POLITECNICO
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SCUOLA DI INGEGNERIA INDUSTRIALE
E DELL'INFORMAZIONE

Executive Summary of the Thesis

Serious Games to assess visual-attentional and phonological-decoding skills for reading development

Laurea Magistrale in Biomedical Engineering - Ingegneria Biomedica

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Academic year: 2020-2021

1. Introduction

Dyslexia is a Specific Learning Disorder associated to an impaired reading ability. It affects phonological decoding, visual perception and memorization of written texts [5]. It is the most widespread learning disorder, often with handwriting difficulties comorbidity. The incidence varies by language and spelling [6]: in Italy, pupils with dyslexia represent the 3.2% of the total number of students attending primary and secondary schools. Dyslexia is a life-lasting disorder, but a prompt diagnosis is important to implement specific and individualized support plans through the use of compensatory tools. However, the diagnosis is often belated, since it can be formulated from the end of the second grade of primary school [2], so when the child has consolidated his or her learning. Before this stage of education, some early indicators such as visual−spatial and auditory discrimination deficits [3] can lead to the identification of subjects more at risk of developing dyslexia, thus enabling an early intervention.

Although the diagnosis must be carried out by professionals, teachers play a decisive role in identifying the disorder, since they are the first who notice if a child is not following the pace of the others. School has the duty of performing the first intervention, while waiting for an official diagnosis. However, the recent pandemic added a new challenge in this process, preventing teachers from a direct training when schools are closed. In such context, the use of technology can be a determining factor in supporting teachers recognition of any pupil's weakness in reading and writing. Therefore, there is the need for a support tool that, on one hand, helps the pupil to independently strengthen his or her reading skills, and on the other hand helps the teacher in the evaluation of the child's performance during the exercise. The combination of these two specifications is aimed at a remote support and an objective monitoring of training effectiveness, towards a more rapid and accurate identification of children at risk of dyslexia.

The goal of this thesis is to design a *Serious Game* that gamifies exercises to assess and reinforce reading skills, in terms of speed and accuracy, through tests of reading and writing, phonological analysis, and text comprehension. Since it is a *Game*, the exercises offered must be fun and challenging in order to motivate players to achieve high scores and improve them over time. However, since it is *Serious*, the game

must also have an educational purpose, through speed−reading tests of single words or whole sentences, and tests of phonological analysis, realized through the use of audio−visual exercises.

2. Materials and Methods

2.1. Game Design

The game has been developed in Unity as an application for Android tablets and includes three different mini−games.
The first mini−game is *Tachistoscopio*, a game that assesses the player's reading speed. It is inspired by the "tachistoscope" [1], a device that tests the attentional skills by presenting visual stimuli for a precisely controlled period of time. Ten Words of different lengths are shown briefly, one at a time, on the screen. The subject must read the word and rewrite it. This game mechanic is aimed at improving reading speed through the development of global reading in addition to letter-by-letter reading.

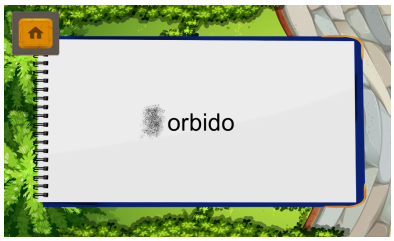

Figure 1: Figure showing the cancellation letter by letter of the word "torbido" in *Tachistoscopio*.

Figure 2: Figure showing the global cancellation of the word in *Tachistoscopio*.

The second mini-game is called *Salta con Opp*, a game that gamifies exercises of comprehension and phonotactic analysis of the word. For each of the 10 levels, a pre−recorded voice pronounces one word at a time, either in the entire form or syllabified. The player must carry out a syllabic analysis of the word and drag the corresponding image on the path that has as many bushes as the number of syllables of the word, thus helping the guiding character, Opp, reaching the image. This game mechanic is aimed at strengthening the ability to relate phonetic correspondence and written word.

Figure 3: Figure showing the tutorial scene with Opp, the guiding character, in *Salta con Opp*.

Figure 4: Figure showing the game scene of *Salta con Opp*.

Finally, the last mini−game is titled *Ernesto l'Aspiratesto*, and it is a game based on text comprehension. Very similar to *Tachistoscopio*, ten sentences are briefly shown, one at a time, on the screen. The subject must read the sentence, before it is erased letter by letter by the guiding character, Ernesto, and then answer a multiple choice question to assess comprehension. This game mechanic is intended to improve comprehension of written text.

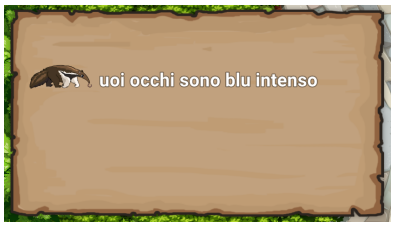

Figure 5: Figure showing the game scene of *Ernesto l'Aspiratesto*, where the guiding character, Ernesto, is eating, letter−by−letter, all the sentence.

Figure 6: Figure showing the multiple choice question about the sentence shown in fig. 5.

The game can be used both independently by the student and under the supervision of the teacher. Each mini−game is preceded by a tutorial, and is designed in such a way that it adapts to the player's reading skills without being either too easy or too complex. Therefore a calibration mechanism that dynamically adapts the exposure time of the word/phrase to the player's reading speed is introduced: with each sequence of three correct or incorrect rewriting in *Tachistoscopio*, or three right or wrong answers in *Ernesto l'Aspiratesto*, the exposure time decreases or increases automatically. Moreover, the teacher can intervene and modify the different parameters at will, including difficulty and exposure time.

2.2. Acquisition protocol

The game was tested on second and third graders, for a total of 28 children. The acquisition protocol provided for each participant to play the first two mini−games in medium difficulty, to assess that the adaptation to the player's reading skills was adequate. Then, children had to perform the BVSCO test (Batteria per la Valutazione della Scrittura e della Competenza Ortografica), a set of three exercises that measures writing speed in reproducing curvilinear signs (BVSCO 4a) and words (BVSCO 4b and 4c), to verify any correlation between reading and handwriting difficulties. *Ernesto l'Aspiratesto* was excluded from the acquisition because it is simliar to *Tachistoscopio*, but not suitable for second graders at the beginning of the school year.
For a sub−group of participants, *Salta con Opp* was also performed in hard difficulty, to evaluate effectiveness of gradualness between the designed difficulties. Then, subjects answered characterization questions that detected potential confounding factors such as gender, age, class, native language, familiarity with the tablet, video games, and questions about enjoyment of the game. Finally, they completed the system usability scale (SUS) aimed at determining whether the game was too easy to use or too difficult and unnecessarily complex.

2.3. Data analysis

Game performance was expressed in a set of variables that included reading speed, scores of the two mini−games and average time to complete each level of *Salta con Opp*. They were compared among classes and gender. In addition, a multiple regression analysis was carried out using all the game variables as predictors and BVSCO scores as the dependent variable.

3. Results

Data analysis shows that, for medium difficulty, third graders score significantly better on the two mini-games than second graders ($p = 0.0046$ for *Tachistoscopio*, $p = 0.0015$ for *Salta con Opp*).

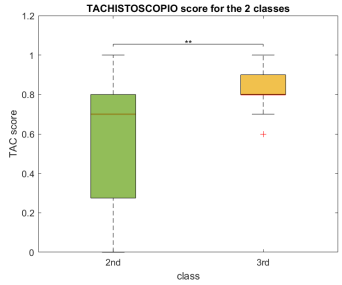

Figure 7: Figure shows the significant difference in score of *Tachistoscopio* among classes.

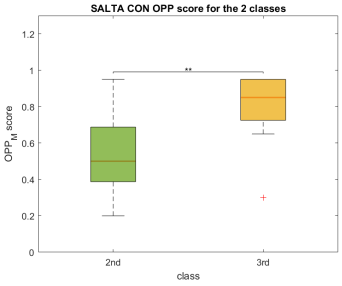

Figure 8: Figure shows the significant difference in score of *Salta con Opp* among classes.

Concerning *Tachistoscopio*, the reading speed is higher ($p = 0.00077$) for the third grade group as well as the improvements in reading speed throughout the ten displayed words ($p =$

0.0034). Regarding *Salta con Opp*, no difference is observed in the average time to complete each level in medium difficulty between the two classes. Yet, when comparing the performances in medium and hard difficulty, the average time is significantly lower when difficulty increases ($p = 0.00012$) and scores seem to be lower, as well, even if statistical significance was not reached ($p = 0.13$).

Figure 9: Figure shows significant greater improvement in reading speed for third graders after playing *Tachistoscopio*.

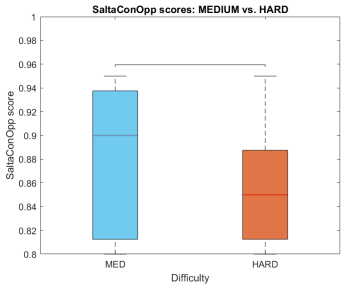

Figure 10: Figure shows scores of *Salta con Opp* in medium and hard difficulty.

The outcome of the BVSCO 4a changed significantly with respect to student gender ($p = 0.011$) and grade ($p = 0.016$), but BVSCO 4b and 4c did not. The multiple regression analysis proves that the difference of reading speed between the end of initial calibration and the end of the levels of *Tachistoscopio*, and the mean time to complete the exercises of *Salta con Opp* turn out to be significant in predicting the outcome of the BVSCO 4a ($p = 0.00048$ and $p = 0.028$ respectively). In contrast, multiple regression was not significant when the results of the BVSCO 4b and 4c were leveraged as dependent variables.

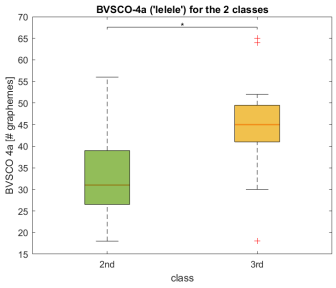

Figure 11: Figure shows the score of BVSCO 4a, measured as the number of graphemes produced, between classes.

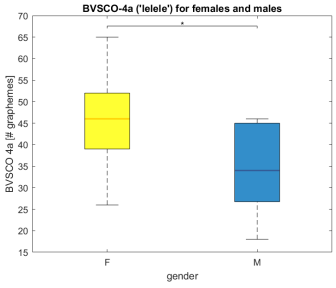

Figure 12: Figure shows the score of BVSCO 4a between genders.

Regarding the characterization, 79% of children enjoyed the game very much and 68% of players preferred *Tachistoscopio* to *Salta con Opp*. Half of the participants were neutral when faced the question of whether the game was easy or not, while 25% found it easy and 21% very easy. The System Usability Scale shows excellent results, with an average score of 86.16 (± 14.43), above the threshold limit to consider the game usable (68).

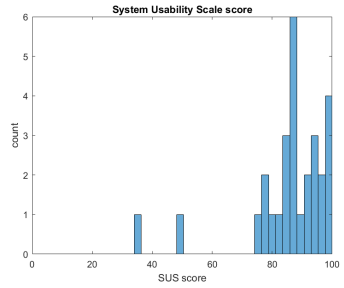

Figure 13: Figure shows the distribution of System Usability Scale scores.

4. Discussion

According to our results, better reading increments, and hence higher scores, occur for partic-

ipants who are faster at reading. Thus players are challenged to improve themselves again and again while having fun, as confirmed by the characterization results. By comparing the levels of difficulty, results seem to prove the presence of a gradualness between the degrees.
Furthermore, the results from multiple regression analysis suggest an association between reading and handwriting, especially when rhythmical patterns are involved, as in BVSCO 4a. This supports literature studies which found that reading problems go beyond simple visual−attentional and phonological deficiencies [4].

5. Conclusions

In conclusion, children's reaction was positive and the game was considered usable, as confirmed by the SUS score. In future developments it would be interesting to delve into the assessment of the difficulty gradualness and to broaden the preventive power of the game for preschoolers.

References

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[5] Enza Sidoti. *Dentro La Dislessia.* Junior, 2014.

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1. Introduzione

La dislessia è un disturbo specifico dell'apprendimento associato a un'alterata capacità di lettura. Colpisce la decodifica fonologica, la percezione visiva e la memorizzazione dei testi scritti [5]. È il disturbo di apprendimento più diffuso, spesso accompagnato da difficoltà di scrittura. L'incidenza varia per lingua e ortografia [6]: in Italia gli alunni con dislessia rappresentano il 3,2% del totale degli studenti che frequentano le scuole primarie e secondarie. La dislessia è un disturbo che dura tutta la vita, ma una diagnosi tempestiva è importante per attuare piani di sostegno specifici e individualizzati attraverso l'utilizzo di strumenti compensativi. Tuttavia, la diagnosi è spesso tardiva, poiché può essere formulata a partire dalla fine della seconda classe della scuola primaria [2], quindi quando il bambino ha consolidato il suo apprendimento. Prima di questa fase dell'istruzione, alcuni indicatori precoci come deficit di discriminazione visuo-spaziale e uditiva [3] possono portare all'identificazione dei soggetti più a rischio di sviluppare dislessia, permettendo così un intervento precoce. Anche se la diagnosi deve essere effettuata da professionisti, gli insegnanti giocano un ruolo decisivo nell'identificazione del disturbo, poiché sono i primi a notare se un bambino non segue il ritmo degli altri. La scuola ha il compito di eseguire il primo intervento, in attesa di una diagnosi ufficiale. Tuttavia, la recente pandemia ha aggiunto una nuova sfida in questo processo, impedendo agli insegnanti una valutazione diretta quando le scuole sono chiuse.

In tale contesto, l'uso della tecnologia può essere un fattore determinante nel sostenere il riconoscimento da parte degli insegnanti della debolezza dell'alunno nella lettura e nella scrittura. Pertanto, vi è la necessità di uno strumento di supporto che, da un lato, aiuti l'alunno a rafforzare autonomamente le sue capacità di lettura, e dall'altro aiuti l'insegnante nella valutazione delle prestazioni del bambino durante l'esercizio. La combinazione di queste due specifiche è finalizzata a un supporto a distanza e a un monitoraggio oggettivo dell'efficacia della formazione, verso un'identificazione più rapida e precisa dei bambini a rischio di dislessia.

L'obiettivo di questa tesi è quello di progettare un *Serious Game* (lett. *Gioco Serio*) che ludicizzi gli esercizi di valutazione e rinforzo delle abilità di lettura, in termini di velocità e ac-

curatezza, attraverso prove di lettura e scrittura, analisi fonologica e comprensione del testo. Trattandosi di un *Gioco*, gli esercizi proposti devono essere divertenti e stimolanti per motivare i giocatori a raggiungere punteggi elevati e a migliorarli nel tempo. Tuttavia, essendo *Serio*, il gioco deve avere anche uno scopo educativo, attraverso prove di lettura veloce di singole parole o intere frasi, e prove di analisi fonologica, realizzate attraverso l'uso di esercizi audiovisivi.

2. Materiali e Metodi

2.1. Design del gioco

Il gioco è stato sviluppato in Unity come applicazione per tablet Android e include tre diversi mini−-giochi.
Il primo mini−gioco è *Tachistoscopio*, un gioco che valuta la velocità di lettura del giocatore. È ispirato al "tachistoscopio" [1], un dispositivo che mette alla prova le capacità attentive presentando stimoli visivi per un periodo di tempo precisamente controllato. Dieci parole di lunghezza diversa sono mostrate brevemente, una alla volta, sullo schermo. Il soggetto deve leggere la parola e riscriverla. Questa meccanica di gioco mira a migliorare la velocità di lettura attraverso lo sviluppo della lettura globale oltre alla lettura lettera per lettera.

Figure 1: La figura mostra la cancellazione lettera per lettera della parola "torbido" in *Tachistoscopio*.

Figure 2: La figura mostra la cancellazione globale della parola in *Tachistoscopio*.

Il secondo mini−gioco si chiama *Salta con Opp*, un gioco che ludicizza esercizi di comprensione e analisi fonotattica della parola. Per ognuno dei 10 livelli, una voce pre−registrata pronuncia una parola alla volta, nella forma intera o sillabata. Il giocatore deve effettuare un'analisi sillabica della parola e trascinare l'immagine corrispondente sul percorso che ha tanti cespugli quante sono le sillabe della parola, aiutando così il personaggio guida, Opp, a raggiungere l'immagine. Questa meccanica di gioco mira a rafforzare la capacità di mettere in relazione la corrispondenza fonetica e la parola scritta.

Figure 3: Figura che mostra la scena del tutorial con Opp, il personaggio guida, in *Salta con Opp*.

Figure 4: Figura che mostra una scena di gioco di *Salta con Opp*.

Infine, l'ultimo mini−gioco si intitola *Ernesto l'Aspiratesto*, ed è un gioco basato sulla comprensione del testo. Molto simile a *Tachistoscopio*, dieci frasi vengono brevemente mostrate, una alla volta, sullo schermo. Il soggetto deve leggere la frase, prima che venga cancellata lettera per lettera dal personaggio guida, Ernesto, e poi rispondere a una domanda a risposta multipla per valutare la comprensione. Questa meccanica di gioco ha lo scopo di migliorare la comprensione del testo scritto.
Il gioco può essere usato sia indipendentemente dallo studente che sotto la supervisione dell'insegnante.

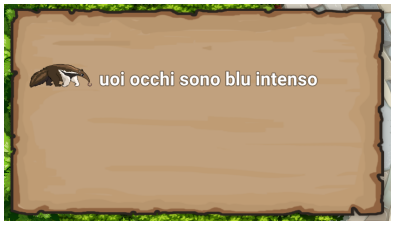

Figure 5: Figura che mostra la scena di gioco di *Ernesto l'Aspiratesto*, dove il personaggio guida, Ernestp, sta mangiando, una lettera alla volta, tutta la frase.

Figure 6: Figura che mostra la domanda a risposta multipla relativa alla frase mostrata in fig. 5.

Ogni mini−gioco è preceduto da un tutorial, ed è progettato in modo tale da adattarsi alle capacità di lettura del giocatore senza essere né troppo facile né troppo complesso. Viene quindi introdotto un meccanismo di calibrazione che adatta dinamicamente il tempo di esposizione della parola/frase alla velocità di lettura del giocatore: ad ogni sequenza di tre riscritture corrette o sbagliate in *Tachistoscopio*, o di tre risposte giuste o sbagliate in *Ernesto l'Aspiratesto*, il tempo di esposizione diminuisce o aumenta automaticamente. Inoltre, l'insegnante può intervenire e modificare a piacimento i diversi parametri, tra cui la difficoltà e il tempo di esposizione.

2.2. Protocollo di acquisizione

Il gioco è stato testato su bambini di seconda e terza elementare, per un totale di 28 bambini. Il protocollo di acquisizione prevedeva che ogni partecipante giocasse i primi due mini−giochi a media difficoltà, per valutare che l'adattamento alle capacità di lettura del giocatore fosse adeguato. Successivamente, i bambini dovevano eseguire il test BVSCO (Batteria per la Valutazione della Scrittura e della Competenza Ortografica), un insieme di tre esercizi che misura la velocità di scrittura nel riprodurre segni curvilinei (BVSCO 4a) e parole (BVSCO 4b e 4c), per verificare eventuali correlazioni tra difficoltà di lettura e scrittura a mano. *Ernesto l'Aspiratesto* è stato escluso dall'acquisizione perché simile a *Tachistoscopio*, ma non adatto ai bambini di seconda elementare all'inizio dell'anno scolastico. Per un sottogruppo di partecipanti, *Salta con Opp* è stato eseguito anche in difficoltà difficile, per valutare l'efficacia della gradualità tra le difficoltà progettate. Poi, i soggetti hanno risposto a domande di caratterizzazione che rilevavano potenziali fattori confondenti come il sesso, l'età, la classe, la lingua madre, la familiarità con il tablet, i videogiochi, e domande sul gradimento del gioco. Infine, hanno completato la Scala di Usabilità del Sistema (SUS) volta a determinare se il gioco fosse troppo facile da usare o troppo difficile e inutilmente complesso.

2.3. Analisi dei dati

Le prestazioni del gioco sono state espresse in un insieme di variabili che includevano la velocità di lettura, i punteggi dei due mini−giochi e il tempo medio per completare ogni livello di *Salta con Opp*, e che sono state poi confrontate tra le classi e il genere. Inoltre, è stata effettuata un'analisi di regressione multipla utilizzando tutte le variabili del gioco come predittori e i punteggi BVSCO come variabile dipendente.

3. Risultati

L'analisi dei dati mostra che, per la difficoltà media, i bambini di terza elementare ottengono un punteggio significativamente migliore nei due mini−giochi rispetto a quelli di seconda ($p = 0.0046$ per *Tachistoscopio*, $p = 0.0015$ per *Salta con Opp*).

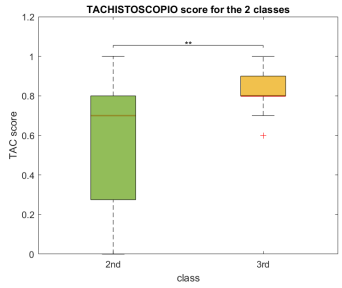

Figure 7: La figura mostra la differenza significativa nel risultato di *Tachistoscopio* per le due classi.

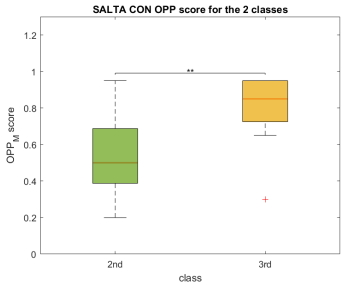

Figure 8: La figura mostra la differenza significativa nel risultato di *Salta con Opp* per le due classi.

Per quanto riguarda *Tachistoscopio*, la velocità di lettura è più alta per il gruppo di terza elementare ($p = 0.00077$), così come i miglioramenti nella velocità di lettura attraverso le dieci parole visualizzate ($p = 0.0034$). Per quanto riguarda *Salta con Opp*, non si osserva alcuna differenza nel tempo medio per completare ogni livello in media difficoltà tra le due classi. Tuttavia, quando si confrontano le prestazioni in difficoltà media e difficile, il tempo medio è significativamente più basso quando la difficoltà aumenta ($p = 0.00012$) e i punteggi sembrano essere più bassi, anche se la significatività statistica non è stata raggiunta ($p = 0.13$).

Figure 9: La figura mostra un incremento della velocità di lettura a fine *Tachistoscopio* significativamente maggiore per gli studenti di terza.

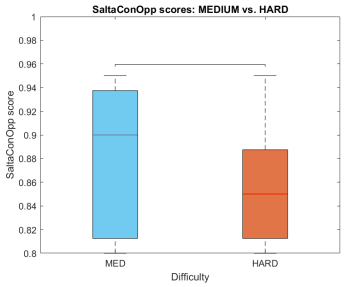

Figure 10: La figura mostra i risultati di *Salta con Opp* in difficoltà media e difficile.

Il risultato del BVSCO 4a cambia significativamente rispetto al sesso dello studente ($p = 0.011$) e alla classe ($p = 0.016$), ma quello del BVSCO 4b e 4c no. L'analisi di regressione multipla dimostra che la differenza di velocità di lettura tra la fine della calibratura iniziale e la fine dei livelli di *Tachistoscopio*, e il tempo medio per completare gli esercizi di *Salta con Opp* risultano essere significativi nel predire l'esito del BVSCO 4a ($p = 0.00048$ e $p = 0.028$ rispettivamente). Al contrario, la regressione multipla non è stata significativa quando i risultati del BVSCO 4b e 4c sono stati utilizzati come variabili dipendenti.

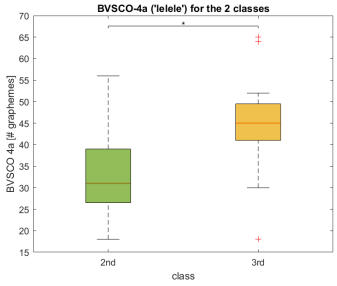

Figure 11: La figura mostra il risultato di BVSCO 4a, misurato in numero di grafemi prodotti, tra le due classi.

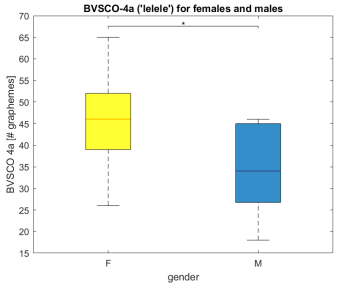

Figure 12: La figura mostra il risultato di BVSCO 4a tra maschi e femmine.

Per quanto riguarda la caratterizzazione, il 79% dei bambini ha apprezzato molto il gioco e il 68% dei giocatori ha preferito *Tachistoscopio* a *Salta con Opp*. La metà dei partecipanti è stata neutrale di fronte alla domanda se il gioco fosse facile o meno, mentre il 25% lo ha trovato facile e il 21% molto facile. La Scala di Usabilità del Sistema mostra ottimi risultati, con un punteggio medio di 86,16 (±14,43), superiore alla soglia limite per considerare il gioco usabile (68).

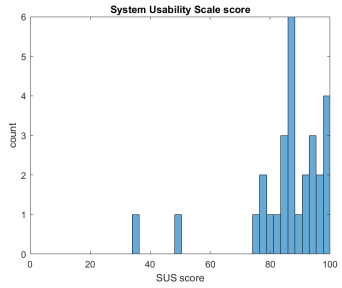

Figure 13: La figura mostra la distribuzione dei risultati della Scala di Usabilità del Sistema.

4. Discussioni

Secondo i nostri risultati, migliori incrementi di lettura, e quindi punteggi più alti, si verificano per i partecipanti che sono più veloci nella lettura. In questo modo i giocatori sono sfidati a migliorarsi ancora e ancora divertendosi, come confermato dai risultati di caratterizzazione. Confrontando i livelli di difficoltà, i risultati sembrano provare la presenza di una gradualità tra i livelli.
Inoltre, i risultati dell'analisi di regressione multipla suggeriscono un'associazione tra lettura e scrittura a mano, specialmente quando sono coinvolti schemi ritmici, come in BVSCO 4a. Questo supporta gli studi della letteratura che hanno trovato che i problemi di lettura vanno oltre le semplici carenze visive−attenzionali e fonologiche [4].

5. Conclusioni

In conclusione, la reazione dei bambini è stata positiva e il gioco è stato considerato utilizzabile, come confermato dal punteggio SUS. Negli sviluppi futuri sarebbe interessante approfondire la valutazione della gradualità della difficoltà e ampliare il potere preventivo del gioco per i bambini in età prescolare.

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POLITECNICO DI MILANO

Department Of Electronics, Information and Bioengineering

Master of Science in Biomedical Engineering

Serious Games to assess visual-attentional and phonological-decoding skills for reading development

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Contents

Abstract

Dyslexia is a life-lasting neurodevelopmental disorder that affects reading ability. Early diagnosis is critical and school has the duty of performing the first evaluation through exercises assessing reading speed and accuracy, phonological decoding, and text comprehension, which can often be tedious and uninspiring for a child. The goal of this thesis is to design a Serious Game that assesses visual-attentional skills and phonological-decoding for reading development. The game consists of 3 mini−games, *Tachistoscopio*, *Salta con Opp* and *Ernesto l'Aspiratesto*, each proposed in 3 difficulties, that gamify exercises of reading−writing, phonological awareness, and comprehension of written text respectively. A group of 28 participants, 13 children from second grade and 15 from third grade of primary school, played the first two mini−games and completed two questionnaires, one for characterization and one for usability assessment. Results suggest that third graders read faster and achieve significantly higher scores in both mini−games than second graders. When comparing the performances in *Salta con Opp* between medium and hard difficulty, participants show a tendency at reaching lower scores in hard difficulty than in medium. Our results suggest that the game tends to be harder for second grade children and for higher levels of difficulty, which means that the game design and difficulty levelling were effectively implemented. Regarding the characterization, 79% of participants consider the game as highly enjoyable, rating the maximum on a fun−scale. The game was considered usable, as confirmed by the average SUS score of 86.16.

Sommario

La dislessia è un disturbo del neurosviluppo che dura tutta la vita e che colpisce la capacità di lettura. La diagnosi precoce è fondamentale e la scuola ha il compito di eseguire la prima valutazione attraverso esercizi che valutano la velocità e la precisione di lettura, la decodifica fonologica e la comprensione del testo, che spesso possono risultare noiosi e poco stimolanti per un bambino. L'obiettivo di questa tesi è quello di progettare un Serious Game che valuti le abilità visivo−attenzionali e di decodifica fonologica per lo sviluppo della lettura. Il gioco consiste in 3 mini−giochi, *Tachistoscopio*, *Salta con Opp* e *Ernesto l'Aspiratesto*, ognuno proposto in 3 difficoltà, che ludicizzano rispettivamente esercizi di lettura−scrittura, consapevolezza fonologica, e comprensione del testo scritto. Un gruppo di 28 partecipanti, 13 bambini di seconda elementare e 15 di terza elementare, ha giocato ai primi due mini−giochi e ha completato due questionari, uno per la caratterizzazione e uno per la valutazione dell'usabilità. I risultati suggeriscono che i bambini di terza elementare leggono più velocemente e ottengono punteggi significativamente più alti in entrambi i mini−giochi rispetto ai bambini di seconda elementare. Quando si confrontano le prestazioni di *Salta con Opp* tra difficoltà media e difficile, i partecipanti mostrano una tendenza a raggiungere punteggi più bassi nella modalità difficile. I nostri risultati suggeriscono che il gioco tende ad essere più difficile per i bambini di classe seconda e per livelli di difficoltà superiori, il che significa che il design del gioco e il livellamento della difficoltà sono stati implementati efficacemente. Per quanto riguarda la caratterizzazione, il 79% dei partecipanti considera il gioco molto divertente, valutando il massimo su una scala di divertimento. Il gioco è stato considerato utilizzabile, come confermato dal punteggio medio SUS di 86.16.

Capitolo 1

STATE OF THE ART

1.1 Specific Learning Disabilities

As children first begin their journey of learning, they are introduced to many different essential skills. Reading, writing and calculation are the core fundamentals of education. Without practicing and encouraging children to master these skills, they will lack knowledge and fall behind in other subjects.

Specific Learning Disabilities (SLD) are disorders in which a disturbance in the normal patterns of skill acquisition results in academic performances that are substantially lower than it would be expected given the individual's chronological age, psychometric assessment of intelligence, and age-appropriate education [1] [2]. Thus, they are not simply a consequence of a lack of opportunity to learn, nor they are due to any form of acquired brain trauma or disease [1]. Rather, according to the most recent studies, Specific Learning Disabilities are neurodevelopmental disorders, and although they occur at early stages of schooling, they may not become fully manifest until the demands for those affected academic skills exceed the individual's limited capacities (e.g., as in timed tests, reading or writing lengthy complex reports for a tight deadline, excessively heavy academic loads) [3]. It is particularly difficult to find children with isolated disorders, while it is more frequent to find heterogeneous frameworks, such as difficulties in reading and calculating, or in writing and paying attention. Therefore, in order to formulate a diagnosis, it is better to investigate on multiple levels: from the

single compromised functions (or less developed) to the more complex systems that orchestrate them. According to the specific type of difficulty that they implicate, SLD can be divided in dyslexia, dysorthographia, dyscalculia and dysgraphia. According to the definitions taken by the work of Vicari and Meneghini [4]:

- Dyslexia is a specific learning disability that compromises in a "selective" way, more or less severely, the reading capability [4]. According to the Diagnostic and Statistical Manual of Mental Disorders [3], the most widely used by mental health professionals, a dyslexic child exhibits:
  - Inaccurate or slow and effortful word reading (e.g., reads single words aloud incorrectly or slowly and hesitantly, frequently guesses words, has difficulty sounding out words)
  - Difficulty understanding the meaning of what is read (e.g., may read text accurately but not understand the sequence, relationships, inferences, or deeper meanings of what is read)
  - Difficulties with spelling (e.g., may add, omit, or substitute vowels or consonants)
  - Difficulties with written expression (e.g., makes multiple grammatical or punctuation errors within sentences; employs poor paragraph organization; written expression of ideas lacks clarity).
- Dysorthography is a specific learning disability that affects writing and is characterized by deficits in following the language specific orthographic rules. The correct translation of the sounds that make up the words in graphemes is altered and numerous errors may become evident. Dysorthographic children produce:
  - Errors of omission or replacement of graphemes: typically, substitution occurs between graphemes that represent similar phonemes (e.g., f and v, or t and d), or with similar graphemes from a visual point of view (e.g., p and q, or b and d)
  - Excessively concise text, poorly organised, with temporal links that are not always appropriate, with limited lexical choice

  - Incorrect and inadequate use of punctuation.

- Dyscalculia is a specific learning disability characterized by difficulties in numerical and calculation skills, especially in quick calculation in mind. Among the diagnostic criteria of dyscalculia, expressed by the Consensus Conference [5], the dyscalculic children show:

  - Deficits in the cognitive structuring of the numerical processing components
  - Difficulties in the executive procedures and in the calculation
  - Difficulties in arithmetic reasoning and in solving mathematical problems.

- Dysgraphia is a specific learning disability concerned with writing speed, legibility, and quality of handwriting. Dysgraphic children often:

  - Mishandle the pen and write slowly in very large or very small characters
  - Can put excessive pressure on the paper causing fatigue and pain in the hand
  - Have difficulty organizing the space on the paper, do not respect the margins, and spaces between words are often irregular.

1.1.1 Incidence

In 2018/2019 [6], pupils attending Italian schools who have been diagnosed with a Specific Learning Disorder are 298.114, representing 4.9% of the total number of pupils. These numbers are specific for those pupils attending the third, fourth and fifth grade of primary school and I and II degree of secondary school with certification of SLD. Entering the details of the individual school orders, as shown in Tab. 1.1, in the school year 2018/2019 pupils with SLD attending the last three grades of elementary school are 52.105, equal to 3.1% of the total number of pupils. Relatively to the I degree of secondary school there are 102.400 pupils with SLD and for the second degree of secondary school 143.609 pupils, respectively equal to 5.9% and 5.3% of the total number of pupils attending these orders of school.

These data refers to children from third grade and above. There is no information for first and second grade children because generally SLD are diagnosed from the second or third grade of primary school [7]. However, the first signs of the presence of SLD can be found as early as preschool, when these disorders are not yet fully manifested and are not yet diagnosable. Guidelines for the right to study of students with SLD indicate, however, that preschool teachers must be able to recognize the signs of risk in order to intervene immediately with targeted teaching and pedagogical activities [8].

Hence the need to enter this age range in which DSA cannot yet be diagnosed in order to support teachers and families in the recognition and intervention of these disorders.

School order	Pupils with SLD	Total pupils	%pupils with SLD
Primary (III-IV-V year)	52.105	1.661.770	3,1%
Sec. I grade	102.400	1.725.037	5,9%
Sec. II grade	143.609	2.690.676	5,3%
TOTAL	298.114	6.077.483	4,9%

Tabella 1.1: *pupils with SLD and total pupils for school order in 2018/2019. Source: MI - DGSIS - Gestione Patrimonio informativo e Statistica - Rilevazioni sulle scuole*

Going into detail about the types of disorders, as shown in Fig. 1.1, referred to the 2018/2019 school year, 187.693 pupils present dyslexia, 87.859 dysgraphia, 101.744 dysorthographia and 96.081 dyscalculia. The total number of students with SLD attending the III, IV and V grade of primary school and secondary school, reported previously, does not coincide with the sum of the number of disorders by type reported in the graph since a student can present more than one type of SLD. The Specific Learning Disorders can coexist with each other and with other types of developmental disorders, such as speech, motor coordination and attention disorders, and there may be a comorbid condition between specific learning and emotional and behavioural disorders. Dyslexia disorders, accounting for 39.6% of the total, are the most diagnosed,

followed by the disorders of dysorthographia with 21.5%, the disorders of dyscalculia and dysgraphia respectively, with 20.3% and 18.6% of the total. Considering the individual school orders, the number of students with dyslexia ranges from 2.4% of the total number of students in primary school to 3.5% in I degree of secondary school [6].

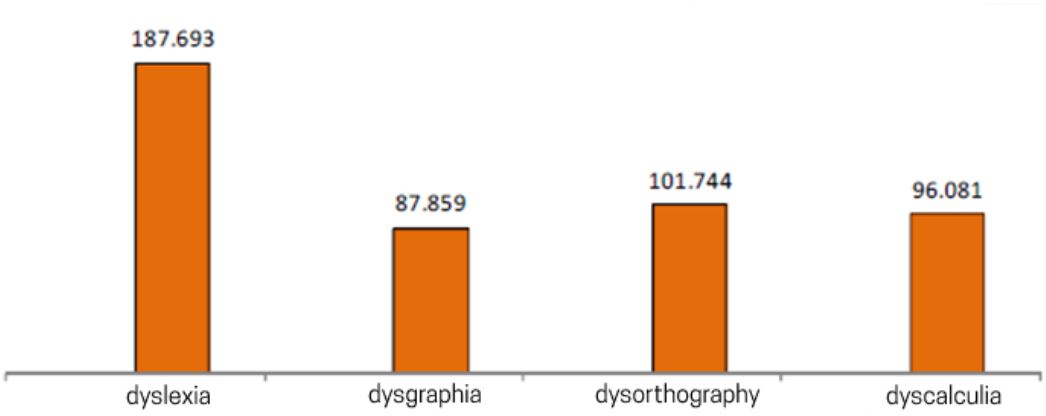


Figura 1.1: *number of disorders for typology in 2018/2019. Source: MI - DGSIS - Gestione Patrimonio informativo e Statistica - Rilevazioni sulle scuole*

Over the years, there has been an increase in the number of diagnoses of SLD. Taking into consideration the last nine years, ministerial data show how the number of students with SLD attending primary, first and second degrees of secondary school, as a percentage of the corresponding total number of students, has raised from 0.9% in the 2010/2011 school year, to 3.9% in 2016/2017. In school years 2017/2018 and 2018/2019 the percentages of 4.5% and 4.9% respectively, take into account for the primary school only the III, IV and V grade (for the previous years it is not possible to distinguish by grade since the data published by the schools were total per school order).

As reported in Fig. 1.2, the percentage of children with SLD among all the attending students has risen from 0.8% in 2004/2005 to 3.1% in 2018/2019 in primary school, from 1.6% to 5.9% in first degree of secondary school and from 0.6% to 5.3% in second degree of secondary school.

The increase in the number of certifications, recorded over five years, is remarkable. As shown in Fig. 1.3:

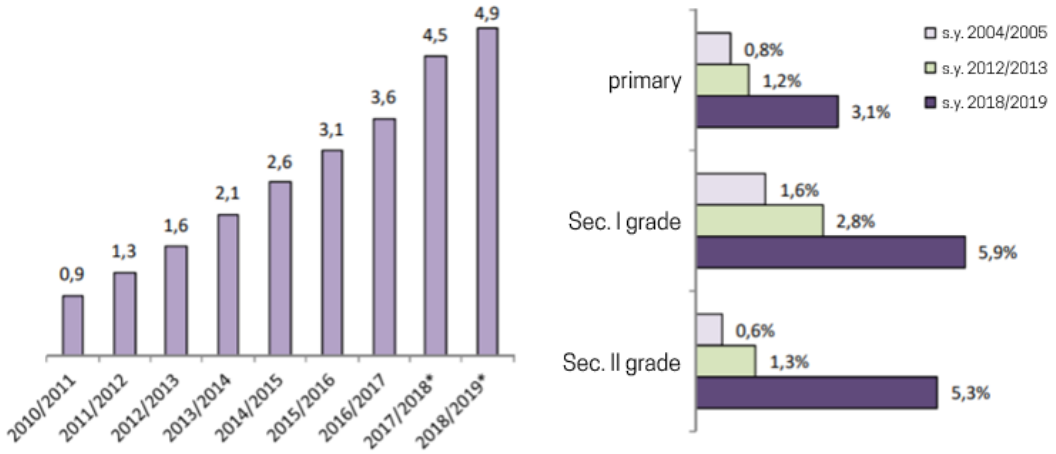


Figura 1.2: *pupils with SLD in percentage of total pupils (primary school, secondary school of I and II degree) - evolution. Source: MI - DGSIS - Gestione Patrimonio informativo e Statistica - Rilevazioni sulle scuole*

- Certifications of dyslexia have risen from about 94 thousands to almost 188 thousands, marking a growth rate of 99.8%
- Certifications of dysgraphia have risen from about 30 thousands to 88 thousands units, marking a growth rate of 192%
- Certifications of dysorthographia have risen from about 37 thousands to 102 thousands, marking a growth rate of 175.3%
- Certifications of dyscalculia have risen from about 33 thousands to 96 thousands, marking a growth rate of 189%.

This increase can be partially attributed to a greater awareness of the problem from families and schools. On the other hand, we can attribute it to a greater caution in the diagnosis of these problems, where even in the case where a child simply has learning difficulties, this is diagnosed as SLD for ”safety”, thus producing a hasty and not thorough diagnosis.

1.1.2 Consequences on quality of life

The specific learning disorder accompanies the person throughout life, but can have a variable course, depending on multiple factors: from the severity of SLDs to the

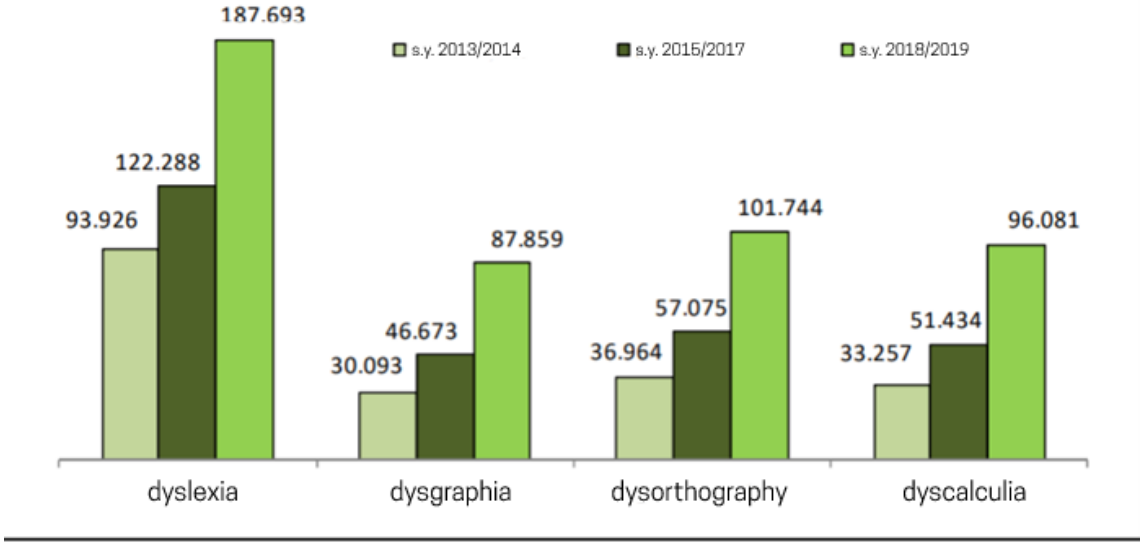


Figura 1.3: *pupils for type of disorder (primary school, secondary school of I and II order): years 2013/2014 – 2015/2016 – 2018/2019. Source: MI - DGSIS - Gestione Patrimonio informativo e Statistica - Rilevazioni sulle scuole*

possible presence of comorbidities.

While in children learning difficulties can cause major obstacles in normal school performance and afternoon homework, in adulthood they can interfere with work performance and daily activities in general that require reading, writing and calculation skills, with negative consequences on the quality of life. According to the Connecticut Longitudinal Study [9], which is one of the first prospective contribution regarding the development of a sample of children who were early diagnosed as dyslexic and followed until early adulthood, children with dyslexia neither spontaneously remit nor demonstrate a lag mechanism for catching up in the development of reading skills. Deficits in phonological coding continue to characterize dyslexic readers even in adolescence, resulting in slower and less fluent reading. Other results in literature indicate how a late diagnosis and the absence of rehabilitative interventions exacerbate the effects of the dyslexic disorder and how this disability interferes with occupational choices [10], has negative consequences on quality of life, economic well-being and degree of self-satisfaction.

Hence the need for a targeted intervention that can help diagnose these deficits as early as possible and help improve learning abilities.

1.2 Dyslexia

Developmental Dyslexia (DD) is the commonest of learning disorders. It affects the ability to read written text, both in the action of decoding and in the action of comprehension [11]. According to the guidelines for the diagnosis of SLD [8]:

- Decoding deficits include deficiency of visual, phonological and orthographic abilities.
- Comprehension deficits include deficiency of cognitive and linguistic abilities, and lack of control in the comprehension process.

The incidence of DD changes according to the language and its specific orthographic system. In the case of anglophone countries, the percentages are higher, between 5% and 15%, because of the specific characteristics of that language and that orthography, which unlike the Italian one, are not shallow, but deep. Italian is a language with a shallow, or "transparent", orthography in which the correspondence between the grapheme and the phoneme, or between the graphic sign and its pronunciation, is more regular and less ambiguous than in other languages. In summary, learning to read in deep orthographies, characterized by an irregular mapping between letters and phonemes, is a much slower process than what happens in shallow orthographies, characterized by a regular mapping between letters and phonemes [12].

1.2.1 Comorbid conditions

A relevant characteristic of developmental dyslexia is comorbidity, that is, the presence in association of other psychopathological conditions or disorders, especially with other specific learning disorders that relate to difficulties in writing system and numerical and calculation systems. A main finding of the study conducted by Kristina Moll et al. [13], was that comorbid learning disorders occurred as frequently as isolated learning disorders in all three learning domains. In this case, the resulting disorder is greater than the sum of the individual difficulties, because each of the disorders involved in the comorbidity negatively influences the development of the overall skills [14]. A recent study revealed significant comorbidity between Reading Disability (RD) and Math

Disability (MD) since 40 – 60% of individuals with RD or MD also meet criteria for the other disorder [15].

Not infrequently, however, other difficulties are observed in language (for example, in recalling the correct word for an object or in organizing speech in a sequential manner), motor coordination (for example, tying shoes or stringing beads), attention and memory. In Italy, comorbidity with Specific Language Disorder has been found from 15% to 20% of children affected by dyslexia. Motor coordination disorder was reported in a percentage from 10.3% to 26% of dyslexics [16]. Comorbidity of attention deficit hyperactivity disorder (ADHD) and dyslexia is frequent. ADHD is one of the most prevalent developmental disorders, characterized by excessive activity, short attention span, and impulsivity. In samples of subjects with ADHD, the rate of dyslexic children is between 18 – 45%, whereas in samples of dyslexic children, 18 – 42% also meet criteria for ADHD [17]. A recent study conducted by Linda Visser et al. [18] on primary school in Germany, showed that children with SLD present high rates of anxiety disorder, depression and conduct disorders.

1.2.2 The dyslexic brain: functional imaging

Extraordinary progress in functional brain imaging, primarily advances in functional magnetic resonance imaging, now allow scientists to understand the neural systems serving reading and how these systems differ in dyslexic readers [19]. In a study of children with dyslexia, Shaywitz et al. found that dysfunction in the left hemisphere posterior reading circuits is already present in dyslexic children and cannot be ascribed simply to a lifetime of poor reading [20]. Many recent brain imaging studies in patients with developmental dyslexia have documented the importance of 3 systems, shown in Fig. 1.4:

- **Parieto-temporal system**, representing the dorsal stream, affects reading, properties involving word analysis, operating on individual units of words (e.g., phonemes). It is intimately related to attentional systems and particularly to areas shown to be involved in attention control [21]. The dorsal pathway is of crucial

importance for the grapheme-phoneme "mapping" process whereby graphemes are translated into phonemes.

- **Occipito-temporal area**, representing the ventral stream, which includes Visual Word Form Area (VWFA), responsible for word recognition and skilled and fluent reading [21] [4].

- **Anterior system in the inferior frontal gyrus (Broca's area)**, associated with articulation and with silent reading and naming [22]. Broca's, together with the Wernicke's region, represents central nodes of the phonological processing network, which are integrated into phonological processes, production, and perception. While Broca's region is associated with phonological word fluency, phonological decisions, and the phonological loop, Wernicke's region is involved in phonological speech perception and auditory word-form recognition.

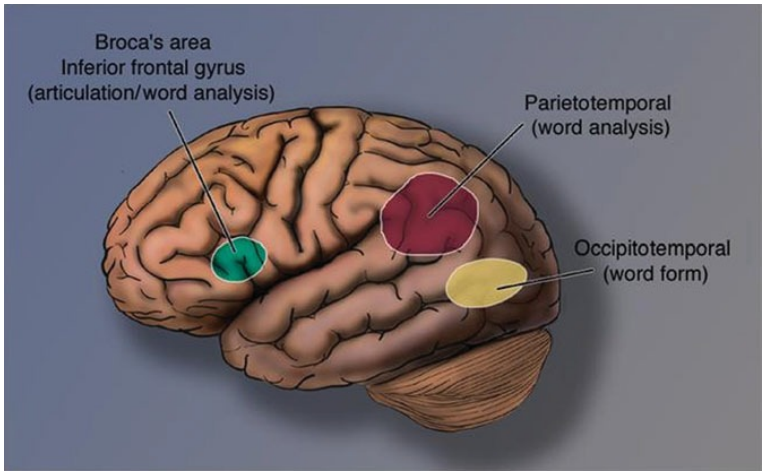


Figura 1.4: *Neural systems for reading in the left hemisphere [22].*

In Fig. 1.5 stands out how in dyslexic readers, the anterior system is slightly overactivated compared with systems of nonimpaired readers. In contrast, the two posterior systems are under-activated. This pattern of under-activation in left posterior reading systems, is referred to as the neural signature for dyslexia. This phenomenon confirms reductions of grey matter volume in posterior reading systems in bilateral inferior and superior temporal lobe areas in familial dyslexia. Nonimpaired readers activate three left hemisphere neural systems for reading: an anterior system and two posterior

systems. Dyslexic readers have a disruption in the left hemisphere posterior neural systems for reading but compensate by developing anterior systems in the left and right hemispheres and the posterior homologous of the visual word form area in the right hemisphere [22], as shown in Fig. 1.6.

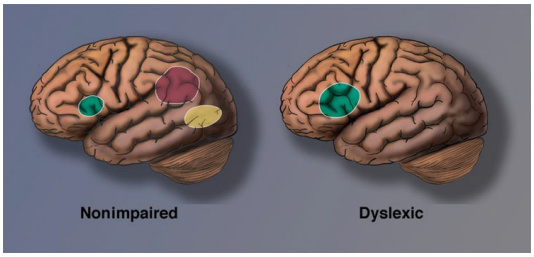


Figura 1.5: *Neural signature for DD: in dyslexic readers the Broca's area (green) is overactivated, while the ventral and dorsal regions (yellow and red respectively for nonimpaired reader) are underactivated.*

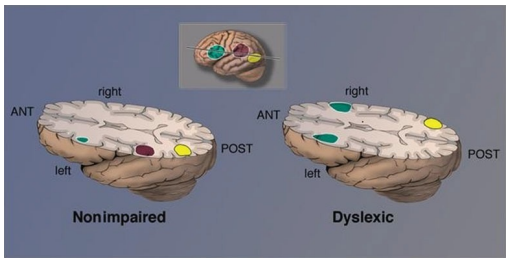


Figura 1.6: *Horizontal section of the brain showing the compensatory neural systems: activation of anterior systems in both left and right hemispheres and posterior homologous of VWFA in the right hemisphere.*

This observation is corroborated by an EEG connectivity analysis for the detection of DD. Results found a reduced bilateral connection between electrodes of the temporal lobe in DD subjects, as well as an increased connectivity of the electrode placed roughly on Broca's area [23].

1.3 Evaluation of dyslexia

The evaluation encompasses identification, screening, testing, diagnosis, and all the other information gathering involved when the student, his or her family, and a team of professionals work together to determine why the student is having difficulty and what can be done to help. According to the International Dyslexia Association (IDA) [24], when a student is having difficulties with reading and spelling, an evaluation is important for:

- Diagnostic reasons: an effective evaluation identifies the likely source of the problem and determines if the student profile of strengths and weaknesses fit the definition of DD.

- Intervention reasons: An effective evaluation develops a focused remedial program. Students who have a specific learning disability in reading need a specialized approach to reading instruction to make progress. It is crucial that this specialized instruction begins at the student's current level of reading skill development, rather than at the student's grade level.

- Documentation reasons: an effective evaluation documents the history of a student's learning disability.

1.3.1 Possible causes

One of the hottest topics in studies of dyslexia is whether it should be considered as one disorder with one cause but with different behavioural outcomes, or as a collection of different disorders with some similar symptoms. One area of disagreement concerns if DD should be classified as a purely phonological deficit, or attentional and perceptual processes (visual and auditory) are also causally implicated.

Phonological deficit

Phonological deficit hypothesis at the base of DD states that dyslexia is caused by a language-specific deficit within the phonological system that arises from difficulty in processing the speech stream: difficulties are noticeable in tasks involving word repetition, phonological learning, phonemic awareness, picture naming and verbal short-term memory [25].

Visual-Attentional deficit

Visual Attentional (VA) deficit hypothesis suggests that dyslexia is caused by a deficiency in the amount of distinct visual elements which can be processed in parallel, independently of a phonological disorder [26] [27].

Visual deficit

Visual deficit hypothesis at the level of the Magnocellular (M) pathway may cause unstable fixations and concomitant difficulty in discriminating and processing orthogra-

phic information [25]. This hypothesis is corroborated by several studies that showed how subjects affected by dyslexia exhibit longer duration fixation and shorter saccades [28] [29] (see Fig. 1.7).

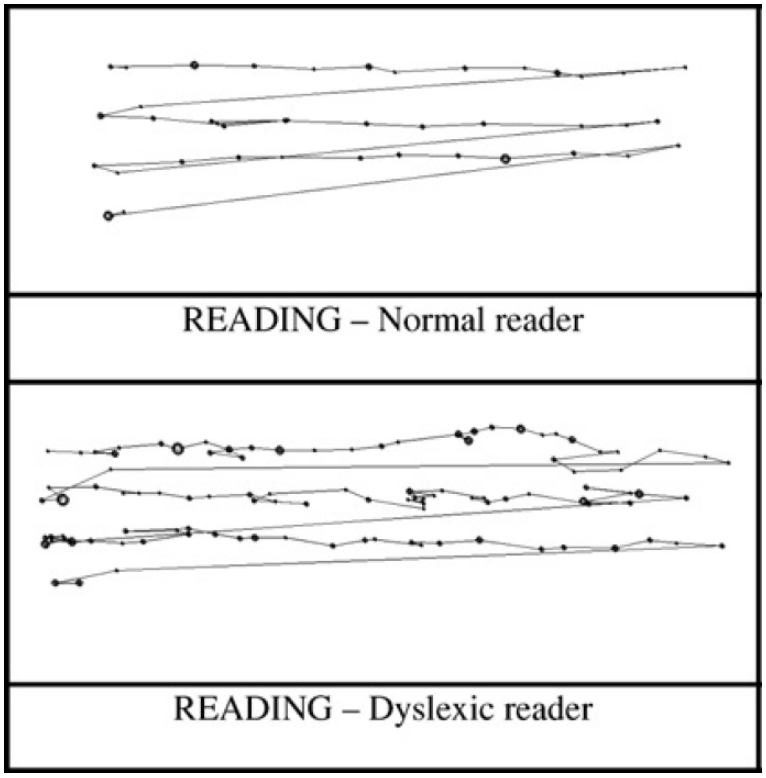


Figura 1.7: *number and duration of fixations for a normal reader (top) and a dyslexic reader (bottom). The size of each circle depicts the duration of each fixation [28]*

Hereditary components

Recent discoveries allowed to highlight some hereditary components of dyslexia, already guessed from the observation of a frequent repetition of the disorder within the members of the same family. Linkage studies have identified, up to now, a total of four candidate genes, DCDC2 and KIAA0319 Chromosome 6), DYX1C1 (Chromosome 15) and ROBO1 (Chromosome 3) [19]. Within this framework, theories on the pathogenesis of dyslexia and specific learning disorders, in general, hypothesize how genetic abnormalities can interfere with neuronal migration, causing changes in grey and white matter in the brain networks involved in the skills of reading, writing and calculation. To confirm the genetic basis of SLD, it is worth remembering that they are not equally

represented in the two sexes, but are much more frequent in males, with a ratio of three males for every female [4].

This debate is complicated by the existence of an overwhelming quantity of reported common associated symptoms.

1.3.2 Symptoms

There is no characteristic error of a child with dyslexia, since he/she makes the same mistakes as his/her classmates, but significantly more frequently. Nevertheless, according to Micheletta S. and Emili E. [2] there are some warnings of dyslexia if the pupil:

- Visually confuses letters that appear graphically similar (e.g., "m/n", "b/d", "p/q", "a/e"),
- Shows poor auditory speech perception by confusing letters that sound similar but differ in the time onset of vocal cord vibration (e.g., "t/d", "f/v", "p/b"),
- Reverses, omits or adds some letters,
- Reads a word correctly at the beginning of the page but may read it in different ways before reaching the end of the text,
- Makes anticipation errors, for example by reading the first letter or letters and guesses the word, sometimes getting it wrong,
- Skips lines and/or words,
- Reads slowly, sometimes by separating the word into distinct syllables. Slower reading leads to great difficulty understanding what has been read, particularly when reading longer sentences.

As discussed previously in Sec. 1.2.1, developmental dyslexia and other learning disabilities, such as writing difficulties can exist together. Writings difficulties can also be explained as symptoms for DD. For example, the writing of students with dyslexia may suffer from one or more of the following issues: a high percentage of mispelled

words, difficult-to-read handwriting, poor organization, a lack of fully developed ideas, and/or a lack of diverse vocabulary [30]. Moreover, recent studies demonstrate that deficits in a specific motor activity, such as handwriting, can be ascribed to DD. According to the study of Pagliarini et al. [31], these impairments can be characterized in terms of compliance with the rhythmic principles at the basis of language/reading and handwriting.

Errors affect accuracy, fluency and reading speed. As the child grows up, the errors affect the complex systems that make up words or spelling rules, which require mainly the ability to memorize the spelling string and the correct pronunciation. However, the number of errors that the child with a reading disorder makes is progressively reduced and, generally, by the end of the elementary school or in secondary school the aspect of reading that remains most compromised is speed, also expressed by reading fluency. In secondary school, children with reading disabilities are therefore generally slow and often manifest difficulties in understanding text and in study activities, due to increasingly specific terms and texts that are enriched with complexity. As for dyslexia, the diagnosis can be made from the end of the second class of primary school [4].

1.3.3 Diagnosis

Diagnosis of reading ability should cover speed, accuracy and comprehension when reading [32]. Predicting the child at risk and administering preventive treatment has become an important current topic in research and clinical practice [33]. A combination of various tests is needed to test word reading and reading comprehension. This involves individual testing of a child by an appropriate multidisciplinary team [33]. The child's performance is compared to that of children in the same school year. As reported by the IDA [24], some areas that should be considered when carrying out an evaluation are:

- Background information. Because dyslexia is genetically linked, a family history of dyslexia indicates that a student is more likely to have DD. Also information about any interventions the student has received at school, home, or through tutoring, as well as the student's response to the intervention is fundamental.

- Word recognition. It is the ability to read single printed words. Tests of word identification require that students read individual words printed in a list. The student is not able to use cues, such as the meaning of a sentence, to help figure out the word.

- Phonological processing. Phonology is the "sound system" of our language. Our spoken language is made up of word, word parts (such as syllables), and individual sounds (phonemes). We must be able to think about, remember, and correctly sequence the sounds for reading and spelling.

- Reading comprehension. Typically, students with DD score lower on test of reading comprehension that on listening comprehension because they have difficulty with decoding and accurately or fluently reading words.

Parameters for diagnosing dyslexia

The two parameters for diagnosing dyslexia are the reading speed (calculated in number of syllables read per second) and the accuracy (number of errors made). In Italy, since the language is shallow, the most significant parameter for the diagnosis of dyslexia is reading speed. The reading speed is a measure that should always appear in medical records, because it clarifies numerically the degree of difficulty of the child. It is expressed as the number of syllables read divided by the number of seconds used [34]. Each school age has, for speed and accuracy, a certain mean and standard deviation, as shown in Tab. 1.2 and Tab. 1.3:

- Mean: number of syllables read per second by the standard readers of a particular age group

- Standard deviation: the range within which the mean can fluctuate.

By diagnostic definition, if a subject's reading speed deviates from the mean by two standard deviations, then the subject is certifiable as dyslexic.

II grade PRIMARY SCHOOL	entry	intermediate	end
MEAN	1.43 syll/sec	1.89 syll/sec	2.48 syll/sec
STANDARD DEVIATION	0.7 syll/sec	0.7 syll/sec	0.9 syll/sec

Tabella 1.2: *Standards for reading speed referred to students of second grade of primary school. Measures taken by MT tests for evaluation of reading skills [35]*

III grade PRIMARY SCHOOL	entry	intermediate	end
MEAN	2.9 syll/sec	2.99 syll/sec	3.35 syll/sec
STANDARD DEVIATION	1.1 syll/sec	1.1 syll/sec	1.1 syll/sec

Tabella 1.3: *Standards for reading speed referred to students of third grade of primary school. Measures taken by MT tests for evaluation of reading skills [35]*

1.3.4 Interventions

According to Associazione Italiana Dislessia (AID) [7], the goal is not to bring the reading parameters of a dyslexic subject to the levels of a normal reader, but to acquire strategies that allow him to study and learn independently from these parameters. In many cases, dyslexic people develop their own compensatory strategies to cope with the demands of school. This is the case of "self-compensation". In Italy, the current legislation stipulates the obligation for educational institutions to guarantee the use of individualized and personalized teaching by means of the introduction of compensatory tools, including alternative learning media and computer technology (Law n. 170/2010), such as speech synthesizers, which turn a reading task into a listening task, or recorders that relieve the student from taking lesson notes. According to the guidelines for the right to study of pupils and students with specific learning disorders [14], individualized and personalized teaching are defined as follows:

- Individualized teaching consists of individual remedial activities that can be car-

ried out by the student to improve certain skills or to acquire specific competencies.

- Personalized teaching calibrates the didactic offer and the teaching strategies in order to promote the potential and educational success in each student.

The compensatory tools are educational and technological tools that replace or facilitate the performance required in the deficient skill. They have the ultimate goal of ensuring student autonomy. In addition, educational institutions should also take care of acquisition, by the student with SLD, of the skills for a proper use of the tools [2].

As recommended by the Consensus conference [5], the classical interventions for the treatment of the dyslexia must focus on:

- Specialized interventions aimed at improving reading speed and accuracy,
- Interventions aimed at learning the rules of conversion between graphemes and phonemes,
- Interventions based on structured exercises to support reading of isolated words or inserted into a context,
- Interventions that propose speed reading of whole words and/or passages, also with encouragement to identify syllables and with the help of voice synthesis software.
- In some cases it may be necessary to intervene on the comprehension of written text.

The main issues underlying the use of compensatory interventions arise when children are not sufficiently stimulated. When these tools start to bore the student, the latter might lose confidence in the educational process. Furthermore, the obstacles that children with SLD encounter in their learning process often lead them to be unmotivated, disinterested, and to enact avoidance attitudes toward schoolwork to escape frustration and expected failure [36]. Instead, it is important that the child feels like a protagonist of small successes, and therefore it is essential that these tools also become entertaining, allowing the child not only to have fun but also to regain confidence in the school environment.

Further treatments

More recent observations have led to effective new types of treatments aimed at improving reading skills. 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, without any cost in accuracy [37] [38] [39] [40] [41].

Recent studies have shown how the use of transcranial Direct Current Stimulation (tDCS), which is a non-invasive brain stimulation through the application of a weak direct electrical current in the scalp, improves memory and linguistic abilities. Results have documented how the application of these technique leads to improved reading performance in terms of increased accuracy and speed in reading [42] [43] [44].

1.4 Serious Games

Game is the main tool through which children express their identity and develop their knowledge, even the most complex. Free and socialized play has an important and fundamental function in the development of cognitive, creative and relational capacities. One way of making children passionate about school life, is by extending the playful dimension not only over motor, perceptive, emotional, social and moral aspects, but also over cognitive, linguistic and learning fields. In such background video games lend a hand: playing games should motivate the students to achieve educational goals.

The multimedia nature of videogames (which often mix images, sounds, music, movies, etc.), the high degree of involvement with which they are typically equipped, their relatively low cost, are some of the elements that make the potential educational use of these tools desirable. When we are using games as a learning technology, by means of an application for tablet, computer or smartphone, we are talking of Serious Games (SG) and edutainment [45].

Serious games are designed for a primary goal different from pure entertainment. They aim at gamify learning activities and combine entertainment with knowledge transfer. They represent an alternative way of learning, as they allow strengthening

various skills such as spatial and analytical skills, strategic and problem solving skills, selective attention, decision making, memory development and social skills such as collaboration, negotiation and the ability to make decisions in a shared way.

A well-constructed gamified activity should have both extrinsic and intrinsic motivators: children can first be motivated extrinsically to play and explore the new topic. Then, in the long term, this will hopefully lead to engagement by creating newfound enjoyment of the topic itself. Possible educational impact is not limited to knowledge acquisition or skill practice; it also includes exploration, problem solving, or incidental learning [46]. According to Fedwa Laamarti et al. [47], the classification of serious games relies on some characteristics that are important in their design:

- Activity. The type of activity performed by the player as required by the game. It can be mental, for example, in games for education, training, or interpersonal communication.
- Modality. It is the channel by which information is communicated from the computer to the player. The most common modalities include visual, auditory and haptic.
- Interaction style. It defines whether the interaction of the player with the game is done using traditional interfaces such as a brain interface, eye gaze, movement tracking, and tangible interfaces.
- Environment. It includes a combination of several criteria from bi-dimensional or tri-dimensional graphics, to online usability and multiplayer modality.
- Application area. It refers to the different applications domains relevant to serious games.

1.4.1 Serious Games for reading and writing

Serious games have a considerable impact on reading and writing. Computer gaming can be enacted in a practical way to better teach writing in a pedagogy form of play that emphasizes active participation, leading to the production of rhetorical texts for a gamespace community. Gamers learn as they play, solving puzzles, learning strategies,

becoming immersed in their writing while staying within the constraints of the game world, transforming the writing classroom from workspace to gamespace [48]. SG are also useful for the early identification of Developmental Dyslexia [49].
An example of a simple and fun online video game to improve the reading and writing skills of children with dyslexia and dysorthographia is "Tachidino" [50]. The game consists on helping Tachidino, who has the appearance of a small dinosaur, to recognize and capture the sweets he is greedy for through the brief presentation of words that must be read and then rewritten.
It is inspired on the only scientific validated tool for the increase of reading speed, the tachistoscope. This tool, according to the definition of the American Psychological Association [51], is a device that displays (usually by projecting) visual material on a screen for a specific amount of time, usually at very brief intervals. Words, numbers, pictures, and symbols can be rapidly presented in the right or left visual field. The device is used in experiments concerned with visual perception, recognition speed, and memory. Tachistoscopic visualization of words has been proven to provide significant enhancement of attentional orienting [52].

1.4.2 IndiPotedns and Essence

A big problem with learning disorders is that they can't be recognized until a certain age and, in the meantime, children run the risk of getting worse. According to the AID association (Associazione Italiana Dislessia) [7], the diagnosis of dyslexia, dysorthographia, and dysgraphia can be made at the end of second grade, while for dyscalculia at the end of third grade. Before then, the variety of test results makes the discernment of a specific learning disorder too difficult. In response to this issue, IndiPotedns, carries out activities of early identification of suspect cases of SLD from last grade of kindergarten to second grade of primary school. IndiPotedns (from latin, "Indi potes", which means: "So you can") is a novel project which aims at testing and observing children on multiple fields. The investigated areas range from psychomotor, attentional and relational for preschool, to linguistic, reading-writing and mathematics for primary school. The tools, in addition to being aimed at supporting the observation and development of students, have the ambition to induce an educational-pedagogical practice,

aimed at increasing the skills of teachers in observing the behavior of their students. All these activities ease and reinforce the detection of children at risk of developing SLDs.

The world has faced an unprecedented crisis due to the COVID-19 pandemic. Schools have been closed and classes shifted to home-based distance-learning models, causing profound changes in the lives of students and their families, with potential consequences on the children's health and well-being. In this new scenario, virtual classes did not help teachers in guiding pupils in their educational growing process. Potential weaknesses in coordination during writing, in the sense of space, in reading a text or in computing could not be directly observed. But behind every problem there is an opportunity, and new information technologies have allowed the implementation of alternative rehabilitation perspectives aimed at reaching patients and students remotely [53]. Essence is a free online platform that aims at digitalizing the strong points of IndiPotedns. It wants to boost the process of creation of a new home-based care that relies on remote monitoring and tele-assistance.

Early screening for reading−writing difficulties is desirable because it allows for intervention aimed at prevention rather than recovery of reading difficulties. Remote tele−monitoring can be a useful way to facilitate multi-point screening with gradually increasing sensitivity to foster early identification of students most likely to need extra resources. For them, Essence allows specialists to carry out remote consultation and observations to evaluate reading and writing skills. Strengthening activities are encouraged in parallel.

1.5 Aims of the work

From literature, some criticalities emerged. First of all, it has been demonstrated how the detection of early signs of dyslexia is fundamental for the educational and then social development of the child. Also the role of school teachers is critical in carrying out an early identification of pupils at risk: teachers are the first ones who may notice a slowdown in a specific student's learning, from coordination during writing, to reading a text. However, the recent pandemic of COVID 19 added a new challenge in this

process, preventing teachers from a direct training when schools are closed. In this framework, technology can be used as a support tool that assesses students' learning indicators and that can help teachers in recognizing any pupil's weakness.

The aim of this thesis is to design a *Serious Game* that on one hand helps the student in improving reading skills, and on the other hand helps the teacher in evaluating the student's performance during the exercise. More in details the goal of this work is to:

- Develop a serious game that gamifies the reading-writing, text comprehension and phonological decoding exercises.
- Test early primary school children on the games developed and analyze the data collected.
- Test the usability of the game on the children who participated to the data acquisition process. It is necessary to ensure that the game is stimulating, but without being too easy or too challenging, in order to gradually test the children's skills. Also this usability test is fundamental to validate this tool as a mean to investigate the aforementioned topic.

Capitolo 2

MATERIALS AND METHODS

2.1 Functional Specifications

Functional specifications encapsulate the requirements underlying the game development. The game to be developed must have a pedagogical function to support reading. It must be able to measure the player's reading level and improve it. It must be simple, user-friendly, flexible and challenging. It must be designed to be used by both the student alone or with the support of the tutor. Finally, the game must allow the tutor to observe what the student's difficulties are so that a training plan can be implemented in order to minimize errors and improve learning skills. The game consists of 3 minigames. The first game, called "Tachistoscopio" is designed to train and assess the quality of reading by imposing the progressive deletion of letters that make up a word: words must be read quickly by the child and be rewritten later. The second one, "Salta con Opp", is a game where the player has to listen to a series of words pronounced by an external voice and associate the image corresponding to these with paths that have a variable length according to the number of syllables of the words pronounced. The last game is "Ernesto l'Aspiratesto" which is similar to Tachistoscopio, with the difference that the child is asked to read an entire sentence before it cancels; the player then must answer a multiple choice quiz in order to evaluate his/her understanding of the sentence. Unlike the Tachistoscopio, however, Ernesto focuses more on text comprehension, besides speed-reading. The three games described above were designed by a

group of clinicians, particularly psychologists, who furnished details about the general idea of the working mechanism of each game. Regarding "Tachistoscopio" the main reference was an online training game called "Read Tachistoscopio" [54] in which the player is asked to read a list of words in a certain amount of time, adjustable from the settings. Before each word, as a mean to grab the attention of the player, an asterisk symbol is shown and after the word disappears a line of hash symbols is displayed, in order to prevent the word from being imprinted on the retina, as shown in Fig. 2.1. The clinicians focused particularly on these two aspects of the game, asking for the implementation of an original and more suitable solution, considering the average age of the game users.

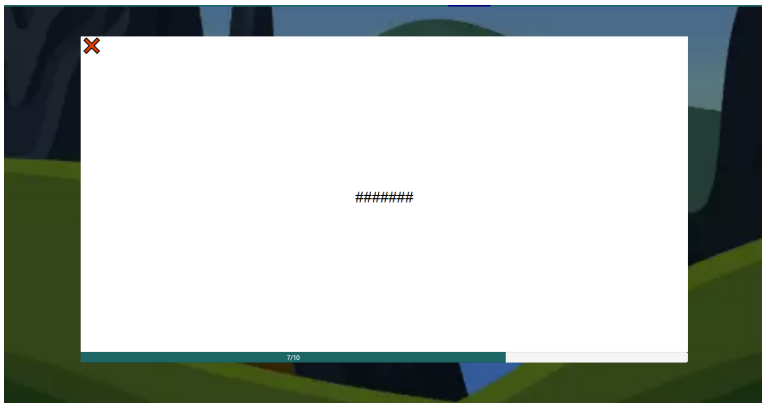


Figura 2.1: *Hash symbols used to prevent the word from imprinting on the retina*

The second game, "Salta con Opp", is created to train and assess the abilities of the player in phonological decoding and in analyzing the phonotactic structure of pronounced words. The clinicians provided with a sketch and a brief description on the main characteristics needed for the creation of the game, see Fig. 2.2. The main focus was on the definition of the target words and the distractors, that must share particular characteristics, like the initial or final syllable. Another important aspect concerns the way in which words can be reproduced. By default, the game has been designed to reproduce spelled words, as this mode allows pupils to better distinguish the individual syllables. However, a mode in which the words are pronounced in full mode has also been included, as this can become an extra challenge for higher-aged students or those with particular skills. Further details about the decision made on the game will be presented in the next sections.

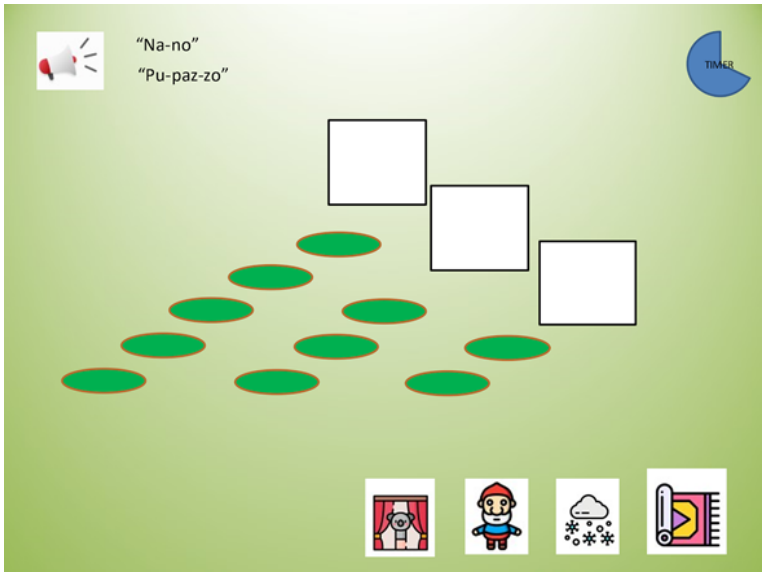


Figura 2.2: *Simple concept of Salta con Opp*

Finally, "Ernesto l'Aspiratesto" has a similar concept to Tachistoscopio, with the main difference that in this game we want to evaluate the speed and especially the quality of reading of whole sentences of varying lengths. So, a sketch and brief description were provided here too, that gave details about the speed at which letters should cancel based on a calibration process. The main concerns were on the definition of a correct speed that could stimulate the player without ever leading to frustration. For all the above games the clinicians provided a list of words, sentences, audio tracks and images that were used as a data repository in the development process.

Figura 2.3: *Simple concept of Ernesto l'Aspiratesto*

An important feature that has united the design of all three games is the feedback.

This is a crucial part of learning as it allows the student to have immediate evaluation of their performance in the game. This allows an effective learning mechanism to be established by rewarding the player when he answers correctly or by promptly reporting the error in the case of wrong answer, all this while being careful not to generate frustration. It was also important to define different difficulty levels for all the games in order to allow the tutor to create personalized challenges for each pupil as their performance improve along time. This graduality is what actually allows growth in reading skills, phonological decoding and text comprehension. Finally, an essential part of the gamification of learning exercises is the inclusion of guide characters to guide the player throughout the game experience, especially useful to introduce the player to the various game mechanics.

2.2 Video game design document

Genre The game is a 2D, single-player reading game.

Target Audience The target audience consists of children of primary school age (from approximately 6 to 8 years old).

Platform The game is developed in Unity 2021.1.3f1 for Android.

Guide Characters Three guide characters were used for the three mini-games. Two included in Ernesto l'Aspiratesto and one in Salta con Opp. In Ernesto l'Aspiratesto the two characters are Carletto, a hawk that introduces the player to the tutorial and the game mechanics, and Ernesto, an anteater that "aspirates" the words in the game session. As for Salta con Opp, the guiding character is Opp, a small rabbit who explains the gameplay features.

Tutorial Each of the three minigames has a short tutorial that introduces the player to the main game mechanics. As for Ernesto l'Aspiratesto, it is Carletto who talks to the player and explains how to perform the calibration and the game session. In Tachistoscopio instead, since it does not have a guiding character, there are simple text

boxes where calibration and game mechanics are explained. Finally, in Salta con Opp, it is Opp himself who presents the various game features, accompanied by animations that show, for example, how to drag images into the corresponding box. It is important to point out that each of the three minigames shows the tutorial only on the first access.

Saving System A crucial part of the game development was the design of an effective and customized saving system for each of the three mini-games. In the case of Tachistoscopio, the most important parameters to save are the reading speed, the number of correct answers, and the time taken to enter the answer. In Salta con Opp it is important to know the total score of the session, the score for each level and the time it took to answer. for Ernesto l'Aspiratesto it is also important to know the reading speed as well as the result of the quizzes at the end of each level.
In addition, two different formats were used for the save files. For Salta con Opp the "json" format has been used, as it allows to better describe the data structure of this game, being able to more comfortably describe the layout of each level (images, sounds, paths). For the other two it was decided to save in "csv" as this format is more readable and analyzable.

Look and Feel The background and style of the UI creates a woods-like environment.

Mini-Games

2.2.1 Tachistoscopio

Game Overview

Concept The game's aim is to gamify the reading exercises in order to evaluate the reading skills by means of the presentation of words that will cancel at a predefined speed.

Flow summary Firstly, the player needs to input his/her name. Then, the player has to carry out the calibration by reading 10 words consecutively as fast as possible. After that, the game menu shows up and the tutor can select the difficulty level based

on the school period or educational level of the pupil. As the level of difficulty increases, words with an increasing number of syllables will be used for the game. Now the actual tachistoscope begins. The player has to read a word in a short time interval and re-write it. This procedure lasts for ten times consecutively. At the end of the last word the game ends.

Mission statement The game is aimed at challenging the player to read words in a progressively shorter time that allows him to develop global reading in addition to reading letter by letter. For this purpose, the monitoring of reading performances is necessary, as well as creating an educational back up mechanism that entertains the player.

Gameplay and Mechanics

Gameplay The player has to read the word presented in the screen. This word cancels with a specific velocity and modality, so the player must hurry and read it before it cancels. After the cancellation of the word, an input field will pop up and the player has to write the word read before in it.

Mechanics During calibration, the performance index of reading is calculated. Here the player must read to 10 words as fast as he/she can and then press a button to move on to the following word. After each word, the player's reading ability is computed by measuring the time needed to read the whole word and dividing it for the number of characters of the word. This index is used more specifically as a delay factor for cancellation of the word. This speed index can be modulated by the tutor on the Game Menu or by the player during runtime. In the first case, the tutor can increase or decrease the speed of a value equivalent to a reduction or increment of the delay factor of 3 milliseconds/character. In the second case, during the tachistoscope, if the player writes the correct word in the input field for three times consecutively, the delay factor is reduced by 6 milliseconds/character, producing an increment in the speed of cancellation. Otherwise, if the player can not write the word correctly for three times

consecutively, the delay factor increases in favour of the player, hence reducing the speed of cancellation.

The modality of cancellation of the word in the tachistoscope depends on the player's reading speed. If the player has a reading speed lower than 3.00 syllables/second, the word will cancel out letter by letter. In this case every letter will fade at a time interval equal to the delay factor estimated during the calibration. Otherwise, if the player reads faster than 3.00 syllables/second, then the word will cancel out globally. In this case the word is displayed for an interval equal to the delay factor multiplied by the number of characters of the current word. In both cases the letter or the word which is cancelled and substituted by a distractor which covers either the letter or the entire word. Without the distractor the word or letter would be held by the retina for a extended time with respect to that estimated by the calibration. This could falsify the the results of the performance.

Finally, talking of visual feedbakcs, the game must provide either a warning if the player makes an error in typing the word, or a positive feedback if the word typed is correct.

Game Options In the Game Menu the tutor can select the best settings in terms of level difficulty, speed (and hence, modality) of cancellation, and finally the specific syllable to which the player should be trained on. The three levels of difficulty are:

- easy: words with 1 or 2 syllables.
- medium: words with 2, 3 or 4 syllables.
- hard: words with 4, 5 or 6 syllables.

Constrains due to the pedagogical objective The constrains for the player are mainly two. Firstly, since the calibration is fundamental for the definition of the player's reading skills, it is important that the pupil does not approach to this part of the game with superficiality: the button for loading the next word should be pressed only when the current word is read, otherwise a bad calibration will influence the mission statement of the game. The second constrain concerns the tachistoscope, especially the

part where the player has to type the word in the input field. If the player wasn't able to read the whole word, then he/she must not write senseless words. On the contrary is fundamental to save every typed word in order to help clinicians and specialists in the analysis of errors and performances.

Use Case Diagram

The "Use Case Diagram" shown in Fig. 2.4 depicts the iteration schema valid for this game: the main actors are the player and the tutor who can be represented either by the teacher or by the clinician. The player starts the game and trains his/her reading skills by the accomplishment of reading and writing tasks. The calibration module has to be executed only if the player is playing for the first time or after a long time. At the end of the tachistoscope the game will generate a file containing the player's performances, saved locally, which can be analyzed by the tutor. The tutor has the possibility to set the level of difficulty, the syllable and the speed of cancellation of the words in the tachistoscope.

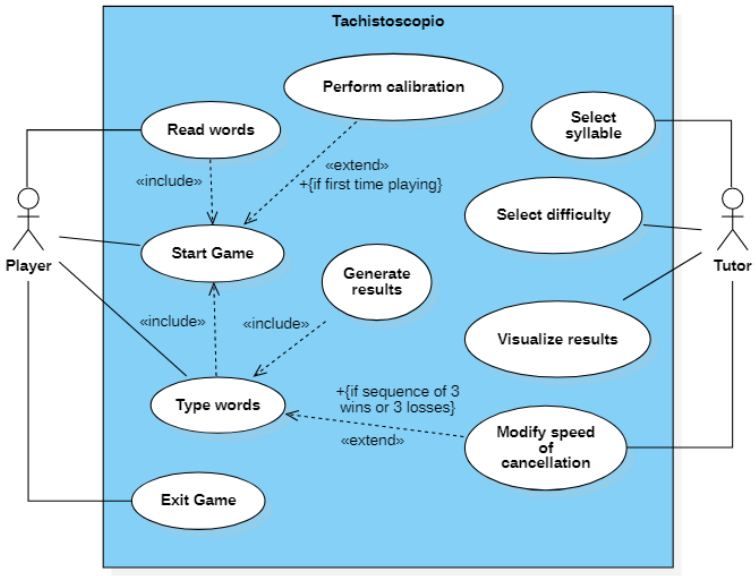


Figura 2.4: *Use Case Diagram of Tachistoscopio, showing the users and the game schema.*

2.2.2 Salta con Opp

Game Overview

Concept The game's aim is to gamify the comprehension and word analysis exercises in order to evaluate and develop the reading skills in a stress-free environment. This is accomplished by means of the spelling of target words, which are associated to images that has to be quickly identified among a series of distractor images and associated to a pathway made of a number of steps equal to the target words syllables.

Flow summary Initially the player is asked to input his/her name. Then, if the player has never been registered before, a brief tutorial about how the game works is introduced to the player. After that, the player will have to choose the difficulty of the game, between easy, medium and hard. The difficulty affects the number of pathways shown, the number of syllables in the target and distractor words and the initial or final syllable of each word. In this scene the player has also the ability to change the modality of pronunciation, between "spelled" and "full" mode. Regardless of the specific difficulty, each session includes 10 levels with 2 target words each. The player has 2 possible attempts for each level. Once all levels have been completed, the game ends.

Mission Statement The game is aimed at challenging the player to distinguish the target words structure in syllables among distractor words that will be more and more similar to the targets as the difficulty increases. Moreover, a countdown timer gives to the player an extra motivation to be quicker in order to complete the level in time. The main objective is to help the player develop quick word comprehension and analysis.

Gameplay and Mechanics

Tutorial A brief tutorial will be shown if a new player is starting the game. It consists of a simple scene where the main character, Opp, presents himself and describes in a dialogue-like way the main characteristics of the game and how it should be played. Also a quick animation shows how to drag and drop the images on the input boxes and

how the countdown timer works. The player has the ability to skip the entire tutorial too, by pressing the “SKIP” button in the top-right corner of the screen.

Gameplay The player listens two words pronounced by an external voice. Each pronounced word is represented by an image on screen. As the voice pronounces the words a countdown timer starts. In the meantime some pathways, made of a number of ”bushes” equal to the target words syllables number, appear on screen with an input box at the end.The player has to identify the listened word the the correct images and, by means of a drag and drop system, assing them to the box at the end of each corresponding pathway. The level ends when two attempts are performed or when the time expires. The whole game ends after 10 levels.

Mechanics For each level are shown four images, two targets and two distractors. Each image, through a drag and drop system, can be dragged on the boxes at the end of each pathway: if the image actually corresponds to that specific pathway, the box glows up green and a short audio clip is played (signaling the correct answer). On the other hand if the image does not correspond to the pathway, the box glows up red and a different audio clip is played.

Game Options The game has three difficulties: easy, medium and hard.

Easy:

- The countdown timer starts from 90 seconds.
- There are only two pathways.
- The two target words (so the pathways) have a number of syllables that differ at least by three.
- The target words have different initial and final syllables from each others.

Medium:

- The countdown timer starts from 30 seconds.

- There are three pathways. The third (distractor) pathway has a different number of syllables from both the target pathways.
- The two target words (so the pathways) have a number of syllables that differ by two or three.
- The target words have same initial or final syllable.

Hard:

- The countdown timer starts from 30 seconds.
- There are three pathways. The third (distractor) pathway has a different number of syllables from both the target pathways.
- The two target words (so the pathways) have a number of syllables that differ by one.
- The target words have same initial or final syllable.

Story, setting and character

Story and narrative The story is very basic, mainly because of target user's age and considered that the primary objective of the game is not storytelling: a little bunny, that likes to jump between bushes, wants the player help in order to find the correct pathway to reach his targets.

Characters In the game there is a single character which is Opp, a little and smiling bunny. The character design is very simple and coloured.

Interface In the game there is only a simple head-up display (HUD) that shows the current level number on a progress bar, placed in the bottom of the screen. This is useful in order to give the player an idea of how much levels are left to complete the session, that could encourage the player to focus in the last levels in order to gain more points.

Control System The player interacts with the game through finger touch, that's more intuitive and straightforward for younger users.

Audio There is a background music played only when the player interacts with the menu. The type of music chosen is based on the most common background songs heard in the vast majority of games for this age. The words pronounced in each level are pre-recorded traks.

Sound Effects There are two types of sound effects played respectively when the image is dragged in the correct box and when is dragged in the wrong box. These two sounds serve the purpose of giving the player a direct acoustic feedback about the performance.

Use Case Diagram

The "Use Case diagram" shown in Fig. 2.5 depicts the iteration schema valid for this game: The main actors are the player and the tutor who can be represented either by the teacher or by the clinician. The tutor can start and exit the game and has the possibility to set the difficulty for the session. Eventually he can also change the pronunciation mode. When the session is over he can visualize the data related to the performance of the single session that is saved locally by the system. When the game is started the player can watch the tutorial if he is playing for the first time. After the game started he can listen to the pronounced words and submit consequently the answers.

2.2.3 Ernesto l'Aspiratesto

Game Overview

Concept The game's aim is to gamify the reading and comprehension exercises in order to evaluate the reading skills in a stress-free environment by means of the presentation of sentences, that will cancel at a predefined speed, and questions which the player has to answer to.

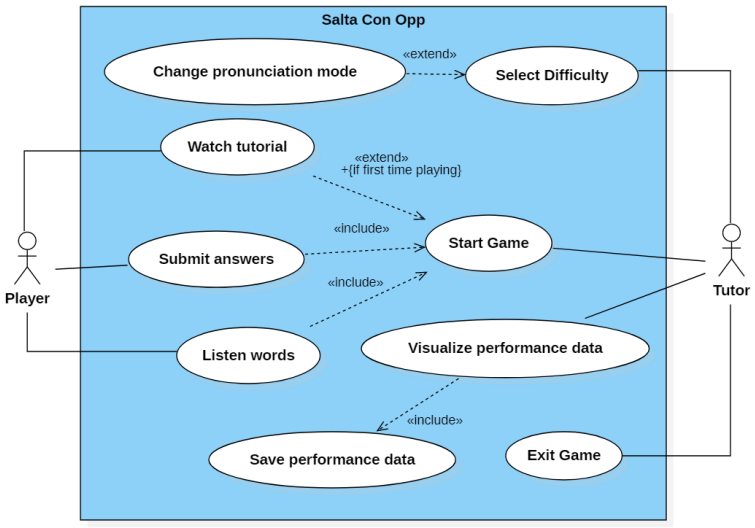


Figura 2.5: *Use Case Diagram of SaltaConOpp, showing the users and the game schema.*

Flow summary Firstly, the player has to type his/her name. After the registration the player has to execute a calibration session where he/she has to read to a series of 10 sentences. After that, the game menu shows up and the tutor can select the level of difficulty for the player's game session. Now the speed-reader starts and the player has to read a series of ten sentences that will cancel at a predefined speed and then answer to a multiple choice question for each of the sentences. At the end of the last question, the game ends and the player is sent back to the main menu.

Mission statement The game is aimed at challenging the player to read words more and more rapidly in order to develop global reading and master the comprehension of the text.

Look and Feel The background and style of the UI creates a woods-like environment.

Gameplay and Mechanics

Gameplay The player has to read the sentence displayed in the screen before it cancels. After the cancellation of the sentence the player has to answer to a multiple choice question with one correct answer out of three.

Mechanics During calibration the player's reading speed is evaluated by dividing the time needed to read the sentence for the total amount of characters contained in the sentence. The resulting index is shown in eq. (2.1).

$$delay(s/character) = \frac{Time\,per\,Sentence}{Sentence\,Length} \tag{2.1}$$

This index is computed for each of the ten sentences in the calibration and at the end, all the values are averaged. The averaged index is used as delay factor in the cancellation of each letter in the speed-reader. This velocity of cancellation can be modulated both by the tutor in the Game Menu and by the player according to his/her performances during runtime, very similar to Tachistoscopio. During the speed-reader the delay of cancellation of each letter can be modulated after every sequence of three correct or wrong answers consecutively. In the first case the delay will be reduced of 3 milliseconds/character, otherwise it will be increased of the same amount. Hence, the more the player answers correctly, the more he/she will be challenged to read faster.

Game Options In the Game Menu the tutor can select the level of difficulty among:

- easy: the sentence contains from a minimum of 1 to a maximum of 38 letters ($\approx$ 33th percentile).
- medium: the sentence contains from a minimum of 39 to a maximum of 48 letters ($\approx$ 66th percentile).
- hard: the sentence contains from a minimum of 49 to a maximum of 84 letters ($\approx$ 100th percentile).

Contrains due to pedagogical objectives The constrain for this game concerns the calibration since it is important that the player reads carefully the sentences. A bad calibration influences negatively the performance in the speed-reader.

Story, setting and character

The main character of the game is Ernesto, which is an ant eater but particularly gluttonous of letters and words: as it sees one, it can't resist from eating it.

Use Case Diagram

The "Use Case Diagram" shown in Fig. 2.6 depicts the iteration schema valid for this game: The main actors are the player and the tutor who can be represented either by the teacher or by the clinician. The player starts the game and reads 10 sentences which he/she has to answer a multiple choice question of. The calibration module has to be executed only if the player is playing for the first time. At the end of the spead-reader the game will generate a file containing the player's performances, saved locally, which can be analyzed by the tutor. The tutor has the possibility to set the level of difficulty and the speed of cancellation of the sentence in the speed-reader.

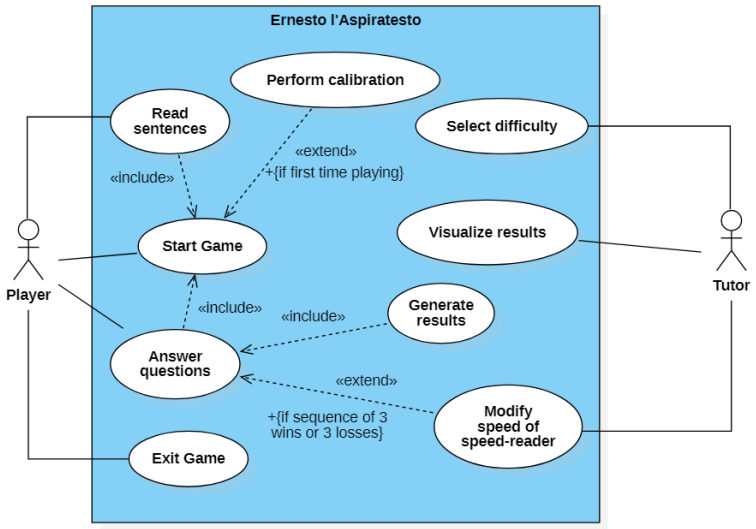


Figura 2.6: *Use Case Diagram of ErnestoL'Aspiratesto, showing the users and the game schema.*

2.3 Nielsen Heuristics

Decisions regarding the game design were made taking into account instructions given by clinicians and guidelines provided to us by the Nielsen heuristics. These heuristics were firstly conceived by Jacob Nielsen, in 1990, and then further developed in 1994. He codified a list of 10 general design principles useful to define good design for interfaces (pc, web mobile). Here is the list of these principles and how they were put into practice [55]:

1. **Visibility of system status**: The design should always keep users informed about what is going on, through appropriate feedback within a reasonable amount of time. To satisfy this principle all the game scenes are equipped with indications about the current state of the game. As an example, in “Salta con Opp” a progression bar tells the player which specific level he is in and how many of these are left to end the session.

2. **Match between system and the real world**: The design should speak the users’ language. It’s important to use words, phrases and concepts familiar to him and to use real-world conventions, in order to make the information appear in a natural and logical order. As a matter of fact, the game has been designed using a language understandable even for primary school students.

3. **User control and freedom**: Users often perform actions by mistake. They need a clearly marked ”emergency exit” to leave the unwanted action without having to go through an extended process. for this reason, the game scenes are provided with specific buttons that allow to retrace your steps in case of error.

4. **Consistency and standards**: Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform and industry conventions. User’s expectation on a digital product is based of what types of application, websites and games they interact with during daily life so it’s important adopt use commonly used conventions for the general design of the product. Principle implemented by using, for example, a gear icon to indicate settings or a back arrow icon to indicate the possibility to return to the previous page.

5. **Error prevention**: Good error messages are important, but the best designs carefully prevent problems from occurring in the first place. Either eliminate error-prone conditions, or check for them and present users with a confirmation option before they commit to the action. For this reason, feedbacks have been inserted both in the actual game scenes but also in the different menus: for

example, in “Tachistoscopio” the system warns the player if an incorrect syllable is chosen to start the game.

6. **Recognition rather than recall**: Minimize the user’s memory load by making elements, actions, and options visible. The user should not have to remember information from one part of the interface to another. Information required to use the design (e.g. field labels or menu items) should be visible or easily retrievable when needed. In fact, every scene is provided with clearly visible titles and each input field has a description about its function.

7. **Flexibility and efficiency of use**: Shortcuts — hidden from novice users — may speed up the interaction for the expert user such that the design can cater to both inexperienced and experienced users. Allow users to tailor frequent actions. For example, in “Salta con Opp” the tutor can skip the tutorial if not needed.

8. **Aesthetic and minimalist design**: Interfaces should not contain information which is irrelevant or rarely needed. Every extra unit of information in an interface competes with the relevant units of information and diminishes. So is important to focus the interface design on the essential aspects. In this way, the game scenes have been designed trying to make them as minimal as possible, especially during the game scene where the aim is to minimize distractions for the player.

9. **Help users recognize, diagnose, and recover from errors**: Error messages should be expressed in plain language (no error codes), precisely indicate the problem, and constructively suggest a solution.

10. **Help and documentation**: It’s better if the system doesn’t need any additional explanation. However, it may be necessary to provide documentation to help users understand how to complete their tasks. This was satisfied by creating ad hoc tutorial for each minigame.

2.4 System Usability Scale

The System Usability Scale (SUS) [49] provides a "quick and dirty", reliable tool for measuring the usability. It consists of a 10 item questionnaire with five response options from 1 (Strongly disagree) to 5 (Strongly agree). This scale helps determining if the video game was easy to use and navigate or too difficult and cumbersome. The ten questions are:

1. I think that I would like to use this game frequently.
2. I found the game unnecessarily complex.
3. I thought the game was easy to use.
4. I think that I would need the support of a technical person to be able to use this game.
5. I found the various functions in this game were well integrated.
6. I thought there was too much inconsistency in this game.
7. I would imagine that most people would learn to use this game very quickly.
8. I found the game very cumbersome to use.
9. I felt very confident using the game.
10. I needed to learn a lot of things before I could get going with this game.

For the evaluation of the perceived usability of the games in this study a particular type of usability questionnaire called P-SUS (Pictorial System Usability Scale) was used. It is a refined version of the classic SUS questionnaire, completed with pictorial images (Fig. 2.7) that are mainly aimed at increasing the motivation and participation of children in the evaluation of the gaming experience [56].

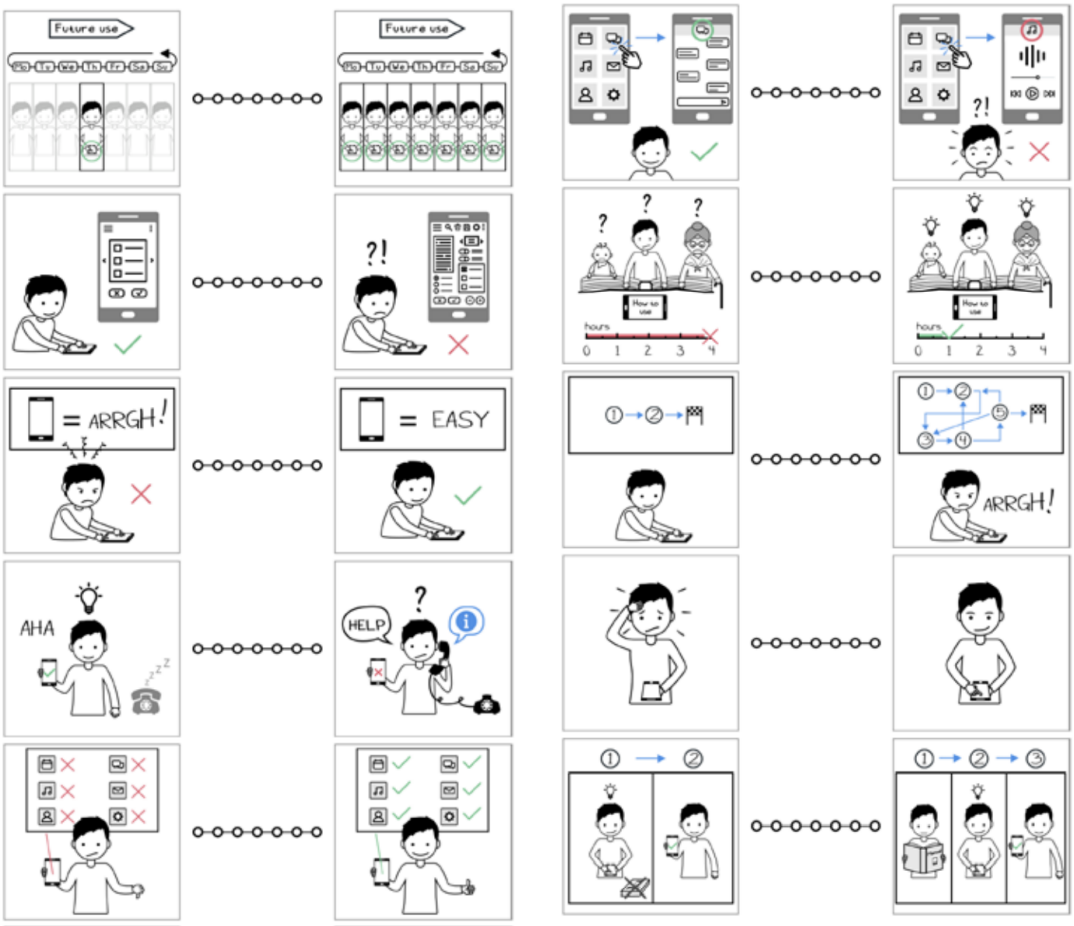


Figura 2.7: *A pictorial version of the ten verbal SUS items with positive and negative extreme points and seven-point scale.*

2.5 Characterization questionnaire

The characterization questionnaire is a set of questions about the participant, including name, gender, class, birth date and dominant hand, experience with a tablet and videogames. The questions along with possible answers are:

1. Subject ID
2. Is Italian your first language?
    - No
    - Yes
3. Have you ever used a tablet?
    - No
    - Yes
4. How frequently do you use a tablet?
    - Everyday
    - At least once a week
    - Less than once a week
    - Other (specify)
5. What do you use a tablet for?
    - Gaming
    - Watching videos
    - Drawing
    - Other (specify)
6. Do you play videogames?
    - Everyday
    - At least once a week

- Less than once a week

7. What type of videogames?

2.6 BVSCO-2

It is the Batteria per la Valutazione della Scrittura e della Competenza Ortografica [57]. It is a comprehensive tool for assessing all aspects involved in the development of writing. Each test is administered on lined paper sheets and lasts one minute. The first test requires to transcribe in a continuous way, and in an alternating way, the cursive letters "l" and "e" joined together so as to be produced with a continuous movement. The second test consists in writing the word "uno" in cursive or in block. The last test consists in writing numbers in letters, again either in cursive or in block. It is important that the examiner warns the participant that these are speed tests, so it is important that the task is understood before starting the trial. These tests were administered to pupils in order to generate a wide-spectrum analysis and therefore investigate the connection between performance in mini-games and performance related to writing.

2.7 Data Acquisition

2.7.1 Protocol

The acquisition was conducted during school-time between the end of October and the beginning of November Fig. 2.8. Firstly the participants played at Tachistoscopio and therefore Salta con Oop. The third game, Ernesto l'Aspiratesto, was excluded from the data acquisition process since it shares lots of characteristics with Tachistoscopio: the indexes of reading speed are basically the same, but while Ernesto calibrates this index by means of sentences, Tachistoscopio uses words. Moreover the tachistoscope is a tool more suitable for a wider range of ages. For these reasons Tachistoscopio was preferred to Ernesto for the acquisitions. For Tachistoscopio the level of difficulty chosen for both students of second and third grade of primary school was medium. As for "Salta con Opp", two difficulties were chosen: medium and hard. The average difficulty

was administered to both second and third grade pupils. The hard difficulty was administered only to third-grade children. This choice was made in order to evaluate the evolution of the reading skills and phonetic elaboration capabilities between the two classes. At the end of the games, the pupil was asked to fill in the characterization questionnaire and the SUS. Finally, the player had to carry out the BVSCO-2.

Figura 2.8: *Picture of the acquisition process taken in the primary school "Baracca" (VA).*

2.8 Data Analysis

2.8.1 System Usability Scale scoring

The answers of the SUS range from 1 to 5, but these scores must not be intended as "worst" or "best"; participants will rank each question from 1 to 5 based on how much they agree with the statement they are reading and, according to the number of the question, a higher score will mean either a better or worse judgement of the user.

- For each of the odd numbered questions, 1 must be subtracted from the score.
- For each of the even numbered questions, the score must be subtracted to 5.
- The new results must be added and multiplied by 2.5.

The final number is the score out of 100, although it is not a percentage but a clearer way of seeing the Usability score. The average SUS score is 68 , obtained as the average scores of 500 studies [58]. A SUS score above a 68 would be considered above average and anything below 68 is below average. More in general the score can be classified through a letter-grade system based on percentile ranks, as shown in Fig. 2.9.

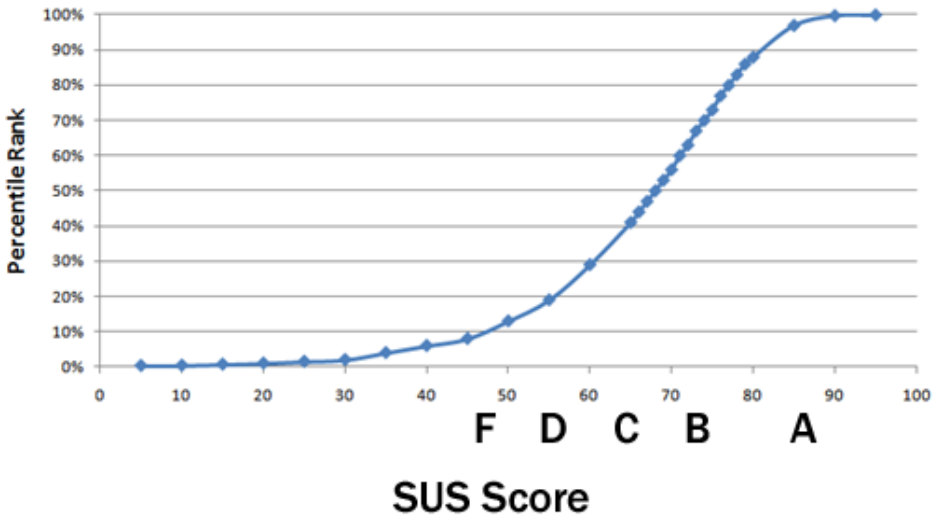


Figura 2.9: *Percentile ranks associate with SUS scores and letter grades*

It is required to score above an 80.3 to get an A (the top 10% of scores). Scoring at the mean score of 68 gets a C and anything below a 51 is an F (putting the score in the bottom 15%).

2.8.2 BVSCO-2 scoring

The final score is computed by counting the number of graphemes made.
For the first test, the "le" sequence, graphemes that do not respect the sequence are not counted. For example, in a sequence "leleele", only 6 graphemes are counted as correct.
For the second and third trials, the "uno" sequence and the numbers written in letters, the number of graphemes are counted without giving relevance to the quality of the form of the grapheme, as it is sufficient to identify it. Every grapheme has to be counted, even if words contain mistakes or are incomplete, but obviously without considering the missing grapheme (e.g., "diciasette" = 10 graphemes).

2.8.3 Statistical analysis

feature selection

Data used to carry out the statistical analysis is the result of a combination of parameters acquired from game, characterization questionnaire, and SUS questionnaire. Not all data were selected. First of all the qualitative evaluation of error on the specific word for both mini−games has not been evaluated. Instead, a quantitative evaluation on the number of errors was carried out, so the parameter used to discern a good performance from a bad one in both mini−games is the score in percentage of the total amount of attempts. In *Tachistoscopio*, the value of reading speed is measured both in seconds/letter and in syllables/second, but only the last mentioned is selected for data analysis. In fact, while the former is used mainly to calibrate the word's exposure time, the latter is the conversion of the former in the unit of measure used by the clinicians to assess reading speed. Other game parameters chosen for statistical analysis were the score measured as a percentage over the 10 words, and the increase of reading speed at the beginning and conclusion of the mini−game. The level of difficulty of *Tachistoscopio* was discarded since all participants were administered on medium difficulty. Moving to *Salta con Opp* mini−game, all participants were tested on medium difficulty and a small sub−group of them also in hard difficulty. Therefore the parameters selected for data analysis were 4: the final score in percentage and the average time to complete the single level both in medium and hard difficulty. Finally, the scores for the three BVSCO tests, which in this case correspond to the total amount of graphemes written during each exercise, are included into the analysis in order to estimate if some correlation between reading and handwriting performances occured.

data analysis

Statistical analysis was performed in Matlab R2020b. To investigate the effect of categorical variables on numerical variables, nonparametric tests were implemented and, since they do not assume that the samples are normally distributed, differences in medians examined. In details, the Wilcoxon rank−sum test was used to compare independent unpaired samples for the analysis of the differences of game parameters and

BVSCO tests between either class or gender. In addition, the Wilcoxon signed−rank test was used to conduct a paired difference test of performances, in playing *Salta con Opp* in two difficulties, on the sub−group of participants who played the mini−game both in medium and hard difficulty. Results were visualized by means of boxplots.

Then, data were analyzed by exploring their distribution through the Lilliefors test. It returns a test decision and its p−value for the null hypothesis that the data comes from a distribution in the normal family, against the alternative hypothesis that it does not come from such a distribution. The Lilliefors test is a two-sided goodness-of-fit test suitable when the parameters of the null distribution are unknown and must be estimated. The test of normality was performed to carry out the correlation analysis to get an idea of the relationship between the data. A matrix of pairwise linear correlation coefficient between each pair of columns in the input matrix of data was developed. The type of correlation differed according to whether the pair of variables had normal distribution or not. In case of two normally distributed variables, the type of correlation was set to "Pearson". Otherwise it was set to "Spearman" if at least one of the two variables was not normal. The correlation matrix was visualized in a heatmap, where all the correlation coefficients are depicted with colors from white to blue: the more the correlation coefficient is higher in absolute value and the more its color becomes blue (if positive correlation) or white (negative correlation).

Finally, a multiple regression was performed in R-4.1.2 to investigate relationships between all the confounding and game's variables, used as independent variables, and the results of the three BVSCO tests separately, used as dependent variables. In order to avoid multicolinearity, a feature selection was performed, and the variable with the lowest Variance Inflation Factor was selected, the other two eliminated.

Variable	**Definition**
Gender	0 = male; 1 = female
Italian mother-tongue	0 = non-Italian; 1 = Italian
Class	0 = II grade; 1 = III grade
Tablet familiarity	0 = non familiar; 1 = familiar
Tablet frequency use	From 1 (less than once a week) to 1 (everyday)
Video Game	0 = non-videogame player; 1 = videogame player
Easy	From 1 (not at all) to 5 (very much)
Entertaining	From 1 (not at all) to 5 (very much)
Boring	From 1 (not at all) to 5 (very much)
Favorite	0 = Salta con Opp; 1 = Tachistoscopio
Reading speed (pre)	[syllable/second] acquired during calibration in Tachistoscopio
Reading speed (post)	[syllable/second] after the 10 words in Tachistoscopio
Reading Δ speed	[syllable/second] Reading speed (post) - Reading speed (pre)
TAC score	Tachistoscopio final score
TAC first	0 = 1st word incorrect; 1 = 1st word right
TAC middle	0 = 5th word incorrect; 1 = 5th word right
TAC last	0 = 10th word incorrect; 1 = 10th word right
OPP_M score	Salta con Opp score at medium difficulty
OPP_H score	Salta con Opp score at hard difficulty
OPP_M time	Average time to complete a single level at medium difficulty
OPP_H time	Average time to complete a single level at hard difficulty
BVSCO 4a	Number of graphemes in 'lelele' exercise
BVSCO 4b	Number of graphemes in 'uno uno uno' exercise
BVSCO 4c	Number of graphemes in 'uno due tre' exercise
SUS	System Usability score

Tabella 2.1: *Data Analysis variables*

Capitolo 3

RESULTS

3.1 Games Implementation

In this section, the developmental results of the three games will be presented, starting from the functional specifications recommended by the clinicians.

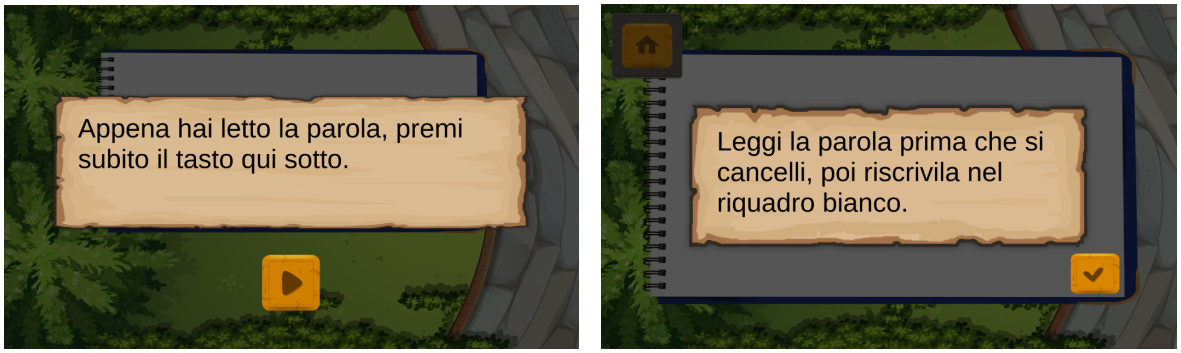
3.1.1 Tachistoscopio

Tutorial

On the first start of the game the player is presented with two tutorials, one for calibration and one for the actual game session. This in accordance with the heuristic of help and documentation, by providing a step-by-step explanation of each game mechanic, to help the user understanding how to complete the task. From the second login the tutorials will be automatically skipped, in accordance with the flexibility and efficieny of use heuristic, which allows to speed up the interaction with the game for a more experienced user. In Fig. 3.1 are shown the instructions respectively for the exploitation of the calibration and tachistoscope.

Calibration

Fig. 3.2 shows an example of the calibration scene. Here the player has to read the word as quick as possible and then press the button down below to proceed. The player's



(a) **(b)**

Figura 3.1: *(a) Instructions before the calibration of Tachistoscopio (b) Instruction before Tachistoscopio game session.*

reading ability is computed by measuring the time needed to read the whole word and dividing it for the number of characters of the word. This calculation allows to obtain a first performance index of speed measured in seconds/character for the single word. See eq. (3.1).

$$delay(sec/ch) = \frac{Time\,per\,Word}{Word\,Length} \tag{3.1}$$

At the end of the calibration, these performance indexes are averaged for the 10 words in order to obtain the final performance index for reading speed. Since the reference measure for reading speed used by clinicians is measured in syllables per second [35], this averaged index is then transformed in a new speed index by means of a constant as shown in eq. (3.2).

$$V(syll/sec) = \frac{1}{v \cdot 2.2\,\frac{characters}{syllable}} \tag{3.2}$$

The design chosen for this scene is minimalist since only the notebook-like background where the word is displayed and the button to move on are needed.

Game Menu

This scene allows the tutor to customize the game session as much as possible very rapidly. In particular, as shown in Fig. 3.3, the tutor can modify the reading speed, by

Figura 3.2: *Calibration scene in Tachistoscopio. The button under the notebook-like background allows to calculate the time needed for reading the current word and to load the next word.*

increasing or decreasing it through the two arrows on the right, and the current speed is constantly visible in red box, to keep the user informed in real time.

Figura 3.3: *Game Menu. The red box is where the reading speed is displayed after the calculation in order to provide a first screening of the player's reading skills.*

Besides that, the tutor can also set a specific syllable by typing it in the green input field, and the level of difficulty by means of a drop-down menu as shown in (Fig. 3.4).

Finally, the bottom left button allows to start the game with the selected game options, the bottom right button allows to reset all the options and the top left button allows to exit the game.

Figura 3.4: *Game Menu of Tachistoscopio. The blue highlighted is the drop-down menu where the tutor can select the level of difficulty (in this case, MEDIO). The green highlighted is an input field where the tutor can type the syllable (in this case DO).*

Game scene

There are two possible scenarios for the gameplay. If the reading speed is lower than 3.00 syllables/second, the word is cancelled out letter by letter and each one of them is substituted with a distractor as shown in (Fig. 3.5). If the reading speed is above 3.00 syllables/second, the word will cancel out globally and a wider distractor, covering all the word length, will be shown instead of it, as shown in (Fig. 3.6). The distractor is represented by a noisy distribution of black dots.

Figura 3.5: *Tachistoscopic cancellation letter by letter of the word TORBIDO*

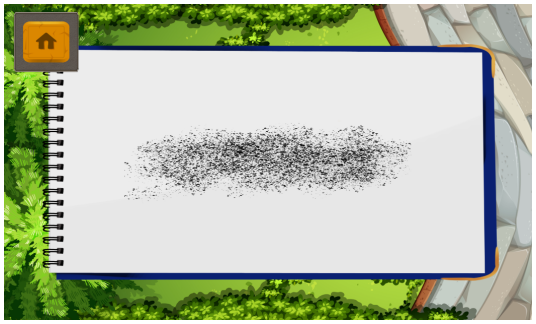


Figura 3.6: *Global tachistoscopic cancellation.*

If the game settings for the current trial seems to be particularly hard or inappropriate for the player, a "Home" button, located in the top left corner of the screen, allows to go back to the game menu and prevents the player to get frustrated.

Feedback

Visual feedbacks pop up at the end of each level. As shown in Fig. 3.7 and Fig. 3.8, the game provides a positive feedback if the typed word is correct, or a warning if the player makes an error typing the word, also showing which is the correct solution. This visual response is designed to help players recognize and recover from errors.

Figura 3.7: *The player made a mistake: the feedback panel shows the error.*

Figura 3.8: *The player has succeed: the next word will be displayed after a countdown from 3 s.*

Another visual warning appears in the game menu if the tutor erroneously selects a syllable which is not included in the list of words, see Fig. 3.9. This prevents the tutor from starting a trial in which the game options could not be respected.

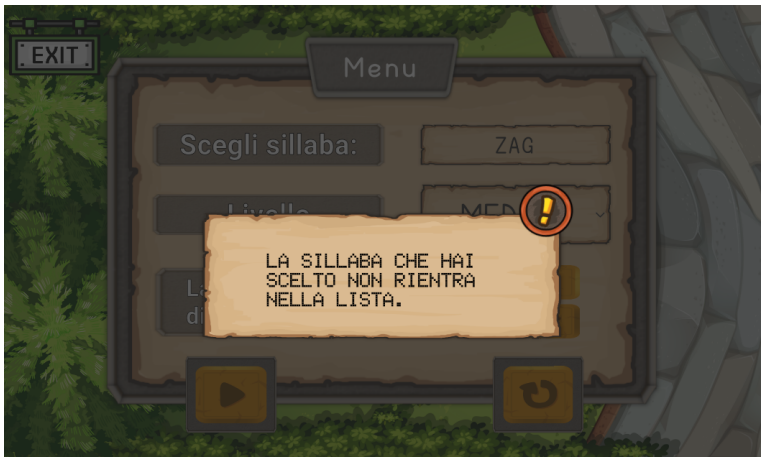
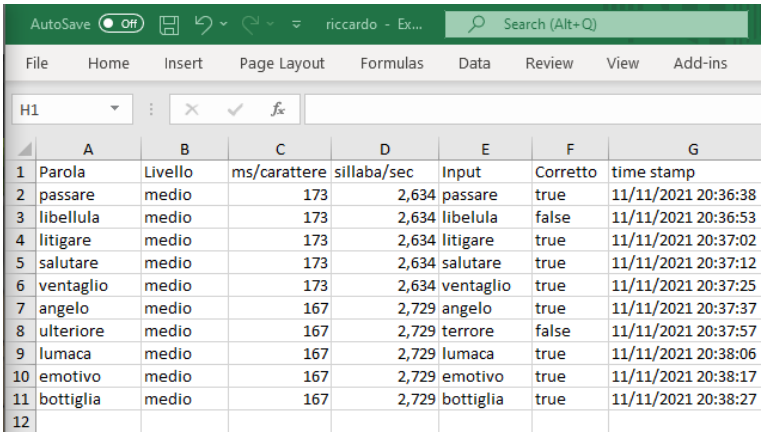


Figura 3.9: *Game Menu of Tachistoscopio. The warning appears because the tutor set the syllable ZAG in the game options.*

Saving system

The player's performances are saved in a csv file named with the player's name. Once the file has been created, every time the players starts the game, he/she won't have to perform the calibration and the csv will update with new performances. As shown in Fig. 3.10, the parameters stored are the following:

- Word displayed
- Level of difficulty chosen for the trial
- Speed of cancellation in milliseconds/character
- Speed of cancellation in syllables/second
- Word typed inside the input field by the player
- Whether the word typed was correct or not
- Time stamp



	A	B	C	D	E	F	G
1	Parola	Livello	ms/carattere	sillaba/sec	Input	Corretto	time stamp
2	passare	medio	173	2,634	passare	true	11/11/2021 20:36:38
3	libellula	medio	173	2,634	libelula	false	11/11/2021 20:36:53
4	litigare	medio	173	2,634	litigare	true	11/11/2021 20:37:02
5	salutare	medio	173	2,634	salutare	true	11/11/2021 20:37:12
6	ventaglio	medio	173	2,634	ventaglio	true	11/11/2021 20:37:25
7	angelo	medio	167	2,729	angelo	true	11/11/2021 20:37:37
8	ulteriore	medio	167	2,729	terrore	false	11/11/2021 20:37:57
9	lumaca	medio	167	2,729	lumaca	true	11/11/2021 20:38:06
10	emotivo	medio	167	2,729	emotivo	true	11/11/2021 20:38:17
11	bottiglia	medio	167	2,729	bottiglia	true	11/11/2021 20:38:27
12							

Figura 3.10: *csv file with including the player's performances after the tachiscoscope.*

3.1.2 Salta con Opp

Tutorial

Fig. 3.11 shows the tutorial of the game, shown only on first access. Here the main character, Opp, presents himself and guides the player through the main mechanisms

of the game. In the top right corner is present a "skip" button that allows the player to skip the tutorial if needed.

Figura 3.11: *Salta con Opp. Tutorial: The tutorial scene is animated showing how to drag and drop the correct images and showing the countdown timer. The skip button stops the tutorial and brings the player to the difficulty selection scene.*

Difficulty selection

Here the tutor selects the difficulty for the game session (Fig. 3.12). In the top right corner the gear icon opens the pronunciation mode settings (Fig. 3.13), where the tutor can select how the external voice should pronounce the target words.

Figura 3.12: *Salta con Opp. Difficulty: There are three selectable difficulties. The gear button opens the pronunciation mode settings.*

Figura 3.13: *Salta con Opp. Pronunciation mode settings: Two selectable modes: whole and hyphenated pronunciation*

Game Scene

In Fig. 3.14 is shown an example of game scene. It is taken from a medium difficulty session. On the left side there are the three pathways, two of which represent the two target words pronounced. On the right side are displayed the four draggable images, among which there are the two target images. In the bottom is shown the progress bar that tells the player which level he is currently playing. In the top left corner is visible the total number of attempts left for this specific level, while in the top central part the "speaker" button allows the player to play back the pronounced words. Finally in the top right corner the timer tells the player how much time is left before the level ends.

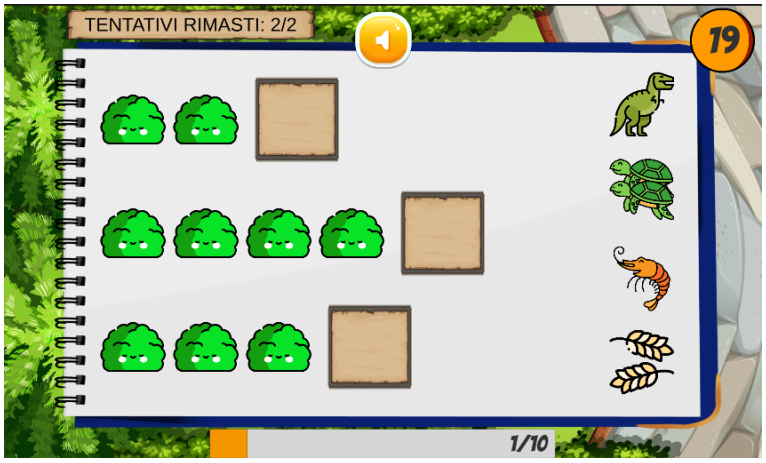


Figura 3.14: *Salta con Opp. Game scene: Example of game level at medium difficulty.*

Feedback

At each level are provided two type of feedback: an auditory feedback, represented by the wrong and correct sounds played at each attempt, and a visual feedback that colors the input box in green if the dragged image was correct (Fig. 3.15) or in red if it was incorrect (Fig. 3.16).

Besides that, at the end of the session a panel showing the total score is displayed (Fig. 3.17).

Figura 3.15: *Salta con Opp. Correct visual feedback.*

Figura 3.16: *Salta con Opp. Wrong visual feedback.*

Figura 3.17: *Salta con Opp. Final score panel.*

Saving system

The game includes a saving system that creates automatically a unique folder for each different player registered in the game. A single json file is created for every single game session and, as shown in Fig. 3.18, contains the following parameters:

- Difficulty
- Draggable images for each level
- Function of each draggable image: target or distractor
- Attempts for each level: input slot, dragged image, outcome, timestamp of the attempt
- Score for each level and total score of the entire session


```
{
    "difficulty": "easy",
    "level": [
        {
            "frasi_tot": [
                "vela_Target",
                "rinoceronte_Target",
                "salsiccia_Distractor",
                "salami_Distractor"
            ],
            "attempts": [
                "Item_Slot: vela; State_Slot: Box_Target; Dragged_Image: vela; SUCCESS; TimeStamp: 22:58:24",
                "Item_Slot: rinoceronte; State_Slot: Box_Target; Dragged_Image: rinoceronte; SUCCESS; TimeStamp: 22:58:25",
                "Start Time: 22:58:20"
            ],
            "levelResult": 2
        },
        {
            "frasi_tot": [
                "buccia_Target",
                "pennarello_Target",
                "pollice_Distractor",
                "bicchiere_Distractor"
            ],
            "attempts": [
                "Item_Slot: buccia; State_Slot: Box_Target; Dragged_Image: buccia; SUCCESS; TimeStamp: 22:58:33",
                "Item_Slot: pennarello; State_Slot: Box_Target; Dragged_Image: pennarello; SUCCESS; TimeStamp: 22:58:36",
                "Start Time: 22:58:30"
            ],
            "levelResult": 2
```


Figura 3.18: *Salta con Opp. Save file structure.*

3.1.3 Ernesto l'Aspiratesto

Tutorial

The tutorial for Ernesto l'Aspiratesto is very basic and consists of a dialogue scene where Carletto the hawk, the character that introduces the player to the game, explains

the main rules to follow for completing the calibration and the main objective of the game (Fig. 3.19). The tutorial can be skipped at the beginning, where the player is asked if is playing the game for the first time.

Figura 3.19: *Ernesto l'Aspiratesto. Tutorial scene with Carletto the hawk.*

Calibration

The calibration is very similar to the one seen in Tachistoscopio. The main changes relate to the UI style (Fig. 3.20).

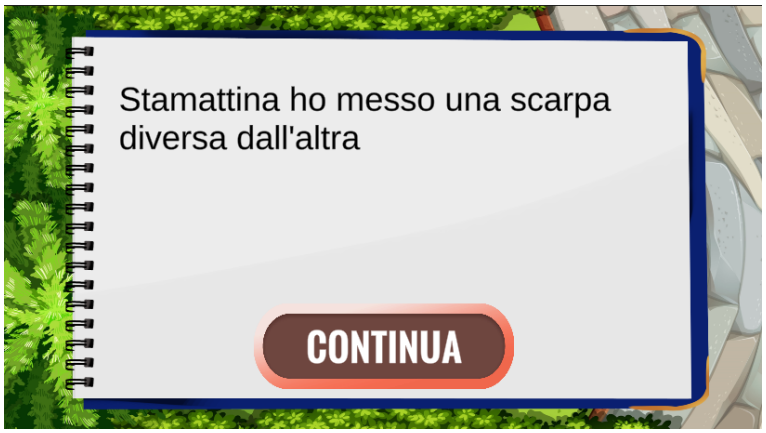


Figura 3.20: *Ernesto l'Aspiratesto. Calibration Example screen.*

Difficulty selection

The difficulty of the game can be modulated in two different ways: by selecting the level of difficulty, as shown in Fig. 3.21, and hence modifying the sentences' length, or

by modifying the speed of cancellation of the letters, as shown in Fig. 3.22, where the tutor can either modify the reading speed or make the player repeat the calibration. The option of repeating the calibration is useful if the tutor wants to calibrate again the player after a training to see whether he/she improved the reading skills after playing constantly.

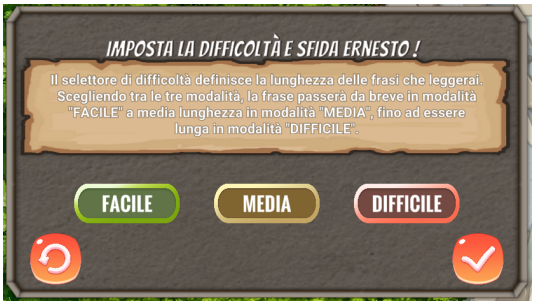


Figura 3.21: *Ernesto l'Aspiratesto. Difficulty selection screen.*

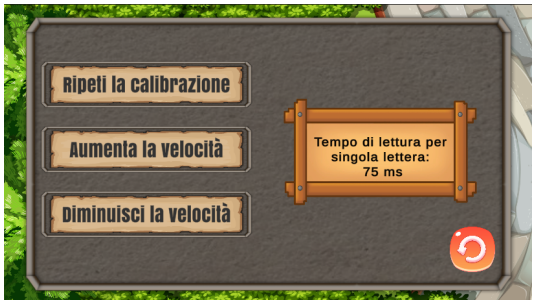


Figura 3.22: *Ernesto l'Aspiratesto. Reading speed settings.*

Game scene

The game scene was designed to be aesthetically simple and minimalist, by choosing a wood-like panel for the background where Ernesto and the sentence could be displayed on. Fig. 3.23 shows Ernesto setting the pace of reading, while Fig. 3.24 shows the question and answer session where the player must select the correct answer to the question about the sentence shown in Fig. 3.23.

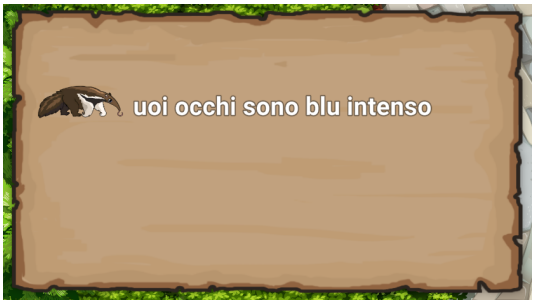


Figura 3.23: *Speed-reader.*

Figura 3.24: *Question and answers: the player has to press the correct answer among three options.*

Feedback

Feedback are simple and clear: if the players answers correctly to the quiz, the box with the correct answers becomes green when pressed, otherwise it colors in red.

Saving system

Similarly to Tachistoscopio the parameters are saved inside a csv file named with the player's name. As shown in Fig. 3.25, the parameters stored are the following:

- Sentence displayed
- Sentence's index inside the original file of words
- Speed of cancellation in syllables/second
- Level of difficulty
- Correct answer
- Wrong answer 1
- Wrong answer 2
- Time to answer in seconds
- Time stamp

File Home Insert Page Layout Formulas Data Review View Add-ins Help

J20

	A	B	C	D	E	F	G	H	I
1	Frase	indiceFrase	syll/sec	Difficoltà	RispostaCorretta	RispostaErrata1	RispostaErrata2	TimeToAnswer	time stamp
2	Quei calzini sono	1251	2,778	Easy	Sciupati	Nuovi	Sporchi	4,741	11/11/2021 21:59:14
3	I pinguini vivono i	732	2,778	Easy	Pinguini	Orsi	Gufi	3,354	11/11/2021 21:59:27
4	La vipera vive sola	1127	2,778	Easy	Vipera	Coccodrillo	Delfino	0,9	11/11/2021 21:59:37
5	La pasta è pronta	724	2,778	Easy	Pronta	Penne	Condita	3,318	11/11/2021 21:59:47
6	Serena lasciò la va	1114	2,83	Easy	In treno	In albergo	A casa	5,515	11/11/2021 22:00:02
7	Il caldo del forno l	189	2,83	Easy	Il caldo	Il fuoco	Il drago	4,102	11/11/2021 22:00:17
8	I pirati hanno una	506	2,83	Easy	Pirati	Piloti	Tavolo	7,868	11/11/2021 22:00:35
9	In primavera ci sor	838	2,884	Easy	In primavera	Sul tetto	In estate	4,023	11/11/2021 22:00:48
10	I suoi occhi sono b	677	2,884	Easy	I suoi occhi	I suoi fiumi	Gli occhiali	2,485	11/11/2021 22:01:45
11	A Giada piace tant	1167	2,884	Easy	Yogurt	Yo yo	Gelato	1,364	11/11/2021 22:01:55

Figura 3.25: *csv file with including the player's performances after the speed-reader.*

3.2 Data Analysis

3.2.1 Participants

Twenty-eight children (age: 7.32 ±0.72) participated in the study: 13 from second grade of primary school (7 females and 6 males, age: 6.69 ±0.48) and 15 from third grade of primary school (8 females and 7 males, age: 7.86 ±0.35). Four children were not Italian native speakers (all in third grade). 26 children were already familiar with a tablet. Among these, 57.7% (n = 15) used it everyday and 42.3% used it at least once a week. Diagnostic parameters of reading speed and accuracy were defined for the assessment of reading in second and third grade students, as shown in Sec. 1.3.3. From the data collected on 28 students, some assessments were made on the grades. For second grade 6 participants have a reading speed below the average value of 1.43 syllables/second, which is the standard value for students at the beginning of second grade of primary school. Concerning third grade, 6 participants read slower than 2.9 syllables/second, which is the average reading speed for third graders at the beginning of the school year. The two standards for reading speed are referred to the measures taken by the MT tests for the evaluation of reading skills [35].

3.2.2 Scores of the game

Tachistoscopio

The results of the Wilcoxon rank sum tests show a significant difference (p = 0.0046) between the scores of *Tachistoscopio* among the two classes: Fig. 3.26 shows how third graders perform better than second graders. No significant difference (p = 0.74) emerges in the final score between females (0.75 ±0.25) and males (0.67 ±0.32). ±0.32).

The other reading parameters that were captured from the game are the reading speed measured at calibration and its increment measured at the end of the mini-game. Again, the results are shown grouped by class and gender.
As shown in Fig. 3.28, reading speed changes significantly from second grade (1.30 Syllables/second ±0.62 Syllables/second) to third grade (2.24 Syllables/second ±0.67

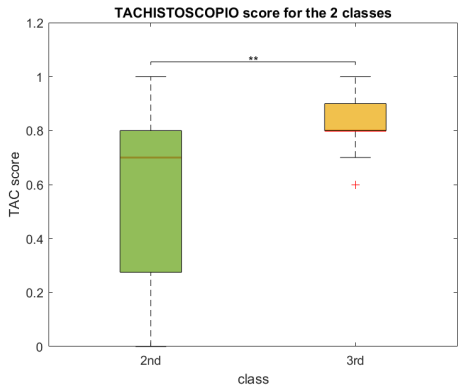


Figura 3.26: *The figure shows the score of Tachistoscopio, in medium difficulty, for the two classes.*

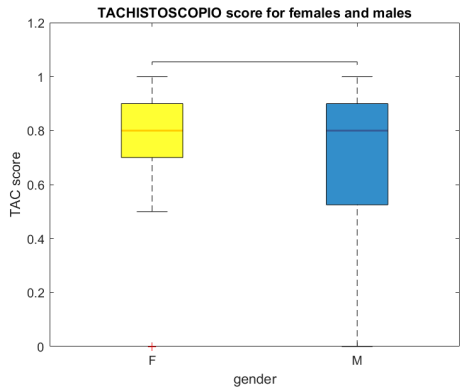


Figura 3.27: *The figure shows the score of Tachistoscopio, in medium difficulty, for the two genders. There is no statistical difference.*

Syllables/second), as confirmed by a p−value of 0.0008. Regarding gender, as seen in Fig. 3.29, males show a tendency to read faster than females (2.11 Syllables/second ±0.93 Syllables/second, against 1.54 Syllables/second ±0.54 Syllables/second), but the difference is not significant (p = 0.052).

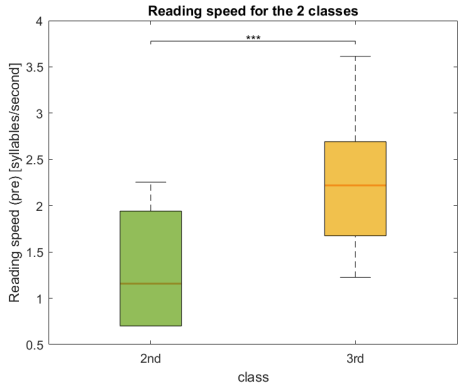


Figura 3.28: *The figure shows the reading speed measured by the mini-game in the two classes. In third grade, the reading speed is significantly higher than in second grade. The three asterisks mean a* $p \leq 0.001$.

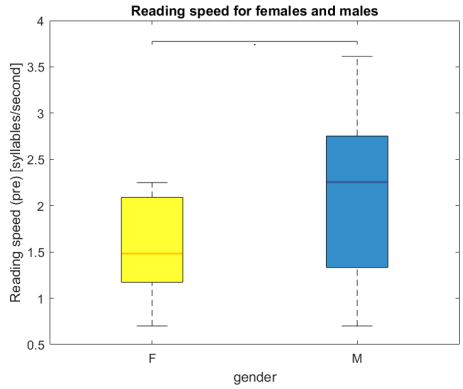


Figura 3.29: *The figure shows how males appear to read faster than females. The difference is not significant.*

Regarding the increase Δ in reading speed, trends by class and gender are shown in Fig. 3.30 and Fig. 3.31 respectively. Similarly to reading speed, the increment at the end of *Tachistoscopio* is significantly greater for third graders than for second graders (p = 0.0034). The increase in speed for males seems more evident than that for females, however, significance is not reached (p = 0.079).

Figura 3.30: *The figure shows the increase in reading speed after playing Tachistoscope assessed for the two classes. Third graders experience a significantly ($p \leq 0.01$) greater increase than second graders.*

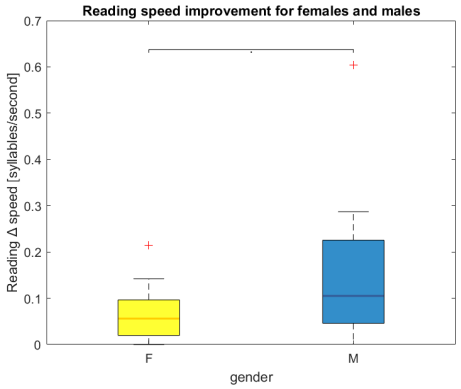


Figura 3.31: *Males show a greater increase in reading speed than females. Non-significant increase ($p \leq 0.1$).*

Salta con Opp

With the same "medium" difficulty, the *Salta con Opp* results, as seen in Fig. 3.32, show a marked difference between the two classes: second graders score a significantly lower final score than third graders (p = 0.0015). Regarding gender, as shown in Fig. 3.33, no significant difference is reached (p = 0.54).

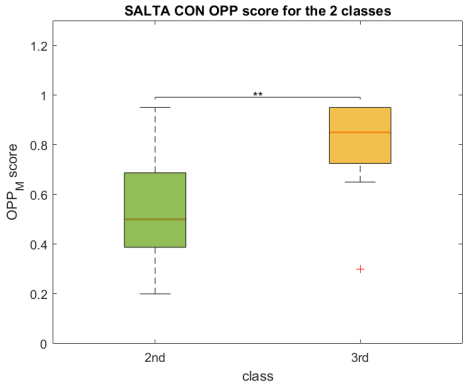


Figura 3.32: *Third graders reach higher scores in Salta con Opp than second graders ($p \leq 0.01$).*

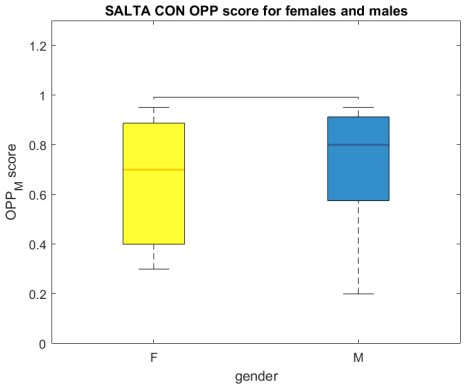


Figura 3.33: *No difference between genders emerges in the score of Salta con Opp*

Another parameter acquired by *Salta con Opp* is the average time taken to complete each level of the mini-game. As shown in Fig. 3.34 and Fig. 3.35, no significant

differences emerge across classes (p = 0.53) and gender (p = 0.29) in the time taken to complete each level in "medium" difficulty.

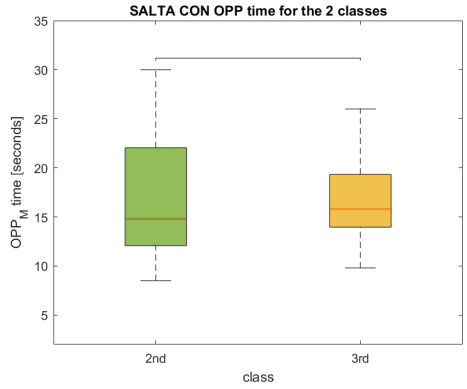


Figura 3.34: *Average time taken by the two classes to finish the single exercise of Salta con Opp in "medium" difficulty.*

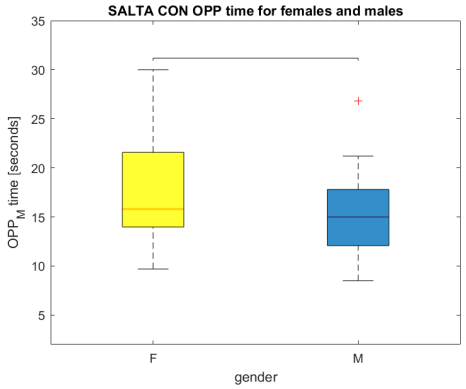


Figura 3.35: *Average time to finish the single exercise of Salta con Opp in "medium" difficulty per gender.*

Seven third graders and one second grader were tested on two difficulties of the minigame to assess any differences in the final score or in the completion time. The results in Fig. 3.36 show a tendency of lower scores for "hard" difficulty. However, this difference between difficulties is not significant (p = 0.13). In contrast, the results shown in Fig. 3.37 show a marked difference between "medium" and "hard" difficulties in the average time to complete levels (p = 0.0001).

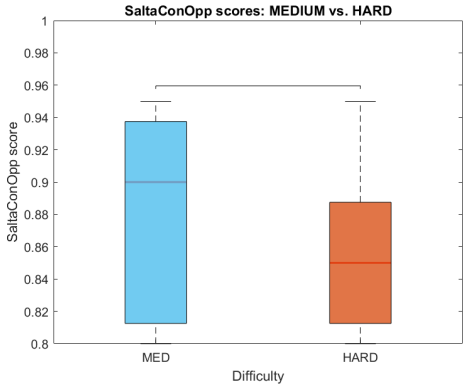


Figura 3.36: *Difference in the score of Salta con Opp for the two difficulties.*

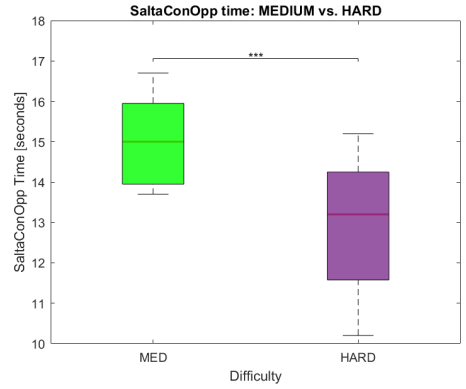


Figura 3.37: *Difference in average time to complete Salta con Opp's levels in "medium" and "hard" difficulties. The two average times are significantly different ($p \leq 0.001$).*

3.2.3 Scores of BVSCO-2

BVSCO trials measure the number of graphemes produced in a certain time interval. Starting from the first test, the one concerning the production of "lelele", in Fig. 3.38 the difference in the number of graphemes produced between the two classes is shown. Second graders produce significantly less graphemes than third graders (p = 0.016). Regarding gender, females score significantly higher than males (p = 0.011).

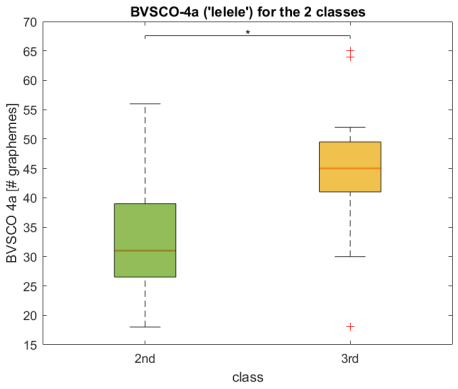


Figura 3.38: *On the BVSCO-a test, third graders produce significantly more graphemes than second graders ($p \leq 0.05$).*

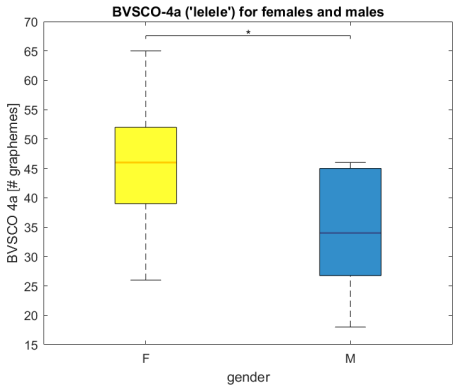


Figura 3.39: *On the BVSCO-a test, females produce more graphemes than males ($p \leq 0.05$).*

Regarding the BVSCO-b ("uno uno uno") and BVSCO-c ("uno due tre"), there are no significant differences neither between classes (p = 0.26) nor genders (p = 0.35), as can be seen in Fig. 3.40 and in Fig. 3.41.

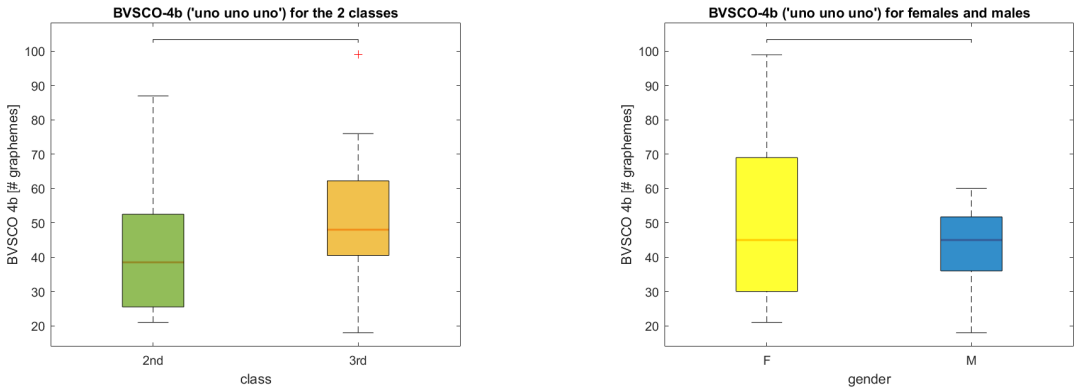


Figura 3.40: *Difference in BVSCO-b among classes (left) and gender (right)*

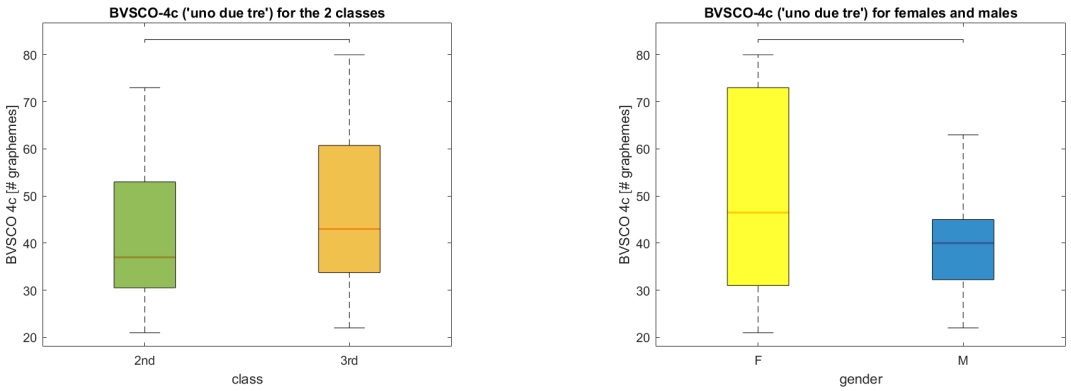


Figura 3.41: *Difference in BVSCO-c among classes (left) and gender (right)*

3.2.4 System Usability Scale

All subjects graded the System Usability Scale statements. Results show an average score of 86.16 (±14.43), which is considerable satisfactory since the minimum result to consider the system usable is 68. Fig. 3.42 shows how the scores are distributed more towards higher values.

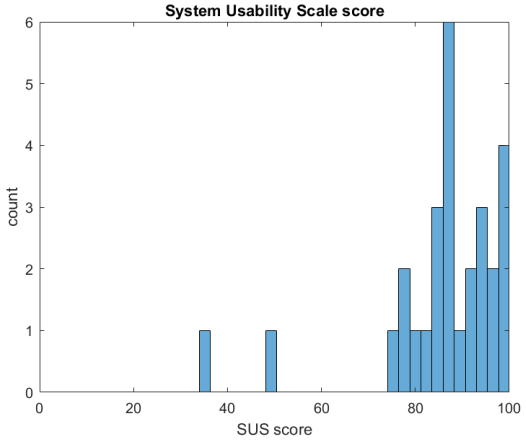


Figura 3.42: *Histogram of the SUS score*

The partial scores were also plotted to identify the most problematic aspects. Since depending on the question number, a high score may coincide with a positive (for odd-numbered questions) or negative (for even-numbered questions) rating, it was decided

to represent the result of each question not by score but by rating. Percentages can be found in Fig. 3.43.

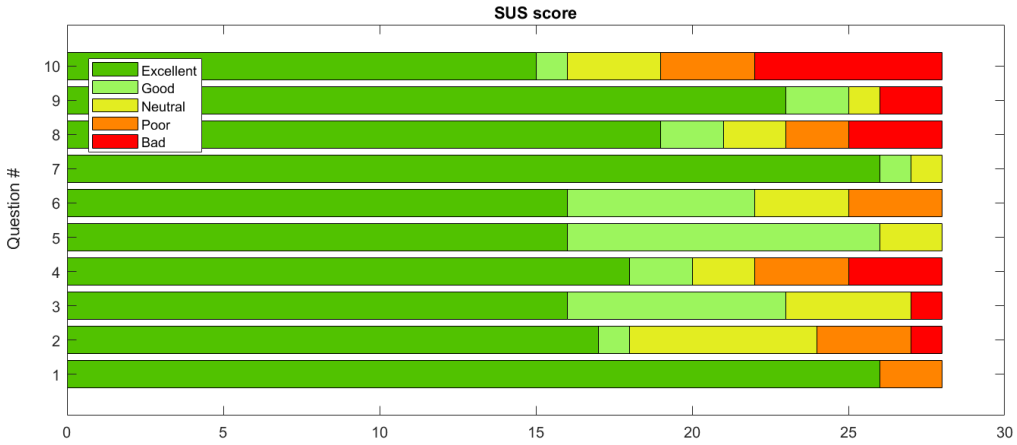


Figura 3.43: *A stacked bar plot to visualize the number of answers for each question.*

3.2.5 Approval

Players rated the mini-games by how easy, fun, and boring they were. The results are in the pie charts shown in Fig. 3.44, where the percentages show that:

- 50% of players found the game neutral in terms of ease. 25% found it very easy and 21% extremely easy.
- 79% of players found the game extremely fun, while 21% declared themselves neutral.
- 89% of the players found the game not boring at all.

The last question the players had to answer was whether they preferred playing to *Tachistoscopio* or *Salta con Opp*. The result is shown in Fig. 3.45, where 68% of players preferred the first mini−game. Among the reasons of the choice, many children responded that they prefer to play games where they have to read. Many children liked the read-write dynamic. One third-grader chose *Tachistoscopio* because she wants to

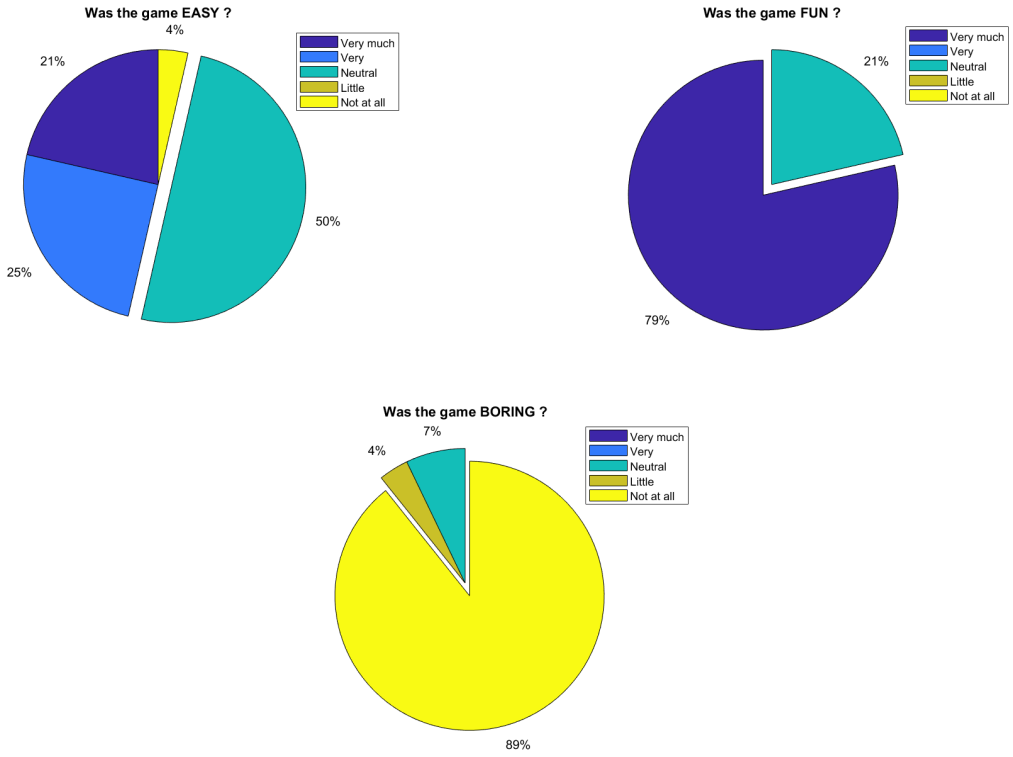


Figura 3.44: *The three pie charts showing the judgements of the players about the easiness, entertainment and monotony of the game*

learn to type on the computer and the tablet's keyboard reminds her so much of a computer keyboard. Among the reasons why 32% of children preferred *Salta con Opp*, the dynamic of being able to drag and drop images onto the tablet stands out.

3.2.6 Qualitative evaluation between two participants

Here two students who performed very differently are compared: more specifically, a third grader who performed very well in both the mini-games (student A) and a second grader who performed worse (student B) were chosen. In Fig. 3.46 is shown how the reading speed acquired by calibration is very different for the 2 students: 3.61 syllables/second for student A, versus 0.85 syllables/second for student B. Starting with the performance on *Tachistoscopio*, the reading increment after the mini-game is very pronounced for student A, while it is even negative for student B. The result of the first mini-game for student A is 100%, while for student B is 30%.

As for *Salt with Opp* in medium difficulty, student A completed 19 levels out of

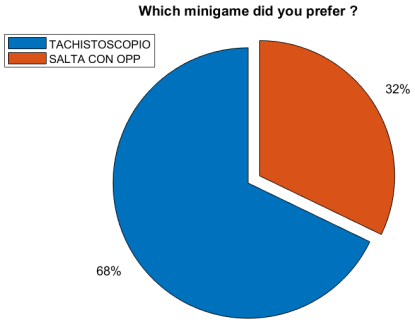


Figura 3.45: *The game that most players liked is Tachistoscopio (68% against 32%)*

20 correctly, thus scoring a percentage score of 95%. Student B on the other hand completed 4 levels correctly, achieving a percentage score of 20%. The average level completion time is also very different: 21.2 seconds for student A against 26.8 for student B.

The number of graphemes produced in the first BVSCO trial is 44 for student A, 18 for student B, as shown in Fig. 3.47.

Finally, the results of the SUS (Fig. 3.48) are evaluated. Student A considers the game more usable than student B: the number of questions that reached excellence are visibly lower in student B than in student A. The scores, in fact, see student A with a final value of 95, well above the average to consider the game usable, and student B with 50, so below the average.

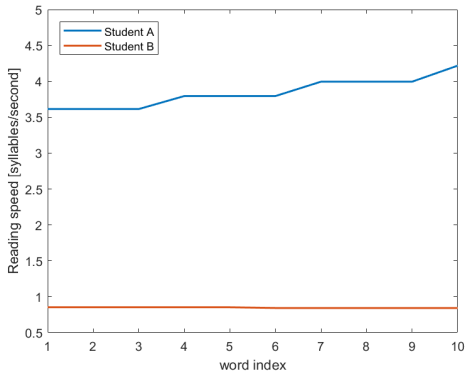


Figura 3.46: *Comparison in reading speed between a good player and bad player, according to the parameters recorded by Tachistoscopio*

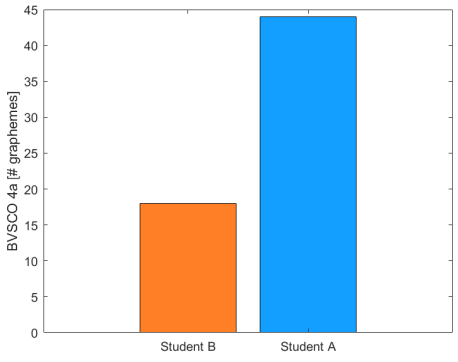


Figura 3.47: *Difference in the BVSCO 4a score between two different players.*

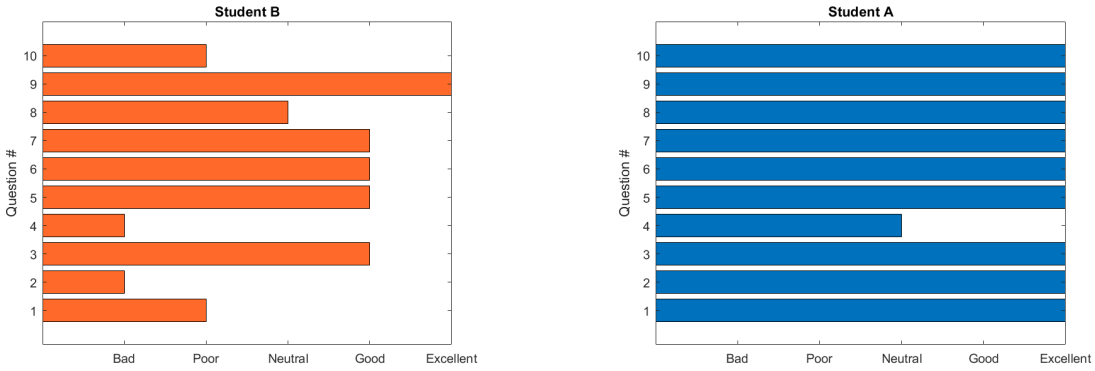


Figura 3.48: *The figure shows the answers of SUS for each question for student B (at left), and student A (at right).*

3.2.7 Correlation

The heatmap in Fig. 3.50 shows the correlation coefficients between each pair of input variables. The black cells are referred to the coefficients with a non-significant p-value, i.e., lower than 0.05 (testing the hypothesis of no correlation against the alternative hypothesis of a nonzero correlation). This choice was made for clearer visualization of the results. Starting with the characterization indicators at the top of Fig. 3.50, gender shows a high correlation in modulus with both the level of ease of the game (r = 0.53, p = 0.004) and the *BVSCO 4a* score ("lelele") (r = 0.44, p = 0.02). Class is a variable that moderately influences the *BVSCO 4a* score, as confirmed by an r coefficient equal to 0.47 (p = 0.01). Class is also highly correlated to the scores of *Tachistoscopio* (0.52) and *Salta con Opp* (0.57). The latters are not correlated neither to the familiarity with tablets, nor to the use of video game. But the familiarity with the use of tablets and the score of *BVSCO 4a* are moderately correlated (r = 0.48, p = 0.01). Moving to the parameters acquired by the mini−games, reading speed measured in *Tachistoscopio* is correlated to the scores of the aforementioned mini−game (r = 0.46, p = 0.01), *Salta con Opp* (r = 0.58, p = 0.001) and *BVSCO 4a* (r = 0.39, p = 0.04). As seen in Fig. 3.49, as the reading speed increases, the score in the two mini−games and in the BVSCO rises.

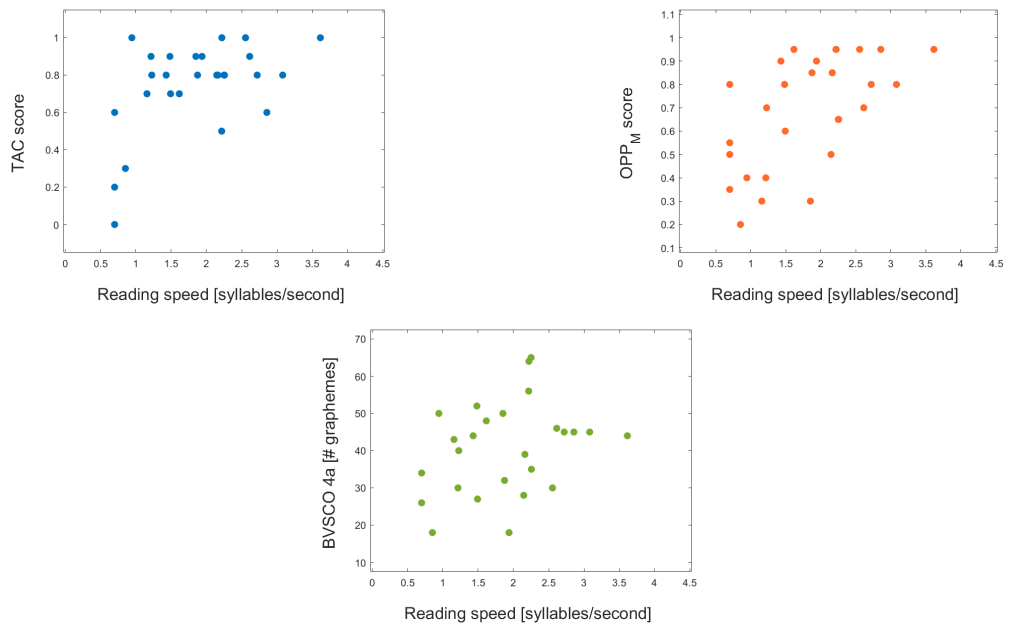


Figura 3.49: *The scatter plots showing the trend of reading speed and the scores of Tachistoscopio (blue, top left), Salta con Opp (orange, top right) and BVSCO 4a (green, bottom centre).*

Tachistoscopio's score is positively correlated to the level of entertainment (r = 0.41, p = 0.03) and negatively correlated to the level of monotony (r = -0.57, p = 0.001). Turning to *Salta con Opp*, its score in medium difficulty correlates negatively with the level of monotony (r = -0.39, p = 0.04) and with the average time taken to complete each level (r = -0.41, p = 0.03), while the score in hard mode shows a high level of correlation with the *BVSCO 4a* score (r = 0.74, p = 0.04).

3.2.8 Multiple regression

A regression model was built to evaluate whether the parameters acquired by the mini−games were useful in predicting writing performances (BVSCO scores). First, an Akaike Information Criterion (AIC)-based bi-directional stepwise feature selection was made. Also in the dataset there are several variables that measure the reading speed of the player that are highly correlated between each other. So feature selection was also important to reduce the risk of multicollinearity: since the reading speed improvement can be linearly predicted by the reading speed acquired before and after playing at *Tachistoscopio*, the variable with the lowest Variance Inflation Factor was selected,

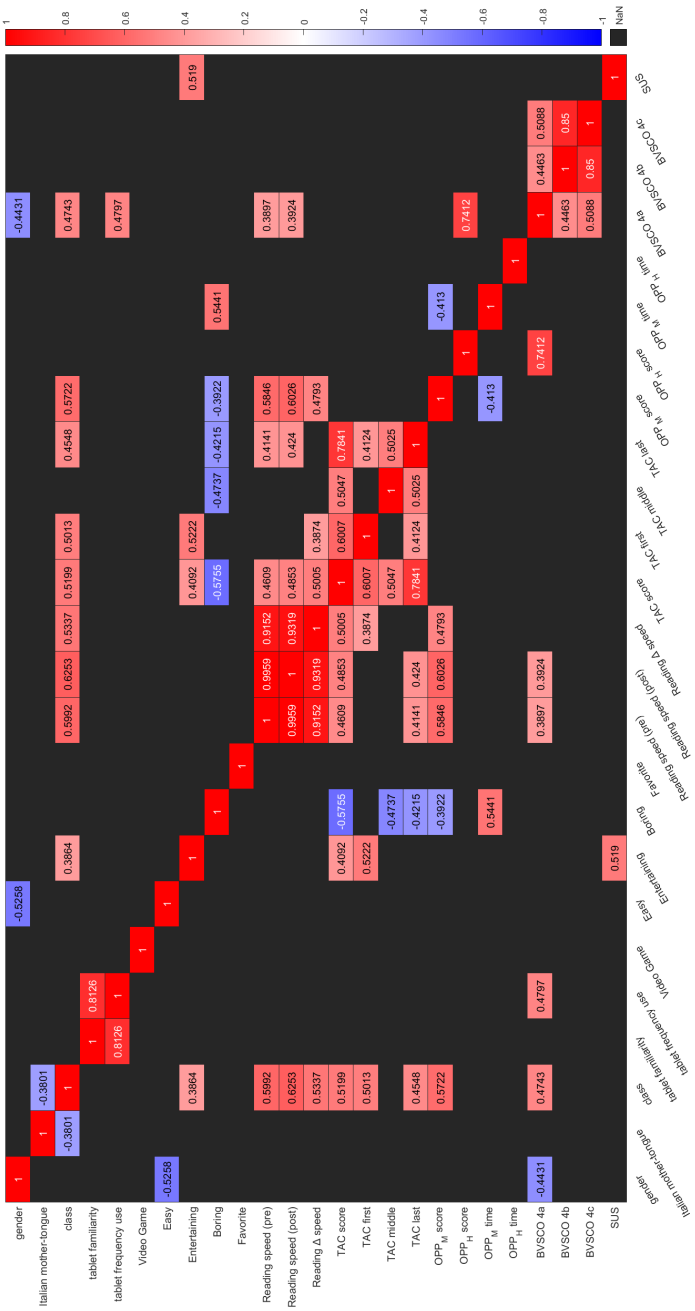


Figura 3.50: *Correlation matrix*

and the other two eliminated. Selected features and resulting models parameters for stepwise AIC feature selection is reported in Tab. 3.1.

Predictors	Estimated Std.	Error	t value	P-value
class	21.890	3.519	6.221	0.01
tablet familiarity	-13.176	8.775	-1.502	0.15
tablet frequency use	7.777	3.071	2.532	0.02
Easy	8.636	1.504	5.744	0.03
Entertaining	-4.542	2.143	-2.119	0.05
Boring	-7.248	4.048	-1.790	0.09
TAC Δ speed	-36.006	7.982	-4.511	0.0005
TAC score	12.551	8.987	1.397	0.18
TAC middle	20.249	3.674	5.481	0.05
TAC last	-21.281	5.617	-3.789	0.002
OPP_M score	6.647	5.070	1.311	0.21
OPP_M time	16.506	6.783	2.433	0.03

Tabella 3.1: *Features selected using AIC stepwise feature selection, along with their statistics and p−values.*

The model with the variables depicted in Tab. 3.1 as predictors and the BVSCO−a score as target was built. Its R^2 is 0.89 and its adjusted−R^2 is 0.808. Among the predictors that have p−value below the significant threshold of 0.05, *TAC* Δ *speed* and OPP_M *time* are included. Regarding BVSCO−b and BVSCO−c, there is no significance by using the parameters acquired by the mini−games as predictors.

Capitolo 4

DISCUSSION

Dyslexia is generally diagnosed late because it is necessary for the process of teaching reading skills to be completed in order to give a definite diagnosis. This study is aimed at providing a tool for early assessment of visual attentional and phonological decoding impairments, which can be a signal for dyslexia before reading development. The use of a serious game as a possible mean to assess and strengthen reading skills at school was explored. The game was developed following the advice from clinical professionals. The game was composed of 3 exercises that gamified visual attentional, phonological decoding and reading comprehension exercises. The visual attentional skills were tested by means of a mini−game, called *Tachistoscopio*, based on the tachistoscopic presentation of words aimed at strengthening letter−by−letter reading and the global reading of words. The phonological decoding skills were tested by means of a mini−game, called *Salta con Opp*, that assesses the syllabic awareness of words. The reading comprehension skills were tested by means of a mini−game, called *Ernesto l'Aspiratesto*, that assesses the word decoding and language comprehension. Each mini−game appears in three difficulties; easy, medium, and hard. They also were designed to be played autonomously or under the supervision of the teacher. Originally the game should have been tested on first and second graders of primary school. However due to the COVID−19 pandemic, which has changed the quality of education since schools were closed and classes shifted to home-based distance-learning models, it was assumed that children received a lower education than it should have been expected

in normal conditions at school. Regardless of the group of participants, second and third graders were recruited at the start of the school year, so their education level was considered similar to that of late first and second graders. 28 children (aged 6-8) were recruited for the study: 13 from second grade and 15 from third grade of primary school were tested at school. Each subject played two mini−games, one for visual attentional assessment and one for the phonological decoding assessment. Then he or she was administered the BVSCO−2 test to evaluate his or her writing ability. At the end of the test, the subject had to fill in two questionnaires: the SUS (System Usability Scale) and the characterization questionnaire. All the subjects were tested in medium difficulty to evaluate the differences between classes. Only 8 subjects were administered *Salta con Opp* both in medium and hard difficulty to examine differences between levels of difficulty. The games' performances were evaluated among classes and gender, and results showed significant differences between classes for both the scores of *Tachistoscopio* ($p \leq 0.01$) and *Salta con Opp* ($p \leq 0.01$): third graders reached higher scores than second graders. This result can be explained by the difference in reading skills between the two classes, since third graders read significantly faster than second graders ($p \leq 0.001$). As a matter of fact, at the end of second grade of primary school children start to master the global recognition of words without activating any graphemic−phonemic transformation process, so a clear difference among classes is expected. This difference is also evident in the increments of reading speed after playing *Tachistoscopio*: significant higher gains are experienced by third graders with respect to second graders ($p \leq 0.01$). All these results lead to a final consideration: the faster a subject reads, the higher the score, the greater the Δ in reading speed, and, finally, the more fun experienced, since the score and the level of monotony are negatively correlated. Against the expectations of a possible correlation between reading speed and the estimated time to process syllables, measured as the average time to complete each level of *Salta con Opp*, no significant differences were detected, neither for gender, nor for class. However, a difference was detected when the two levels of difficulty, medium and hard, were compared. As expected, results show a tendency to reach lower scores in hard than medium, in line with the desired difficulty design.

Regarding the average time to complete each level, significant less time was required

in hard difficulty than in medium ($p \leq 0.001$). In this case the outcome can be explained by the fact that participants were administered medium and hard difficulty levels without taking a break between the two runs. As they became familiar with the dynamics of the game, they may have completed the exercise faster, thus improving time in concluding the exercise rather than score. However the overall result is very interesting and it should be assessed more carefully in future to see whether the findings were too affected by the acquisition methods. The game performances were compared to the BVSCO−2 data to see whether reading and writing skills follow similar patterns. Very similarly to the scores of the two mini−games, in fact, the score of the BVCSO−a, the one which required to write in a continuous and alternating way two curvilinear signs of different heights ("lelele"), was significantly higher for third graders than for second graders ($p \leq 0.01$). Yet, the score of BVSCO−b and BVSCO−c, which instead require the production of actual words (in the first case "uno uno uno", in the second case "uno due tre") did not differ according to the participants' class or gender. The correlation between reading speed and the score of BVSCO−a was significant. A multiple regression model built using game data as predictors and the BVSCO−a as the target, revealed that the Δ in reading speed and the average time to complete each level of *Salta con Opp* are significative in predicting the first writing test (BVSCO 4a). This outcomes corroborate the hypothesis that handwriting and reading/language deficits are both linked to the principle of rhythmic organization. On the other hand, they do not seem to be linked to general writing (BVSCO 4b and 4c).

The SUS scores were high without revealing criticalities. The majority of participants considered the game usable and the first statement, "I would like to use this game very often", received the best answers ($\approx$ 4,79/5). This results were corroborated by the positive opinions of the participants about the game. The majority of them found it "extremely fun" (79%) and "not boring at all" (89%). They also expressed their preference among the mini−games, choosing *Tachistoscopio* as the best one (68%).

Capitolo 5

LIMITATION AND FURTHER DEVELOPMENTS

The first limitation of this study is that the game has not been tested on the whole group of participants in all three difficulties due to time reasons. This, in addition to limiting the statistical analysis, did not allow to assess if the difficulty gradualness easy−medium−hard was challenging enough. Also, in future studies a larger group of participants should be tested in order to obtain a more accurate analysis of the game's outcomes. A future development of the data analysis could focus on a more qualitative evaluation of the errors made by the participants: in fact mistakes have been estimated quantitatively in order to calculate the final scores in both mini−games. It would be interesting to study the type of errors more closely in order to see if there is a correlation between visual−attentional and phonological errors. Moreover, some comparisons between the performance of children with Specific Learning Disabilities and that of healthy subjects could be carried out. In addition, a longitudinal study by means of repeated assessments on the same individuals throughout an entire school cycle could enrich the current findings.

Regarding the game design aspect, some improvements could be carried out starting with upgrading the source file of words, images, audio files used by the mini−games. In fact, sometimes happened that in *Salta con Opp*, the same image to drag was repeated twice during the whole session. Alternatively, the possibility for the teacher

to add words, sentences or images which are more familiar to the participant, thus customizing the game experience, should be considered. Moreover, a new indicator could be saved in *Salta con Opp* that indicates if and how many times the player has replayed the words in each level (by clicking on the appropriate button in the game screen) so that it can be evaluated which words and which syllable structures create the most problems. Also, the introduction of audio recorded dialogues inside the tutorials or as audio feedback could cheer the player on. Another future development could be the introduction of games more oriented to early prevention activities for preschoolers, who are too young to be administered reading tasks of written text. One example could be the gamification of tachistoscopic presentation of images, instead of words, to stimulate the fast reading and memorization of pictures, thus improving visual−attentional skills. In this way the pupil, by "reading" images from left to right, can learn the spatial method that characterizes the reading of a text. Furthermore, by looking for differences between various images proposed, will learn to grasp the details, to stay focused over long periods of time and to exercise visual exploration. This will then support the distinction of the characteristics of the letters. Finally, another future advancement in the game design, concerns the addition of user−customizable avatars which would make the gaming experience more stimulating, engaging and inclusive.

Elenco delle figure

Elenco delle tabelle

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