Digital technologies and learning: from medical science to Action Video Games for enhancing attention and reading in Dyslexia

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Abstract

This paper traces the history of technological applications to disability, from the early days until today, highlighting how science and technology, although different entities, are closely complementary and functional in promoting a significant improvement in the quality of life of people with disabilities or learning disorders. Specifically, the focus will be on dyslexia, resulting from the combination of impairments in phonological processing and visual-attentional mechanisms. Much of the literature has shown that action video games (AVG) are able to improve perceptual, attentional and academic skills of subjects with reading deficits. The purpose of this contribution is, therefore, to show the benefits of AVG training on Dyslexia through changes in neurocognitive functions underlying the learning of reading.

Keywords

Medical science, Action Video Games, Dyslexia, Learning Disorder, Digital technologies

[1] Although it is the result of a joint work of the two authors, paragraphs 1, 2, 3 e 4 are to be attributed to Luigi Traetta,while paragraphs 5, 6 and 7 are to be attributed to Giuliana Nardacchione.

1. Introduction

The history of medicine and the history of disability, always develop under different epistemological assumptions: one will more likely use medical models of disability while the other will challenge them [1]. This reflection, however, the author continues, should not lead to reconstructing the history of disability by adopting an opposite point of view than the history of medicine. A similar discourse may apply with regard to the complex relationship between disability and another history closely related to it, namely the evolution of technology. If “the idea (or the desire) to build automaticmachines appeared in the human mind much earlier than is commonly believed” [2] the idea of applying technology to disability with the aim of creating automatic machines capable of offering solutions to overcome the functional limitations, whether physical or mental, induced by the main types of disability is much more recent.

It is significant, in this regard, that in 1989, the statement in the *Encyclopedia of architecture* appeared tobe revolutionary, according to which, instead of responding only to the minimum level (which requires some special characteristics for disabled people), it is possible to design building elements in such a way as to make them usable by a wider range of human beings, including elderly people, children, people with disabilities and people of different sizes [3].

The objective of this essay is, on the one hand, the reconstruction of the history of technical applications to disability, the history that preceded (allowing the official birth) the development of assistive technologies and design for all (but that appears, today, still too neglected) and, on the other hand, through one of the many possible examples, that of dyslexia, highlight the current outcomes of this history.

2. The beginnings

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The union between science and technology realized during the Renaissance and the consequent revaluation of the technique itself, which gradually begins to take on the value of "knowledge", means that the collaboration between the scientist and the mechanic becomes a reality so consolidated, that even surgeons, notes Rossi, "came into increasingly close contact with artists, doctors and anatomists" [4]. If, on the other hand, in the work of Leonardo we encounter the first attempts to make androids – among whose noteworthy aspects should be mentioned, in this context, the projects of joints with automatic movements –, it was a surgeon, the French Ambroise Paré, who developed the first examples of mechanical prostheses.

In his treatise *Dix livres de la chirurgie*, after pointing out how inhumane the practice of amputating a limb was, on the one hand, and, on the other, how necessary this practice was, at times, for the patient's survival, Paré proclaimed his immense faith in surgical practice, which was now able to "provide the means to imitate nature and make up for the lack of a lost limb" [5]. The three models of prostheses developed by Paré – a leg, a hand and an arm – responded, however, to the need to promote the recovery of voluntary movements in the patient.

Great attention was also paid to the operational aspects of amputation surgery and the subsequent positioning of the prosthesis. Even though Paré's pages on artificial limbs are substantially dedicated to soldiers wounded during battles, they appear to be extremely topical, also from a technical point of view, because one of the first attempts to reproduce even the joints of the fingers through an actuator mechanism can be glimpsed.

The epistemological separation between the figure of the physician and that of the surgeon, a separation that would survive in part even in the late sixteenth century and that would continue to sanction, in fact, the superiority of theoretical medical knowledge over the surgical one, ended up obscuring Paré's study on prostheses to the advantage of his discoveries – which were directly related to the realization of artificial limbs – on the lacing of blood vessels instead of the ancient practice of cauterization.

In the eighteenth century, then, when confidence in technology came to exceed that in man [6], the interest in technological applications to disability, returned to grow, as evidenced by the attention of mechanics to the sick, in the wake of that enthusiasm caused by the "popular health education" [7] inaugurated in 1761 by the Swiss physician Samuel A. Tissot.

It is not surprising, therefore, to discover in the seven volumes, published since 1735 and dedicated to the machines approved by the Parisian Academy of Sciences, some mechanical instruments designed for the disabled.

Among these, it is worth mentioning, first of all, the bed for the sick with a structure of four columns on which it could rotate, by means of a system of cranks, the support surface: this, by lowering and raising, facilitated the descent and ascent of the patient in bed [8]. To remember, too, a particular bandage, consisting of a plate with straps, for the containment of hernias a military bed, elaboration of a traditional hammock, with the addition, however, of supports (so as to make unnecessary the use of trees) and a tent, able to protect from insects and, finally, the fan to renew the air in the rooms of the sick.

Also worthy of note was the artificial arm presented in 1732 by Mathieu Kriegseissen, an expert in the construction of precision instruments [9]. Composed of four copper elements and three articulated joints to allow the movement of fingers, wrist and forearm, this prosthesis was valuable in cases of amputation of the arm that had not exceeded, however, the elbow, since this was essential to allow the movement through a system of ropes.

In a period in which science and technology were becoming part of the collective imagination also through the flights of hot air balloons, the Bottles of Leiden or mesmeric fluids, the attempt to imitate the phenomena of the living in an artificial limb became a paradigmatic example of eighteenth-century trends that would lead to the birth of androids. Yet the android, intended as a representation of the human body and as an attempt to imitate not only its forms but also some of its movements or even some vital functions, ended up by "showing" mechanics, engineers and scientists the main way to extend to the nascent human physiology those principles, now mature, which had allowed the application of mathematical analysis to Newtonian physics. These were the works that had given life to rational mechanics and that were immediately confronted with the characteristic element of the late eighteenth century, the growing "scientificisation" of technology caused by the massive diffusion of machines.

3. The Anatomical Artificial

The affirmation, in the nineteenth century, of experimental physiology provided new lifeblood to the union between medicine and technology, especially in the field of surgical instrumentation where, moreover, the rapid progress of vivisectionist methodologies, although contested, required increasingly precise and appropriate tools. The American War of Secession, moreover, produced in the second half of the nineteenth century a new emergency in the field of prostheses because of the high number of combatants who were mutilated: this is witnessed by the considerable number of patents that, since 1862 and in a few years, brought a series of innovations in the construction of prostheses.

Among the patents, we should certainly mention the "anatomical leg" developed by the doctor and surgeon Douglas Bly (1870), on the path indicated by his compatriot Benjamin Palmer in 1846 [10]. The need to use expensive materials such as ivory in the construction of the prosthesis, while allowing a significant increase in mobility compared to previous models, did not guarantee Bly an immediate success in terms of government funding.

The qualitative leap in the design of prostheses occurred shortly thereafter, with the affirmation of the principle that not only amputees could be the object of attention by medical technology, but also – as we read in the presentation edited by the *Chicago Orthopedic Institute for the surgical and mechanical treatment of the deformities and deficiencies of the human body* – children and young people suffering from "incipient or established deformities in various parts of the body" [11]. Problems of the spine, ligaments and bone malformations finally found a definitive solution thanks to the refinement of increasingly specific and "custom-made" prostheses.

In the second half of the nineteenth century, on the other hand, the basic principles of postural re-education of the individual were affirmed, starting with the pioneering research of the physiologist and medical physics expert Adolf Eugen Fick, who inaugurated the modern interpretation, in kinesiological and energetic terms, of muscular movements.

On the way to the design of the twentieth century artificial limbs, is also placed the surgeon Friedrich Trendelenburg who in 1895 described the shortening of the leg following a fracture of the femur or a dislocation of the hip. In case of congenital dislocation of the hip, Trendelenburg observed, the patient tended to tilt the shoulders on the dislocated side during walking, while in the standing position on the dislocated side (and, therefore, with the healthy limb raised), a lowering of the pelvis was observed on the healthy side, while the trunk remained vertical and the line of the shoulders horizontal [12]. The search for the so-called "Trendelenburg sign" will become a constant in examinations of mobility and motility in contemporary orthopedic clinics.

4. The 20th century: residual capacity

In the first twenty years of the twentieth century, the A.A. Marks Society of New York published several editions of the *Manual of Artificial Limbs*, in which, in addition to a series of typically medical and mechanical innovations in the design and manufacture of artificial limbs, there is a real publicity campaign aimed at disabled individuals – often career men or women particularly attentive to elegance – to show them the versatility of prostheses, now no longer the exclusive prerogative of severe disabilities, but essential in the most common gestures of everyday life.

Thanks to these prostheses, the American Society promised men and women that they would be able to return to a wide variety of jobs, play their favorite sport or attend gala evenings again without any difficulty.

The manual, the various editions of which did not present major innovations, except for updates due to the needs of veterans of the First World War, is particularly significant because it testifies both to the tendency to consider the concept of disability in a social key, leading it to a more widespread need for well-being and quality of life, and to the turning point, which took place in the medical field, regarding the consideration of impairment in terms of residual physiological capacity.

It was the French physiologist Jules Amar who was the spokesman of the new trend: within a vast program of professional re-education of individuals disabled by the war, Amar developed in 1915 the *arthrodynamomètre*, an instrument designed to "measure the values of angular displacements of the limbs and the absolute efforts of a given muscle group for all possible levels of flexion" [13]. This was a fundamental object for Amar's research, which was increasingly aimed at analyzing both the energy expenditure during work and the annexed reparative action of the organism, since – as he thought – the mission of the physiologist concerned the knowledge of the residual capacities of war invalids and the subsequent drafting of a rehabilitation program starting from these residual capacities.

Amar, moreover, was also involved in the realization of prostheses, supports and orthopedic crutches: the prosthesis became both a pretext to study in depth the problem of residual strength to be maximized, and a tool to give back to the invalid a driving force not affected by the energy expenditure related to the prosthesis itself [14] [15].

But Amar's physiological investigation of amputees went beyond simple measurements of the residual strength of amputated limbs. Neither the anatomical data related to the reduction in volume and length of a given muscle, nor the consequent decrease in mechanical power due to the amputation of a part of a limb could, according to him, account for the complex synergies that the human motor put in place to restore a functioning as natural as possible.

Opposing, therefore, the surgical techniques of the time, based on the principle of preserving as much as possible the damaged muscle fibers in order to save their length and, therefore, their power, Amar affirmed the need to consider from a different point of view the proportion between the residual length and power of the amputated limb [16]. Amputating a segment slightly more than strictly necessary, in addition to preventing degenerative processes caused by infected portions of muscle left *in loco*, could ensure the implantation of prostheses lighter and stronger than the amputated limb. Surgery, in these cases, would have had to submit itself to the needs of the professional re-education of war invalids. In order to accurately assess the muscular activity of amputated limbs, Amar made use not only of the *arthrodynamomètre* and the *cycle ergométrique*, but above all, with regard to the walking of patients with artificial legs, of the *Trottoir dynamographique* which he developed in the first decade of the twentieth century.

5. Dyslexia: general diagnostic criteria

Developmental Dyslexia is framed by some international diagnostic manuals such as the DSM, now in its fifth edition [17], and the WHO document, in its tenth revision [18]. According to the DSM-5, reading and writing acquisition disorders belong, together with calculus disorder, to a single diagnostic category called "specific learning disorder" (code 315) and are enrolled in the section of "neurodevelopmental disorders". On the other hand, the ICD-10 indicates the DSA with the wording "specific developmental disorders of scholastic skills" (F81) highlighting as the main feature of the Specific Reading Disorder (F81.0) a significant impairment in the development of reading ability, which is not entirely explained by mental age, problems of visual acuity or inadequate schooling.

In the Italian reality it is essential to consider the document issued by the Consensus conference (CC) of 2010 on DSA [19] and the clarifications contained in the document entitled Clinical recommendations on DSA [20]. Both documents aim to improve health care and produce evidence-based recommendations for clinical practice. The latter define ASDs as disorders that, while leaving general intellectual functioning intact, affect a specific domain of abilities. In the specific case of Dyslexia, it is defined as a reading disorder, understood as the ability to decode text.

The school repercussions are regulated by Law 8 October 2010, n.170 (New rules on specific learning disorders in schools) [21], created to protect students who receive a diagnosis of DSA, which defines Dyslexia as a specific disorder that manifests itself in a difficulty in learning to read, especially in the deciphering of linguistic signs, or in the correctness and speed of reading.

As for the diagnosis of dyslexia, it can only be made from the end of the second class of elementary school, given the wide physiological variability in the time of acquisition of the ability to read deciphering, in order to avoid an excessive number of false positives. Standardized tests that analyze deciphering reading skills separately evaluate the accuracy parameter, expressed as the number of errors, and the speed parameter, expressed as the average number of syllables read per second [22].

Reading in Dyslexia is characterized by the presence of errors of substitution, omission, addition or transposition of one or more letters and/or exchange between visually visible words (e.g., "castello" instead of "hat") and, therefore, errors in word recognition, and by frequent hesitation, slowness, poor turnout and failure to respect prosody. Sometimes the subject misses the mark and commits skips or rereads [23].

The clinical manifestations of dyslexia tend to change depending on the specific evolutive stage. In the initial intermediate stages of literacy, i.e., up to the third/fourth primary grade, the decipherment of many written words remains sub-lexical, i.e., based on the sequential recognition of syllables, or of single letters in the most severe cases, resulting very slow and stunted, often starred with numerous errors. When the deciphering is very fragmented and laborious, the phonemic/syllabic assemblage may be difficult and the lexical recognition may not take place. Later (usually from the end of elementary school), some subjects speed up reading significantly, trying to recognize in a “direct” way most of the written words, at the price, however, of committing numerous errors in their recognition. In many other cases, reading reaches a fair degree of accuracy, but remains slow and stunted, proceeding in a “sub-lexical” way for many words [24].

6. Dyslexia and Action Video Games

While historically video games were developed for purely entertainment purposes, today research suggests that they have the ability to powerfully alter the brain and behavior, leading researchers to probe whether they can be developed or used for educational and/or therapeutic purposes. Below, we examine the impact in the real world (specifically, in the educational system) of a specific genre of video games, action video games (AVG). These are action-packed video games and, as such, require players to actively move through the game environment, effectively monitor their surroundings, and provide frequent, rapid, and accurate motor responses to new and different stimuli, functional, first, to induce learning and neuroplasticity and, second, to improve attentional control and cognitive flexibility by providing a motivating and enjoyable experience via the dopaminergic reward system [25] [26].

Video games could, therefore, be efficient learning tools, as the fun they provide fuels intrinsic motivation to train more of one's skills, including attentional control and cognitive flexibility. Increased attentional control, i.e., the ability to focus for a period of time while ignoring sources of disruption or distraction, is potentially very beneficial for classroom learning [27] [28]. For this reason, action video games could be leveraged to support positive changes in learning academic skills in individuals with reading deficits [29].

Extensive research has shown that deficits in reading are associated with both phonological processing [30] [31] and visual-attentional mechanisms [32] [33].

With respect to the latter, attention dysfunction is a major deficit in dyslexic individuals. Thus, although the main theoretical account of the cognitive causes underlying Dyslexia coinvolves a phonological deficit, a subsample of dyslexic children appears to be affected by attention deficit [34].

Franceschini and colleagues (2013) evaluated the ability of action video games to improve attention and reading skills in an Italian dyslexic population. The authors used a child-friendly video game (Rayman Raving Rabbids) containing both action mini-games (AVG) and non-action mini-games (NAVG). They recruited children diagnosed with dyslexia and pretested them on attentional skills and reading skills. Half of the children were then addestratified on the action mini-games and the other half of the children played the non-action mini-games, for a total training time for both groups of 12 hours, spread over several weeks. At the end of training, all children were post-tested using the same measures of attention and reading. Results showed a greater improvement in attention for the dyslexic group trained with the action mini-games (AVG) [35].

Regarding attention, these results are in agreement with several studies illustrating the beneficial effects of video games for attention development [36], which studies showed that AVG-controlled training was related to improvements in visual spatial (e.g., a spatial visual search task) and temporal (e.g., an "Attentional Blink" – AB task) attention [37].

In a serial visual search task (Figure 1), it may be difficult to capture targets of interest, as they may not possess those special characteristics that allow them to visually emerge among the various distractors within a scene. In reading, children with Dyslexia experience this same difficulty, showing, consequently, slower search times than neurotypical children [38].

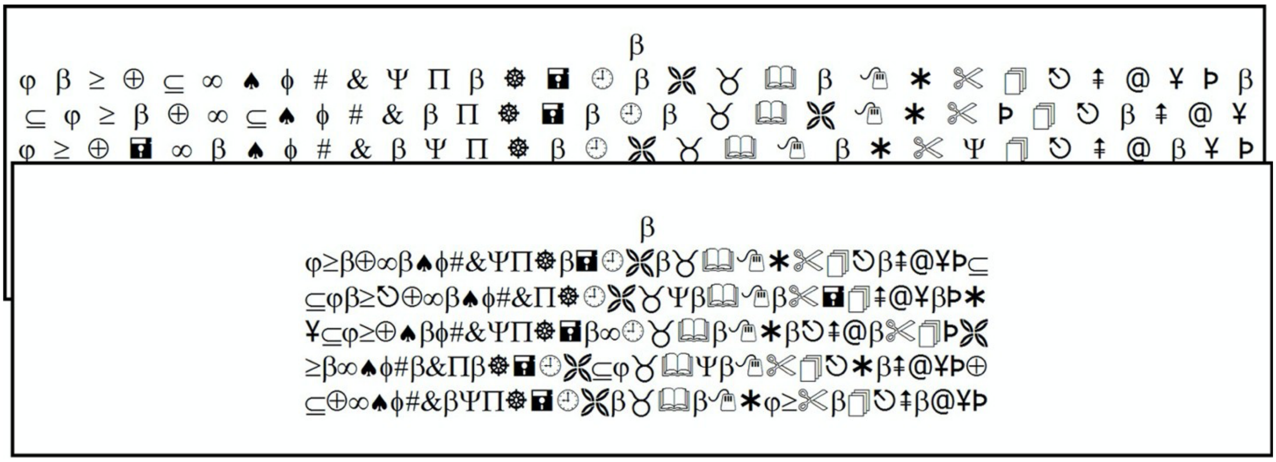


Figure 1: The two types of serial visual search tasks (large and small spacing between symbols) used by Franceschini and collaborators in 2012: children must delete all the target symbols, proceeding from left to right and line by line.

In a recent study [39] showed that in visual search tasks, in the presence of a highly complex scenario (e.g., a letter with more than twenty distractors), action video game players (AVG) performed better than non-action video game players (NAVG).

Moreover, in accordance with the impaired visual spatial attention capacity, it is understandable how word analysis in individuals with Dyslexia is slowed down due to increased crowding effects [40]: the alteration of recognition of a specific stimulus is caused by the presence of nearby objects in peripheral vision. In fact, the extra-large spacing between letters and words, by reducing crowding, makes possible an improvement in the reading accuracy and speed of children with Dyslexia [41]. AVG players showed significantly reduced crowding compared to NAVG players. Therefore, the use of AVG training could reduce crowding in Dyslexia.

People with Dyslexia also show a deficit in visual temporal attention [42]. The "Attentional Blink" task (Figure 2) [43] consists of identifying two targets among several distractors shown in rapid sequence. This task assesses the time interval required for individuals to recognize the first target and also the ability to restart a second attentional analysis in order to discriminate the second one.

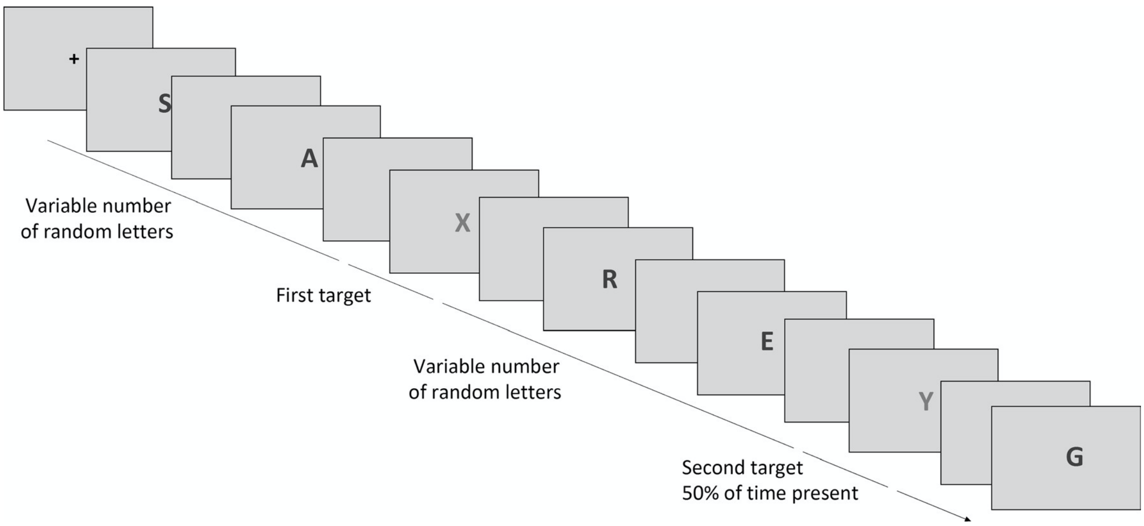


Figure 2: The Attentional Blink (Raymond et al., 1992) consists of two targets (letters in light gray in the example above) between distractors shown in rapid sequence.

Longer recovery times were found in adults and children with Dyslexia compared to controls in disengaging attention from the first target [44]. Individuals with Dyslexia also had poorer performance in

recognizing the first stimulus (the target) when a second stimulus (the distractor) appears interrupting visual processing [45] [46]. This temporal attention deficit has recently been shown to be linked to Dyslexia [47].
Training with AVG can produce significant increases in this performance compared to those achievable with NAVG training [48].

In this regard, Mishra et al. (2011) highlighted that, from a behavioral perspective, AVGPs outperformed NVGPs, as their brain responses revealed that they suppressed irrelevant and distracting information to a greater extent than NVGPs. Importantly, these two outcome measures-behavioral performance and measured neural suppression-were correlated in that the greater the suppression of distracting (i.e., to be ignored) information, the greater the speed of response in goal identification. Thus, the study of brain responses in this attentional task provided evidence for a potential mechanism of attentional enhancement in AVGPs and, thus, more efficient suppression of distracting information [49].

The improvement in attentional capacity translated into an improvement in phonological decoding of pseudowords and, consequently, in the ability to read word texts.

In the study by Franceschini et al. (2013), pseudowords and word text reading skills were measured before (T1) and after (T2) NAVG and AVG treatment in children with dyslexia. Only AVG readers showed significant overall improvements in reading compared to the NAVG group [50].

Thus, AVG training improves not only basic letter-to-voice sound integration, as indexed by increased pseudowords reading efficiency, but also lexical recognition, as measured by reading the word text [51].

It should be noted that these observations were made on Italian children, who learn to read a very transparent orthography (i.e., Italian), in which the association between letters or groups of letters and speech sounds is highly consistent. This is not the case with more opaque spelling systems, such as French or English, where it is necessary to rely on context to decipher and pronounce irregular words. Interestingly, results similar to those described for the Italian sample have been reported on dyslexic children learning to read English with benefits of action mini-game training in terms of reading speed, at no cost to reading accuracy.

In a study by Franceschini et al. (2017), English children were evaluated and it was found that regardless of spelling, AVG training in children with dyslexia would improve visual, auditory, and crossmodal attentional shift, with cascading effects on audiovisual processing and phonological working memory, as well as reading speed. In this study, two groups of English-speaking children with dyslexia were matched and tested their reading skills, phonological working memory, visuospatial, auditory, visual attention, stimulus localization, and crossmodal attentional shift before and after playing action video games (AVG) or non-action video games (NAVG) [52]. Word reading performance was measured before (T1) and after (T2) NAVG and AVG training in English-speaking children with dyslexia. Time to word recognition was significantly reduced only after AVG training (Figure 3).

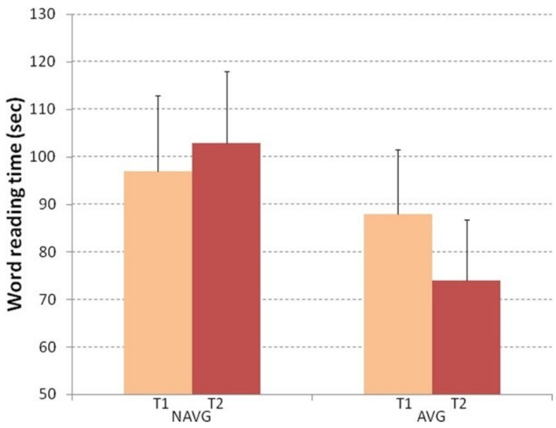


Figure 3

Pseudoword reading performance was also measured before (T1) and after (T2) NAVG and AVG training in English speaking children with dyslexia. Time to phonological decoding was significantly reduced only after AVG training (Figure 4).

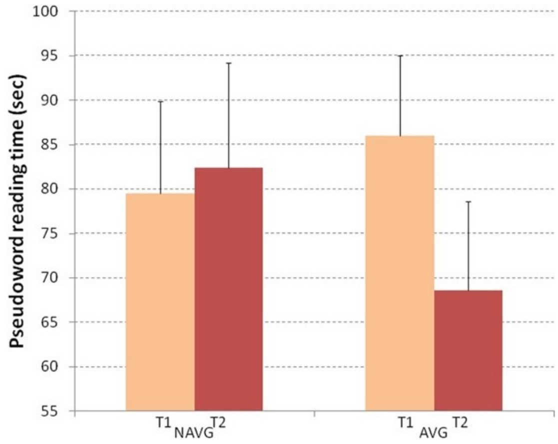


Figure 4

Focused visuo-spatial attention was also measured before (T1) and after (T2) NAVG and AVG training in English-speaking children with dyslexia (Figure 5). Significant improvement in focused visuo-spatial attention was observed only after AVG training.

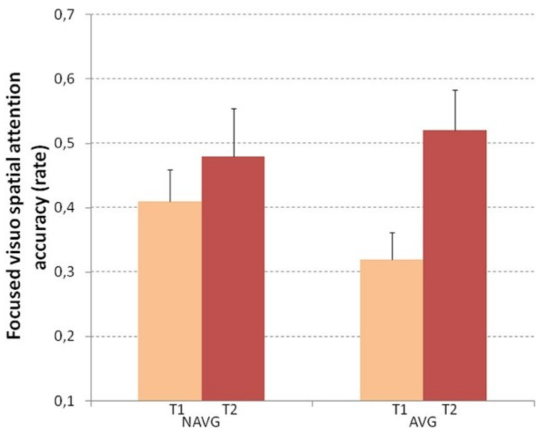


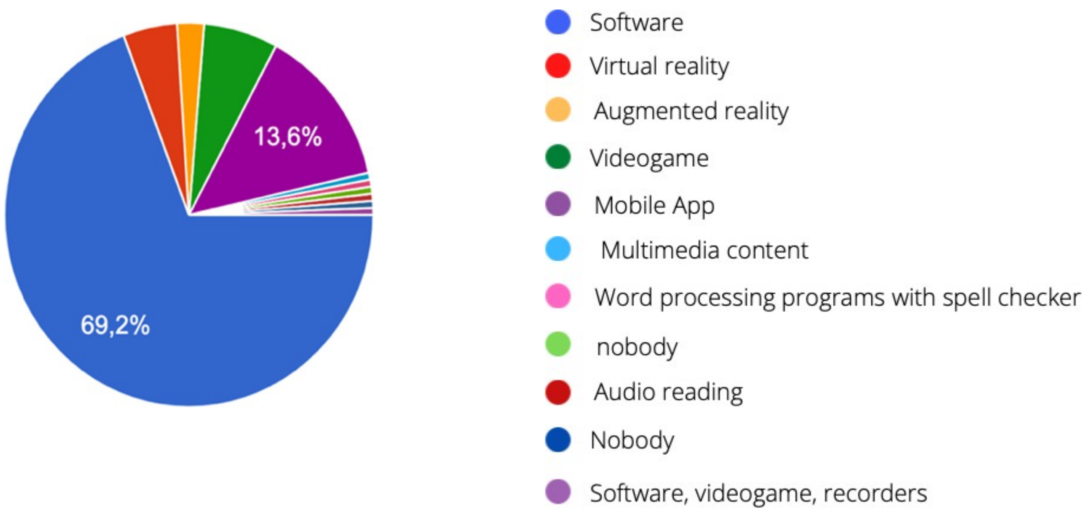
Figure 5

7. Conclusions

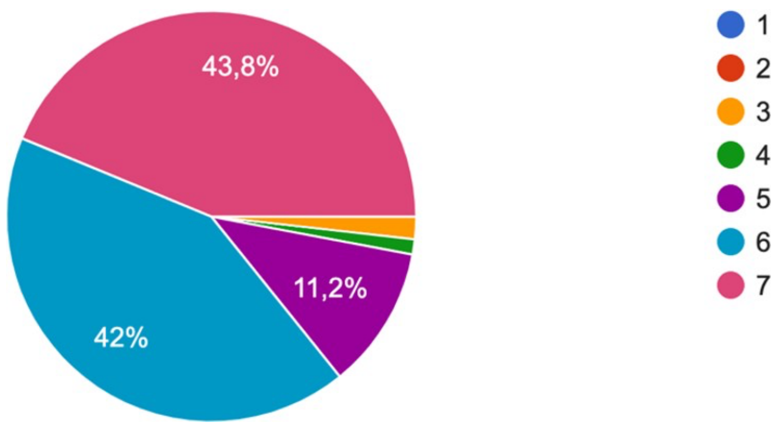
Retrospectively reviewing the history of technological applications to different abilities, we can see how from the beginning until today giant steps have been taken, such as "to outrun a running horse" (Fontana, XV sec., table 18). There is no doubt that in this field the collaborative and interdependent relationship between science and technology has been crucial, a relationship capable of linking scientific intuitions and discoveries to the realization of assistive machines capable of overcoming the functional limitations of the various types of disabilities or learning difficulties, both organic and acquired (as in the case of world conflicts). The researches analyzed highlight precisely this aspect: the potential that digital technologies – and, specifically, action videogames – have, for example, to improve visual-attentional processing and, in turn, on the processes related to reading in cases of subjects with reading deficits. It is evident, therefore, that the use of Information and Communication Technologies (ICT) as well as the learning, application and use of new teaching methodologies are now essential elements to promote adequate teacher training [53]. In this context, it is necessary to reflect on the innovative contribution to learning and teaching processes brought by the resources and potential offered by digital technologies in education [54]. To this end, an exploratory questionnaire was administered to some trainees - mostly already teachers - attending the Specialization Course for Support at the University of Foggia to assess the perception of teachers with respect to the application of digital technologies functional to the learning of subjects with Dyslexia.

Below, we report what emerged from the 169 completed questionnaires:

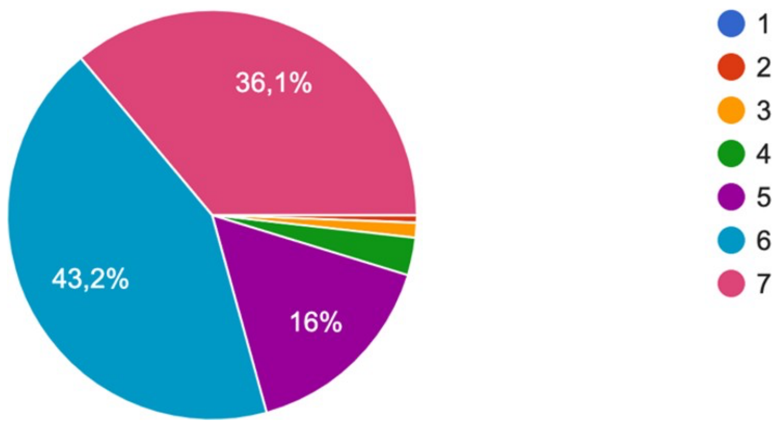
1. In your experience as a teacher and/or TFA trainee, which of the following technology devices do you know are functional in supporting the learning of individuals with Dyslexia?



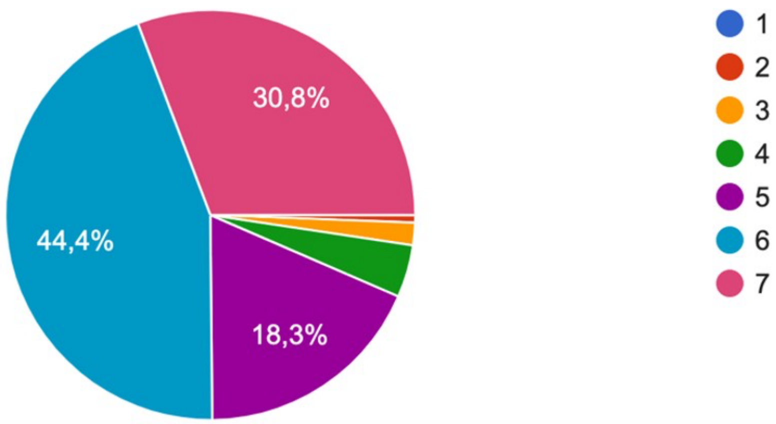
2. Indicate your level of agreement or disagreement with the following statements, using the scale: 1=strongly disagree; 2=disagree; 3=sometimes disagree; 4=undecided; 5=sometimes agree; 6=agree; 7=strongly agree. The use of technology improves the quality of my work.



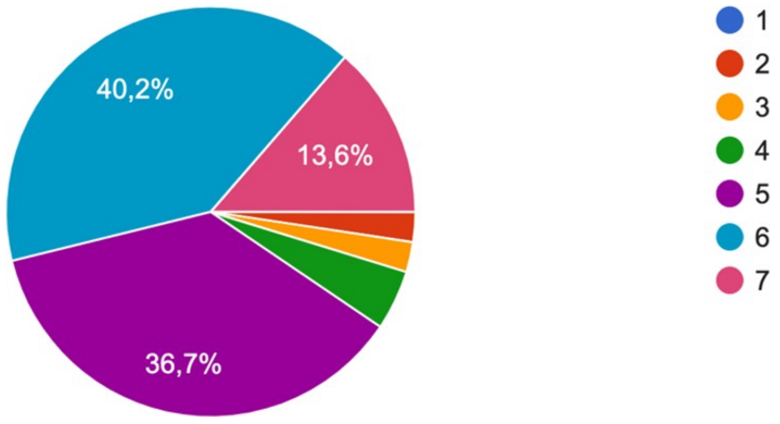
3. Indicate your level of agreement or disagreement with the following statements, using the scale: 1=strongly disagree; 2=disagree; 3=sometimes disagree; 4=undecided; 5=sometimes agree; 6=agree; 7=strongly agree. The use of digital technologies makes my job easier.



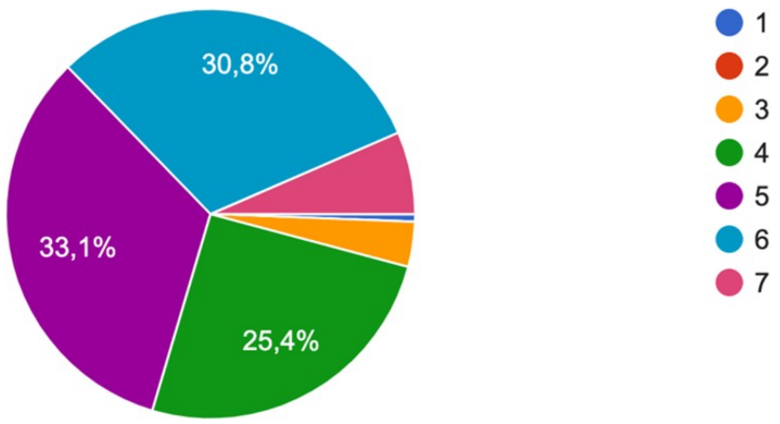
4. Indicate your level of agreement or disagreement with the following statements, using the scale: 1=strongly disagree; 2=disagree; 3=sometimes disagree; 4=undecided; 5=sometimes agree; 6=agree; 7=strongly agree. The use of digital technologies increases my work productivity.



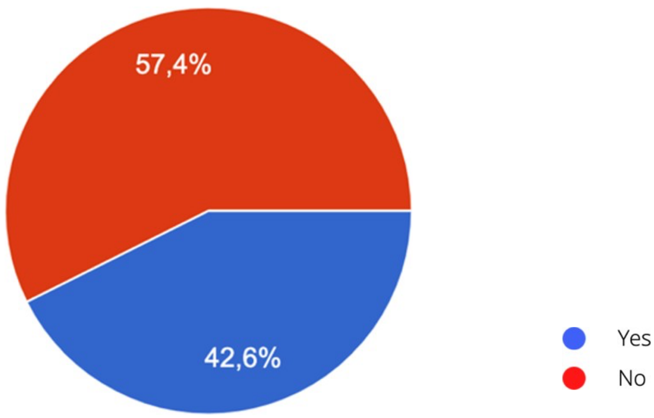
5. Indicate your level of agreement or disagreement with the following statements, using the scale: 1=strongly disagree; 2=disagree; 3=sometimes disagree; 4=undecided; 5=sometimes agree; 6=agree; 7=strongly agree. In general, I feel that the use of technologies are easy to use.



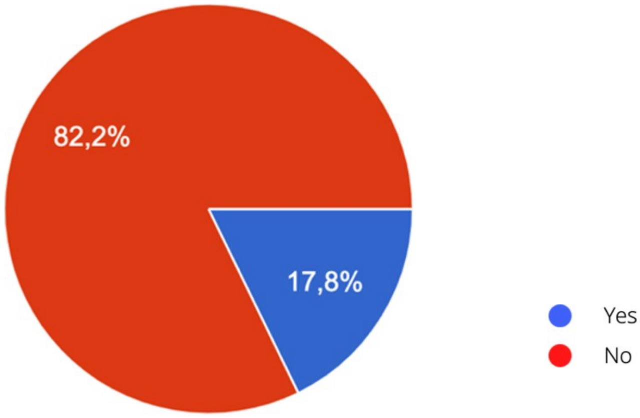
6. Indicate your level of agreement or disagreement with the following statements, using the scale: 1=strongly disagree; 2=disagree; 3=sometimes disagree; 4=undecided; 5=sometimes agree; 6=agree; 7=strongly agree. Learning enhanced by serious games provides real benefits to individuals with Dyslexia in terms of academic and co-occurring improvement.



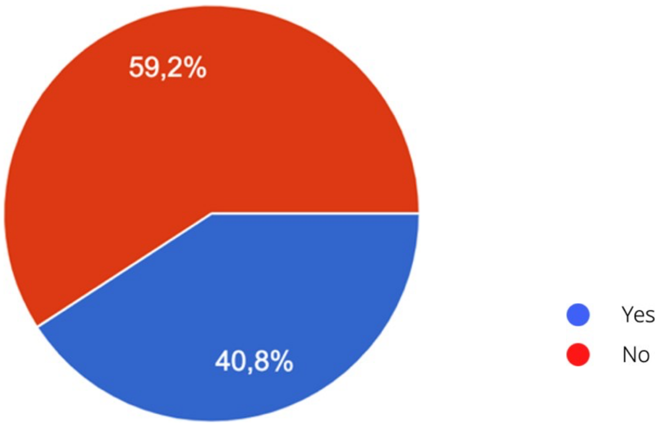
7. Have you ever used software to support and enhance the learning of individuals with Dyslexia?



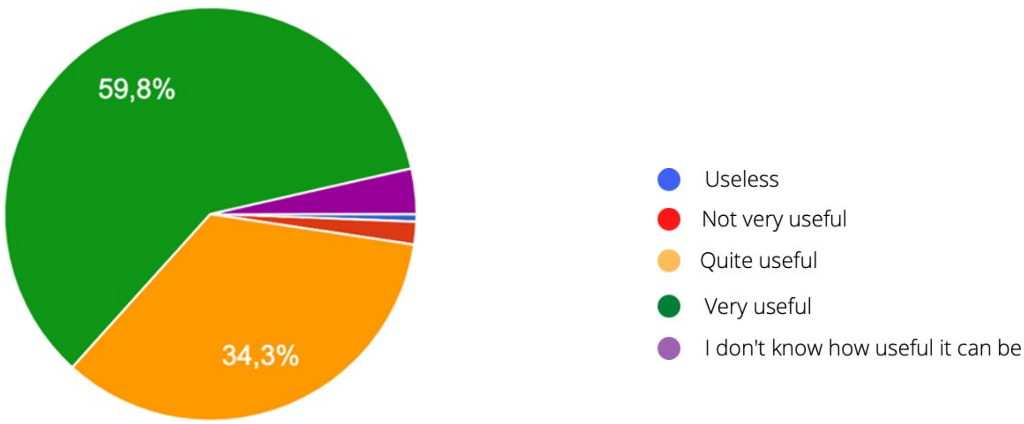
8. Have you ever used video games to support and enhance the learning of individuals with Dyslexia?



9. Have you ever read any texts or articles concerning the use of video games in education?



10. Do you think it would be useful to provide ad hoc training for teachers on the use of serious games in education to support the learning of people with Dyslexia?



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