Developing Visual Perceptual Skills with Assistive Technology Supported Application for Children with Cerebral Palsy

Márk Ágoston Pulay[1,2], Éva Feketéné Szabó[2]

[1]Department of Ergonomics and Psychology, Faculty of Economic and Social Sciences, Budapest University of Technology and Economics, Műegyetem rkp. 3, H-1111 Budapest, Hungary, pulay.mark@gtk.bme.hu

[2] Pető András Faculty, Semmelweis University, Üllői út 26, H-1085 Budapest, Hungary, feketene.szabo.eva@semmelweis.hu

Abstract: Visual perception (VP) allows us to process visual stimuli to identify what we see and, thus, understand the world in which we live. VP ability is one of the many cognitive areas often affected in children with cerebral palsy (CP). VP deficits may lead to difficulties in learning, recognizing, and remembering letters and words and learning basic mathematical concepts. We created and applied special educational software for children with CP to develop their VP skills. This study aimed to investigate the long-term effects of the software we created to develop the VP skills of CP patients. We randomly assigned 18 participants to equally sized intervention (n=9) and control (n=9) groups and another 12 typically developing samples to compare VP skills. The duration of the intervention was 15 minutes, three times a week, for one school semester (9 months). We used the Motor-Free Visual Perception Test – 4 (MVPT-4) before and after the intervention to evaluate the VP skills, combined with eye-tracking to identify gaze patterns that provide valuable information on the participants during the test solving. Due to the small sample size, we did not expect significant changes, but a positive tendency is captured in the VP skills of the intervention group. We found significant differences (p<0,001) in comparing VP skills of typically and atypically developing children. In this study, we present only preliminary results of the eye-tracking data, which seems an appropriate method combined with the MVPT-4 assessment.

Keywords: special educational application; visual perception; cerebral palsy; MVPT-4; eye-tracking

1 Introduction

For children with physical and cognitive disabilities, information and communications technology (ICT) is indispensable. Our main aim was to develop and apply educational applications for children with cerebral palsy (CP). CP is a movement disorder characterized by permanent damage to the development of posture and movement caused by non-progressive disturbances that occur during fetal or infant brain development [1]. CP can be classified by functional ability and by neurological subgroup, which is determined according to the limbs affected (hemiparesis, tetraparesis, diparesis), clinical signs and symptoms (spasticity, dyskinesia or ataxia), and muscle tone (hypotonic, or hypertonic) [2] [3]. There are often sensory, perception, cognition, communication, and behavior problems associated with CP. It is the most common childhood physical disability and affects 2 to 2.5 children per 1,000 born in western countries [1] [4] [5]. Studies dealing with CP tend to focus mostly on motor impairments and neglect the impact of cognition, like visual perception on functional ability [6] [7]. Visual perception allows us to process visual stimuli to identify what we see and, thus understand the world in which we live. Visual perceptual ability is one of the many areas that is often affected in children with CP [8]. A study by Schmetz et al. [9] found that children with CP aged 5-18 years experience persistent deficits in visual perception or visual perceptual impairment (VPI) compared with typically developing children. Visual perception includes several specific subsections (e.g. visual discrimination, visual form-constancy, figure-ground). All of these subsections contribute to visual perception and have important implications for functional tasks. This specific subsection and the characteristic of CP – different lesion patterns in the brain – indicate that there is no accepted prevalence rate of VPI in children with CP [10]. In children with CP, perception deficits can affect their academic performance in regard to reading ability and learning as well as activities of daily living (ADL), such as dressing [8] [11] [12]. The relationship between motor-visual and visual-motor development is powerful, and CP can lead to both impaired motor skills and perceptual and cognitive visual impairments [8] [13] [14].

In recent years, with widespread access to information, advances in ICT applied to the education sector are changing to traditional approaches to special education and early intervention [3] [15]. These findings lead us to create an application that supports visual perception skills development.

2 Features of the Application

The idea of developing these applications came from the daily practice of conductive education (Pető Method) – demand-driven project – lack of software for early intervention, sub-skills development, e.g. visual-auditory perceptual skills.

2.1 Technical Features

In the course of development, special attention was paid to running the software on many kinds of IT assistive technology such as eye-tracking, switch technology, and special mouse - to open the door for the main target group – for children with severe physical disabilities.

Applications are running on PC (web-based) and on tablets (IOS, Android). The software collect statistical data about users, so positive change and problematic areas become observable. It gives the parents/teachers real-time feedback about the children's performance. Beyond the functional software design, usability and ergonomic features were also considered to assess these software positive effect on cognition, especially for visual perceptual skills. Another essential feature is gamification to get and maintain the user's attention and motivation. The design and the characteristic of the user interface fit the needs of the children – playful, colourful, different levels of difficulty and reward collection opportunities.

2.2 Main Targeted Developmental Areas

- Visual perception skills: such as visual discrimination, spatial relationships, visual memory, figure-ground, visual closure, perception and recognition of colours and shapes.
- Auditory perception skills: such as auditory closure, auditory conceptualizing, auditory discrimination, auditory memory, and auditory sequential memory.
- Basic mathematical operations (summations, subtractions), and problem-solving skills,
- On tablet: eye-hand coordination, fine manipulation, hand dominance,
- Rule consciousness,
- Decision making skills,
- Self-awareness.

3 Materials and Methods

A matched-pairs control randomized controlled research investigated the effectiveness of special educational software, learning games created to enhance different kinds of sub-skills of preschool and elementary school children with typical and atypical development (e.g. CP). The intervention period was a school year (9 months); during this period, the participants belonging to the intervention group were allowed to play with the applications for 15 minutes at least three times a week. This time-frame was set up together with the specialist and teachers, and it fits the daily schedule of their daily conductive educational program. The control group did not use the applications; they participated in their conductive educational program.

3.1 Participants

The participants, aged between 4-8 years (mean 6.77), came from the András Pető Faculty Elementary School and Kindergarten. The extent of the observed group N=18, test group N=9, control group N=9. By diagnosis: Tetraparesis: N=6, Athetosis: N=2, Ataxia: N=2, Hemiplegia N=2, slightly affected developmental disorders: N=6. Participants who consented to the study were matched in pairs based on age and the type of diagnosis. The sample size of the intervention group is small. but not unusual in this patient population.

We also conducted the baseline measurement (MVPT-4 test and eye-tracking) with typically developing (N=12) children to analyze and compare this population's visual perceptual skills and gaze patterns.

3.2 Research Tools

3.2.1 Motor-Free Visual Perception Test – 4 (MVPT-4) (Colarusso & Hammil, 2015)

The MVPT-4 is a revised version of the MVPT-third edition, the original version of the MVPT was developed in 1972. It was revised to the MVPT-Revised (MVPT-R) in 1996, the MVPT-3 in 2003, and the MVPT-4 in 2015. The MVPT-4 was designed to assess the visual-perceptual ability of individuals aged 4.0 through 80+ years via a series of visual-perceptual tasks that do not require a motor response [16] [17]. The test assesses five visual perceptual abilities: visual discrimination, spatial relationships, visual memory, figure-ground, and visual closure. The scores from these subtests cannot be calculated alone; instead, they are summed together in one overall visual perceptual ability standard score. Colarusso and Hammill - the test's authors - reported that MVPT-4 is a quick, accurate, reliable, and valid assessment of overall visual perceptual ability [18]. Stimuli are composed of black-and-white line drawings and designs, with answer choices presented in multiple-choice format.

3.2.2 Eye-Tracking

Tobii Pro X3: Screen-based eye tracker capturing gaze data at 120 Hz, an unobtrusive and direct technique that allows researchers to not rely exclusively on self-report measures [19] [20]. We digitalized the test sheets of the MVPT-4 for allowing us to fill the test on the computer and to be able to capture the gaze patterns of the participants. The pattern of eye-gaze fixations and saccades to be used to infer a person's intention or goal within a particular context [21] [22]. Data collected from eye tracking is a record of the position of the eyes in relation to the scene viewed over time. Two essential features relate to fixations (steady gaze on a particular location for some period of time) and saccades (quick eye movements between locations) [21] [23] [24].

In the particular study, we tried to identify gaze patterns that provide valuable information on the participants' during the MVPT-4 test solving: certain patterns where the eye fixates on what the typically developing children are processing and others where the atypically developing children do not hold.

3.3 Research Questions

3.3.1 Research Questions Concerning the MVPT-4

- Are there any differences in MVPT-4 scores between typically and atypically developed children?
- After the intervention period, are there any differences in MVPT-4 scores between the intervention and control group?
- Are there any differences in MVPT-4 scores among CP diagnosis?

3.3.2 Research Questions Concerning Eye-Tracking Data

- Are there any differences in gaze patterns between typically and atypically developed children?
- Are there any differences in gaze patterns and the level of visual attention between baseline and re-test?

4 Results

4.1 Results of the MVPT-4 Test

For the data analysis, we used IBM SPSS 26 software. Due to the non-normal distribution and the small dataset sample size, we used the Wilcoxon signed-rank test (Wilcoxon matched pairs test) to compare the baseline and the re-test values of each group (test and control). The Wilcoxon signed-rank test aims to examine the difference between the available samples. It can be used when two continuous measurements are made on the same group. In these cases, the test examines how much the median of the differences deviates from zero. Small sample size research conducted on the comparative power of the t-test, the Wilcoxon test is appropriate for increased statistical power when the assumption of normality is violated [25]. We applied the Mann-Whitney test to compare the MVPT-4 test results of the two independent groups (intervention and control). The Mann-Whitney U test mainly compares differences between two independent groups when the dependent variable is either ordinal or continuous but not normally distributed [26] [27].

The first research question concerning the MVPT-4 test was: are there any differences in MVPT-4 scores between typically and atypically developed children? Based on the literature, we hypothesised that the visual-perceptual skills of children with cerebral palsy are affected [10] [28] [29] [30]. We have found the same results; the MVPT-4 was used to determine whether children with cerebral palsy demonstrated problems in visual perception on a motor-free visual perception test. Both the baseline and the re-test results showed that children with cerebral palsy attained significantly (p=<,001) lower mean perceptual quotients than typically developed children did (see the visualisation in Fig. 1). The MVPT-4 appears to be a valuable tool for evaluating visual perception in children with cerebral palsy.

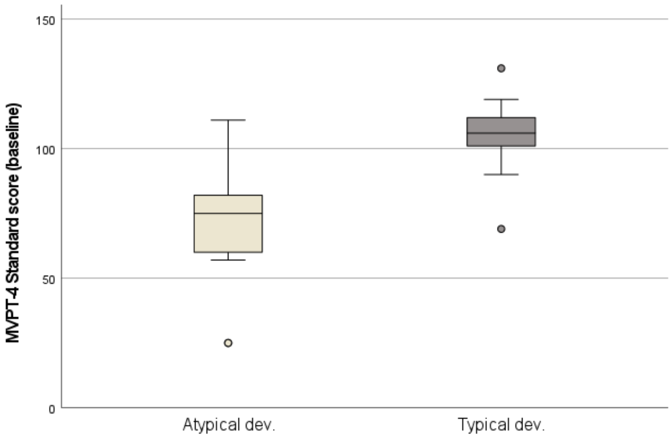

Figure 1
MVPT-4 test results comparison of typically and atypically developing children

Our second research question concerning the MVPT-4 test was: after the intervention period, are there any differences in MVPT-4 scores between the intervention and control group? We found promising tendencies in comparing the difference in baseline and re-test values between the intervention and control groups, but the difference is not statistically significant (Table 1).

Table 1
MVPT-4 test results in both groups at baseline and re-test and the difference of the difference compared the two groups (pre-post) results

		MVPT-4 test standard score at baseline		**MVPT-4 test standard score at re-test**		**MVPT-4 test Standard score difference**
		Count	**Median**	**Count**	**Median**	**Median**
Group	Intervention (test)	9	77	9	101	21,00
	Control	9	72	9	89	21,00
	Sig. Mann-Whitney		0,546		0,222	0,666

One of the possible causes behind the lack of significant differences is an interesting outcome. The difference between baseline and re-test is significant in both groups. It means that the development of visual perceptual skills in this childhood period is very progressive.

Our third research question concerning the MVPT-4 test was: are there any differences in MVPT-4 scores between CP diagnosis? Due to the small sample size, if we divide it into CP diagnosis we got quite small subgroups; this is why we present only visualisation (fig. 2). On this small sample, we can also confirm that better physical condition supposes better visual perceptual scores. This finding refers to the strong relationship between physical abilities and visual perceptual skills.

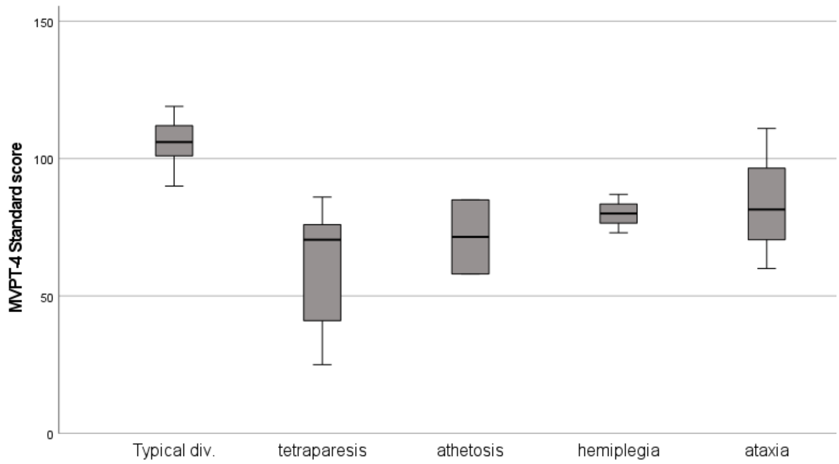

Figure 2

MVPT-4 test results comparison of each CP diagnosis and typically developing participants (N=30)

4.2 Results of the Eye-Tracking Data

We digitalized the test sheets of the MVPT-4 to allow us to fill the test on the computer and to be able to capture gaze patterns. The test does not require a motor response from the participants (motor-free), so digitization should not affect the results. The eye-tracking device has software (Tobii studio) to create the study design and select what outcomes are important for the analysis. This software generates and provides the visualization of the gaze pattern. Raw data such as time of fixation and amount of fixation on any visual subject that appears on the screen can be exported for statistical analysis. Due to a large amount of eye-tracking data, we now provide some promising preliminary results within the present framework, mostly visualization.

We found some changes in the gaze patterns of the atypically developed children. Figure 3 shows the gaze pattern of a typically developing child (fixations and saccades) while solving one of the digitized tasks of MVPT-4.

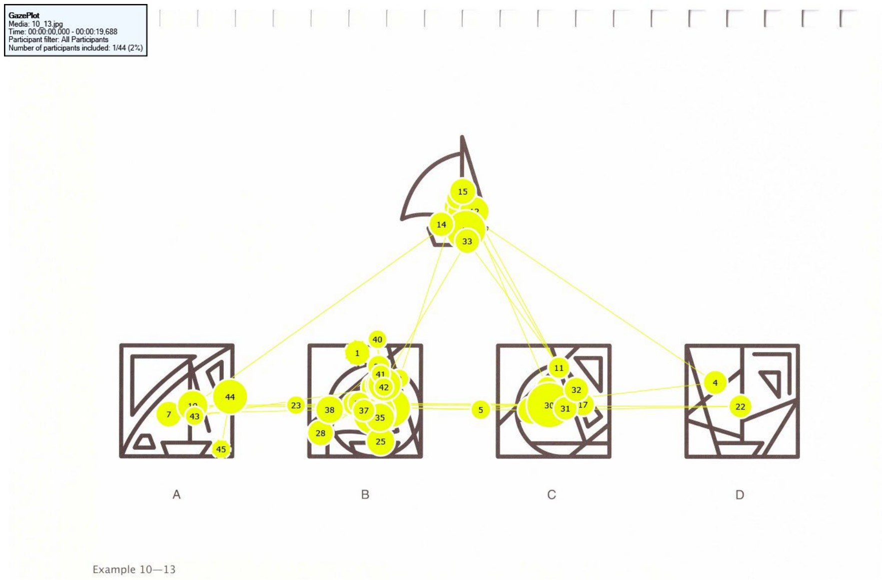

Figure 3

Gaze pattern (fixations and saccades) of a typically developing child

Figure 4 shows the scanning pattern of an athetoid child while solving the same task. The comparison shows that the pattern of a typically developing child is more orderly and purposeful, there are fixations only on subjects (shapes), and the resolution time was less than 10 seconds until the correct answer was announced. In contrast, in the case of an atypically developing child, we see a more unordered pattern, there are more fixations in empty spaces, and it took more than 35 seconds to respond, which was incorrect in the first test.

Figure 5 shows the gaze pattern obtained at the re-test in the same atypically developing child from the intervention group. The comparison shows positive changes, mostly in visual attention. This time he managed to find the correct item in less time than before (27 seconds), and it is clear that the pattern is more organized.

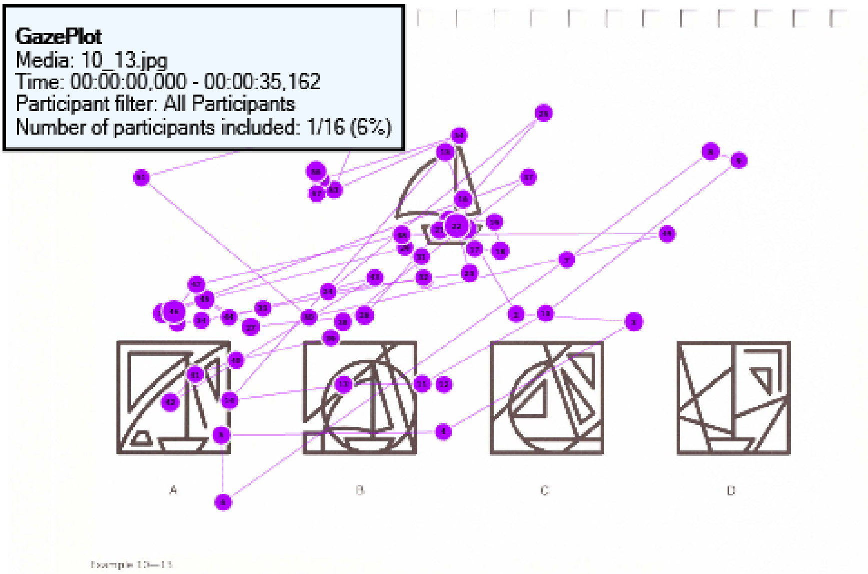

Figure 4
Gaze pattern of an atypically developing child (test group) at baseline measurement

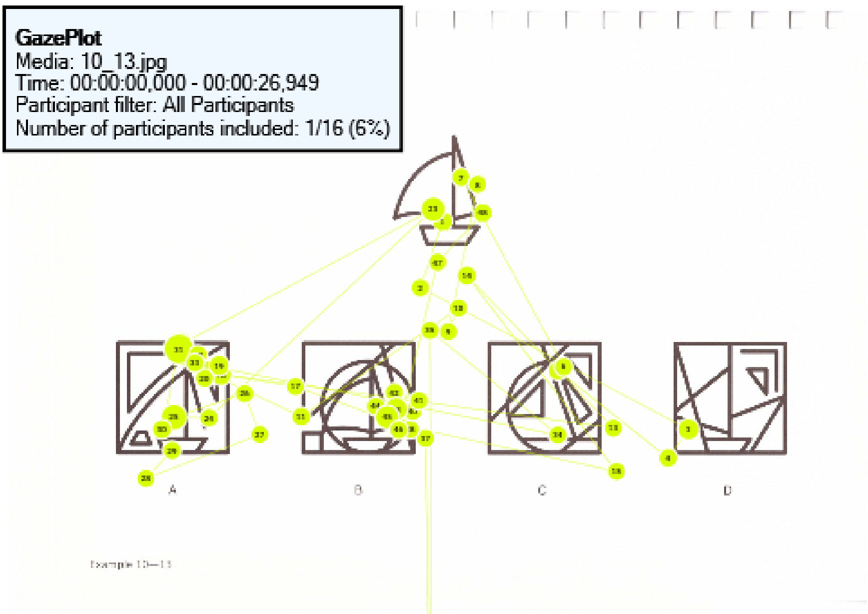

Figure 5
Gaze pattern of an atypically developing child (test group) at re-test after intervention

Conclusions

Cerebral palsy is often associated with cognitive dysfunction that leads to cognitive disabilities, such as visual perceptual skills deficits. Our results confirm this association; the MVPT-4 assessment results showed that children with CP attained significantly (p=<,001) lower mean perceptual quotients than typically developed children did. The MVPT-4 appears to be a valuable tool for evaluating visual perception in children with cerebral palsy.

This study aimed to investigate the long-term effects of the applications we created on the visual perceptual skills of children with Cerebral palsy. To assess the effects, we randomly assigned 18 participants to equally sized intervention (n=9) and control (n=9) groups, and we used the MVPT-4 combined with screen-based eye-tracking. The effect size did not reach a statistically significant level, but the differences are promising; we are suggesting to involve such an educational application in special education programs. The difference between baseline and re-test was significant in both groups (intervention and control), it is suggesting that the development of visual perceptual skills in this childhood period is very progressive.

The preliminary eye-tracking results show that the intervention group's gaze pattern has changed compared to the baseline and the re-test results (e.g., more organized fixations on the subjects), which suggests that positive changes can be recognized in visual attention.

Limitations and Directions for Future Research

The sample size is small, but not unusual in this patient population, even limiting the effect size and the statistical analysis. Another challenge is measuring the application-generated effect on visual perceptual skills because children, especially atypically developing children, get many different kinds of therapies and educational interventions daily. Our data analysis confirmed that this childhood period is very progressive in cognitive and physical development.

We are planning to make a comprehensive eye-tracking data analysis. Based on the results, we would like to create a protocol - for how to apply and implement eye-tracking to motor-free visual perception skills assessment, such as MVPT-4.

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