A Serious Game to Anticipate Handwriting Difficulties Screening Through Visual Perception Assessment

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Abstract: Dysgraphia is a learning disability that causes handwritten production below the expectancies. Its diagnosis is delayed until handwriting development should be completed, with the possible worsening of children's weaknesses. To allow a preventive empowerment program, abilities not directly related to handwriting should be evaluated, and one of them is visual perception.

To investigate the role of visual perception in handwriting skills, we gamified standard clinical tests of form constancy, figure-ground discrimination and visual closure exercises, to be played with an eye tracker at three difficulty levels. Then, we related game performances to a handwriting speed test. The aims of this work are: to test game usability and design effectiveness, and to preliminarily explore the relationship between visual performance and writing skills.

Game performances were computed with principal component analysis, combining time-to-completion and errors in each game. A linear regression related game performance (predictors) with writing speed (target). Perceived increase in difficulty among levels was tested by means of an ANOVA. As for usability, participants answered the System Usability Scale.

In total, 28 subjects – 3 children, 19 young adults and 6 older adults – participated in the study. Game scores provided a good quality of fitting (R^2= 0.67, p<0.001) of handwriting speed in the regression model. ANOVA suggested that *masked form constancy* and *visual closure* games were perceived as more challenging as difficulty raised (game score significantly decreased, p<0.001), while in *form constancy* and *figure-ground perception* a learning effect was observed (game score significantly increased, p<0.001). Interesting qualitative observations emerged from eye-tracking data, drawing suggestions for exploiting ocular strategy to better investigate its role in game performance. The game reached excellent usability (92.86±5.08), which allows to confidently extend the study to a younger, more adequate sample.

These results are promising to suggest a new tool for dysgraphia early screening, based on visual perception skills.

Keywords: Serious games, Visual perception, Eye tracking, Handwriting, Development

1. Introduction

Dysgraphia is a learning disability which affects 7-15% of school-aged children (Döhla & Heim, 2016), and results in inadequate handwriting, notwithstanding age, intelligence, and instruction (American Psychiatric Association, 2013). Its diagnosis comes after two-three years of frustrating attempts of mastering handwriting (Feder & Majnemer, 2007; Overvelde & Hulstijn, 2011), as it focuses on handwriting production itself. However, some abilities indirectly related to proficient handwriting develop beforehand, and could be leveraged to anticipate dysgraphia screening (Dui et al., 2020a; Dui et al., 2020b).

Among others, dysgraphia is linked with impairments in visual perception (Mona et al., 2015), i.e, the ability to elaborate meaningful representations of visual inputs to complete tasks. Conversely, good visual perception correlates with higher speed and quality in handwriting (Brown & Link, 2016).

Visual perception is normally investigated through pen-and-paper standardized tests (Beery & Beery, 2004, Hammill et al., 2014), but subjectivity and test-induced performance alterations (McCambridge et al., 2014) can affect the evaluation. Tests' digitalization addresses the subjectivity shortcoming with measurable outcomes (Howe et al., 2017), but the study of ocular strategies with eye-tracking devices potentially ensures

higher levels of objectivity (Martinez-Conde et al., 2004). To assure a stress-free evaluation and enhance engagement, gamification should be proposed.
In this work, a serious game which gamifies visual perception tests was devised and developed, with the aim of testing its usability and design effectiveness. Moreover, the feasibility of relating its scores with handwriting proficiency was explored, by providing preliminary results on the relationship between visual and writing performance.

2. Methods

2.1 Game design

The serious game was developed in Unity 2020.1.6f1.

The exercises included in the game were adapted from standardized tests, such as the Beery VMI (Beery & Beery, 2004) and the DTVP-3 (Hammill et al., 2014), and tested different visual perception skills. A description of the exercises can be found in Table 1.

Table 1: Visual perception games.

Screenshot	Tested ability	Game mechanics
	*Form constancy*: the ability to recognize a shape when size, color or orientation changes.	A white shape is presented on the left, and three smaller colored shapes (one target, two non-target) are displayed on the right.
	*Masked form constancy*: similar to form constancy, but the shape that has to be recognized is part of a larger image.	An image with missing piece is presented on the left, while cut-outs that could fill the hole are displayed on the right.
	*Figure-ground perception*: the ability to recognize a shape on a confusing background.	Shapes are scattered on the screen. The target shape is shown on the lower left corner.
	*Visual closure*: the ability to recognize a partially hidden shape.	On the left, the reference images are showed; on the right, the options appear. This game is proposed in two variants: (1) the options are partially hidden, (2) the reference image miss some parts.

2.2 Protocol

Volunteer subjects were recruited according to the protocol approved by Ethical Committee of Politecnico di Milano (n. 25/2020). To asess visual-perceptual skills, they played the game on an iPad, three difficulty levels each. To investigate the role of ocular movements, they wore an eye tracker (Pupil Labs, Berlin, Germany, https://pupil-labs.com/) during games administration. To estimate handwriting proficiency, three writing speed tests (BVSCO-2) (Tressoldi, 2019) were executed. As for usability, subjects answered the System Usability Scale (SUS) (Brooke, 1996).

2.3 Data analysis

Data analysis was performed in Python 3.8. For each level, game performance (time and errors) was synthetized in a single score using Principal Component Analysis. The three BVSCO-2 scores were synthesized into a single one, leveraging PCA, as well. The normality of variables was checked through the Kolmogorov-Smirnov test. Statistical significance was set to 0.05.

To assess usability, the SUS score was computed. As for design effectiveness, to test whether perceived difficulty affected performances, repeated measures ANOVA with Bonferroni-corrected post hoc was applied to normal data (independent variable = difficulty, dependent variable = game score).
To investigate the relationship between visuo-perceptual abilities and handwriting proficiency, linear regression was leveraged, using game scores as predictors and the BVSCO-2 score as the target variable. The most informative features were selected using Akaike Information Criterion (AIC) bi-directional stepwise feature selection.
To assess ocular strategy, exploratory analysis was carried out on eye-tracking data. We developed algorithms to visualize gaze positions, fixations, and scanpath, which together inform about the strategy adopted. Gaze positions were clustered into game panels using mean shift. This allowed to compute: the percentage of time spent looking on the correct option; the number of saccades between two different panels; the number of times the gaze moved into the correct portion.

3. Results

Twenty-eight participants were recruited in October 2020 (Table 2). Usability scores were excellent, mean±SD=92.86±5.08 (Figure 1).

Table 2: Sample composition.

Variable	n(%)
Gender	
Male	16(57%)
Female	12(43%)
Age (years)	
9-11	3(11%)
20-28	19(68%)
54-60	6(21%)

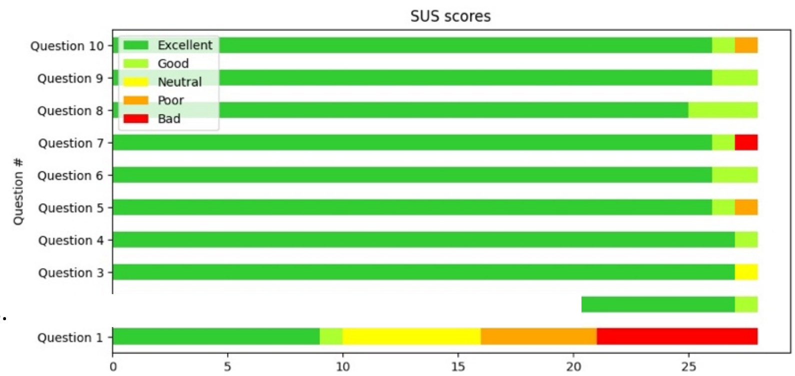

Figure 1: SUS results.

ANOVA tests on game performance showed a significant effect of difficulty in all exercises, except for *visual closure* with masked reference. In *form constancy* and *figure-ground perception*, performance improved across difficulties, while in others the trend was opposite (Figure 2).

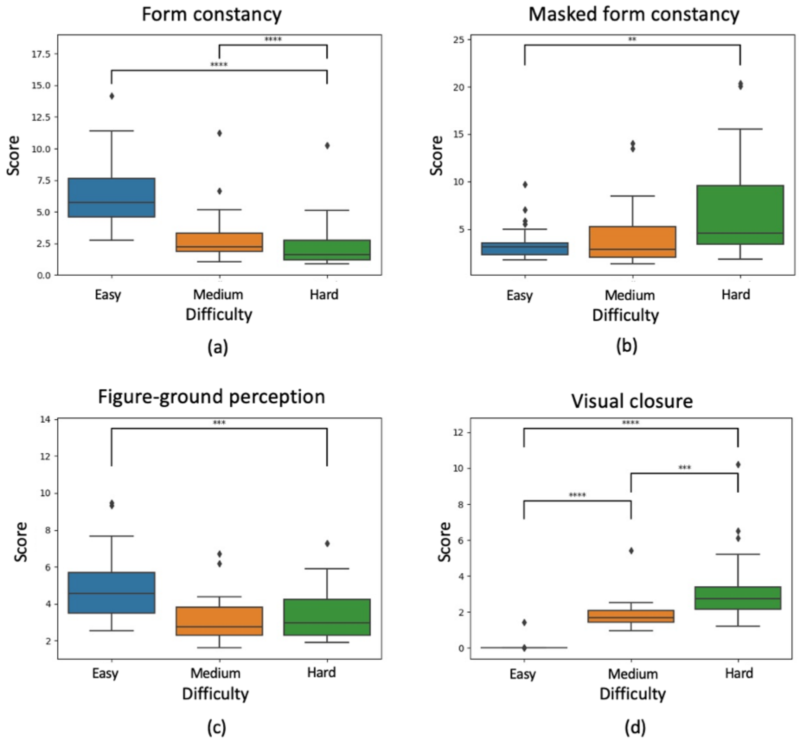

Figure 2: (a) *Form constancy*, (b) *Masked form constancy*, (c) *Figure-ground perception* and (d) *Visual closure* with masked options. X-axis: level; Y-axis: score. **p<0.01, ***p<0.001, ****p<0.0001.

Regression models with game scores as predictors and the BVSCO-2 score as target achieved good fitting when all game scores were used (adjusted-R^2=0.67, p<0.001). Feature selection constructed a model with moderately good fittings (adjusted-R^2 =0.53, p<0.001).

Regarding eye tracking, *masked form constancy* recordings were analyzed, since it was the most challenging exercise. Eye-tracking data were clustered in game panels (Figure 3a) to perform qualitative analyses on ocular strategies. We observed that worse game performances were linked to a plethora of frantic saccades (Figure 3b) that often returned to the same panels, while better scores corresponded to linear scanpaths (Figure 3c).

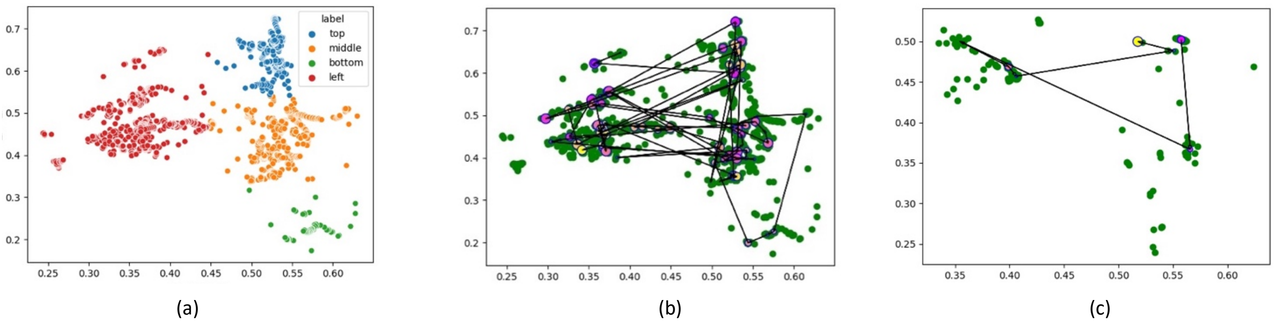

Figure 3: Plots for eye-tracking data visualization. (a) gaze positions after clustering into panels: left (red), top (blue), middle (yellow), and bottom (green). (b) Scanpath of a subject that performed poorly. (c) Scanpath of a subject that performed well.

4. Discussion

This study presents a tablet-based app aimed at investigating visual-perceptual abilities, compared to handwriting proficiency. It was inspired by standard pen-and-paper tests (Beery et al., 2004; Hammill et al., 2014), and paired with an eye tracker to include ocular strategy in the evaluation.
According to the regression results, a relationship between game scores and handwriting speed emerged. As these exercises can be abstracted from handwriting, the app seems promising to anticipate handwriting problems screening. A clearer effect would arise if testing on school-aged children, where bigger differences in performance are expected, due to less consolidated visual-perceptual and handwriting skills.

Difficulty effect was not always as designed: performance improvement in *form constancy* and *figure-ground perception* hints a learning curve steeper than the perceived increase in difficulty. This suggests modifying the game design, to actually achieve increasing staircase difficulty.
Usability results were very good. Even though adults were not enthusiastic about playing often, children were. Hence, in the target population games are well-accepted.

In conclusion, children reaction was positive, and the game was deemed usable.
Eye-tracking data should be explored more deeply, automatizing strategy identification, to find more informative elements.
Overall, the results are promising to suggest a new tool for dysgraphia early screening, based on visual perception skills evaluation.

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