

“Shall We Play a Game?”: Improving Reading Through Action Video Games in Developmental Dyslexia

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Abstract Impaired linguistic-phonological processing is the most accepted explanation of developmental dyslexia (DD). However, growing literature shows that DD is the result of the combination of several neurocognitive causes. Visual attention and magnocellular-dorsal (MD) pathway deficits are now considered causes of DD. Interestingly, a large portion of literature showed that action video games (AVG) are able to improve attentional and perceptual skills in typical readers. Consequently, employing AVG trainings in individuals with DD could improve attention and perception, resulting in better reading skills. The aim of our review is to show the benefits of the AVG training on DD through the changes in the neurocognitive functions at the basis of learning to read. Since visual attentional and MD dysfunctions can be diagnosed in infancy, our review paves the way for possible early prevention programs that could use AVG training.

Keywords Selective attention · Attentional rehabilitation · Reading disability · Dyslexia remediation · Video games training · Perceptual learning · Developmental disorders · Developmental dyslexia · Linguistic-phonological processing · Action video games · Magnocellular-dorsal pathway deficits

Introduction

Difficulties in reading acquisition are the most common neurodevelopmental disorder across cultures (about 10 % of children) and are present in both alphabetic and logographic languages. This disorder is called developmental dyslexia [1].

The etiology of developmental dyslexia (DD) is complex and hotly debated, and the main causes are attributed to auditory-phonological, visuo-attentional and procedural learning deficits [2, 3, 4, 5, 6]. Often, DD presents important comorbidity with other disorders such as, for example, developmental dyscalculia, dysgraphia, attention deficit hyperactivity disorder (ADHD), specific language impairment (SLI) and speech-sound disorder [7].

The abilities to extract visual information and combine that with auditory information are considered at the basis of reading acquisition [8]. The act of reading must be sufficiently fast to operate within the constraints of limited capacity and rapid decay of the information processing [9].

The lack of synchronization among auditory and visual processes could lead to weak consolidation of letter-to-speech sound integration [10, 11, 12].

A mild impairment in the magnocellular-dorsal (MD) visual pathway, with or without a corresponding deficit in the auditory system, has been hypothesized as possible core deficit in DD [4, 5, 6, 13–17].

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The parieto-frontal attentional network is included in the MD pathway [18, 19]. Several studies showed perceptual and attentional deficit in DD (e.g. [2, 20–34, 35•, 36–42, 43•, 44–51, 52•, 53•, 54, 55•, 56•, 57•]). Efficient abilities in extraction and selection of the visual information allow to create stronger visual object representations [8, 58–62].

This short overview showed that neurocognitive developmental dysfunctions in DD may not be limited to the linguistic brain areas, and that several neurocognitive functions are related to DD [50].

Nevertheless, currently, the most common approach to DD remediation is the direct intervention with explicit, systematic instruction on letter-to-speech sound integration [63]. These treatments are highly demanding, and the cognitive processes underlying the reading improvements remain unclear [1, 64]. Moreover, a relevant problem is the dropout during the training [1]. Unfortunately, and unsurprisingly, DD is associated with less literacy-related activities, and children with DD probably feel much more pressed in reading and learning compared with typical readers. This could explain a high tendency in individuals with DD to spend time at computer and watching TV [65]. These behaviours aggravate their reading problems, leading to a vicious circle [65].

Considering that the amount of time spent in playing video games is associated with poorer academic performance [66, 67], we can introduce our idea about the use of action video game (AVG) to improve reading abilities.

In the next sections, we make a connection between two research fields that are apparently far from each other. We review the literature about the perceptual and attentional skills that are usually compromised in people with DD, and the amelioration of the same functions that has been found studying AVG players or the effects of the AVG training.

Action Video Games

Video games present a big variety of platforms and genres, which can produce different effects on information processing (for a review, see [68•]). Little or nothing can be inferred by merely knowing that an individual plays video games [69].

Here, we will analyse mainly the effects of the most studied type of video games, the so-called AVG. This specific kind of games share a set of qualitative features, including extraordinary speed (both in terms of very transient events and in terms of the velocity of moving objects), a high degree of perceptual, cognitive, and motor load in the service of an accurate motor plan (multiple items that need to be tracked and/or kept in memory, multiple action plans that need to be considered and quickly executed typically through precise and timely aiming at a target), unpredictability (both temporal and spatial) and an emphasis on peripheral processing [70]. As for sport or music, an AVG player is a person that had played at least

4 days per week for a minimum of 1 h per day for the previous 6 months [71].

To establish the effects of AVG, intervention studies are conducted by training with AVG those individuals who do not play video games. Usually, these trainings have a duration from 10 to 50 h spaced over the course of weeks or months [69].

Perceptual and attentional abilities have been extensively studied in AVG players, and in trained non-video gamers (see [70, 72] for reviews). These findings will be reconsidered in the perspective of AVG as a possible training tool for DD.

Visual Spatial Attention in Dyslexia and Action Video Games

One of the most relevant neurocognitive functions involved in reading is probably what has been termed “spotlight of attention” [73]. Attention orienting is often compared with a “spotlight” that moves to a specific region in the visual space, improving information processing in the attended area at the expense of other locations (see [18, 74] for reviews).

In a visual search task (Fig. 1), targets of interest rarely possess unique features that help them to pop out from among distracting elements in a scene.

The attentional spotlight helps to recognize one item at the time and to “bind” the different attributes of each object such as its form, color, depth, motion and size [17]. In reading, the same mechanisms are used to sweep the spotlight of attention serially over the letters of a word during the periods of fixation. Reading disabled children presents slower search times than typical children when the search involves increasingly larger number of distractors (e.g. [29, 75, 76]). Moreover, serial visual search abilities at kindergarten resulted predictive of future reading skills at first and second grade of primary school [57•, 77, 78•].

In visual search tasks, in the presence of a highly complex scenario (for example, a letter with more than twenty distractors), AVG players had better performance than non-action video games (NAVIG) players [72]. In tasks that do not employ linguistic stimuli, both AVG players and individuals without video games experience but trained with AVG (or driving games) were found to have better skills than control group [79]. Where participants have simply to count the amount of stimuli (dots) on the screen, children with DD resulted mildly impaired, mainly with larger quantities [80, 81]. In these tasks, AVG players are capable of more accurate performance than NAVIG ones [71, 82].

However, the attention spotlight is not only oriented in a specific location, but has also to be varied in its size (e.g. [22, 83–93]). The data regarding the useful field of view (UFOV, Fig. 2) task and the effect of AVG seem crucial in developing future video game training for DD. The UFOV

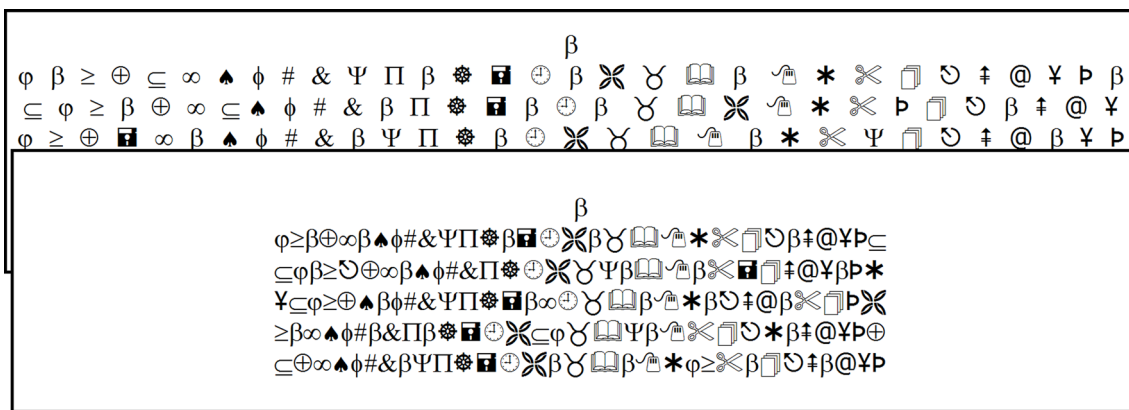


Fig. 1 The two types of serial visual search task (*large and small spacing between symbols*) employed by Franceschini et al. [78]: children have to cancel all the target symbols, proceeding from left to right and line by line

is a task that evaluates the total area of the visual field within which individuals can obtain useful information without moving their head or eyes [94].

Participants had to detect stimuli that appear at different eccentricities from the centre of the screen. Laasonen et al. [95] testing adults with and without DD or ADHD showed that DD group was poorer than controls, and accuracy threshold of the UFOV resulted correlated with reading abilities. In exactly the same task, AVG players demonstrated far superior performance as compared to NAVG players across all eccentricities [71, 82, 96–98]. Not only AVG players, but also naive participants after training with AVG, showed greater detection abilities in the UFOV ([71]; but see [99]).

Franceschini et al. [100•] showed a direct effect of the AVG training on the spotlight of attention in children with DD. An improvement in the distribution and allocation of visuo-spatial attention was obtained in the Visual Attention Span task (e.g. [20, 101–105]), where participants have to discriminate one of

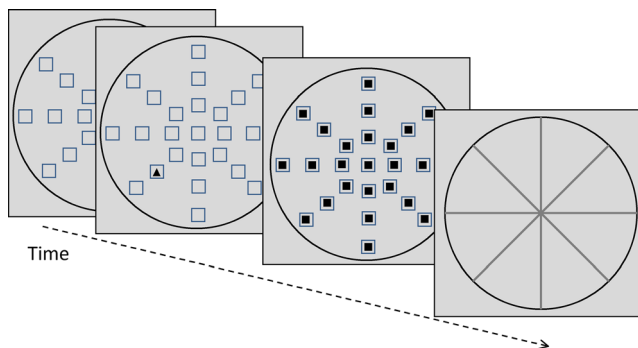


Fig. 2 The useful field of view (UFOV) is a task that evaluates the total area of the visual field within which individuals can obtain useful information without moving their head or eyes [94]. Participants had to detect stimuli that appear at different eccentricities from the centre of the screen (e.g., [71])

six visual stimuli. The training with AVG, compared to a NAVG training, allowed children with DD to improve their abilities in stimulus discrimination both in a condition of distributed and focused attention [100•]. While the focused attention is crucial in shallow languages (e.g. Italian) because the single or the couple of letters are essentially the unit of reading, the distributed attention is necessary to read the trigrams or larger group of letters that are at the basis of reading in opaque languages (e.g. English) [106]. A direct training with AVG appears useful to ameliorate the smaller and weaker attention spotlight [107] of people with DD.

In agreement to the difference found in spatial distribution of attention, word analysis in individuals with DD is slowed because of greater crowding effects ([108, 109•], see [6•] for a recent review), that is, the impaired recognition of a target due to the presence of neighboring objects in the peripheral vision [110]. In the extra-large spacing between letters and words—while reducing crowding—it also improved children (Italian and French) reading accuracy and speed on the fly (without any training) [109•]. Difficulties for both words and symbols indicate that the crowding effect takes place before the process of letter-to-speech-sound mapping [111–113], confirming that this visual deficit is independent from the language transparency.

Across a wide range of eccentricities, AVG players showed significantly reduced crowding as compared to NAVG players. Moreover, people without AVG experience could also reduce their crowding effect with 20 h of AVG training [114]. Consequently, using AVG training could reduce the crowding in DD.

In individuals with DD, evidence of a deficit in automatic orienting of attention (Posner task, [115]) have been largely demonstrated ([5•, 25, 40, 116] see [5•, 6•] for a review) and causally connected to future reading skills [27, 57•, 78•].

The effect of AVG on the exogenous processes of attention is still controversial [71, 72]. AVG players presented no differences in attentional orienting mechanisms, but overall shorter reaction time compared to non-gamers [72, 117].

Chisholm and Kingstone [118, 119] showed a marginal effect in saccade latencies (with AVG players faster than NAVG players) during a cued visual search task (but see [98, 118, 120]). West et al. [98] found greater attentional allocation to the cued target location in AVG players compared to NAVG ones.

Visual Temporal Attention in Dyslexia and Action Video Games

People with DD show also deficit in visual temporal attention [116]. The attentional blink (AB Fig. 3) [121] consists in a two targets among distractors shown in rapid sequence. This task evaluates the time frame necessary for individuals to recognize the first target and also the ability to restart a second attentional analysis in order to discriminate the second one.

Longer recovery times were found in adults and children with DD and with SLI relative to controls in disengaging attention from the first target ([28, 122], see [123] for a review). Individuals with DD and SLI had also poorer performance in recognizing the first stimulus (the target) when a second stimulus (the distractor) appears interrupting the visual processing (i.e. backward masking; [26, 42, 43, 124–126]). This temporal attention deficit was recently demonstrated to be causally linked to DD by using perceptual learning training [57•].

The literature on AVG effects on the AB shows that AVG players have faster recovery time than non-AVG players [71, 97]. A training with AVG can produce significant increases in AB performance compared with those obtainable with a NAVG training ([97, 127], but see [128]).

Li et al. [129] showed differences between AVG player and non-videogamers in the backward masking. These authors showed that AVG training significantly increases these skills in non-video gamers.

Cross-sensory Attention in Dyslexia and Action Video Games

Individuals with DD suffer from a deficit of sequences rapid processing, affecting both uni-sensory and cross-sensory perception [15, 130–132].

Very few works investigated the effects of AVG on cross-sensory processing. Donohue and colleagues [133] found that people with extensive experience playing video games show benefits that impact cross-sensory processing.

Attentional shifting between modalities is impaired in individuals with DD [134•], and Franceschini et al. [100•] demonstrated that only 12 h of playing AVG improved cross-sensory attentional shifting in children with DD.

Auditory Attention in Dyslexia and Action Video Games

Auditory processing deficits are potentially connected to the phonological deficits and possible causes of DD (see [2, 135] for reviews). Children with SLI and DD [136] show difficulties in perceiving speech when it is presented in background noise [51, 137–139]. Atypical auditory processing characterizes children at risk for DD (e.g. [140]). During infancy, future fluent readers were better in speech processing in comparison to those who became non-fluent readers [141, 142]. Poor readers (with or without SLI) show lower signal to noise ratio in perceiving sounds relative to good readers [139, 143–145]. These disorders in perceptual noise exclusion could be caused by an auditory attentional deficit [25, 27, 89, 146]. Rapid auditory processing in infants and toddlers can predict the future language acquisition skills [147]. Computer games were proved to be efficient auditory temporal processing in language-learning impaired children [148].

Few works have investigated the effects of AVG on auditory processing, probably because of the mainly visual nature of the video games. However, Green et al. [70] demonstrated that AVG players showed better discrimination of pure tones embedded in different levels of white noise, suggesting a possible attentional multi-sensory effect of perceptual noise exclusion mechanism. The ability to sample information over time (i.e. processing speed) was significantly greater in AVG players than in NAVG players.

In the same study, two groups of participants without any experience in video games performed 50 h of AVG or NAVG training. Only AVG training improved auditory discrimination showing a causal relationship between the more efficient use of auditory stimuli and the AVG play [70].

These results are relevant for a possible AVG training for auditory-phonological processing deficits in individuals with DD. Gori et al. [57•] comparing AVG and NAVG training in children with DD found that pseudo-word repetition accuracy—involving both efficient auditory processing and phonological short-term memory—increased only after an AVG training.

Action Video Game Training in Dyslexia

Franceschini et al. [100•] demonstrated, for the first time, the positive effects of AVG training on reading abilities in children with DD. These authors measured the phonological

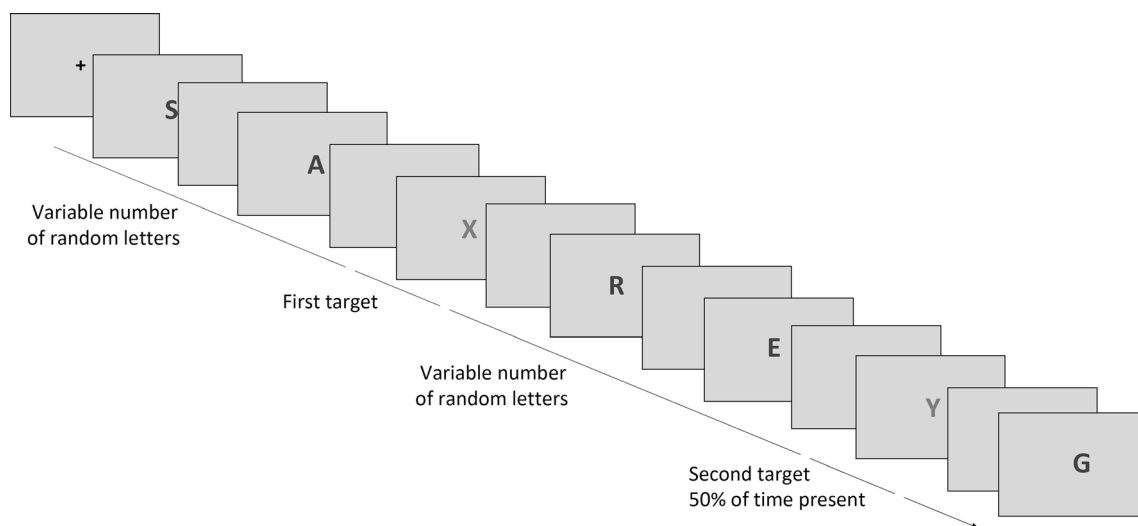


Fig. 3 The attentional blink (AB; Raymond, Shapiro and Amell, [121]) consists in a two targets (letters in light grey in the example above) among distractors shown in rapid sequence. This task evaluates the time frame

necessary for individuals to recognize the first target and also the ability to restart a second attentional analysis in order to discriminate the second one

decoding of pseudo-words and word text reading skills in children with DD before and after two video game trainings (AVG or NAVG). After 12 h of treatment (spaced over 9 days), the AVG training players improves in basic phonological decoding and in lexical recognition measured by the word text reading. Results measured in syllables per seconds showed that children had an improvement higher than what would be expected in a child with after 1 year of spontaneous reading development and bigger or equal than those obtained by the highly demanding traditional DD training [100•]. Individual analysis showed that 80 % of AVG players improved their reading abilities compared to the NAVG group. These results were confirmed by a second study [57•], where a group of children with DD was trained using NAVG before and AVG after in a within-subject design. Whereas the NAVG training led to non-significant results, training with AVG showed large improvements in words and pseudo-words text reading, confirming the importance of using AVG as a possible training in DD. In both studies no drop out was observed.

Neural Substrates of the Action Video Games Training

Visual system consists of two major pathways: the magnocellular-dorsal (MD) and parvocellular-ventral (PV) streams [149, 150]. The MD pathway presents a high degree of sensitivity to low contrast, low spatial frequency, high temporal frequency and achromatic visual information. The MD pathway consists of large heavily myelinated neurons with fast conduction velocity and responds maximally to rapid temporal changes [151•].

The MD pathway is appointed to the motion perception, both real and illusory [56•, 152–158], and it contains the anatomical neural network responsible for the attention orienting [18, 19]. The MD theory of DD stems from the observation that most reading disabled children are impaired in the specific visual MD pathway (see [5•, 6•, 13, 16, 17, 151•, 159] for reviews). Difficulties in discrimination of global motion (i.e. coherent dot motion, [150]; Fig. 4) or specific spatial frequencies grids perception (i.e. frequency doubling illusion; [160]) have been found in individuals with DD (e.g. [41, 56•, 161]) and in pre-reading children who will later develop reading difficulties ([49, 51, 57•]; but see [162]).

It has been shown that children with DD have a specific deficit in the MD pathway also compared with younger typically developing children, at the same reading level of DD [52•, 53•]. Recently, Gori et al. [53•] identified, for the first

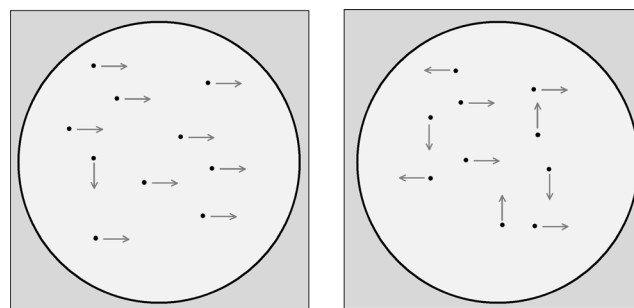


Fig. 4 The coherent dot motion task consists in a circular display where dots are moving. Dots can move coherently with different percentage (in the example above 90 %, left; and 40 % right are depicted). Participants were asked to discriminate the direction of dot moving coherently. This task measures the global motion discrimination, and it is the most accepted proxy to evaluate the magnocellular-dorsal pathway functionality

time, a genetic basis of the MD pathway deficit using two motion illusions (the rotating tilted lines illusion, [154, 163, 164]; and the accordion grating, [165–167]).

In parallel, the performance in the same tasks showed improvements due to the use of AVG (see [168]; but see also [169] for a different result). Crucially, an AVG training has been recently found to improve the ability in real and illusory motion discrimination in children with DD [57•]. AVG players showed better performance in stimulus detection based on spatial frequencies compared to NAVG players [170]. These authors showed that NAVG players improved their stimulus recognition abilities after AVG training.

Alternative explanation of the visual-perceptual difficulties in DD was developed to explain the deficits that children with DD have in detecting gratings when they were embedded in external noise, but not when the same stimuli were presented without noise ([171]; but see [53•]). This alternative hypothesis affirms that DD is associated with deficits in perceptual-noise exclusion, rather than to signal enhancement, supporting the explanation of AVG effects on perception [70]. AVG make individuals more efficient in identifying the signal embedded in noise improving the ability to extract task-relevant statistics from the environment and to develop better templates for the task at hand [172]. In contrast, perceptual learning is very feature specific (e.g. [173–176]). As well as habitual AVG players or individuals trained with AVG, who present fine-tuned perceptual templates, children with DD, after AVG training, could be more efficient in speech-sound and letter-to-speech-sound learning.

Video game experience could be associated with changes in high-order cognitive functions and with improved connectivity between visual and pre-frontal control areas. These changes may be connected to the improved perceptual learning [177•].

These findings, together with the emerging literature about the involvement of basal ganglia in video game performances [178], extend our comprehension about the possible neural substrates of the video games processing. Briefly, basal ganglia are at the basis of the cortico-cortico connections development and are involved in the acquisition of new behavioural and cognitive schemes [179]. Striatum volume and activation resulted related to DD [180] to phonological processing and SLI [181, 182]. Children with DD and SLI could show deficit in procedural learning [183–185] and also in automatize skills (tested by a Pacman video game, see [186]), suggesting possible deficits in both ventral and dorsal striatum. The volume of basal ganglia resulted strictly related to video game habits [178, 187]. The cortico-basal ganglia circuit [188] seems to be a good candidate for a neural substrate for both, the changes observed after AVG playing and the documented visual-attention deficit showed in DD.

Conclusions

People with DD show difficulties in several perceptual modalities [50]. These difficulties are connected to the information extraction due to a basic perceptual and/or attentional deficit in the fast information segregation and selection.

In this review, we show that the perceptual and attentional deficits at the basis of DD are influenced by the use of AVG. The findings by Franceschini et al. [100•] and Gori et al. [57•] showed that AVG dramatically improved reading.

The cognitive mechanisms that are specifically trained by the AVG precede the orthographic-to-phonological mapping [31, 61, 109•]. In particular, the engagement and disengagement mechanisms of visuo-attentional orienting act before the linguistic sub-lexical and lexical conversion routes, making the efficient training of these mechanisms crucial for reading remediation independently from writing systems with varying degrees of consistency in letter-to-speech sound relationships. Thus, an AVG training should be beneficial to individuals with DD regardless the DD subtypes and the deepness of the language.

A recent meta-analysis [68•] shows that although we must be very cautious about the influence of various types of video game on the different cognitive functions, video games led to improved information processing in both quasi-experimental and true experiment studies. Boot et al. [189] also warned about possible placebo effects related to the AVG trainings. However, in both Franceschini et al. [100•] and Gori et al. [57•], the experimental and control groups were equally likely to expect improvements (i.e. children were not aware whether AVG or NAVG had positive effects on reading abilities), and evaluators were blind, making these results not at risk for placebo effects.

As for sport, music, television and video games, playing quantity and quality could make the difference. In the introduction of this review, we reported that the amount of time spent playing video games resulted associated with poorer academic performance [66, 67]. Moreover, He et al. [65] showed that children with DD spend more time than typical readers on computers, instead of studying. Those results could be considered in contradiction with the reading improvement found in children with DD after playing AVG [57•, 100•]. Exactly like knowing that not all the sports are equal in stressing specific abilities, and not all kinds of musical instruments leverage the same mechanisms, only specific video games are useful in increasing reading abilities.

In sum, AVG training is a perfect candidate to be associated to typical trainings (which, however, need to be scientific validated too) in order to reduce DD bad outcomes.

Similar intervention in conjunction was suggested for musical training aiming to improve reading abilities [190–192].

AVG, or video game in general, are one of the most active, absorbing experience from which children can develop visual

(and probably auditory as well as cross-sensory) perceptual and attentional abilities. The reviewed results show that even few hours of AVG can have profound effects on perceptual and visuo-attentional mechanism directly translating in better reading abilities. Although the results in the literature demonstrated that also at individual level the vast majority of the children showed significant reading improvements, in the worst case scenario, where a given child receives no video game benefit, no negative effects were reported and she/he will have fun.

Finally, since visual attentional and MD dysfunctions can be identified in infancy, our review paves the way for possible early prevention programs that could use AVG training to battle DD even before the diagnosis.

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Compliance with Ethics Guideline

Conflict of Interest Sandro Franceschini, Sara Bertoni, Luca Ronconi, Massimo Molteni, Simone Gori, and Andrea Facoetti declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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