.g., Irons et al., 2011). 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; Wilms et al., 2013) but not consistently in automatic two-location cueing tasks (e.g., Castel et al., 2005; West et al., 2008) and a review of the literature by Bavelier and Green (2019) highlights that action video game experience appears to be most associated with training of voluntary attention processes (see also Hubert-Wallander et al., 2011). 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 (e.g., Gori et al., 2014, 2016; see also Boden & Giaschi, 2007; Stein & Walsh, 1997, for reviews). 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 both their spatial and temporal attentional abilities in comparison to their age-matched peers, demonstrating that attentional deficits are relevant to the reading disorder (e.g., Facoetti et al., 2000, 2008; 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., Bertoni et al., 2021; Franceschini et al., 2017). Additionally, Antzaka et al. (2017) observed a positive correlation between visual attention span and French pseudo-word reading speed in their group of skilled adult readers, and action video gamers performed better than non-gamers in these tasks. This combination of findings in the literature suggests that visual-spatial attentional processes may be driving the relationship between video games, reading, and attention.

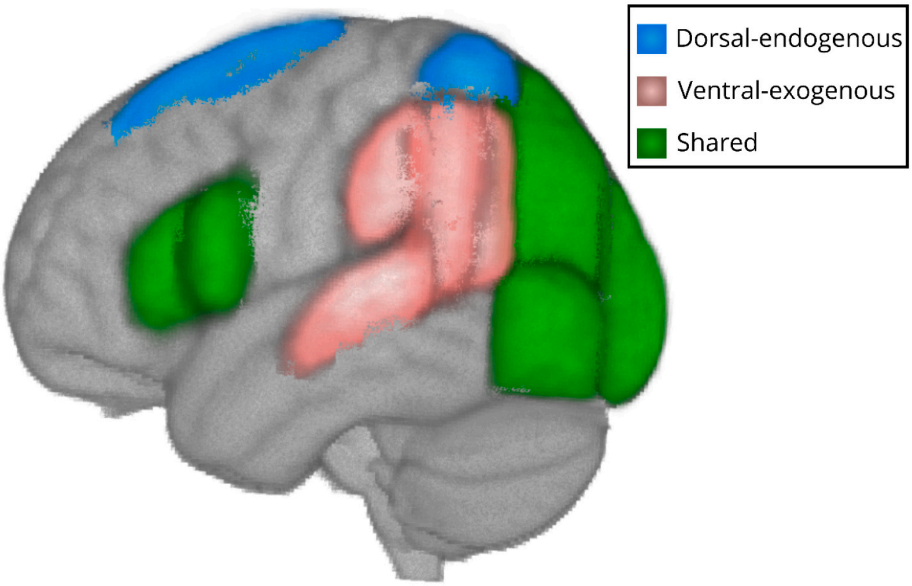

Fig. 2. The dorsal-endogenous and ventral-exogenous attention streams

Note. The dorsal-endogenous stream is depicted in blue and includes regions such as the superior parietal lobule/intraparietal sulcus and frontal eye field. The ventral-exogenous stream is depicted in pink and includes regions such as the temporal-parietal junction (inferior parietal lobule and superior temporal gyrus) and supramarginal gyrus. Shared regions are depicted in green and include the occipital cortex and inferior frontal gyrus. Attention processes are typically right-hemisphere dominant, and recent research has demonstrated some shared reading and attention activation in both hemispheres (e.g., Ekstrand, Neudorf, Gould, et al., 2019; Ekstrand, Neudorf, Kress, & Borowsky, 2019). See also Corbetta & Shulman, 2002 and Mickleborough et al., 2015. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

1.4. The problem with action video game classification

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). 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 by Green and Bavelier (2012). As discussed by Bavelier and Green (2019), modern video games tend to blend genres, which makes categorization complicated. For example, Bavelier and 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, as noted by Wilms et al. (2013), 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 and 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, Kowalczyk et al. (2018) compared structural connectivity in 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.

2. The current study

This study consists of two parts. First, we examined the proposed link between video game experience, 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). For this study we focused on endogenous-voluntary attentional cueing, as that has been previously associated with video game experience (e.g., Dye et al., 2009). Furthermore, previous studies have identified overlap between central (endogenous) visual attention and phonetic decoding (e.g., Ekstrand, Neudorf, Gould, et al., 2019; Ekstrand, Neudorf, Kress, & Borowsky, 2019), and phonetic decoding has been most consistently related to video game experience in the literature (e.g., Bertoni et al., 2021; Franceschini et al., 2017; Franceschini & Bertoni, 2019). Second, we then investigated whether specific visual features in video games are related to performance differences in reading and attention. To answer this question, we have developed an individually-relevant and continuous measure of visual-spatial demands in the video games regularly played by each of our participants to evaluate whether the frequency of these demands is related to reading and attentional performance.

2.1. Hypotheses

1a. Previous research has observed larger orienting effects in video game players than non-video game players (e.g., Dye et al., 2009). If this is generalizable to other cueing tasks and video game player samples, we would expect cueing effects to be of a larger magnitude for individuals with higher levels of video game experience in our attentional cueing paradigm.

1b. Alternatively, West et al. (2008) observed video game players are better at attending to multiple locations than non-video game players. If this is consistent across other video game players then one could predict that increased video game experience would be related to decreased cueing effect sizes.

2. Consistent with previous studies (Bertoni et al., 2021; Franceschini et al., 2013; Franceschini et al., 2017 and Franceschini & Bertoni, 2019), we expect video game experience to be associated with better phonetic decoding, which should present as faster PH reading RTs.

3. Our previous neuroimaging research identified overlap between EW (lexical) reading and peripheral visual attention processes and between PH reading (phonetic decoding) and 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 could be the case during lexical reading, which we expect should be associated with peripherally located visual-spatial demands.

2.2. Method

2.2.1. 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.

2.2.2. Apparatus and stimuli

Thirty-two pairs of monosyllabic EWs and the corresponding PHs were selected as the stimuli for this study (see Appendix A). The stimuli were grouped in EW and PH blocks, which contained 32 trials each. Each trial included a centrally presented one or two letter cue representing one of eight cardinal compass directions and cue validity was 75 %. The order of the EW and PH blocks was counterbalanced and the order of trials within a block was randomized. Target stimuli were in 18 pt. Courier New white font on a black background and appeared in either valid or invalid locations along an invisible square that was 7 cm × 7 cm, with the fixation cross in the centre. The experiment was run using E-Prime (Psychology Software Tools, https://pstnet.com) with a Compaq 7500 CRT monitor and an eye-to-screen distance of approximately 40 cm. 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. The experimenter instructed participants to pay attention to the letter cue at the centre of the screen, as it would indicate where the target word or letter string was most likely to appear. 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 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. The cardinal compass cue appeared on screen for 1000 ms, then the target EW or PH would appear at one of the eight locations (cue validity was 75 %, the eight location layout adapted from Borowsky et al., 2005). To ensure all eight locations were utilized equally, the locations of the stimuli were randomized and 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. Fig. 3 illustrates the progression of a single trial. After the experiment, participants would respond to some questions about their video game experience (see Appendix B).

2.2.4. Visual-spatial demand analysis

The visual-spatial demand analysis conducted in this experiment is a novel technique we have developed as an individually-based 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 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 chosen with the constraint that the one-minute segment consisted primarily of gameplay footage. For mobile games, an iPhone 6 was used to download the reported games. Between 17 and 40 min 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 in.) HP monitor, and the mobile game clips were watched on the iPhone 6 with a 16:9, 11.9 cm (4.7 in.) display. Each clip was viewed at least once to score each visual demand measurement separately. Complete analysis typically took 30 min 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 approximately 2.5° visual angle (as discussed by Gutwin et al., 2017; 2.6° in Wandell, 1995, as cited in Strasburger et al., 2011). 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 Fig. 4). Events of the same category that occurred in close temporal and spatial proximity (approximately <500 ms and $<1^\circ$ apart) were clustered as a single event. For example, multiple notifications appearing at the same time would be counted as one text demand.

2.3. Results

Participants' mean video game experience was 7.39 hr/week ($SD = 9.84$; min = 0 hr/week, max = 35 hr/week) and 51 unique video games were reported when participants were asked to list their top five games (Question 1 of Appendix B, see Appendix C for the list of reported games). The median RT of each participant's correct trials was used as the RT measure for the following analyses. Error rates were very low (ranging from 1.14 % to 7.25 %, see Fig. 5)[1]. To complement the significance-tests reported throughout the following sections, we additionally include the Bayes Factors and posterior probabilities in favour of the effects calculated using the BayesFactor package in R, with priors set to 1 (Masson, 2011; Rouder et al., 2009). Posterior probability values >.99 correspond to very strong evidence in favour of the effect, values between .95 and .99 correspond to strong evidence in favour of the effect, values between .75 and .95 correspond to positive evidence in favour of the effect, and values between .50 and .75 correspond to weak evidence in favour of the effect (Masson, 2011).

2.3.1. Hybrid reading-attention results

A median split was used to categorize participants into two groups: high experience video game players (Hi: ≥3 hr per week of video game

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[1] Although the error rates are very low, we did the same ANOVA on error rates as was done on RT, and there were no significant effects. Nonetheless, we note a trend for higher error rates in the validly cued conditions than invalidly cued conditions. Future research should examine whether processing of these central and controlled attentional compass cues would elicit stronger (and more typical) effects on target processing during a longer stimulus onset asynchrony (SOA) between the cue and target.

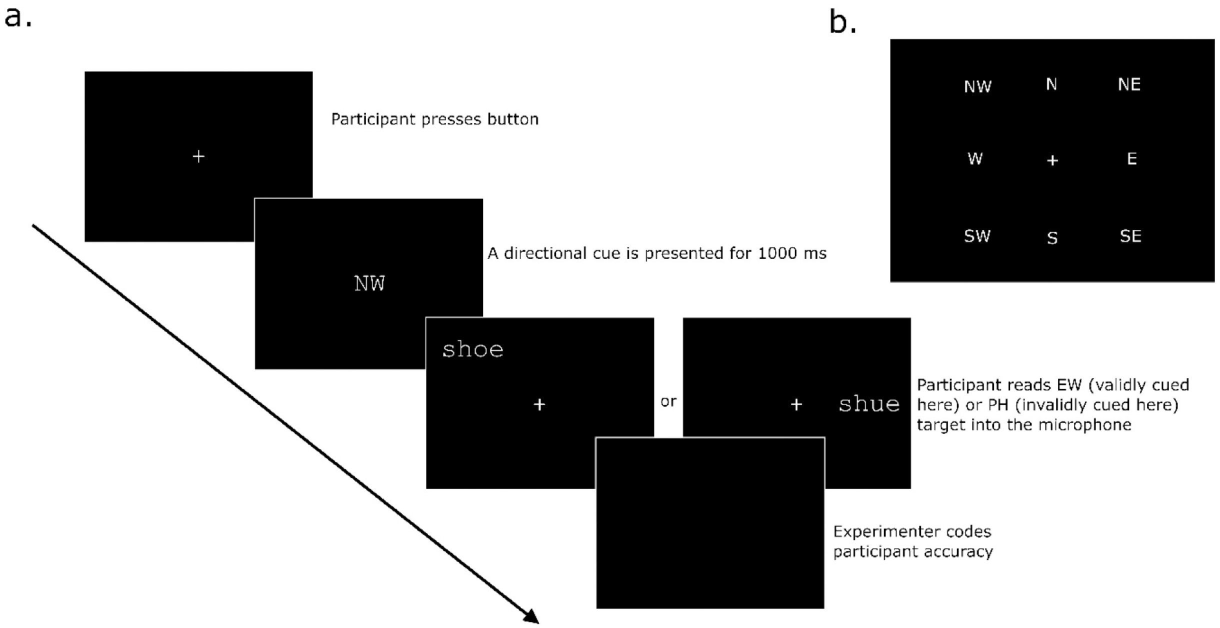

Fig. 3. Example of a) trial progression and b) relative layout of target locations corresponding to each respective cue.

Fig. 4. Depiction of central and peripheral demand locations in a game.
Note. The yellow circle represents the center area of the screen. Blue dotted lines indicate example central demand locations. Red dashed lines indicate example 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). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

experience; $N = 12$, $M = 13.71$, $SD = 10.11$) and low experience video game players (Lo: <3 hr per week of video game experience; $N = 11$, $M = 0.50$, $SD = 0.55$). Analyses were conducted on EWs and PHs separately to reflect ventral-lexical vs dorsal-sublexical stream processing, respectively. When utilizing ventral-lexical stream processes during EW reading, there was a main effect of Validity on reaction time, participants read validly cued EWs more quickly ($M = 680.44$, $SD = 101.62$) than invalidly cued EWs ($M = 707.08$, $SD = 101.05$), $F(1,21) = 5.32$, $MSE = 1529.73$, $p = .031$, Bayes Factor = 1.61, posterior probability = .62. The main effect of Video Game Experience was not significant, $F(1,21) = 0.39$, $MSE = 18{,}973.29$, $p = .537$, Bayes Factor = 0.34, posterior probability = .26, but the interaction between Validity and Video Game Experience approached significance, $F(1,21) = 4.27$, $MSE = 159.73$, $p = .051$, Bayes Factor = 1.51, posterior probability = .60. Fig. 5a illustrates these results and the 95 % CIs indicate that this interaction manifests in the form of a significant effect of Validity for the high experience video game players, but no effect of Validity for the low experience video game players.

For dorsal-sublexical processing during PH reading, there was no effect of Validity, $F(1,21) = 0.84$, $MSE = 2985.52$, $p = .370$, Bayes Factor = 0.24, posterior probability = .19, and no Validity × Video Game Experience interaction, $F(1,21) = 0.28$, $MSE = 2985.52$, $p = .602$, Bayes Factor = 0.33, posterior probability = .25. The ANOVA yielded a trend for Video Game Experience, $F(1,21) = 3.09$, $MSE = 51{,}155.53$, $p = .093$, Bayes Factor = 0.99, posterior probability = .50 which is further supported by a significant difference based on the 95 % CIs whereby Hi experience participants were significantly faster ($M = 727.44$, $SD = 221.42$) than Lo experience participants ($M = 844.84$, $SD = 231.25$; see

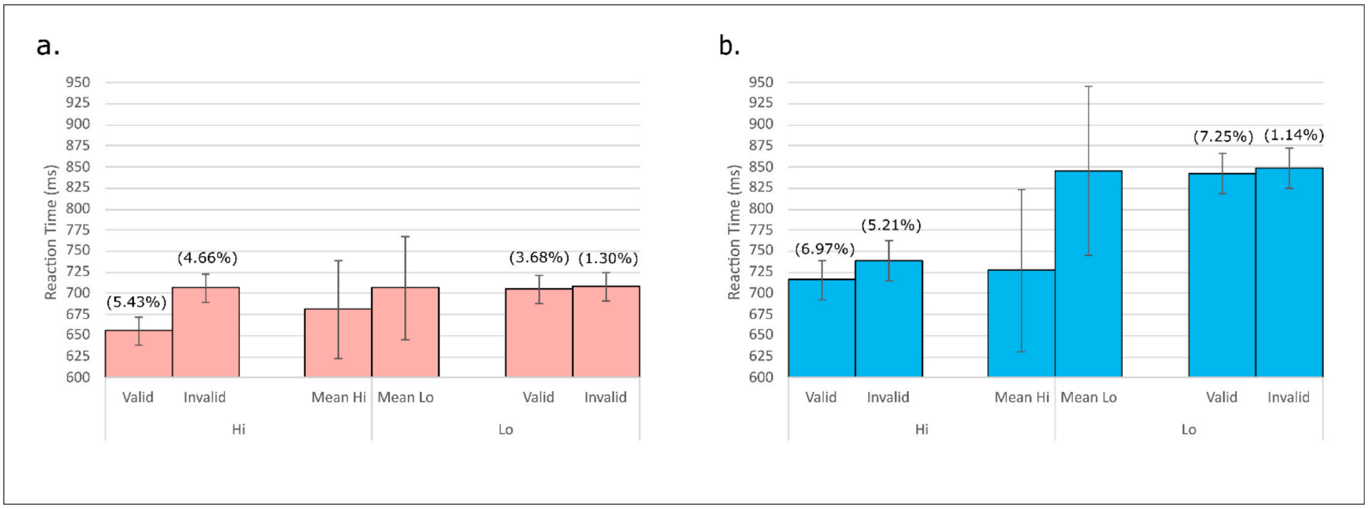

Fig. 5. Reaction time as a function of Validity and Video Game Experience for a) EWs and b) PHs
Note. Lo = <3 hr of video game experience per week; Hi = ≥3 hr of video game experience per week. Error bars are 95 % confidence intervals, following the calculation methods of Masson and Loftus (2003), with the middle pair of error bars representing the between-subjects effect of video game experience. Labels in brackets represent error rate for each condition.

Fig. 5b).

Given the debate in the field regarding the representation of video game experience as a dichotomous rather than continuous variable (Green et al., 2017; Unsworth et al., 2015), we repeated these analyses with video game experience represented as a $\log_{10}$-transformed continuous variable, rather than as a median split. This transformation resolved significant skewness in the video game experience measure (skewness = 1.53, $SE = 0.48$; after transformation $M = 0.63$, $SD = 0.53$, skewness = 0.32, SE = 0.48). When utilizing ventral-lexical stream processes during EW reading, the interaction between Validity and video game experience persists when video game experience is represented as a $\log_{10}$-transformed continuous variable, $F(1,21) = 13.03$, $MSE = 1136.20$, $p = .002$, Bayes Factor = 22.41, posterior probability = .96, supporting our median split results. The main effects were not significant, (all F's < 1.00, all p's > .330, all Bayes Factors <0.26, all posterior probabilities <.20). For dorsal-sublexical processing during PH reading, there were no significant effects or interactions when video game experience is represented as a continuous variable (all F's < 2.73, all p's > .113, all Bayes Factors <0.56, all posterior probabilities <.36).

2.3.2. Visual demand analysis results

The participants in the two groups had a wide range of video game experience and played a combination of games that could be classified as "action" or "non-action". This continuum of experience provides a unique opportunity to look at how different visual-spatial demands in video games (as determined by our visual demand analysis in the above Methods section) are related to reading and attentional performance.

Weighted scores for each of the four analysed video game visual demands (CG, CT, PG, and PT) were calculated for each participant, to approximate participants' monthly exposure to these visual demands. The formula for weighted scores is as follows, with the units of the weighted score being *(hours/month)*(occurrences/min)*:

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

Descriptive statistics and $\log_{10}$-tranformation details (to resolve skewness) for the four weighted scores can be found in Table 1. Participants' $\log_{10}$-transformed weighted scores were correlated with each other, with r-values ranging between 0.803 and 0.985.

A pair of General Linear Models (GLM) 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, and the high correlation between text-based and graphical-based demands ($r = 0.852$ between $\lg_{10}$CT and $\lg_{10}$CG; $r = 0.985$ between $\lg_{10}$PT and $\lg_{10}$PG) 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.

Table 1
Descriptive statistics for monthly exposure to video game visual demands.

	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)

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, $SD = 156.48$), $F(1,20) = 21.48$, $MSE = 8148.33$, $p < .001$, Bayes Factor = 221.09, posterior probability = .995. There was also a significant Target × $\lg_{10}$PT interaction, $F(1,20) = 6.08$, $MSE = 8148.33$, $p = .023$, Bayes Factor = 2.15, posterior probability = .68. Finally, there was a significant Validity × $\lg_{10}$PT interaction, $F(1,20) = 5.85$, $MSE = 2846.66$, $p = .025$, Bayes Factor = 1.97, posterior probability = .66. No other main effects or interactions were significant. When CG and 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 ($M = 783.59$, $SD = 147.18$), $F(1,20) = 18.93$, $MSE = 8939.82$, $p < .001$, Bayes Factor = 116.63, posterior probability = .99. There was also a significant effect of $\lg_{10}$PG, $F(1,20) = 8.23$, $MSE = 47{,}624.38$, $p = .009$, Bayes Factor = 4.70, posterior probability = .82 and a significant Target × $\lg_{10}$PG interaction, $F(1,20) = 4.44$, $MSE = 8939.82$, $p = .048$, Bayes Factor = 1.13, posterior probability = .53. 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 2). The Target × $\log_{10}$PT and Target × $\log_{10}$PG interactions appear to be attributable to larger *b* magnitudes for PHs than EWs, and the Validity × $\log_{10}$PT interaction appears to be related to larger *b* magnitudes in valid trials than invalid trials, although the partial-coefficients involving $\log_{10}$PT were not significant. Increases in lg_{10}PG were associated with decreases in RT during invalidly cued PH trials (Fig. 6a), validly cued PH trials (Fig. 6b), and validly cued EW trials (Fig. 6c). Conversely, increases in lg_{10}CG were associated with increases in RT during validly cued EW trials (Fig. 6d) and validly cued PH trials (Fig. 6e). Fig. 6 focuses on the valid cued conditions, which are most similar to the highly valid cues that video game players would experience during the games they play.

3. General discussion

In this study, we have used an attentionally-demanding, hybridized reading-attention task along with our novel visual demand analysis to examine the relationship between video game experience, reading, and attention, as well as the specific visual-spatial demands of participants' most frequently played video games that may drive these relationships. During lexical EW reading, we observed that attentional cueing effects increased as a function of video game experience, supporting our hypothesis 1a and the previous research of Dye et al. (2009). Visual cues/demands in video games usually have 100 % 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 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 differences observed here.

During sublexical PH reading, our group of high experience video game players had marginally faster reading RTs than our low experience video game players (although this was not observed with the analysis of video game experience as a continuous variable, 95 % confidence intervals did support this effect), providing some weak support for our hypothesis 2 and previous research on phonetic decoding ability (Bertoni et al., 2021; Franceschini et al., 2013; Franceschini et al., 2017 and Franceschini & Bertoni, 2019). The reliability of this effect should be examined further with additional participants in future research to increase power.

Table 2
Summary of partial-coefficients from GLM 1 (text demands) and GLM 2 (graphic demands).

			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	0.83	−1.56	1.95	−2.62
		p	.415	.136	.066	.016
	Bayes factor		0.22	0.49	0.87	2.88
	Posterior probability		.18	.33	.47	.74
	Valid	b	117.98	−133.09	126.49*	−154.35 *
		t	1.23	−2.02	2.09	−2.89
		p	.233	.057	.050	.009
	Bayes factor		0.32	0.98	1.10	4.91
	Posterior probability		.25	.49	.52	.83
EW	Invalid	b	−22.00	10.18	61.60	−49.40
		t	−0.36	0.24	1.90	−1.45
		p	.722	.811	.125	.161
	Bayes Factor		0.17	0.16	0.81	0.42
	Posterior probability		.15	.14	.45	.30
	Valid	b	52.18	−63.78	95.67*	−104.41 *
		t	0.90	−1.60	2.88	−3.57
		p	.379	.126	.009	.002
	Bayes Factor		0.24	0.52	4.81	20.6
	Posterior probability		.19	.34	.83	.95

Note. *b*-values are in milliseconds per $\log_{10}$-transformed weighted demand score. Asterisks indicate *b*-values which are significant at p .05. Seven of eight Visual Demand × Target Type cells show positive coefficients for central demands and negative coefficients for peripheral demands, which is significant by a χ^2 sign test, χ^2 (1) = 4.5, p = .034, supporting a double dissociation between visual demand location and reading performance.

With our development of the visual-demand analysis technique to measure visual-spatial demands in video games, we were able to determine peripheral graphic visual demands are associated with this improvement in reading RTs during validly cued trials. These results suggest that these visual demands are particularly important to the relationship between video games and reading when attentional cueing is a factor, which aligns with the emphasis on peripheral demands in the action video game definition provided by Green and Bavelier (2012). Additionally, we observed that central graphic demands are associated with slower reaction times. The combined observations of peripheral graphic demands speeding up reading RTs while central graphic demands slow down reading RTs demonstrates an important double dissociation that goes beyond our predictions in hypothesis 3. As predicted, we observed lexical reading of EWs benefiting from peripheral demands, and these results extend to phonetic decoding of PHs as well. We did not predict the detrimental effect of central graphic demands, which is a novel and important finding to consider. These results 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 used in this experiment. 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 benefit. Further research will need to be conducted to clarify the nature of this significant double dissociation between peripheral vs central graphic demands and reading performance. It is also important to note that although often similar in sign, text demands in video games did not show a significant double dissociation, which may point to key differences in the information that text and graphic cues provide in video games. For example, graphics may require an additional stage of cognitive analysis whereby the graphic is first mapped onto a linguistic representation (e.g., blue dots could mean friendly allies, while red dots mean enemies on a mini-map), which may serve to enhance these effects for graphics over text.

These results are informative for researchers studying models of basic reading and attentional processes. Contrary to our expectations, peripheral visual demands were related to both lexical (EWs) and sublexical (PHs) reading, rather than just to lexical reading. Although we specifically hypothesized peripheral visual demands to be related to lexical reading, given the overlap observed in previous neuroimaging studies (e.g., Ekstrand, Neudorf, Gould, et al., 2019; Ekstrand, Neudorf, Kress, & Borowsky, 2019), our results suggest both lexical and sublexical reading may benefit from peripheral graphic demands. Given the hybrid attention-reading paradigm used here, it seems plausible that both reading streams may employ some shared attentional processes, and video game experience may facilitate 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). Models of both reading and attention will benefit from these visual-spatial considerations which provides opportunities for further integration of reading and attentional processing models beyond what we have discussed elsewhere (e.g., Ekstrand et al., 2016; Ekstrand, Neudorf, Gould, et al., 2019; Ekstrand, Neudorf, Kress, & Borowsky, 2019). The integration of reading and attention processes also has applications in the clinical field for the development of dyslexia

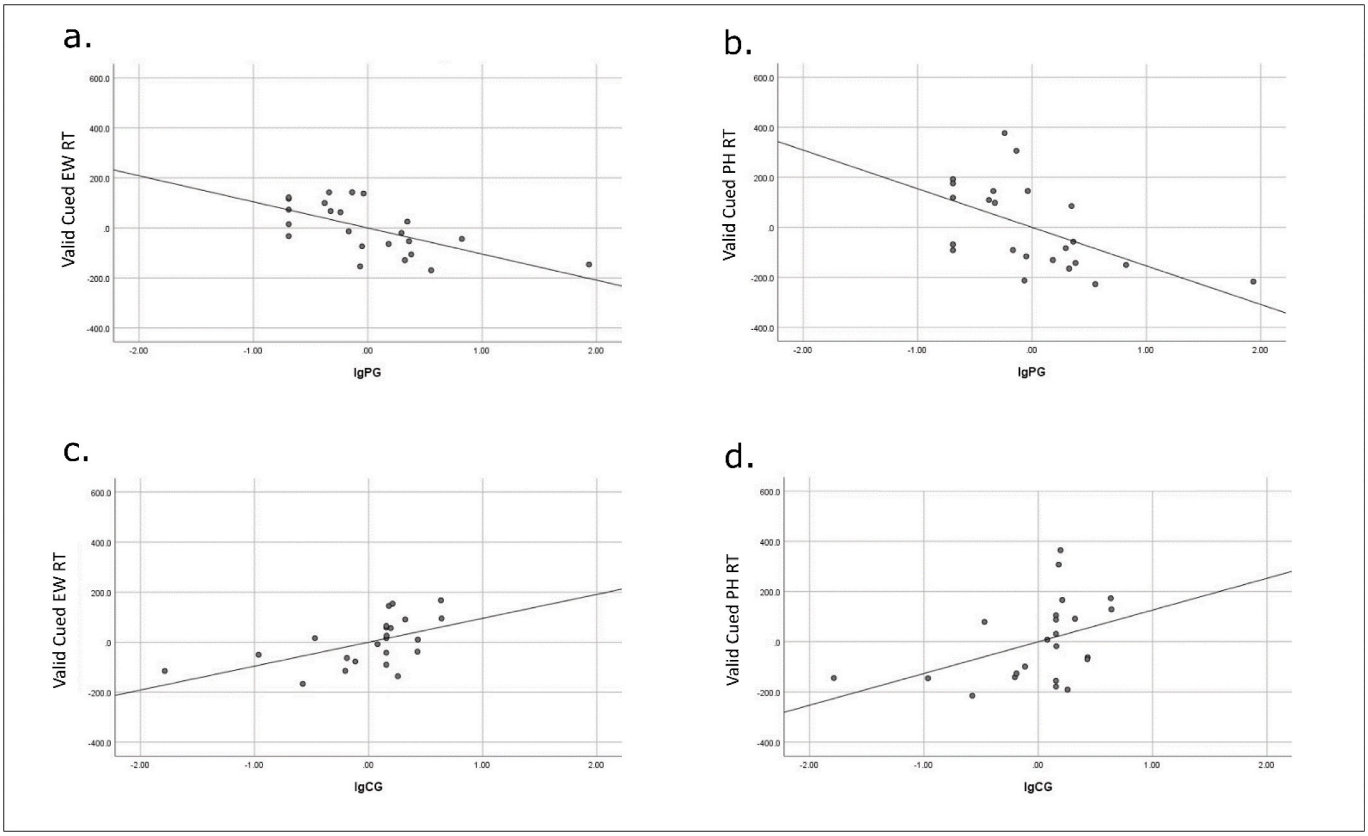

Fig. 6. Partial regression plots of reaction time for validly cued trials as a function of $\log_{10}$-transformed weighted demand scores
Note. X-axes represent $\log_{10}$-transformed weighted visual demand scores (indicated by the 'lg' abbreviation). PG corresponds to the peripheral graphic weighted visual demand score, while CG corresponds to the central graphic weighted visual demand score. This figure illustrates the double-dissociation between peripheral (negative) and central (positive) graphic demands on reading RTs.

diagnostics and treatment. Both lexical and sublexical reading were associated with peripheral graphic demands in our hybrid attentional reading task, which suggests videogame-style treatments that exercise mostly peripheral graphic demands could broadly benefit individuals with multiple forms of reading deficits.

3.1. *Future directions*

With the visual-demand measures introduced in this study, 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 this study are included in Appendix C, 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.

Future behavioural studies could also expand the field further by including different visual language processing tasks, for example lexical decision tasks, to help determine which aspects of language processing are improved by video games (e.g., lexical decision tasks can be more focused on lexical and semantic processing than naming tasks, Borowsky & Masson, 1996). Additionally, the double dissociation between peripheral and central demands should be investigated further, such as by experimentally manipulating exposure to peripheral and central stimuli in cueing tasks with high validity (similar to the high cue validity present in video games). We are currently developing such a paradigm to further investigate the extent of these effects during short term exposure.

Future research could investigate the potential for educational video games to be developed to help children practice their reading skills. Franceschini et al. (2017) have shown training with commercial video games improves reading ability in children with dyslexia and Pasqualotto et al. (2022) demonstrated the use of the cognitive video game "*Skies of Manawak*" as a tool to improve reading skills in school-aged children with normal reading ability. 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. As mentioned earlier, such a video game may want to emphasize peripheral graphic 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.

3.2. Conclusion

These studies demonstrate support for the relationships between video games, reading, and attentional processes. Our visual-demand analysis provides an individually-relevant measure with which future studies can assess visual demands in video games of interest, and suggests that there are benefits to both lexical and sublexical reading performance with increases in video game peripheral graphic demands, and detriments to lexical and sublexical reading performance with increases in central graphic demands. With the novel techniques and results presented here, this research will help inform models of reading and attention, as well as game developers in their game design to create games or game mechanics that promote reading ability, which would provide immense benefits to individuals with reading deficits such as surface or phonological dyslexia.

Declaration of competing interest

The authors have no competing interests to declare.

Data availability

The datasets for this study are openly available at https://doi.org/10.5281/zenodo.6366587.

Appendix A

Exception word	Pseudohomophone
Bear	bair
Blood	bludd
Break	braik
Broad	brawd
Comb	coam
Foot	fuht
Front	frunt
Gauge	gaige
Glove	gluv
Great	grait
Heart	hawrt
Monk	munk
Month	munth
Mould	mohld
Mourn	mohrn
Ninth	nynth
Pear	payr
Pint	pynt
Pour	pohr
Roll	rohl
Seize	seeze
Shoe	shue
Soot	suht
Soul	soal
Soup	soop
Sponge	spunge
Steak	staik
Ton	tun
Tour	toor
Wear	wair
Wood	wuhd
World	werld

Appendix B

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).

Appendix C

		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

(*continued on next page*)

(*continued*)

		Demands/Minute			
		Peripheral		Central	
Game	Platform	Text	Graphic	Text	Graphic
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

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